COSEWIC Assessment and Status Report

on the

Mudpuppy
Necturus maculosus

Manitoba population
Great Lakes / St. Lawrence population

in Canada

Manitoba population – THREATENED
Great Lakes / St. Lawrence population – SPECIAL CONCERN
2023

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:

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Previous report(s):

COSEWIC. 2000. (unpublished draft report). COSEWIC assessment and status report on the Mudpuppy *Necturus maculosus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. v + 89 pp.

Gendron, A.D. 2000. (unpublished draft report). COSEWIC status report on the Mudpuppy *Necturus maculosus* in Canada *in* COSEWIC assessment and status report on the Mudpuppy *Necturus maculosus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-89 pp.

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Mudpuppy — photo courtesy of Matthew Keevil.

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COSEWIC
Assessment Summary

Assessment Summary – December 2023

Common name
Mudpuppy - Manitoba population

Scientific name
Necturus maculosus

Status
Threatened

Reason for designation
The range of the central Canadian population of this large, long-lived salamander is restricted to southeastern Lake Winnipeg and its tributaries in southern Manitoba. It is uncommon and has not been observed recently within much of its historical Canadian range. This population has a limited and declining distribution, with observed or inferred declines in its occupied area, number of locations, and quality of habitat. Its fully aquatic lifestyle, sedentary nature, and low reproductive potential make it vulnerable to a range of threats across all watersheds. This salamander is particularly vulnerable to sedimentation and pollutants from agriculture and forestry, flood control and river channelization activities, and impacts of invasive species, including Zebra Mussel and the recently arrived Rusty Crayfish.

Occurrence
Manitoba

Status history
The species was considered a single unit and designated Not at Risk in May 2000. Split into two populations in December 2023. The Manitoba population was designated Threatened in December 2023.

Assessment Summary – December 2023

Common name
Mudpuppy - Great Lakes / St. Lawrence population

Scientific name
Necturus maculosus

Status
Special Concern

Reason for designation
The eastern Canadian population of this large, long-lived salamander is widely distributed in southern Ontario and Québec, along the edge of the Great Lakes and the St. Lawrence Lowlands. It remains widespread but recently appears to be missing from 14 percent of sites where it occurred historically, primarily in southern Ontario. Its fully aquatic lifestyle, sedentary nature, and low reproductive potential make it vulnerable to a range of widely occurring and increasing threats to water quality, including sedimentation and pollutants from agriculture, industry, forestry, and urban development. It is also at risk from flood control activities, river channelization, and impacts of invasive species. It is especially sensitive to lampricides used routinely for Sea Lamprey control across the Great Lakes Basin. This population may become Threatened if these threats are neither reversed nor managed.

Occurrence
Ontario, Québec

Status history
The species was considered a single unit and designated Not at Risk in May 2000. Split into two populations in December 2023. The Great Lakes / St. Lawrence population was designated Special Concern in December 2023.

COSEWIC
Executive Summary

Mudpuppy
Necturus maculosus

Wildlife Species Description and Significance

The Mudpuppy (*Necturus maculosus*) is a large aquatic salamander that ranges up to 49 cm in length. Its most obvious feature is prominent, red, ear-like external gills, which are retained throughout adulthood. It is the sole representative of the family Proteidae in Canada and plays a vital ecological role as the only known host of the endangered Salamander Mussel (*Simpsonaias ambigua*).

Distribution

The Mudpuppy is distributed across most of the east-central United States, from the Appalachian Mountains west to the Great Plains, south to Louisiana, and north into the southernmost parts of Manitoba, Ontario, and Quebec. In Canada, it occurs in two discrete populations, which are considered here as separate designatable units (DUs): (1) “Manitoba,” which is restricted to the southeastern part of Lake Winnipeg and its tributaries in Manitoba; and (2) “Great Lakes / St. Lawrence,” which extends across southern Ontario and Quebec along the edge of the Great Lakes and adjacent water bodies, and includes the Sydenham River, the Ottawa River basin, the St. Lawrence Lowlands along the Ottawa River, and the St. Lawrence River and some of its tributaries.

Habitat

Mudpuppies occupy permanent aquatic habitats, including both clear and turbid water in lakes, reservoirs, canals, ditches, and streams. They are absent from ephemeral water bodies and from small ponds that may freeze in the winter. Adults seek out deep, cold water during summer, moving toward areas where the water is cooler and better oxygenated. The species uses a variety of substrates (including rock, gravel, sand, and mud) but appears to be intolerant of heavy siltation. Mudpuppies prefer areas with an abundance of refuges and retreats. Adults prefer well-aerated waters but avoid high flows, and have been captured at depths as great as 32 m.

Biology

The Mudpuppy is a generalist and opportunistic predator that feeds on a variety of benthic organisms. It is mainly nocturnal and tends to avoid exposure to sunlight. The Mudpuppy is long-lived (> 30 years), and, in Canada, females first reproduce between the ages of 7 and 10. Generation time is conservatively estimated at 15 years. Breeding occurs in shallow water in late September and October. Eggs are deposited on the roof of a small cavity dug under rocks, tree trunks, planks, and other debris, usually near riffles. Although generally sedentary, the Mudpuppy remains active throughout the winter, with an increase in activity during the coldest months. Dispersal appears to be limited, resulting in considerable population structuring both within and between watersheds.

Population Sizes and Trends

There are few quantitative data on population size or trends in either Canadian population. The Mudpuppy appears to reach high local densities, particularly in the Great Lakes / St. Lawrence population, although there is evidence of decline from historical levels on the Canadian side of the Great Lakes and in the Manitoba population. Both the extent of occupancy (EOO) and the index of area of occupancy (IAO) in the Great Lakes / St. Lawrence population have apparently declined from historical (pre-1997) levels by 7% and 14%, respectively. However, it is unclear how much of the decline is due to sampling effort versus population loss. In the Manitoba population, EOO and IAO have apparently declined by up to 68% and 35%, respectively. While sampling effort is a confounding factor in this DU as well, it is unlikely to have a significant impact on observations of Mudpuppies, because search effort has consistently been low in Manitoba and is largely a function of ice fishing bycatch, which is likely to be at least as great as or greater than it was pre-1997.

Threats and Limiting Factors

The Mudpuppy faces significant threats from (1) agricultural, forestry, industrial, and domestic pollutants including lampricides; (2) dams and water management that result in rapid changes in water levels; (3) erosion, siltation, and habitat modification by recently introduced invasive species. Additional threats include shoreline alteration due to residential development and mortality associated with fishing bycatch. Botulism, extreme weather events, and lampricide use have all been implicated in mass mortality events in the Great Lakes region over the past 20 years, resulting in estimated mortality of 13,000 to 33,000 individuals.

The Mudpuppy’s sedentary and obligately aquatic nature, its longevity, and its late maturation increase its susceptibility to habitat degradation and to long-term accumulation of lipophilic toxins, and reduce its resilience to catastrophic mortality events.

Protection, Status and Ranks

Because the Mudpuppy is designated “Not at Risk” in Canada, it does not benefit from any legal protection under the *Species at Risk Act* (SARA). However, as this species is the obligate host of Salamander Mussel (which is federally listed as Endangered), threats to it within the range of Salamander Mussel are also considered threats to the mussel. Protection is therefore limited to one locality on the Sydenham River where the Salamander Mussel is found. The Mudpuppy is not protected under provincial legislation in Canada; it is considered “Not at Risk” in Manitoba, Ontario, and Quebec.

NatureServe ranks the Mudpuppy as Globally Secure (rank G5 and rank G5T5 for the subspecies *N. m. maculosus*), owing to its extensive distribution in North America and its abundance in several regions. It is ranked as Vulnerable (S3) in Manitoba and Apparently Secure in Quebec and Ontario (S4). The species is classified as “Least Concern” on the IUCN Red List.

TECHNICAL SUMMARY - Manitoba population

Necturus maculosus

Mudpuppy (Manitoba population)

Necture tacheté (Population du Manitoba)

Range of occurrence in Canada: Manitoba

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	15 yrs
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, whichever is longer up to a maximum of 100 years]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations, whichever is longer up to a maximum of 100 years].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations, whichever is longer up to a maximum of 100 years].	Suspected reduction based on threats calculator (Overall Threat Impact: High - projected decline of 10% to 70%)
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any period [10 years, or 3 generations, whichever is longer up to a maximum of 100 years], including both the past and the future.	Unknown
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. Unknown b. No c. Unknown
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	29,116 km² (based on extant records only)
Index of area of occupancy (IAO) (Always report 2x2 grid value).	60 km² (based on extant records only)
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. Unknown b. Unknown

Number of “locations” (use plausible range to reflect uncertainty if appropriate)	six6 (treating each watercourse in which the species occurs as a separate location and all Lake Winnipeg records as a single location) – nine (treating each record as single location, except those < 5 km apart on the same watercourse and those on Lake Winnipeg)
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes, inferred decline of up to 68%, based on extant vs. all (historical + extant) records (90,643 km^2) [assumes Mudpuppies were present but undetected prior to 1997 at all extant sites, due to limited search effort and the species low dispersal capacity]
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, inferred decline of up to 35%, based on extant vs. all (historical + extant) records (92 km^2). [assumes Mudpuppies were present but undetected prior to 1997 at all extant sites, due to limited search effort and the species’ low dispersal capacity]
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Yes, inferred decline given the lack of observations in the Assiniboine River near the Saskatchewan border post-1997
Is there an [observed, inferred, or projected] decline in number of “locations”?	Yes, inferred decline from 8 to 6 (assuming that all extant locations also contained the Mudpuppy historically)
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Projected decline in extent and quality of habitat
Are there extreme fluctuations in number of subpopulations?	Unknown but unlikely
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 whichever is longer up to a maximum of 100 years, 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 (22 February 2023) Calculated and Assigned Overall Threat Impact: High i. Pollution (High-Medium) - Agricultural & Forestry Effluents (9.3), Domestic & Urban Wastewater (9.1); (Unknown) Garbage & solid waste (9.4), Airborne Pollutants (9.5) ii. Natural System Modifications (Medium-Low) - Dams & Water Management/Use (7.2), Other Ecosystem Modifications (7.3) iii. Residential & Commercial Development (Low) - Housing and Urban Areas (1.1) iv. Biological Resource Use (Low) - Fishing & Harvesting Aquatic Resources (5.4) v. Invasive & Other Problematic Species & Genes (Unknown) - Invasive Non-native/Alien Species (8.1); Problematic Native Species (8.2) vi. Climate Change & Severe Weather (Unknown) – Storms & Flooding (11.4) What additional limiting factors are relevant? Sedentary and obligate aquatic nature, extended longevity, and late maturation increase susceptibility to habitat degradation and long-term accumulation of lipophilic toxins.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	Minnesota (S3, vulnerable), North Dakota (S4, apparently secure)
Is immigration known or possible?	Not known, but likely to be limited due to low dispersal rates
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Unknown
Are conditions deteriorating in Canada?	Probably
Are conditions for the source (i.e., outside) population deteriorating?	Unknown
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: The species was considered a single unit and designated Not at Risk in May 2000. Split into two populations in December 2023. The Manitoba population was designated Threatened in December 2023.

Status and Reasons for Designation:

Status: Threatened	Alpha-numeric codes: B2ab(i,ii,iii,iv)
Reasons for designation: The range of the central Canadian population of this large, long-lived salamander is restricted to southeastern Lake Winnipeg and its tributaries in southern Manitoba. It is uncommon and has not been observed recently within much of its historical Canadian range. This population has a limited and declining distribution, with observed or inferred declines in its occupied area, number of locations, and quality of habitat. Its fully aquatic lifestyle, sedentary nature, and low reproductive potential make it vulnerable to a range of threats across all watersheds. This salamander is particularly vulnerable to sedimentation and pollutants from agriculture and forestry, flood control and river channelization activities, and impacts of invasive species, including Zebra Mussel and the recently arrived Rusty Crayfish.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. Insufficient data to document change in total number of mature individuals.
Criterion B (Small Distribution Range and Decline or Fluctuation): Meets Threatened, B2ab(i,ii,iii,iv). IAO of 60 km² <2,000 km², and number of locations (6-9) <10. Continuing observed and projected decline in both EOO and IAO. Continuing projected decline in extent and quality of habitat (see **Threats**), observed decline in number of locations, and an inferred decline in number of subpopulations.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. Total number of mature individuals is unknown.
Criterion D (Very Small or Restricted Population): Not applicable. Total number of mature individuals is unknown, and IAO exceeds 20 km^2.
Criterion E (Quantitative Analysis): Not applicable. Analysis not conducted.

TECHNICAL SUMMARY - Great Lakes / St. Lawrence population

Mudpuppy (Great Lakes / St. Lawrence population)

Necture tacheté (Population des Grands Lacs et du Saint-Laurent)
Necturus maculosus

Range of occurrence in Canada: Ontario, Quebec

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	15 yrs
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Yes, inferred from lack of extant records, particularly along northern shores of Lake Erie and Lake Ontario
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations, whichever is longer up to a maximum of 100 years]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations, whichever is longer up to a maximum of 100 years].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations, whichever is longer up to a maximum of 100 years].	Suspected reduction based on threats calculator (Overall Impact: High, projected decline of 10% to 70%)
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any period [10 years, or 3 generations, whichever is longer up to a maximum of 100 years], including both the past and the future.	Suspected reduction of 10% to 70% based on lack of extant records particularly along northern shores of Lake Erie and Lake Ontario and ongoing threats (calculator Overall Impact: High)
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. unknown b. no c. unknown
Are there extreme fluctuations in number of mature individuals?	Unknown. There are documented mass mortality events, but it is unclear what proportion of mature individuals in a population are included in these events.

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	569,859 km² (based on extant records only)
Index of area of occupancy (IAO) (Always report 2x2 grid value).	1,636 km² (based on extant records only)

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)	>10
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes, inferred decline of up to 7%, based on extant vs. all (historical + extant) records (613,259 km^2) [assumes Mudpuppies were present but undetected prior to 1997 at all extant sites, due to limited search effort and the species’ low dispersal capacity]
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, inferred decline of about 14%, based on apparent loss (0.86) of historical cells × detection probability (0.16)
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Inferred decline due to lack of extant records along most of the northern shores of Lake Erie and Lake Ontario
Is there an [observed, inferred, or projected] decline in number of “locations?	Inferred decline due to lack of extant records along most of the northern shores of Lake Erie and Lake Ontario
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Inferred decline in extent and quality of habitat
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
	Unknown, but well over 10,000
Total	> 10,000

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations whichever is longer up to a maximum of 100 years, or 10% within 100 years]?	Not calculated

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

Was a threats calculator completed for this species? Yes (9 January 2019; updated 22 February 2023) Calculated and Assigned Overall Threat Impact: High i. Pollution (High-Medium) - Agricultural & Forestry Effluents (9.3), Domestic & Urban Wastewater (9.1), Industrial & Military Effluents (9.2) ii. Natural System Modifications (Medium-Low) - Dams & Water Management/Use (7.2), Other Ecosystem Modifications (7.3) iii. Residential & Commercial Development (Low) - Housing and Urban Areas (1.1) iv. Biological Resource Use (Low) - Fishing & Harvesting Aquatic Resources (5.4) v. Agriculture & Aquaculture (Unknown) - Marine & Freshwater Aquaculture (2.4) vi. Energy Production & Mining (Unknown) - Oil & Gas Drilling (3.1); Mining & Quarrying (3.2); Renewable Energy (3.3) vii. Transportation & Service Corridors (Unknown) – Shipping Lanes (4.3) viii. Invasive & Other Problematic Species & Genes (Unknown) - Invasive Non-native/Alien Species (8.1); Problematic Native Species (8.2) ix. Climate Change & Severe Weather (Unknown) – Droughts (11.2); Storms & Flooding (11.4) What additional limiting factors are relevant? Sedentary and obligate aquatic nature, extended longevity, and late maturation increase susceptibility to habitat degradation and long-term accumulation of lipophilic toxins.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	S2 imperilled (Vermont); S3 vulnerable (Minnesota, Michigan, Pennsylvania, New York); S4 apparently secure (Ohio); introduced in New Hampshire and Maine
Is immigration known or possible?	Likely possible, especially in shared transborder water bodies
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Unknown
Are conditions deteriorating in Canada?	Possibly
Are conditions for the source (i.e., outside) population deteriorating?	Unknown
Is the Canadian population considered to be a sink?	No
Is rescue from outside populations likely?	Unlikely. As Canada and the US share a border through the Great Lakes and St. Lawrence, it is likely that any dramatic changes to conditions in either country will be felt across these contiguous water bodies.

Data Sensitive Species

Is this a data sensitive species?	No

Status History

COSEWIC: The species was considered a single unit and designated Not at Risk in May 2000. Split into two populations in December 2023. The Great Lakes / St. Lawrence population was designated Special Concern in December 2023.

Status and Reasons for Designation:

Status: Special Concern	Alpha-numeric codes: Not applicable
Reasons for designation: The eastern Canadian population of this large, long-lived salamander is widely distributed in southern Ontario and Québec, along the edge of the Great Lakes and the St. Lawrence Lowlands. It remains widespread but recently appears to be missing from 14 percent of sites where it occurred historically, primarily in southern Ontario. Its fully aquatic lifestyle, sedentary nature, and low reproductive potential make it vulnerable to a range of widely occurring and increasing threats to water quality, including sedimentation and pollutants from agriculture, industry, forestry, and urban development. It is also at risk from flood control activities, river channelization, and impacts of invasive species. It is especially sensitive to lampricides used routinely for Sea Lamprey control across the Great Lakes Basin. This population may become Threatened if these threats are neither reversed nor managed.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. Insufficient data to document change in total number of mature individuals.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable. Although the observed IAO of 1,636 km² is below the threshold for Threatened, the population is not severely fragmented, the number of locations is > 10, and it does not experience extreme fluctuations.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. Total number of mature individuals is unknown, and evidence to document a decline is inadequate.
Criterion D (Very Small or Restricted Population): Not applicable. Population is neither very small nor restricted.
Criterion E (Quantitative Analysis): No analysis conducted. Not applicable. Analysis not conducted.

PREFACE

Since the previous status report, prepared by Gendron (1999), new information on the demography and genetic structure of Mudpuppy populations as well as on threats has become available new information on threats. Different sampling methods have also since been tested, with new capture gear developed. Three sequences (549–655 bp) of mitochondrial DNA (COI region) were recently isolated to obtain DNA barcodes for species identification and are now publicly available (Chambers and Hebert 2016). Genetic analysis has provided new insight into population structure, supporting the separation of the species into two designatable units in Canada: the Great Lakes / St. Lawrence and Manitoba populations (Greenwald *et al.* 2020). Targeted surveys and recent observations have validated the persistence of the species at several sites in Ontario and Quebec. Although population trends are unknown, threats related to aquatic contaminants such as polychlorinated biphenyls (PCBs), agricultural and municipal runoff, and the lampricide 3-trifluoromethyl-4-nitrophenol (TFM)—as well as invasive alien species, diseases, and parasites—are well documented, and it is reasonable to expect the adverse impacts of these threats to increase with climate change.

The 1997 cut-off for “extant” versus “historical” observations, which extends beyond the normal 20-year period, reflects delays between the initiation and completion of the present report.

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
(2023)

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 is 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

Mudpuppy
Necturus maculosus

Manitoba population
Great Lakes / St. Lawrence population

in Canada

2023

TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Necturus maculosus (Rafinesque 1818) is a salamander in the family Proteidae, which includes the extant genera *Necturus* and *Proteus* (Larson 2006; Frost 2021). The currently accepted standard name for *Necturus maculosus* is “Mudpuppy” in English (Crother 2017) and “necture tacheté” in French (Mazerolle *et al.* 2012). The Mudpuppy is the most widely distributed member of the family Proteidae and its sole representative in Canada (Petranka 2010).

Frost (2021) recognizes nine species in this family: eight in the genus *Necturus* that inhabit eastern North America, and a single species, *Proteus anguinus*, that inhabits subterranean waters near the Adriatic Sea. Petranka (2010), Crother (2017), and NatureServe (2021b) recognize five species of *Necturus*, treating *N. m. louisianensis* and *N. m. maculosus* as subspecies of *N. maculosus*. The names “Common Mudpuppy” in English and “necture tacheté commun” in French refer to the subspecies found in Canada, *N. m. maculosus* (Mazerolle *et al.* 2012; Crother 2017).

Morphological Description

The Mudpuppy is the largest salamander in Canada and throughout its range. Adult size ranges from 20 to 49 cm total length (TL) (Petranka 2010). The largest reported specimen from Canada, captured at Long Point in Lake Erie, ON, was 45.5 cm long (Gendron 1999). The Mudpuppy is a permanently aquatic salamander which retains reddish, external gills retained throughout its life (Petranka 2010). It has a truncated snout, a long body with short legs and four toes on each foot, and a laterally compressed tail with dorsal and ventral fins (Figure 1). Adult coloration ranges from a cream or rusty brown to grey or black, with scattered, darker blotches or spots (though these can occasionally be absent or fused into a dorsolateral stripe). A dark stripe runs through the eyes to the gills (Petranka 2010). Albino forms are rare, but have been captured in Quebec (Desroches and Rodrigue 2004).

At hatching, Mudpuppy larvae average 2.2 cm total length and have prominent yolk reserves (Bishop 1941). The larvae have a dark dorsal band on the upper half of the trunk, which extends from the snout to the tip of the tail and is bordered on either side by a light yellow stripe (Figure 1). The stripes fade toward the fourth year of life (Desroches and Rodrigue 2004), with the colour pattern of juveniles beginning to resemble that of adults once they exceed approximately 15 cm total length (Bishop 1941).

Figure 1. Adult Mudpuppy (*Necturus maculosus*) photo (top) courtesy of Matthew Keevil. Juvenile Mudpuppy photo (bottom) courtesy Jean-Marc Vallières.

Population Spatial Structure and Variability

Information on the population structure of the Mudpuppy in Canada is sparse. However, since the species is entirely aquatic, its range is arguably limited to areas with current or historical hydrological connectivity. Genomic analysis of Mudpuppies sampled across three major river basins in Kentucky revealed that population structure is influenced in part by isolation by distance, but also by other, unresolved factors that limit gene flow at a local scale (Murphy *et al.* 2018). An isolation-by-distance pattern of genetic structure among populations across the Mudpuppy range was also supported by mitochondrial analyses, but isolation by distance did not explain observed genetic structuring within watersheds (Greenwald *et al.* 2020).

Designatable Units

This report identifies two designatable units (DUs) for the Mudpuppy in Canada, (1) Great Lakes / St. Lawrence, and (2) Manitoba, on the basis of the discreteness and evolutionary significance criteria discussed below, which are described in Appendix F5 of the COSEWIC Operations and Procedures Manual (COSEWIC 2020).

Discreteness

D1. Evidence of heritable traits or markers that clearly distinguish the putative DU from other DUs (e.g., evidence from genetic markers or heritable morphology, behaviour, life history, phenology, migration routes, vocal dialects), indicating limited transmission of this heritable information with other DUs (COSEWIC 2020).

D2. Natural (i.e., not the product of human disturbance) geographic disjunction between putative DUs, such that transmission of information (e.g., individuals, seeds, gametes) between these “range portions” has been severely limited for an extended time and is not likely in the foreseeable future. “Extended time” is intended to mean that sufficient time has passed that either natural selection or genetic drift are likely to have produced discrete units, given the specific biology of the taxon (COSEWIC 2020).

Significance

S1. Direct evidence or strong inference that the putative DU has been on an independent evolutionary trajectory for an evolutionarily significant period, usually intraspecific phylogenetic divergence indicating origins in separate Pleistocene refugia.

S2. Direct evidence or strong inference that can be used to infer that the putative DU possesses adaptive, heritable traits, that cannot be practically reconstituted if lost. For example, persistence of the discrete, putative DU in an ecological setting where a selective regime is likely to have given rise to DU-wide local adaptations that could not be reconstituted.

Evidence

The Mudpuppy is fully aquatic and likely recolonized regions of southern Canada following glacial retreat via routes similar to those used by freshwater fishes (Greenwald *et al.* 2020). The two potential DUs likely followed separate postglacial dispersal routes (O'Connor and Green 2016). The ranges of the two potential DUs are disjunct in both Canada and the United States (Figures 2A, 3). There is no evidence of movement between the Manitoba and Ontario populations, and no reason to expect movement by this obligately aquatic species between rivers or lake systems that are not hydrologically connected. In Canada, the two potential DUs occupy different National Freshwater Biogeographic Zones (COSEWIC 2021): Saskatchewan–Nelson River, Great Lakes–Upper St. Lawrence (Figure 2A). All the above observations lend support to the argument that the two populations meet **Criterion D2** (geographic disjunction limiting transmission of information between "range portions" into the extended past and future).

Sequencing of a single mitochondrial DNA gene (cytochrome b) revealed 24 haplotypes showing distinct eastern and western lineages on either side of the Mississippi River (Greenwald *et al.* 2020) (Figure 2B). This provides support for the argument that the two populations meet **Criterion D1** (evidence from genetic markers indicating limited transmission of this heritable information with other DUs) and **Criterion S1** (evidence that DUs have been on independent evolutionary trajectories for an evolutionarily significant period).

Further support for **Criterion S1** comes from Mills and Hill (2016), who provided evidence that Mudpuppy distribution in southern Ontario reflects colonization events in the Great Lakes during the Nipissing Phase of postglaciation, 4,000 to 5,000 years ago. As noted above, natural dispersal between the Manitoba and Great Lakes–Upper St. Lawrence DUs is unlikely, and these areas have not been hydrologically connected for thousands of years. Although no genetic analysis is available for the Manitoba DU (for direct comparison with the Great Lakes / St. Lawrence DU), the three most northwestern sample groups (#1, 2, and 3) from Minnesota mentioned in Greenwald *et al.* (2020) are from the Souris-Red-Rainy Watershed, which has a direct connection to Manitoba waters and the Manitoba DU. Those Minnesota samples were found to be highly distinct from the eastern Great Lakes samples, including those from the Great Lakes / St. Lawrence DU in Canada.

The Mudpuppy is relatively sedentary and there is no evidence of large-scale dispersal even within hydrologically connected systems. Greenwald *et al.* (2020) found highly significant isolation-by-distance patterns in a population-level analysis of mitochondrial DNA. A genomic analysis by Murphy *et al.* (2018) found evidence of subpopulation structuring within river basins in Kentucky, due in part to isolation-by-distance, but also to other, unknown factors. This characteristic is likely to give rise to local adaptation, a feature consistent with **Criterion S2** (persistence of the discrete, putative DU in an ecological setting likely to have given rise to DU-wide local adaptations that could not be reconstituted).

A

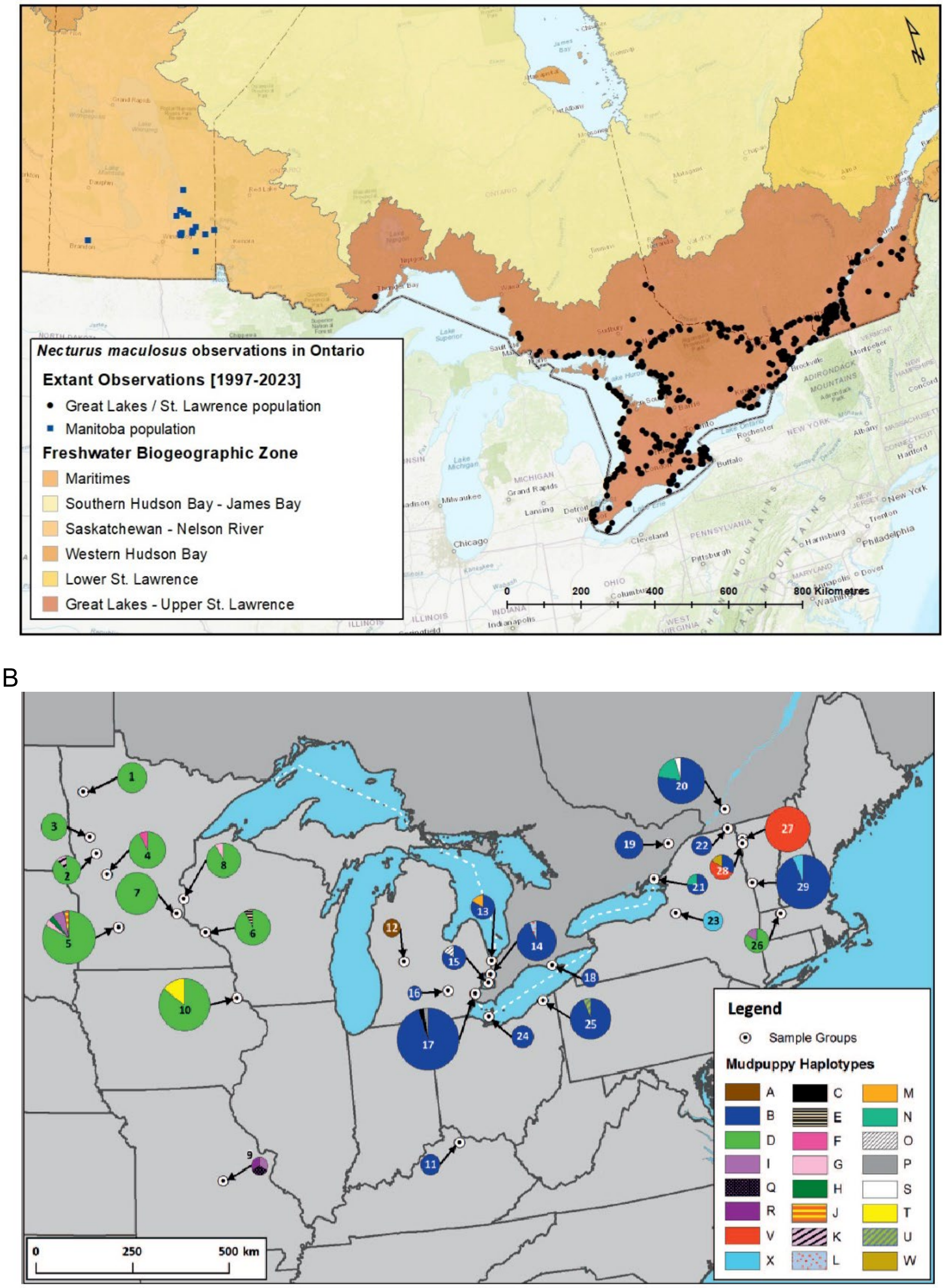


Figure 2. (A) Mudpuppy (*Necturus maculosus*) observations in Canada (1997-2023) overlaid on the Freshwater Biogeographic Zone. (B) cytochrome b haplotypes for Mudpuppy documented in Greenwald *et al.* (2020). Haplotype pie charts for each group are scaled according to sample size. Numbers associated with each pie chart indicate the sample group number. Group Numbers 1, 2, and 3 fall within the Saskatchewan–Nelson River watershed.

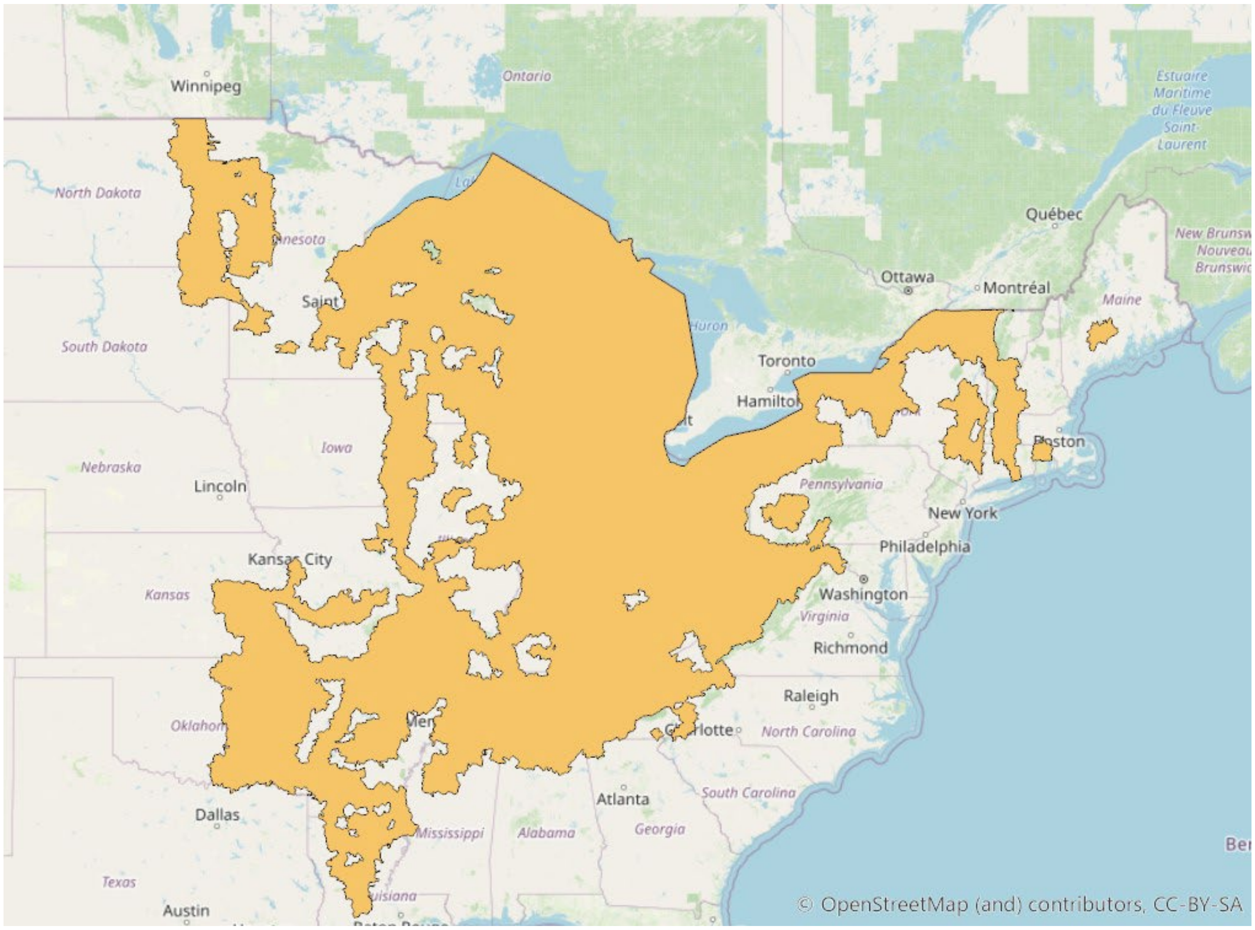


Figure 3. Mudpuppy (*Necturus maculosus*) range in the United States, based on occupied sub-watershed polygons (U.S. Geological Survey [USGS] - Gap Analysis Project [GAP], 2018, https://doi.org/10.5066/F7057F0C). Note: no accurate global range map was available.

In conclusion, the current physical disjunction, limited dispersal capability, and likely separate evolutionary lineage in the two areas since the last glaciation support a weight-of-evidence argument for the recommended DU structure. Available biogeographic and genetic evidence provides strong support for D2, moderate support for D1 and S1, and limited inferential support for S2. Therefore, the status of Mudpuppy is considered here based on two DUs, namely the Manitoba population and the Great Lakes / St. Lawrence population.

Special Significance

The Mudpuppy is the sole representative of the family Proteidae in Canada. It is the only completely aquatic salamander and also the largest salamander species in the country. The species is at the extreme northern limit of its global range in Canada, a situation that could potentially create local adaptations that are absent from populations living farther south. The Mudpuppy plays a vital ecological role as the only known host of the endangered Salamander Mussel (*Simpsonaias ambigua*) (COSEWIC 2001; DFO

2019). The Salamander Mussel is ranked globally as Vulnerable (G3) by NatureServe. In the United States, it is at risk across its range (NatureServe 2021a). In Canada, the Salamander Mussel is known to occur only in the east Sydenham River in Ontario (DFO 2019). The Mudpuppy has been widely used as an animal model for physiology research and for educational purposes (reviewed in Gendron 1999). As the species is sensitive to contaminants, pollution, and sedimentation, it may also serve as an indicator of the health of aquatic ecosystems (Gendron *et al.* 1997; Marcogliese *et al.* 2000; Barrett and Guyer 2008), thereby providing an early warning of environmental problems that can affect fish and other aquatic organisms (Bonin *et al.* 1995; Bishop and Gendron 1998).

DISTRIBUTION

Global Range

The distribution of the Mudpuppy includes most of the east-central United States, from the Appalachian Mountains west to the Great Plains, south to Louisiana, and north into the southernmost parts of Manitoba, Ontario, and Quebec (Figures 2A, 3). The subspecies *N. m. lousianensis* occurs in Louisiana, Arkansas, and Oklahoma, reaching into, but not overlapping with, the northern subspecies, *N. m. maculosus*, in Kansas and Missouri, (Gendron 1999; Petranka 2010; Chabarria *et al*. 2018). Mudpuppy is considered exotic (i.e., introduced) in Maine, Massachusetts, New Hampshire, and Rhode Island (NatureServe 2021b). The species was notably introduced in the Connecticut River, Massachusetts (Warfel 1936), and this introduced status has been supported by recent genetic analysis that places individuals from the Connecticut River as more closely related to the western clade (i.e., Mudpuppy from Minnesota) (Greenwald *et al.* 2020). In Maine, Collins (2003) recounts how, in 1939, 85 individuals escaped a fish hatchery; several years later a second escape was documented from the same hatchery. In New York, Mudpuppy is generally accepted to be native to Lake Champlain and its tributaries and is arguably native to the Hudson Valley (Schmidt *et al.* 2004).

Canadian Range

<u>Manitoba DU</u>

Historical records (pre-1997) indicate that the distribution of Mudpuppy in Manitoba included southern Lake Winnipeg and its tributaries (the Red, Assiniboine, and Winnipeg rivers), the municipality of Lac du Bonnet, and two sites in the Assiniboine River near the border with Saskatchewan (Gendron 1999). Observations from 1997 to 2023 are concentrated near the southern portion of Lake Winnipeg and its tributaries, with one observation farther south in the Whitemouth River near Hadashville in 2017, and an unconfirmed but credible sighting in the Assiniboine River in Brandon in 2006 (Cairns pers. comm. 2023) (Figure 4A). Mudpuppy has been observed in five watershed subdrainage areas (Red, Western Lake Winnipeg, Lake Winnipeg, Winnipeg, and Assiniboine). Notably, there have been no recent observations of Mudpuppy near the border with Saskatchewan (Figure 5A).

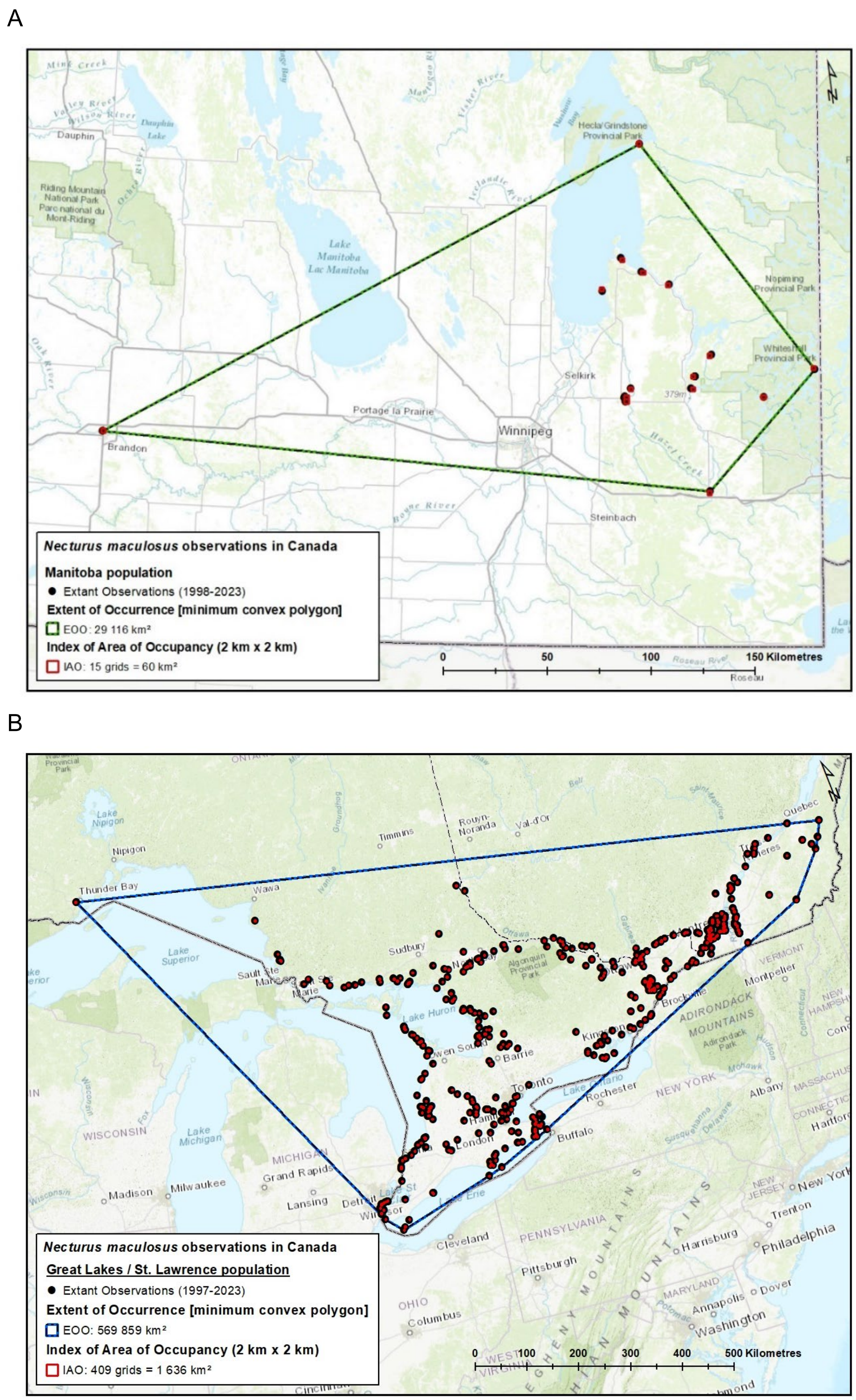
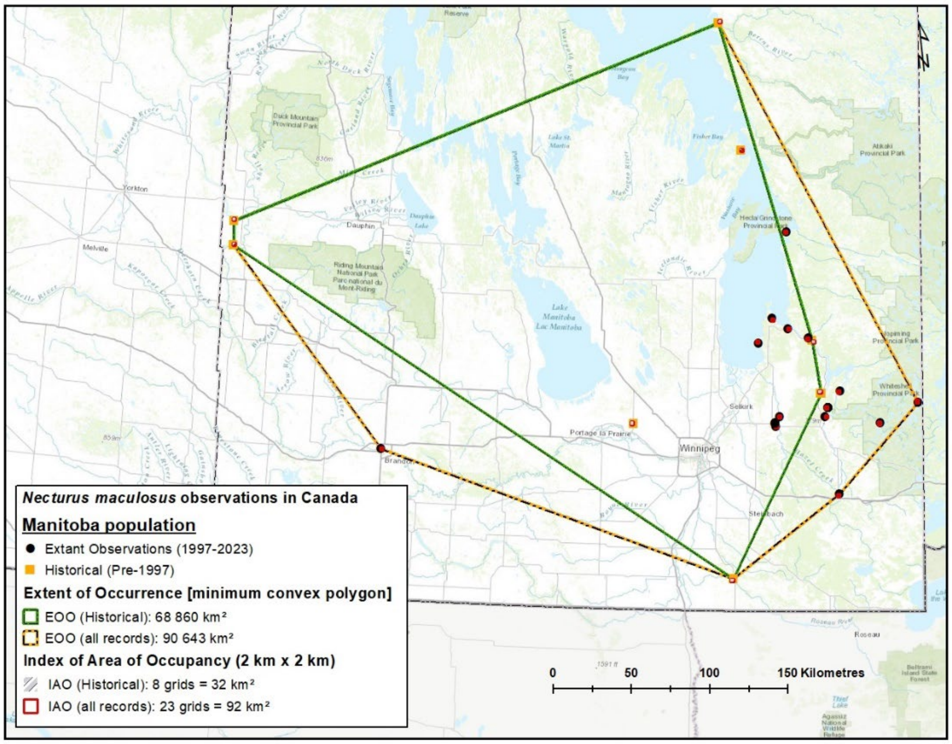


Figure 4. Canadian range of Mudpuppy. EOO and IAO calculations for Manitoba (A) and Great Lakes / St. Lawrence (B) populations (Saini COSEWIC Secretariat).

A



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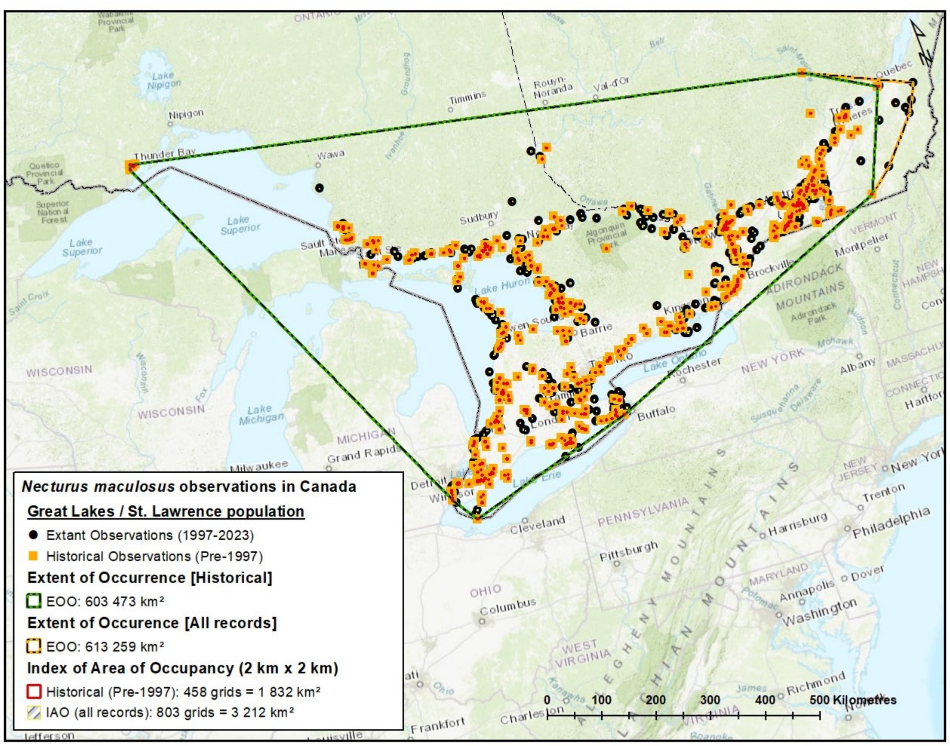

Figure 5. Historical Canadian range of Mudpuppy. EOO and IAO calculations for Manitoba (A) and Great Lakes / St. Lawrence (B) populations (Saini COSEWIC Secretariat).

Great Lakes / St. Lawrence DU

In Ontario, the Mudpuppy is widely distributed in the southern part of the province (Figure 4B), particularly along the edge of the Great Lakes and adjacent water bodies (Lake Simcoe and Lake Nipissing), as well as in the Ottawa River basin (Gendron 1999) and the Sydenham River (McDaniel *et al.* 2009). In Ontario, the species is found as far north as Thunder Bay in the west and Blanche River in the east (Gendron 1999). The species appears to be absent from Lake Nipigon, from upstream of the Petawawa River, and from the Algonquin Dome (Gendron 1999) (Mills and Hill 2016). In Quebec, the Mudpuppy is present in the St. Lawrence Lowlands in the southern portion of the province, along the Ottawa River from Lake Timiskaming to the St. Lawrence River (Gendron 1999). The species is present in the St. Lawrence and some of its tributaries, including the Rivière des Milles Îles, the Rivière des Prairies, and the Richelieu River, and is found from the western part of Lake Saint-François to Quebec City. The species occurs in a small lake near the mouth of the Saguenay River and in the Nabissipi River on the North Shore (Bider and Matte 1994). It appears to be absent from the Laurentians region and from the Gaspé Peninsula (Gendron 1999). Three individuals have been caught in Saint-Anne-de-Bellevue Canal National Historic Site, which is located at the westernmost tip of the Island of Montreal and comprises a set of locks linking Lake Saint-Louis and Lac des Deux Montagnes (Pruss pers. comm. 2018). Overall, the Mudpuppy has been observed in 15 watershed subdrainage areas: northwestern and northeastern Lake Superior; northern and eastern Lake Huron; upper, central, and lower Ottawa River; upper, central, and lower St. Lawrence River; Wanipitai and French rivers; Eastern Georgian Bay; Lake Ontario and Niagara Peninsula; and the Saint-Maurice River. No recent (post-1997) observations of Mudpuppy have been reported from the Saint-Maurice, however.

Extent of Occurrence and Area of Occupancy

In this report, the extent of occurrence (EOO) and area of occupancy (IAO) are portrayed and measured from three datasets: (1) extant records only (1997-present); (2) historical records only (pre-1997); and (3) all records (historical+extant). Because targeted searches for Mudpuppy have been limited and uneven both historically and recently (see **Search Effort**), it is difficult to distinguish between true absence and undetected presence in both time periods. Search effort for herpetofauna has generally been greater in recent years than in the past, but the extent to which that has influenced recent measures of true absence versus undetected presence is uncertain.

Estimates of extant and historical EOO and IAO, based respectively on extant and historical records only, are conservative. Estimates of true historical presence can be improved by combining historical and recent (extant) records of presence. This approach assumes that all sites with recent observations were also occupied historically, which seems reasonable given the species' limited dispersal capacity. There is no directly comparable mechanism to improve estimates of true recent (extant) presence, although an indirect measure of detectability is discussed and applied below.

Manitoba DU

Assuming that all recent observations also represent historical occurrences, as argued above (i.e., Mudpuppies were present but undetected prior to 1997), estimated historical EOO incorporating both historical and extant records would be 90,643 km^2 (versus 68,860 km^2, historical records only), and estimated historical IAO incorporating both historical and extant records is 92 km^2 (versus 32 km^2, historical records only) (Figure 5A).

For extant observations, it is unclear whether the absence of observations of Mudpuppy in the Assiniboine River near the Saskatchewan border post-1997 reflects a loss of that subpopulation or a lack of search effort in the area. However, given that search effort has only ever included incidental observations and ice fishing bycatch across the province, and that ice fishing continues in these areas, it is possible that the lack of observations reflects a loss of the species from the area. Based on extant observations (1997–2023) alone, recent EOO is 29,116 km^2 and IAO is 60 km^2 (Figure 4A). A comparison of extant values with historical values (inclusive of historical and recent records as described above) (Figure 5A) suggests that the DU may have experienced a decrease of up to 68% in EOO and 35% in IAO since 1997.

Great Lakes / St. Lawrence DU

Assuming that all recent observations also represent historical occurrences, as argued above (i.e., Mudpuppies were present but undetected prior to 1997), then estimated historical EOO incorporating both historical and extant records would be 613,259 km^2 (versus 603,473 km^2, historical records only), and estimated historical IAO incorporating both historical and extant records is 3,212 km^2 (versus 1,832 km^2, historical records only) (Figure 5B).

Based on extant observations (1997–2023) alone, EOO is 569,859 km^2, and IAO is 1,636 km^2 (Figure 4B). The DU may therefore have experienced a decrease of up to 7% in EOO and 49% in IAO since 1997, based on a comparison of these extant values with historical values (inclusive of historical and recent records as described above) (Figure 5B).

For both DUs, the above estimates of decline in EOO and IAO are likely exaggerated, given the remaining uncertainty (i.e., absent vs. undetected) about the absence of extant observations in historical IAO grid cells. In the Manitoba DU, extant observations are lacking in all eight historical grid cells (100% absence). Alternatively, assuming that all 15 extant grid cells were also historically occupied, the recent absence estimates would decrease to 35% (8 of 23 total grid cells). In the Great Lakes / St. Lawrence DU, extant observations are lacking in 394 of 458 historical grid cells (86% absence); again, assuming that all 409 extant grid cells (including 64 with historical records) were also historically occupied, those recent absence estimates would decrease to 49% (394 of 803 total grid cells).

Recent observations in both DUs which extend the EOO beyond the boundaries of historical sites (as described above) lend further support to the argument that historical sites have gone undetected. Despite apparently low detectability, these numbers still suggest a high loss of IAO cells, although uncertainty exists regarding the exact nature of observed declines. Additionally, search effort has likely increased both intensively (within cells) and extensively (across cells) in both DUs in the past 25 years, adding further complexity.

While low detectability can influence apparent distribution patterns and trends, it can also be factored into estimates of loss. In the Great Lakes / St. Lawrence DU, 345 of 409 extant grid cells (84%) had no historical detections (records). Assuming that all extant cells also supported the Mudpuppy historically, this would yield a detection probability of 0.16. With this caveat, a more accurate estimate (albeit coarse) of loss of IAO cells in the Great Lakes / St. Lawrence DU would incorporate both detection probability (0.16) and apparent loss (394/458=0.86) and would yield a value of about 14%. There are too few observations to perform a comparable analysis of the Manitoba DU.

Search Effort

In Canada, targeted searches for the Mudpuppy have been carried out in the St. Lawrence River, the Ottawa River, and the Great Lakes (Bonin *et al.* 1995; Gendron *et al.* 1997; Gendron 1999; McDaniel *et al.* 2009). Bycatch by anglers, particularly ice fishers, and chance observations are the only data available on Mudpuppy distribution in Manitoba, and these sources constitute a large proportion of the data available in Ontario and Quebec as well (ORAA 2017; BORAQ 2018; MHA 2018). Mudpuppy bycatch during ice fishing appears to be relatively common in at least some areas. For example, approximately 10 individuals were hooked by ice fishers while fishing for Walleye (*Sander vitreus*) in the winters of 2020 and 2021 on the Ottawa River at dusk near the Masson-Angers and Aylmer boat launches (Calvé pers. comm. 2023). In Manitoba, a fisher sharing Mudpuppy bycatch data with a local biologist reported consistently hooking Mudpuppy in Lac du Bonnet on excursions and capturing between one and four individuals per trip in the winter months, with notably fewer captures in the spring and summer (Watkins pers. comm. 2023). Ice fishing is a widespread activity in Manitoba (Cairns pers. comm. 2023), and observations of ray-finned fishes in Manitoba reported on iNaturalist.org from December to March suggest the ongoing presence of ice fishers throughout the historical range of the Mudpuppy in Manitoba (iNaturalist.org 2023a).

Herpetofaunal databases consulted for this report—the Manitoba Herp Atlas (MHA 2018), the Ontario Reptile and Amphibian Atlas (ORAA 2017), and the Banque des observations des reptiles et amphibiens du Québec (BORAQ 2018)include only presence (not absence) data. Localities searched for the species without success are not reported, and unproductive search efforts are not documented. In general, few amphibian surveys are done in remote northern regions, especially during winter when the probability of capturing the Mudpuppy is higher (Gendron 1999). However, there has been a substantial increase in search effort over the past two decades in Ontario, particularly between 2009 and 2020, due to the efforts of the Ontario Reptile and Amphibian Atlas, which included a program targeting ice fishers in an effort to solicit observations of Mudpuppy (Ontario Nature 2015). Given this increase in search effort, the lack of recent observations at historical sites is likely evidence of local extirpations. Nonetheless, the lack of targeted search effort at many of these sites increases uncertainty.

Following the previous status report (Gendron 1999), McDaniel *et al.* (2009) conducted searches for the Mudpuppy at seven sites along the Sydenham River in the Great Lakes region. Fish surveys conducted by Craig *et al.* (2015) along the Detroit River for 10 years resulted in incidental catches of 411 individuals at different life stages (total length ranging from 37 to 392 mm). Since 1999, weekly counts have been done in the wadable area of Kemptville Creek immediately below the dam at Oxford Mills, Ontario, from mid-October until spring high water (Schueler pers. comm. 2021).

HABITAT

Habitat Requirements

Gendron (1999) provides a thorough description of Mudpuppy habitat requirements, which are briefly summarized below. New or confirmatory evidence regarding Mudpuppy habitat published since then is included with references.

The Mudpuppy occupies permanent aquatic habitats, including both clear and turbid water in lakes, reservoirs, canals, ditches, and streams (Petranka 2010). It is absent from ephemeral water bodies and from small ponds that dry up or freeze. The species uses a variety of substrates (including rock, gravel, sand, and mud) but appears to be intolerant of heavy siltation. It prefers areas with an abundance of refuges and retreats (Matson 2005). Scarcity of shelters may explain the absence of the Mudpuppy from rivers or stream sections that lack this critical habitat component (Sutherland *et al.* 2020). Based on the limited available information, home ranges may be approximately 100 m^2 in size. Although the Mudpuppy does not hibernate, spring migrations have been observed from deep water toward the shore. Adults prefer well-aerated waters downstream from, or at the sides of, riffles, but they avoid high flows. Individuals have been captured at depths as great as 27 m in Lake Michigan (Reigle 1967) and 17 m in Lake Erie (Pfingsten and White 1989).

Breeding takes place in shallow water. Eggs are deposited on the roof of a small cavity dug under rocks, tree trunks, planks, and other debris. Nests are usually located near riffles at a depth of 50 to 200 cm but may be closer to the surface. Larvae and juveniles are rarely observed in association with adults, appearing to prefer deeper water with slow current and gathering under flat rocks in pools (Beattie *et al.* 2017). In Ontario and Quebec, young individuals have been found in shallow water among leaves and under flat rocks on the bottom of creeks, streams, and ponds. Matson (1990) found large numbers in substrate in pools in the Grand River, Ohio, where silt and organic debris had accumulated to a minimum thickness of several centimetres. Later in their development, juveniles are found under shelters not occupied by adults or predatory fish in portions of streams that are free of organic debris.

Habitat Trends

The Mudpuppy occurs in 14 of 17 identified Areas of Concern (AOCs) under the 1987 Great Lakes Water Quality Agreement (ECCC 2017a). Three AOCs have since been restored through recovery measures (as of 2016), and two others are currently in recovery (ECCC 2017b). Considerable progress has been made in reducing the discharge of toxic municipal and industrial effluents into the Great Lakes–St. Lawrence system (ECCC 2017b). The long-term trends for contaminants such as PCBs show a decline over the past 40 years in the Great Lakes; however, generally little to no change has occurred over the past 10 years (ECCC and US EPA 2021).

The overall status of toxic chemicals in the Great Lakes is rated as “Fair” and “Unchanging,” as is the overall status of wildlife habitat (ECCC and US EPA 2021). Notably, while aquatic habitat connectivity has been improving across the Great Lakes, it is still rated as “Fair” (Lakes Superior and Erie) or “Poor” (Lakes Michigan, Huron, Ontario) (ECCC and US EPA 2021). Harmful algal blooms are increasing in frequency, distribution, and severity, and are adversely impacting ecosystem health (ECCC and US EPA 2021). The status and trends for the Great Lakes area are as follows: Lake Erie - “Poor” and “Unchanging,” Lake Ontario - “Fair” and “Improving,” Lake Huron - “Fair” and “Unchanging,” and Lake Superior - “Good” and “Unchanging” (ECCC and US EPA 2021). An assessment of human activities, environmental factors, and freshwater fish biodiversity in 953 tertiary watersheds in Canada reveals that watersheds occupied by *Mudpuppies* are subjected to considerable anthropogenic stress and are considered “critical” in terms of conservation priority (Chu *et al.* 2015; Ontario Biodiversity Council 2015).

In the *Overview of the State of the St. Lawrence 2019* (Working Group on the State of the St. Lawrence Monitoring 2020), the overall health of the St. Lawrence River is assessed as “moderate-good,” with 5 of 14 indicators measured between 2014 and 2019 showing positive improvements, 9 remaining stable, and none showing deterioration. However, the percentage of natural areas found within a 100 m riparian buffer declined in the Montreal Region and the Yamaska River sub-watershed. Agricultural activities have exacerbated siltation and eutrophication in several tributaries of the St. Lawrence River in Quebec (Gendron 1999; Patoine and D'Auteuil-Potvin 2013). In many sections of watercourses, siltation has reduced the availability of shelters for the Mudpuppy and other species (Gendron 1999). Siltation and turbidity also pose a primary threat to the endangered Salamander Mussel and other at-risk mussel species in southwestern Ontario, both directly by reducing habitat quality and indirectly by reducing access to Mudpuppy nesting and refuge sites (DFO 2019). Nutrient loads and agricultural inputs, including pesticides, have also been identified as threats to the Salamander Mussel and other aquatic organisms (DFO 2019). Changes in the water level of the Sydenham River and potentially other rivers in southwestern Ontario could also affect Mudpuppy subpopulations (Boles pers. comm. 2018).

BIOLOGY

The biology of the Mudpuppy in Canada is poorly understood, with limited information available on subpopulations in the St. Lawrence River, the Ottawa River, and the Great Lakes basin. However, Gendron (1999) and Petranka (2010) provide an overview of the species' biology across its global range, which is summarized below. New or confirmatory evidence regarding Mudpuppy biology published in the intervening years is also included with references.

Life Cycle and Reproduction

Breeding is aquatic and occurs in late September and October in New York State, though the presence of adult aggregations in reproductive condition in February and April suggests that there is a second breeding season in late winter/early spring in some subpopulations. In Pennsylvania, New York, and Ontario, egg laying takes place mainly between mid-May and June. Mudpuppy nests contain 18 to 180 eggs. Mudpuppy fecundity, estimated based on the number of vitellogenic oocytes in the gonads of the female, varies between 11 and 217 oocytes, depending on the site and female body size. After egg laying, the female remains with her clutch, using the nest cavity until the eggs hatch. The duration of the embryonic stage depends on water temperature, with incubation lasting between 38 and 68 days, and hatching occurring between July and August in northern populations. Larvae emerge at an average total length of 22.5 mm (range: 18 to 25 mm) with yolk reserves clearly visible. They remain in the nest cavity for at least six to eight weeks until the yolk sac has been absorbed, after which they seek shelter under objects in the stream channel (Matson 2005). The Mudpuppy is mainly nocturnal and tends to avoid exposure to sunlight. Adults seek out deep, cold water during summer. The species is active throughout the winter, with an increase in activity during the coldest months (Figure 6A).

In Canada, females reproduce for the first time when they reach a total length of 190 to 250 mm, or between 7 and 10 years of age (Gendron 1999). The age structure of Mudpuppy subpopulations varies among individual subpopulations. A subpopulation in the Ottawa River system was found to comprise 6- to 16-year-olds (mean age of 10), while one in the St. Lawrence River system included individuals 5 to 26 years old (mean age of 14) (Gendron 1999). The age structure of the Sydenham River subpopulation is dominated by 6- to 10-year-olds, whereas individuals at Long Point (Lake Erie) and in the Detroit River are older, with more individuals in the 11- to 15-year and 16+ year age classes (McDaniel *et al.* 2009). Mudpuppy life expectancy is at least 34 years (Petranka 2010). Individuals older than 20 years were captured at 11 sites in Ontario and Quebec, with the oldest a 34-year-old male, suggesting that the reproductive period extends beyond 25 years (Gendron 1999). Considering that in Canada Mudpuppies first reproduce around age 8, and that the oldest wild-captured breeding specimens are over 25 years old, the species' generation time is estimated to be 15 years.

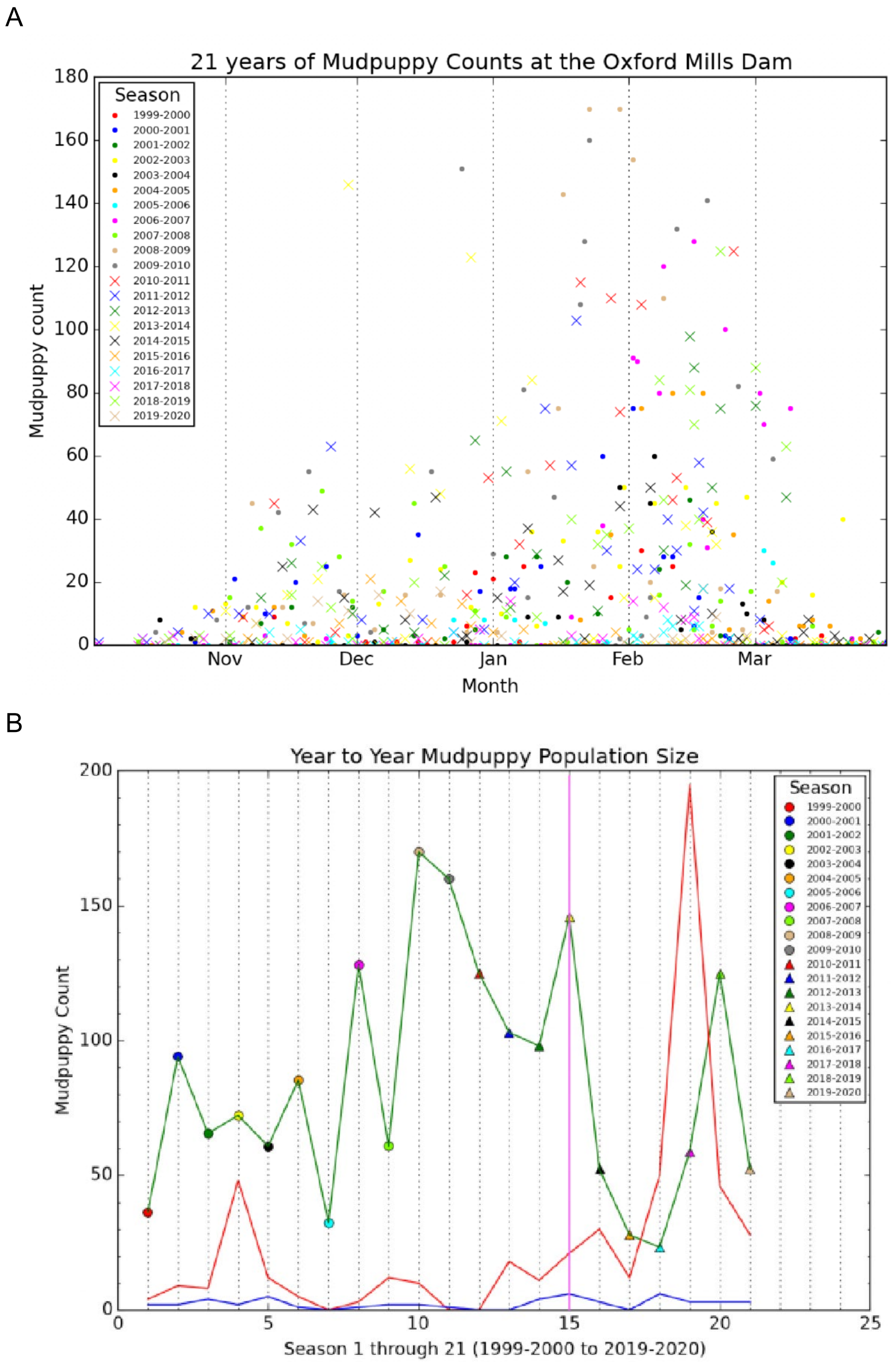

Figure 6. Mudpuppy counts at the Oxford Mills dam on Kemptville Creek, Oxford Mills, ON, 1999 to 2020. Weekly total counts (A) and estimated yearly Mudpuppy population size after accounting for the flow coefficient (green line: (B). The Crayfish (red line: B) to the left of the vertical magenta line in 2013 are native species *Orconectes virilis*. To the right of the magenta line is a combination of *O. virilis* and hybrid *O. rusticus/propinquus*. The blue line represents Northern Pike, *Esox lucius*, for comparison, as its presence appears unrelated to changes in crayfish numbers (Zieleman 2020).

Physiology and Adaptability

Beattie *et al.* (2017) found that Mudpuppy capture rates in Lake Michigan were very low at temperatures above 14.1°C during fall and winter, suggesting that optimal and preferred temperatures are considerably lower than 15°C. Critical thermal maxima range from 32 to 35.5°C when acclimated at 5, 15, and 25°C; these values are lower than for most salamanders and similar to those for cold mountain stream species (Hutchison and Rowlan 1975). Aquatic respiration is responsible for more than 90% of the total volume of oxygen and carbon dioxide exchanged, although Mudpuppies can survive for 5 to 11 days at 20°C in almost anoxic water by means of pulmonary respiration. Among salamanders, this species also has the greatest hemoglobin–oxygen affinity (Weber et al. 1985), giving it the ability to absorb oxygen more efficiently from poorly aerated environments. The Mudpuppy may be able to shunt blood to the appropriate respiratory organs (skin, gills, lungs), depending on the oxygen tension of the water.

The range of pH tolerated by the Mudpuppy has not been determined, but the species is believed to be absent from typically acidic environments and peat bogs (Gendron 1999). The species is reportedly absent from the poorly buffered lakes of northern Quebec and Ontario, where the pH commonly reaches values below 5.0. At Mudpuppy capture sites in the St. Lawrence and Ottawa River basins, pH varied between 6.8 and 8.2. The species does not inhabit salt water or brackish water, but observations of Mudpuppy in tributaries of the St. Lawrence River estuary raise the possibility that it may be able to survive dispersal movements in salt water (Gendron 1999).

As noted above (see **Global Range**), Mudpuppy subpopulations have been established following accidental releases from laboratory stock in Maine, Massachusetts, New Hampshire, and Rhode Island (NatureServe 2021b). A genetic analysis by Greenwald *et al.* (2020) suggests that, at least for the Connecticut River subpopulation in Massachusetts, individuals are most closely related to Mudpuppies from Minnesota. Thus, some evidence supports the feasibility of transplanting individuals from wild stock and, possibly, from artificially reared individuals. However, captive breeding protocols for *Necturus* spp. are not well established and there are sparse reports of successful reproduction in captivity for the Mudpuppy in particular (Stoops *et al.* 2014).

Dispersal and Migration

Mudpuppy movement patterns, to the extent that they are known, have been previously described (Gendron 1999). Given that this salamander is entirely aquatic, recolonization of suitable habitats that are not hydrologically connected is unlikely. Dams may create barriers to gene flow, and high flows, opposing currents, insufficient water depth, and the temporary drying of water bodies are all factors that hinder dispersal and have the potential to isolate subpopulations (Mills and Hill 2016). The Mudpuppy is widespread throughout the connected lakes and river systems in the Great Lakes / St. Lawrence DU. There is currently no evidence for fragmentation; however, genetic studies have yet to be performed at a resolution that would allow the estimation of gene flow across recent anthropogenic barriers. The state of fragmentation for Mudpuppy subpopulations in the Manitoba DU is unknown due to a lack of sampling effort. However, the absence of recent observations in western Manitoba suggests the potential for increasing isolation of some subpopulations in the region.

Interspecific Interactions

The Mudpuppy is a generalist and opportunistic predator that feeds on a variety of benthic organisms (Beattie *et al.* 2017). The Mottled Sculpin (*Cottus bairdii*) was historically a preferred prey of Mudpuppy; however, the proportion of sculpins in the species' diet has declined rapidly with the arrival of Round Goby (*Neogobius melanostomus*), which is consumed opportunistically when available in Mudpuppy habitat (Craig *et al.* 2015; Beattie *et al.* 2017). Various invasive species, including the Round Goby, Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena rostriformis bugensis*), have been found in Mudpuppy stomach contents. Mussels are consumed less frequently, probably owing to their hard shells (Beattie *et al.* 2017). The Mudpuppy, including its eggs and larvae, is preyed on by a wide variety of vertebrates and invertebrates in freshwater ecosystems.

As noted above (**Special Significance**), the Mudpuppy plays a vital ecological role as the only known host of the endangered Salamander Mussel (COSEWIC 2001; DFO 2019). The mussel's glochidia (larvae) attach themselves to the salamander's gills for the duration of their larval development. In Canada, the Salamander Mussel is currently found in only one locality on the Sydenham River, which is also occupied by the Mudpuppy (McDaniel *et al.* 2009) (DFO 2019) (Figure 7).

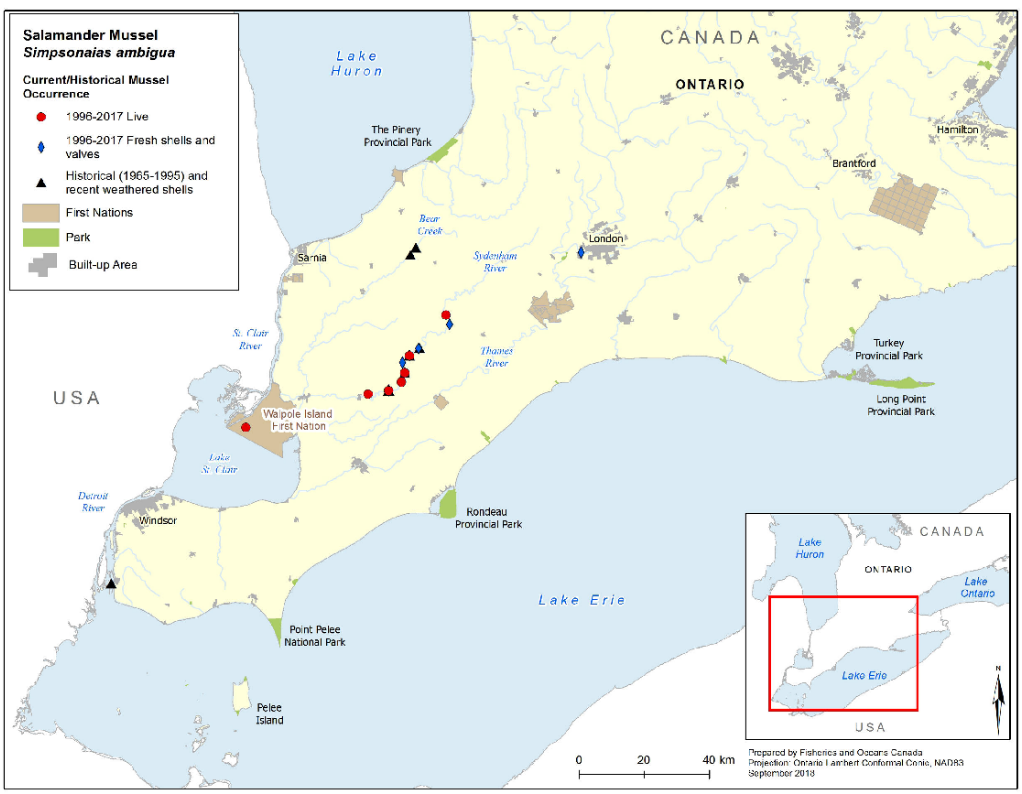

Figure 7. Distribution of the Salamander Mussel (*Simpsonaias ambigua*) in Canada (DFO 2019).

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Manitoba DU

No coordinated search effort for the Mudpuppy has been made in Manitoba, and all 15 recent observations (four entries in iNaturalist.org and 11 from the MHA) reflect incidental encounters (MHA 2018; iNaturalist.org 2023b).

Great Lakes / St. Lawrence DU

There are few quantitative data on Mudpuppy subpopulations in this DU. Most of the information available comes from anecdotal sightings and incidental catches (see **Search Effort**). The sampling effort and methods used to estimate catch per unit of effort (CPUE) in Canadian populations are summarized below.

Bonin *et al.* (1995) used Mudpuppies taken as bycatch by fishers during winter and spring along the Ottawa and St. Lawrence rivers for toxicological research. Four individuals from the Ottawa River were collected in 1988, and 37 specimens were collected from 12 sites along both rivers in 1990. An additional 12 mature females were "easily obtained" using baited minnow traps at one site each on the Ottawa and St. Lawrence rivers in winter 1992 (Bonin *et al.* 1995).

In the early 1990s, adult Mudpuppies was collected at nine locations (five in the Ottawa River system and four in the St. Lawrence River system) for physiological research (Gendron *et al.* 1997). Individuals were trapped using baited minnow traps (opening enlarged to 2.5 cm) from January to March, with traps set overnight and checked in the morning. The number of traps per site ranged from 20 to 50 (Gendron 1999). Forty adults (20 males, 20 females) were captured at each of the nine sampling sites (360 in total) for use in acute stress experiments in 1992–1993. Two sites were sampled in the Ottawa River system in 1995 for further stress experiments, with 60 individuals per site reported captured (120 total) (Gendron *et al.* 1997). Mean CPUE ranged from 0.3 to 2.6 individuals per trap per night (Gendron 1999).

In 1995, Mudpuppy trapping was conducted at Lake St. Clair (two sites), Long Point (one site), and the Detroit River (one site) using modified funnel-type minnow traps (openings widened to 6.0 cm) baited with dead fish (McDaniel *et al.* 2009). Fifty traps were set per site, 5 to 10 m apart, for a single night (Long Point) or two consecutive nights (Lake St. Clair and Detroit River). CPUE was 0.113 at Lake St. Clair, 0.69 at Detroit River, and 0.60 at Long Point (McDaniel *et al.* 2009). Three years (2014–2016) of Mudpuppy trapping were conducted by the U.S. Fish and Wildlife Service, the USGS, and Herpetological Resources and Management in Lakes Huron, Erie, and St. Clair, as well as along the St. Clair, Huron, and Detroit rivers (Stapleton *et al.* 2018). Setlines and minnow traps were used. The minnow traps had a CPUE of 0.0074 ± 0.0014 and setlines had a CPUE of 0.0014 ± 0.0022. The detection probability was 0.21 for minnow traps and 0.60 for setlines (Stapleton *et al.* 2018).

Mudpuppy sampling was conducted at seven sites along the Sydenham River in late November to March 2002 (40 traps set each evening approximately 5 m apart on the river bottom for three consecutive nights and checked the following day) and more intensively at two sites (30 traps per site for 15 trap nights) late November to March 2003 (McDaniel *et al.* 2009). CPUE in 2002 was 0.130 overall (range: 0 to 0.17) and 0.042 overall in 2003 (range: 0.033 to 0.055) (McDaniel *et al.* 2009).

During 10 years of fisheries sampling on the Detroit River (2003–2014), Craig *et al.* (2015) recorded juvenile and adult Mudpuppy bycatch with fyke nets (occurrence frequency 10%), baited minnow traps (8.8%), and setlines (18%). Young-of-the-year were also captured on egg mats which they used as refugia (occurrence frequency 16.7%), and adults were observed using cement anchors as refugia (8.8%), as well as a nesting site on two occasions (Craig *et al.* 2015).

As noted above (**Search Effort**), since 1999 Mudpuppy counts have been done in Oxford Mills, Ontario, on Friday evenings, from the Friday after Thanksgiving (second Monday in October) until spring high water (Schueler pers. comm. 2021). Visual encounter surveys are conducted in Kemptville Creek immediately below the dam at Oxford Mills; they begin at approximately 20:00 hrs and cover the wadable area (approximately 0.001 km^2, depending on water flow and ice cover) (Schueler pers. comm. 2021).

Abundance

Manitoba DU

Unknown. Although data are sparse and incidental, multiple individuals are occasionally mentioned in reports. One report in 2011 documented the presence of more than five individuals, and one in 1990 documented simultaneous observations of more than four individuals (MHA 2018). Fisheries bycatch reports from 2010 to 2014 in Lac du Bonnet ranged from one to four individuals per day (Watkins pers. comm. 2023).

Great Lakes / St. Lawrence DU

Unknown. Mudpuppy subpopulations have declined in several parts of the Great Lakes region (Pfingsten and White 1989; Mifsud 2014; Harding and Mifsud 2017). In Ontario, 25 Mudpuppy reports documented more than 100 individuals, including records of 300 and 1,000 individuals observed in 2012 (ORAA 2017). In Quebec, experimental catches using baited traps yielded up to 166 individuals over three days in a single stream in 1995 (BORAQ 2018). Reports from anglers generally mention about 10 individuals observed locally (BORAQ 2018). Gendron (1999) reported that at highly successful trapping sites on the Ottawa and St. Lawrence rivers, up to 500 adult-size individuals could be removed from a sampling site during a short sampling period without a perceptible decrease in CPUE. Year-to-year Mudpuppy count maxima at Oxford Mills range from lows of 20 to 50 individuals to highs upwards of 150 to 170 individuals counted on a single night in an area smaller than 0.001 km^2 (Zieleman 2020; Schueler pers. comm. 2021).

Documented mass mortality events in the Great Lakes region may provide some insight into abundance. Mean ± SD estimated mortality per event from 2000 to 2019 in the region was 962 ± 2,560 individuals (Table 1). For mass mortality events documented on the Canadian shores of Lake Erie and Lake Huron, mean ± SD estimated mortality per event was 1,019 ± 1,206 individuals over a 12-year period (2000 to 2012) (Table 1). Estimated total mortality on the Canadian shores of Lake Erie over this 12-year period was between 4,115 and 6,115 individuals. Note that this total consists solely of documented mass mortality events. The largest Mudpuppy mortality event was documented in Lake Erie from June to October 2002, when 5,000 dead individuals were found along the eastern half of the lake on both the northern (Canada) and southern (US) shores—estimated total mortality was 20,000 (WHISPers 2002). In sum, this species can likely reach high local densities, and is present throughout much of a broad geographic area spanning the Great Lakes, St. Lawrence River, and Ottawa River systems. While currently available data are insufficient to estimate the total number of mature individuals in this DU, it is extremely unlikely to be close to or fewer than 10,000 individuals.

Table 1. Mudpuppy mass mortality events reported from popular media, grey literature, government websites, and social media, from 2000 to 2019. This table does not include a survey of primary (scholarly) literature.

Date	Location	No. reported	Min No.	Max No.	Mean N	Cause of Death (COD)	COD confirmed?	Source
24-July-2000	Ontario County, New York	9	9	9	9	Unknown	NA	1
11-Sept-2000	Lake Erie, ON (Crystal Beach)	“thousands”	2000*	3000*	2500*	Type E botulism	Suspected	2.
23-Aug-2001	Lake Erie, ON (between Port Maitland and Port Dover)	5	5	5	5	Type E botulism	Suspected	2
Jun – Oct, 2002	Lake Erie, PA (Erie)	5000 to 20000	5000	20000	12500	Botulism	Suspected	3
NA-Nov-2005	Lake Huron, ON (2 locations: Huron Sands Rd, Bayfield)	No value	NA	NA	NA	Type E botulism	Suspected	2
NA-Jun-2006 (late)	Lake Erie, ON (lower reaches of Detroit River, Amherstburg)	“thousands”	2000*	3000*	2500*	*Edwardsiella piscicida*/*tarda*	Confirmed	4
23-Jun-2006	Wayne County, MI	1 to 1000	1	1000	500	Chytridiomycosis, parasitism	Suspected	5
04-July-2006	Lake Erie, ON (Holiday Beach)	128	128	128	128	*Edwardsiella piscicida*/*tarda*	Suspected	6
19-July-2008	Lake Erie, NY (4 locations: Point Gratiot, Sunset Bay, State Park, Sturgeon Point)	No value	NA	NA	NA	Type E botulism	Suspected	7
09-Oct-2009	Lamoille River, VT (downstream of Peterson Dam)	512	512	512	512	Lampricide treatment	Confirmed	8
21-Jun-2010	Lake Erie, ON (Mohawk Island)	No value	NA	NA	NA	Type E botulism	Suspected	2
Jul – Aug, 2010	Douglas, MN	1000	1000	1000	1000	Unknown	NA	10

Date	Location	No. reported	Min No.	Max No.	Mean N	Cause of Death (COD)	COD confirmed?	Source
28-July-2010	Lake Erie, ON (Haldimand, east of Grand River mouth)	100	100	100	100	Unknown	NA	11
30-Aug-2010	Lake Erie, ON (Nickel Beach)	20	50	100	75	Type E botulism	Suspected	23
31-Aug-2010	Lake Erie, ON (Point Abino)	10	10	10	10	Type E botulism	Suspected	2
May-Jun, 2012	Becker County, MN	7 – 1000	7	1000	504	Unknown	NA	12
30-Oct-2012	Niagara, NY	121	121	121	121	Unknown	NA	13
NA-Nov-2012	Lake Huron, ON (Sarnia)	1000	1000	1000	1000	Hurricane Sandy	Suspected	14
NA-Nov-2012	Lake Huron, MI (Fort Gratiot)	40	40	40	40	Hurricane Sandy	Suspected	14
NA-Nov-2012	Lake Huron, MI (Lakeside Beach)	50	50	50	50	Hurricane Sandy	Suspected	14
Jun – Aug, 2014	Becker County, MN	200	200	200	200	Unknown	NA	15
Jul – Aug, 2016	Becker County, MN	12	12	12	12	Anemia	Suspected	16
12-Jul-2017	Becker County, MN	20	20	20	20	Unknown	NA	17
NA-Apr-2018	Lake Huron, MI (Saginaw Bay)	“several dozen”	24*	36*	30*	Storm activity and heavy wave action	Suspected	18
21-Jun-2018	Otter Tail County, MN	1106	1106	1106	1106	Bacterial infection (multisystemic)	Suspected	19
27-May-2019	Becker County, MN	1 to 200	1	200	200	Unknown	NA	20
NA-Jun-2019 (early)	Oakland, MI	15 to 30	15	30	23	Parasitism (nematode, trematode)	Confirmed	21
15-Jul-2019	Otter Tail County, MN	7	7	7	7	Septicemia	Confirmed	22

*Values represent minimum conservative interpretation of verbal reporting; e.g., “thousands” is interpreted as a minimum of 2,000, and a maximum of 3,000.

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Fluctuations and Trends

Manitoba DU

Unknown, but the absence of incidental observations near the Saskatchewan border since 1997 raises concern over a potential decline (or even extirpation) in Mudpuppy numbers in this part of the Assiniboine River system.

Great Lakes / St. Lawrence DU

Unknown. Circumstantial evidence suggests that, historically, large Mudpuppy subpopulations may have existed in the Great Lakes. Milner (1874) suggests that in Michigan, Mudpuppies are "very numerous in some of the streams and portions of the lakeshore" (Milner 1874, p. 62), and based on seine net samples, he provides a density estimate of 4 salamanders per square rod (approximately 1 salamander per 6 m^2) at a site on the Detroit River, near Ecorse, MI. The same report states that a fisherman set 900 hooks near Evanston, IL, and caught 500 individuals over the course of one day. Other qualitative reports published since the early 20th century also underscore local Mudpuppy abundance (reviewed in Gendron 1999). Further, it is notable that the Salamander Mussel has evolved a strategy in which its larvae attach exclusively to the gills of Mudpuppies to complete their larval development. The Mudpuppy is the sole host of the Salamander Mussel. Both theory (Poulin 2007) and data (Svensson-Coelho *et al.* 2016) suggest that host specialization evolves when the host resource is predictable, which in the present case would likely equate to large, stable Mudpuppy population sizes. Theory also suggests that the coextinction of a host and parasite is more likely when the parasite is a specialist

(Dunn *et al.* 2009; Lafferty 2012). A substantial decline in Mudpuppy abundance over the last century may help to explain why the Salamander Mussel is federally listed as Endangered in Ontario (COSEWIC 2001) and is considered imperilled throughout most of its southern range (Roe 2003).

At sites where CPUE data were collected between 1992 and 1995, mean CPUE values remained stable or increased over time (Gendron 1999). Surveys conducted on the Sydenham River in 2002 gave CPUE values lower than those reported for other sites in Ontario surveyed in the 1990s using similar methodology. CPUE values for the Sydenham River ranged from 0 to 0.17 Mudpuppy individuals per trap night, while CPUEs from Lake St. Clair, the Detroit River, and Long Point in 1995 were 0.113, 0.69, and 0.60, respectively (McDaniel *et al.* 2009). Sutherland (2019) reported 0.03 and 0.06 individuals per trap night in Lake St. Clair and the Detroit River during April and May, 2014 to 2016.

Since the late 1990s, records of the species in Ontario have almost doubled, largely due to the observation activities organized at Oxford Mills and increased voluntary reporting through provincial atlases (Gendron 1999; Schueler 2014; ORAA 2017).

Globally, the Mudpuppy's distribution is extensive, and its status is secure (G5). However, the species' status in the United States varies substantially from state to state, ranging from extirpated or critically imperilled to secure (NatureServe 2021b). Populations along the Mississippi River in Iowa have declined or are extirpated (Christiansen 1998; Walley 2002), and declines have been reported in Lake Erie and in certain areas of the Great Lakes (reviewed in Gendron 1999). Currently, the species is reported to be absent from the Lake Ontario basin in New York State (Hunsinger 2001), although it was abundant there in the 1930s (Bishop 1941). According to several reports, Mudpuppy populations have declined substantially in several areas in the Great Lakes region, including sections of the Detroit River (King *et al.* 1997; Faisal 2006). In the early 1920s, the annual harvest of this species could reach 2,000 individuals in Sandusky Bay (eastern Lake Erie) in the United States; however, efforts made between 1979 and 1984 to locate the species in that area indicate that its numbers had declined considerably (reviewed in Gendron 1999).

There is some evidence of decline in subpopulations on the Canadian side of the Great Lakes and St. Lawrence River systems (reviewed in Gendron 1999). Records dating back to 1928 for Hamilton Bay and Dundas Marsh at the western end of Lake Ontario indicate that the species was formerly present; however, no individuals were captured in Hamilton Harbour during surveys conducted in 1995. Similarly, the Mudpuppy was found in the upper Richelieu River as far as Lake Champlain prior to 1970, but no captures by commercial fishers have been reported since 1995. The species was commercially harvested in Lake Erie and Lake Ontario and exploited by biological supply companies (Holman 2012). The absence of recent IAO cells along the western halves of northern lakes Erie and Ontario is notable (Figure 5b).

An estimated 13,368 to 32,586 individuals died between 2000 and 2019 during mass mortality events in the Great Lakes region (Table 1). Most of these mortality events are suspected to be linked to Type E botulism, but extreme weather and lampricide use have also been implicated. It is unclear whether losses of this magnitude represent a conservation concern or are in line with natural mortality of Mudpuppy. Life history theory suggests that delayed maturity and a long lifespan evolve when natural adult mortality is low (Roff 1992). This suggests that the cumulative effects of mass mortality on this species' population viability is cause for concern. However, at least one 19th century author noted a mass mortality event in June in the Grand River (Ontario or Ohio), where Mudpuppy carcasses lined the shore "by the hundreds" (Milner 1874). While such die-offs clearly establish a decline in the number of individuals in a population, without an estimate of population size it is not possible to estimate the relative magnitude of the decline or fluctuation.

Episodes of anoxia reported since 2001 are believed to be responsible for the absence of Mudpuppies during several visits to the Oxford Mills site (Schueler 2014). However, consistently low Mudpuppy numbers were recorded from winter 2014/2015 until winter 2018/2019, when "normal" numbers were observed (Schueler pers. comm. 2019). Maximum seasonal counts (green line), corrected for differences in water flow (Mudpuppies are not detectable below the dam during excessive flow), show no specific trend in population size (Figure 6B, Zieleman 2020).

Rescue Effect

Manitoba DU

While Manitoba shares the Red River Basin with North Dakota and Minnesota, it is unclear whether a rescue effect from U.S. Mudpuppy populations is plausible given the paucity of observations in either jurisdiction.

Great Lakes / St. Lawrence DU

Native Mudpuppy populations in the United States adjacent to Canadian populations are either vulnerable (Minnesota, Michigan, New York, Pennsylvania), imperilled (Vermont), or exotic (New Hampshire, Maine), except those in Ohio (apparently secure) (NatureServe 2021b). Because the Great Lakes and some water bodies occupied by the species are interconnected and straddle the border with the United States, Canadian subpopulations are likely in contact with American subpopulations. As the Mudpuppy is strictly aquatic, any rescue from the United States is restricted to watersheds that overlap the border (Mills and Hill 2016).

The potential for natural migration between Canadian populations and from American subpopulations to Canadian subpopulations appears to exist over short geographic distances within an interconnected hydrographic system where connectivity is not hindered (dams, falls, inhospitable habitats, etc.). Temporary streams that form during heavy rains can offer dispersal opportunities for aquatic salamanders occupying permanent habitats such as otherwise isolated rivers and lakes (Schalk and Luhring 2010). In the event of a catastrophic loss in Canada, Mudpuppy subpopulations in Michigan, Ohio, Pennsylvania, or New York could provide a potential source of individuals.

THREATS AND LIMITING FACTORS

Several aspects of the Mudpuppy's life history, including its carnivorous diet, longevity, and late sexual maturity, make it vulnerable to human disturbances and susceptible to long-term accumulation of lipophilic toxic substances (Gendron *et al.* 1997). In this species, most persistent contaminants are stored in the liver or transferred to, and trapped in, growing oocytes (Bonin *et al.* 1995). Because embryonic development lasts more than a month and is followed by a long period during which the larva feed on yolk reserves, the species is exposed to maternal contaminants for a long period (Gendron 1999). The Mudpuppy's strictly aquatic life and sedentary nature make it particularly sensitive to the degradation of its environment, random weather events and climate change, from which it cannot escape. However, the impacts of climate change on habitat shifting and alteration, temperature extremes, and storms and flooding have not been studied for this species. Therefore, the threat posed by climate change is considered pervasive in scope and ongoing, with an unknown impact.

The direct threats to the Mudpuppy assessed in this report are organized and evaluated based on the IUCN-CMP (International Union for the Conservation of Nature–Conservation Measures Partnership) unified threats classification system (Master *et al.* 2009). Threats are defined as the proximate activities or processes that directly and negatively affect the population. Assessments by a panel of experts of the impact, scope, severity, and timing of threats are presented in Appendices 1 and 2. The overall calculated and assigned threat impacts for both Mudpuppy DUs are high (projected decline 10% to 70% over three generations).

Threats: Great Lakes / St. Lawrence

When applied to the Great Lakes / St. Lawrence DU, the IUCN Threats Calculator yielded an overall threat impact of "high," based on a "high-medium" impact from Pollution (threat 9), particularly Agricultural & Forestry Effluents (threat 9.3) as well as Domestic & Urban Wastewater (threat 9.1), and a "medium-low" impact from Natural System Modifications (threat 7), particularly Dams & Water Management/Use (threat 7.2) and Other Ecosystem Modifications (threat 7.3) (Appendix 2). Other threats that scored low, but that could exacerbate the main threats included Residential & Commercial Development (threat 1), particularly Housing & Urban Areas (threat 1.1), Biological Resource Use (threat 5), particularly Fishing & Harvesting Aquatic Resources (threat 5.4) and Industrial &

Military Effluents (threat 9.2). In addition, Invasive Non-native/Alien Species (threat 8.1), Problematic Native Species (threat 8.2), and increased frequency and intensity of Storms and Flooding associated with climate change (threat 11.4) also threaten the species, but their severity is largely unknown (Appendix 2). Threats are discussed below in their perceived order of importance. The length of the discussion reflects the amount of available literature as much as relative impact.

<u>Pollution (Category 9): Threat impact High-Medium</u>

Chemical water pollution and siltation have reduced habitat suitability for the Mudpuppy in several regions and have contributed to declines in the size of Mudpuppy populations in the U.S. (Matson 2005). Mudpuppy subpopulations in Canada, particularly in the Great Lakes, the St. Lawrence River, and their tributaries, are exposed to high levels of contaminants (see the **Habitat Trends** section for details on the status of pollution in the Great Lakes and St. Lawrence River systems).

<u>Agricultural & Forestry Effluents (9.3): Threat impact High-Medium</u>

Trend

Pesticide concentrations remain stable and below water quality guideline values in the St. Lawrence River at Quebec City (Working Group on the State of the St. Lawrence Monitoring 2020). However, annual loads of phosphorus, nitrogen, and suspended solids remain at or above water quality criterion thresholds across 12 sampling sites on Lake St. Pierre (the largest wetland and fluvial lake in the St. Lawrence River system and a UNESCO World Biosphere Reserve) measured between 2009 and 2012. Furthermore, more recent data (2015 to 2017) indicate an ongoing issue of high annual nutrient loads. Tributaries on the south shore are characterized by watersheds with widespread, intensive agricultural land use (Working Group on the State of the St. Lawrence Monitoring 2020). Nutrient conditions are also deteriorating over the long term (from about 1970 to 2017) in the Great Lakes, with conditions currently rated as “Fair” (ECCC and US EPA 2021). While nutrient concentrations in Lake Superior are stable and meet objectives, offshore phosphorus concentrations have fallen below objectives in Lakes Michigan, Huron, and Ontario, indicating poor lake productivity. In addition, some nearshore areas in all three lakes show elevated concentrations of nutrients (including phosphorus) which may be supporting nuisance algae growth. Lake Erie consistently exceeds phosphorus objectives and experiences both harmful (western and parts of the central basin) and nuisance (eastern basin) algal blooms (ECCC and US EPA 2021).

Impact

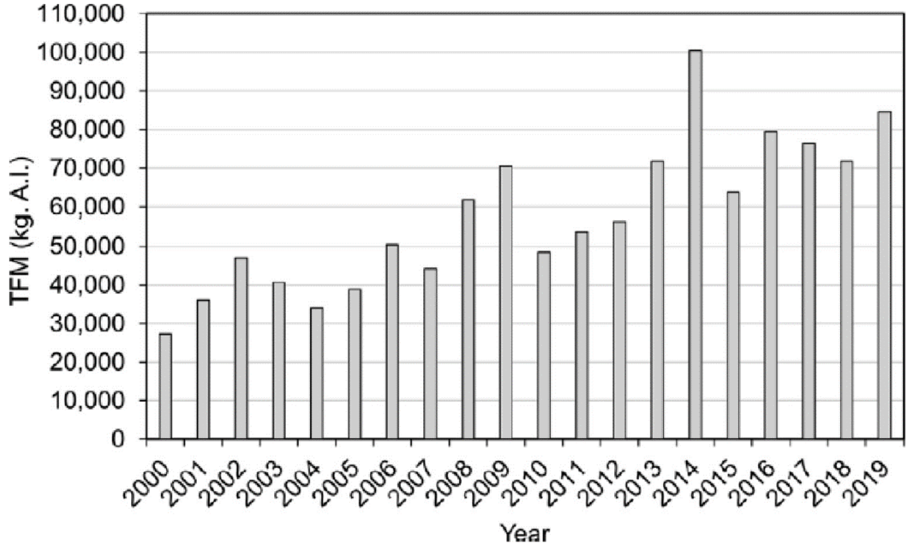
As reviewed in Gendron (1999), silting of watercourses reduces Mudpuppy access to benthic shelters that are used for nesting and as refuges. Alteration of rivers and streambeds can also reduce the availability of food resources for *Necturus*. Certain tributaries of the St. Lawrence where the Mudpuppy is absent, particularly the Yamaska River and the Noire River in Quebec, are heavily degraded by siltation along most of their length. This is also an issue in the Sydenham River and in other southwestern Ontario rivers (DFO 2016). The timing of egg laying and embryonic development in the Mudpuppy coincides with a period of intensive agricultural activity, which may increase the vulnerability of early life stages to runoff from agricultural land (McDaniel *et al.* 2009). In temperate regions of North America, nitrate concentrations in aquatic environments reach the highest levels in late fall, winter, and spring (Rouse *et al.* 1999), which are important periods for the Mudpuppy (feeding, breeding, egg, and larval development). Nitrate concentrations increase with changes in land use from woodlands to pasture and crop production on arable land (Hooda *et al.* 1997). In wetlands in a vegetable-growing area in Ontario, Bishop *et al.* (1999) concluded that habitat loss and nitrate levels had a greater impact than pesticide use on the survival and diversity of amphibians.

Lampricide use

Trend

The lampricide 3-trifluoromethyl-4-nitrophenol (TFM) has been widely used since 1958 for Sea Lamprey (*Petromyzon marinus*) control in the Great Lakes basin (Sullivan *et al.* 2021). About 200 Great Lakes tributaries are treated at regular intervals with TFM. The Sea Lamprey Control Map shows where TFM is currently used in the Great Lakes system (Great Lakes Commission, n.d.). TFM does not persist in the environment, is rapidly detoxified and photodegrades (Hubert 2003). In the 1960s, the use of powdered niclosamide as an additive (and subsequently a granular formulation called Bayluscide®) allowed for a reduction in the amount of TFM applied (reviewed in Sullivan *et al.* 2021). Average lampricide applications were reduced from 52,904 kg active ingredient (TFM) and 195 kg (niclosamide) across 67 tributaries annually between 1979 and 1989, to 38,698 kg (TFM) and 164 kg (niclosamide) across 55 tributaries annually between 1990 and1999 (Brege *et al.* 2003). However, the reduction in lampricide use resulted in an increase in lamprey numbers, which led to an increase in applications of TFM and niclosamide over the last two decades (Sullivan *et al.* 2021) (Figure 8). As well, the interval between two applications of TFM (3 to 5 years) is significantly shorter than the species' generation time (15 years), and the number of tributaries of the Great Lakes re-treated with lampricides to target surviving lamprey larvae has increased from 0–2 (1999–2000) to 12–15 (2017–2019) in response to a reduction in the effectiveness of treatments (Sullivan *et al.* 2021). Physical barriers are also used to control Sea Lamprey in the Great Lakes (Great Lakes Commission 2019); however, these have the potential to reduce Mudpuppy movements and increase isolation.

A



B

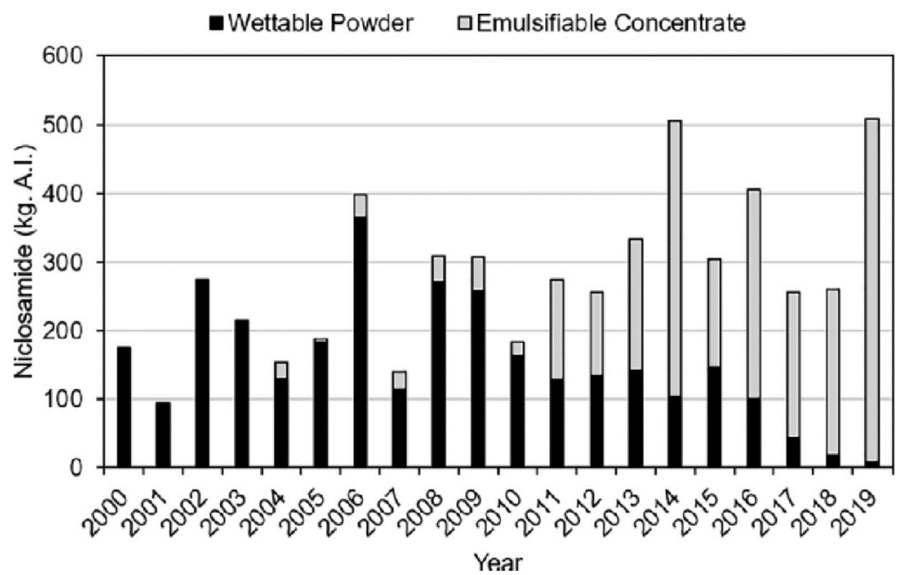


Figure 8. 3-trifluoromethy-4-nitrophenol (TFM) in kilograms of active ingredient (kg A.I.) applied during treatments of tributaries in the Great Lakes (A) and niclosamide (kg A.I.) applied as Bayluscide® wettable powder or Bayluscide® emulsifiable concentrate (B) during lampricide treatments of tributaries to the Great Lakes, 2009–2019 (Sullivan *et al.* 2021).

Impact

In the 1970s and 1980s, Mudpuppy mortalities were reported following lampricide (TFM) applications in 30% of observations from tributaries of lakes Superior and Michigan (Gilderhus and Johnson 1980; Matson 1990) and tributaries of Lake Champlain (Schmidt *et al.* 2004). The magnitude of these mortalities is not known, but hundreds of dead individuals have sometimes been observed along the Serpent River (400 in 1989; 300 in 1993) and the Musquash River (200 in 1989) in Ontario (Ontario Herpetofaunal Summary Database 1998 cited in Gendron 1999). Matson (1990) estimated a decline of at least 29% in the size of a Mudpuppy subpopulation over a one-year period in the Grand River, a tributary of Lake Erie, in Ohio, after lampricide treatment. At the concentrations used in the 1990s, treatments made at or above the minimum lethal concentration for Sea Lamprey did not have a significant impact on Mudpuppy subpopulations (observed NOECs [no observed effect concentrations]) for adults were 1.6 times greater than observed minimum lethal concentrations for Sea Lampreys (TFM alone) and 1.5 times greater in tests with combined TFM/1% niclosamide formulations (Boogaard *et al.* 2003). However, Boogaard *et al.* (2003) noted that applications made during stressful times of the year (mating and spawning) may increase Mudpuppy sensitivity to lampricides. TFM is typically used at critical periods in the Mudpuppy's reproductive cycle, i.e., in fall (October), when spermatophore exchange occurs, and in spring (late April), just before egg laying (Bettoli and Macena 1996). Boogaard *et al.* (2003) tested only adults and pointed out that their results may not apply to juveniles and that, moreover, the mortalities observed during lampricide treatments in New York consisted mostly of juveniles. Similarly, Chellman *et al.* (2017) observed 528 dead individuals post-TFM treatment in the Lamoille River, Vermont, in October 2009. On the basis of body size, they estimated that approximately 70% of the recovered individuals were juveniles (Chellman *et al.* 2017).

<u>Domestic & Urban Wastewater (9.1): Threat impact Medium-Low</u>

Trend

Despite the growth of human populations, and hence the increasing volume of wastewater generated, the quality of municipal effluents has improved in general due to a move towards more secondary and tertiary wastewater treatment plants. Furthermore, there is evidence of a reduction in the toxicity of municipal effluents to aquatic organisms (ECCC 2020). In Ontario, during the period 2002 to 2018, water quality remained unchanged in 69% of tributaries, deteriorated in 14%, and improved in 19%. Recent estimates indicate that toxicity to aquatic animals in Great Lakes tributaries is mainly attributable to non-persistent compounds in surface waters. These include compounds such as organophosphate flame retardants, plasticizers, and pharmaceuticals in municipal effluent releases. Some chemicals associated with industrial activities are also released primarily through municipal wastewater.

Some water quality parameters have deteriorated, as evidenced by increasing chloride levels, which are largely due to road salt use and partly due to effluent releases. Chloride-induced salinization of Great Lakes tributaries, especially in urban areas, has an increasing potential to negatively affect amphibians. This is an existing threat that will continue in the future. However, there is considerable uncertainty about the effects on subpopulations and the average impact across the entire Canadian range.

Impact

Water runoff in urbanized watersheds is a source of contamination and causes siltation which reduces available habitat and reproductive success. For example, in urban areas of southern Quebec, untreated household sewage and urban wastewater may overflow into rivers and natural habitat when the volumes of water to be treated exceed the capacity of treatment plants, due to excessive loads or system malfunction. This causes contamination (fecal coliforms, nitrates, ammonia, heavy metals, etc. and reduced oxygen) and decreases water quality. Scope may be localized, but also large, considering that many watersheds are in urban areas that receive significant amounts of urban runoff and wastewater.

Industrial & Military Effluents (9.2): Threat impact Low

The overall status of toxic chemicals in the water of the Great Lakes (2004–2017) was assessed as “Fair” and “Unchanging” in the *State of the Great Lakes 2019 Technical Report*. This indicates that the concentrations of toxic chemicals exceed ecosystem objectives (or barely meet minimum standards) and that there is no change in the concentration or frequency of detection over time (ECCC and US EPA 2021). The overall status of the St. Lawrence River (2013–2017) was assessed as “Moderate-Good,” indicating an improvement over previous assessments (Working Group on the State of the St. Lawrence Monitoring 2020). Specific contaminants of concern for the Mudpuppy are considered below:

Polychlorinated biphenyls (PCBs) and other organochlorine compounds

Trend

Banned in 1977, PCBs are legacy contaminants that continue to be used illegally and held in storage. Overall PCB levels in the Great Lakes are much lower than in the 1990s, with a decline of over 90% recorded in some cases (De Solla *et al.* 2016). However, PCBs continue to be detected throughout the Great Lakes (ECCC and US EPA 2021). Historical PCB contamination also persists in the southern sector of the St. Lawrence, with concentrations at over 10% of sites exceeding the threshold effect level (i.e., the minimum level at which a toxic response is observed in benthic organisms) (Working Group on the State of the St. Lawrence Monitoring 2020).

Impact

High levels of PCBs and other organochlorine compounds were detected in the ovaries of Mudpuppies captured in winter at various sites in the St. Lawrence River, Ottawa River, and Great Lakes basins in the 1990s (Bonin *et al.* 1995; Gendron *et al.* 1997). Adults from PCB-contaminated sites had an abnormally high prevalence of limb deformities, which are believed to be correlated with contaminant loading (Bishop and Gendron 1998; Gendron 1999). More than half of individuals caught in the Akwesasne area exhibited limb abnormalities, and levels of deformities were 30% in the Detroit River. In comparison, deformities were observed in only 6% of individuals in the Kemptville Creek and 9.5% in the Ottawa River (Gendron 1999; Schueler 1999; Grasman *et al.* 2002). In the Sydenham River, the proportion of individuals with digit deformities was 11% in 2002 and 9% in 2003, with a range from 0% to 23% among different sites (McDaniel *et al.* 2009). However, PCBs were not assessed. In anurans, deformity rates exceeding 5% are considered high (Ouellet *et al.* 2000). Although other environmental factors (e.g., parasites) can cause limb deformities in amphibians, Gendron (1999) suggests that the increase in deformities beyond normal levels is at least partly due to contaminants. PCBs and organochlorine pesticides have also been linked to hormonal disturbances in Mudpuppies in the St. Lawrence River and the Ottawa River (Gendron *et al.* 1997). Mudpuppies from polluted environments showed a reduction in liver glycogen and a reduced corticosterone response (Gendron *et al.* 1997). As discussed in Gendron *et al.* (1997), alteration of the corticosterone response can have a negative impact on survival, fecundity, and disease resistance. Doses of PCBs comparable to the levels accumulated in gonads of individuals at contaminated sites in Quebec and Ontario affect corticosteroid production in fish and mammals.

Mercury and heavy metals

Trend

In the Great Lakes, the guideline for mercury in water has not been exceeded. Total concentrations of mercury are highest in Lake Erie and maximum concentrations there have occasionally approached the guideline (ECCC and US EPA 2021). While there has been an overall decline in mercury from historically high levels, predatory fish in the Great Lakes have exhibited a stable or increasing trend in mercury contamination (without an increasing concentration in the water), which suggests that changes in mercury cycling may be occurring in the Great Lakes (ECCC and US EPA 2021). The overall state of heavy metal contamination in the St. Lawrence (2012–2017) was rated as “Good,” with no values exceeding water quality guidelines. This reflects an ongoing improvement relative to historical values (Working Group on the State of the St. Lawrence Monitoring 2020). As in the Great Lakes, mercury contamination increased in two fish species monitored in the St. Lawrence River (Walleye and Northern Pike); however, this increase was not consistent across all sampling sites (Working Group on the State of the St. Lawrence Monitoring 2020).

Impact

Mercury was detected in tissue samples from Mudpuppies collected from the St. Lawrence and Ottawa rivers in the 1990s, with concentrations ranging from < 20 to 445 ng/g (Bonin *et al.* 1995). While there is an absence of research on the direct impacts of mercury contamination on the Mudpuppy, mercury is broadly recognized as a toxin to vertebrates, including amphibians, and has been implicated in some amphibian declines (Bergeron *et al.* 2010, 2011).

<u>Natural System Modifications (Category 7): Threat impact Medium-Low</u>

Dams & Water Management/Use (7.2): Threat impact Medium-Low

As a completely aquatic salamander, the Mudpuppy is vulnerable to sudden changes in water levels (reviewed in Gendron 1999). Numerous carcasses have been observed along shorelines on several occasions after major storms or severe flooding; they are washed onto banks or beaches where they die because they cannot get back to the water. Abrupt changes in water levels and rapid draining of large areas may leave large numbers of Mudpuppies stranded in small pools in the vicinity of hydroelectric power stations. Human activities that modify the flooding regime (e.g., dams) and affect the connectivity of watersheds (e.g., roads) also have an impact on habitat connectivity and the viability of metapopulations of aquatic salamanders (Schalk and Luhring 2010). The scope of this threat is restricted to parts of the population that are under water management, and while the severity of this threat can be high locally, the frequency and extent of events involving rapid changes in water levels is not known.

Other Ecosystem Modifications (7.3): Threat impact Medium-Low

Erosion associated with housing and shoreline development along with existing land uses (agriculture, forestry) causes degradation of Mudpuppy habitat. Siltation is a particular concern in Ontario, with impacts primarily due to the loss of crevices and refuges in the bottom substrate rather than to turbidity. The scope and severity for this category are based primarily on erosion, but the population effects are uncertain, which is reflected in the latitude of both scores.

<u>Residential & Commercial Development (Category 1) – Threat impact Low</u>

The Great Lakes region has undergone significant changes over the years. The increasing human population density and associated human-generated threats have contributed to deterioration of coastal ecosystems and their watersheds. Close to the Detroit River, areas occupied by coastal wetlands in 1815 have been reduced by 97% and shorelines have been hardened (Manny 2003). Conversion of forest habitat to housing developments and urban areas is likely to occur in the next 10 years along shorelines currently occupied by Mudpuppies, particularly in Ontario, where the projected average annual population growth rate exceeds that of the total Canadian population (StatCan 2015). The metropolitan areas of the cities of Detroit, Michigan (United States), and

Windsor, Ontario (Canada), which border the Detroit River, have suffered significant losses and degradation of terrestrial and aquatic habitats related to shipping. However, habitat restoration efforts at sites in the St. Clair-Detroit River system show increased Mudpuppy occupancy compared to control sites, suggesting a possible recovery in an otherwise impacted area (Sutherland *et al.* 2020). Projects to build new port facilities are planned in Montreal and Quebec City; these could potentially affect the species and cause habitat loss in the future (Lamarre pers. comm. 2019). In sum, shoreline alteration has undoubtedly contributed to degradation of Mudpuppy habitat over the past decades. It is anticipated to continue to do so, but it will likely affect a relatively small proportion of the Mudpuppy population.

<u>Biological Resource Use (Category 5) – Threat impact Low</u>

Fishing & Harvesting Aquatic Resources (5.4): Threat impact Low

Mudpuppies were commercially harvested in Lake Erie and Lake Ontario (Pfingsten and White 1989; Bonin 1991) and exploited by biological supply companies (Holman 2012). The status of exploitation is largely unknown and is not monitored in Canada. The Mudpuppy is not explicitly mentioned in either Ontario's or Quebec's fishing or harvesting regulations (Government of Canada 2021a,b; Government of Ontario 2021). While Mudpuppies may be harvested for personal use with a small game licence in Ontario (as per regulations governing the harvest of wildlife otherwise not explicitly mentioned in regulations), a commercial licence is required for commercial fisheries. At present, there is no known legal commercial harvest of the Mudpuppy in Ontario (Crowley pers. comm. 2023).

The collection and sale of Mudpuppy in an Asian food market were reported on the news feed of the Facebook page of the Ontario Reptile and Amphibian Atlas in 2016 (Mills pers. comm. 2016). Although the prevalence of this threat is not quantified, Mudpuppy has also been seen in Asian grocery stores in Ottawa and Markham, Ontario (A. Bennett, unpub. data). *Necturus* is also often seen in the pet trade (AmphibiaWeb 2017), and is used as fishing bait; however, the magnitude of this practice is not known (Gendron 1999). The species has also faced persecution in the past; it was considered venomous, vile, and harmful to fish populations, and subjected to extermination efforts in the early to mid-1900s (reviewed in Gendron 1999). There is no evidence that the Mudpuppy poses a threat to fish populations, and it is unclear to what extent these misperceptions persist today.

Mudpuppies are caught incidentally during ice fishing and angling. Because anglers are sometimes reluctant to handle these salamanders, which tend to swallow the hook, many cut the line, throw them aside and leave them for dead instead of removing the hook and releasing them back into the water (reviewed in Gendron 1999). Lennox *et al.* (2018) reported the capture of 80 individuals at a rate of approximately 0.02/hour on Lake Nipissing in 2017; most were captured at night and on passive baited lines. Approximately 91% of individuals captured for further study (n = 47 total) had ingested the baited hook. One of 13 individuals that had swallowed the hook died during a 24-hour holding period after the line was cut (8% mortality) (Lennox *et al.* 2018). Gendron (1999) reports many dead individuals frozen on the ice near ice fishing huts as a common sight. Craig *et al.* (2015) reported that, along the Detroit River, 211 Mudpuppies were caught on baited lines between April and May during the 10-year period from 2003 to 2013. In most cases, these salamanders had completely swallowed the bait and hook, making the hook difficult to remove and likely resulting in post-release mortalities (Craig *et al.* 2015). In the absence of evidence to the contrary, severity for this threat was deemed slight; however, the scope was considered to be between large and restricted, reflecting uncertainty in the proportion of the population exposed to ice fishing or harvest.

Invasive & Other Problematic Species & Genes (Category 8): Threat impact Unknown

While the severity of this threat is unknown, there are several potentially problematic species, both native and invasive, that could pose a serious threat to the Mudpuppy in Canada, or exacerbate existing threats. For example, a summary of information on Mudpuppy mass mortality events in (Table 1) suggests that type E botulism infection may be a leading cause of mortality for some subpopulations; it is suspected to have caused the death of 7,015 to 23,015 individuals in Lake Erie from 2000 to 2010 (Table 1). The Mudpuppy is believed to be affected through the food chain, by eating contaminated dead or live fish (including gobies) that concentrated the botulism toxin by feeding on Zebra Mussels or Quagga Mussels (Wellington 2009). Further research into the causes of mass mortality events, natural rates of infection, and interactions with invasive species are necessary to determine their potential impact on the Mudpuppy. Some of these are discussed below.

Ranavirus (Rv) infections have caused mass mortality of amphibians in the eastern United States, particularly among ambystomatid salamanders and anurans in the family Ranidae (Green *et al.* 2002; Dodd Jr. 2004; Petranka *et al.* 2007; Gray *et al.* 2009a). Rv has been detected in 10 salamander species of the family Plethodontidae (seven Dusky Salamander *Desmognathus* spp., Blue Ridge Two-lined Salamander *Eurycea wilderae*, Spring Salamander *Gyrinophilus porphyriticus,* and Red-cheeked Salamander *Plethodon jordani*) of the southern Appalachians (United States), with a greater prevalence in species with aquatic larvae (Gray *et al.* 2009b), as well as the Proteidae salamander, Eastern Hellbender *Cryptobranchus alleganiensis alleganiensis* (Souza *et al.* 2012). Rv has been observed to cause mortality in Leopard Frog (*Lithobates pipiens*) populations in southern Ontario, near the Great Lakes, more specifically in the regions of lakes Erie and Huron (Greer *et al.* 2005). No information is currently available on the occurrence of Rv in the Mudpuppy in Canada, and no mass die-off has ever been attributed to Rv in Ontario (Table 1).

Chytridiomycosis has caused the extirpation of more than 40% of amphibian species in parts of Central America, as well as serious declines in Europe, Australia, and North America (Crawford *et al.* 2010; Fisher *et al.* 2012). This disease is caused by the fungal pathogen *Batrachochytrium dendrobatidis* (Bd), which affects the upper epidermis in amphibians. The disease may break out virulently in a population and cause 100% mortality, or it may be present for a long time at a moderate, non-lethal level of virulence (Lips 2014). Bd has been detected in *N. maculosus* in captivity (Speare and Berger 2000, cited in Chatfield *et al.* 2012), and in a wild specimen from the Detroit River near the Ontario border in 2006, as well as in 10 individuals of *N. punctatus* (out of 33 tested) in an industrial park near Prineville, Oregon in 2004 (Bd-Maps 2017). Bd is present in Quebec and Ontario (Ouellet *et al.* 2005; James *et al.* 2015; Bd-Maps 2017). Of the 12 Mudpuppy specimens captured in Quebec between 1960 and 2001, none tested positive for Bd (Ouellet *et al.* 2005), and no cases of chytridiomycosis have yet been reported in *N. maculosus* in Canada (Bd-Maps 2017).

A recently emerged pathogenic fungus, *Batrachochytrium salamandrivorans* (Bsal), is reported to have brought the Fire Salamander (*Salamandra salamandra*) to the edge of extirpation in the Netherlands: in 2013, only 4% of the population remained (Martel *et al.* 2013; Spitzen-van der Sluijs *et al.* 2013). This pathogen also killed 49% of captive animals in an ex situ conservation program implemented for the remaining Fire Salamanders (Martel *et al.* 2013). Bsal has markedly lower thermal preferences than Bd; it grows at temperatures as low as 5°C, with optimal growth between 10°C and 15°C, and death at temperatures above 25°C (Martel *et al.* 2013). Therefore, this pathogen may be better adapted to the climatic conditions typically found in Canada. However, there are no reports of Bsal in North America so far. In order to prevent the introduction of Bsal into Canadian ecosystems, Environment and Climate Change Canada has prohibited the importation of all species of the order Caudata (salamanders, newts, and mudpuppies), unless a permit is granted (Canada Gazette 2018).

Invasive species introduced into the Great Lakes, such as the Zebra Mussel, Quagga Mussel, and Eurasian Watermilfoil (*Myriophyllum spicatum*), can indirectly harm the Mudpuppy by altering the composition of habitats and the food chain (Holman 2012). In an assessment of the Great Lakes, the status of the invasive species indicator was assessed "Poor" and its trend as "Deteriorating" (ECCC and US EPA 2021). The state of invasive aquatic animal species in the St. Lawrence was ranked "Moderate-Poor" but stable (2014–2017), while invasive plants were assessed as "Moderate" and stable (Working Group on the State of the St. Lawrence Monitoring 2020). Wellington (2009) raised the possibility that the exotic fish species Round Goby may pose a serious threat to the Mudpuppy if it consumes or attacks young-of-the-year. The Round Goby is extremely abundant in certain areas of Lake Erie in Pennsylvania. It has been found in lake bottom areas from the shoreline out to water depths of 18 m or greater, where it eats fish, Zebra Mussel, and prey that are active on the bottom at night (Wellington 2009). The recent appearance and rapid population growth of the Rusty Crayfish (*Orconectes rusticus*) and hybrids below the dam at Oxford Mills was associated with a sudden decline in Mudpuppy counts (Figure 6B, red line). It is unclear whether changes in the weather or crayfish numbers (or both) were responsible for the steep decline in Mudpuppy counts. However, the appearance of the crayfish roughly coincided with low counts despite relatively fair conditions on Mudpuppy sampling nights (Schueler pers. comm. 2019).

Threats: Manitoba DU

When applied to the Manitoba DU, the IUCN Threats Calculator yielded an overall threat impact of “high,” based on a “high-medium” impact from Pollution (9), particularly Agricultural & Forestry Effluents (9.3), and a “medium-low” impact from Natural System Modifications (7), particularly Dams & Water Management/Use (7.2), and Other Ecosystem Modifications (7.3), as well as Domestic & Urban Wastewater (9.1) (Appendix 1). Other threats that were scored low, but that could exacerbate the main threats included Housing & Urban Areas (1.1), Residential & Commercial Development (1.), Fishing & Harvesting Aquatic Resources (5.4), and Biological Resource Use (5.). In addition, Invasive Non-native/Alien Species (8.1), Problematic Native Species (8.2), and increased frequency and intensity of Storms and Flooding associated with climate change (11.4) also constitute threats to the species, but the severity is largely unknown (Appendix 1). Threats are discussed below in their perceived order of importance. The length of the discussion reflects the amount of available literature as much as relative impact.

The threats (including scope, severity, and timing) in this DU are quite similar to those in the Great Lakes / St. Lawrence DU, although the threats are better evaluated and understood in the latter. In the Manitoba DU, exposure to an array of agricultural and forestry effluents, recent exposure to new invasive species, and potential exposure to disruptive flooding of unknown severity are considered of particular concern and are reflected in the High Overall Threat score.

Pollution (Category 9): Threat impact High-Medium

Agricultural & Forestry Effluents (9.3): Threat impact High-Medium

Pesticides and fertilizers are commonly used in the agricultural watersheds inhabited by the species. Legacy contaminants include DDT, DDE, and other persistent compounds, but these have generally declined substantially and are likely not currently a major issue. Recent estimates in Great Lakes tributaries indicated that toxicity in surface waters to aquatic animals is mostly due to non-persistent compounds such as current use pesticides (e.g., metolachlor, atrazine); this is likely also true in this DU.

Nutrients such as nitrates, ammonia, and phosphates are likely also (directly or indirectly) important sources of toxicity or chemical stress. Agricultural effluents and runoff can also intensify siltation rates by increasing suspended sediments, a situation thought to be detrimental to the Mudpuppy. Loadings of nutrients, including nitrates, is a threat across the Mudpuppy range in both DUs. Nitrates, which can be highly toxic, increase following the conversion of forest cover to pasture and to crops, and their effects on amphibian species can be significant.

Impacts of runoff from agricultural and forestry operations include pollutants and sedimentation which can decrease available habitat and reproductive success. The long-term impact of effluents on the species is potentially severe (with large scope and serious-moderate severity), especially when combined with other stressors. Siltation and runoff from agriculture and forestry activities are potentially significant in this DU; their impacts elsewhere are well documented (Matson 2005). Although there is no exposure to lampricides in this DU, there is potential for pollutants from the U.S. to enter the area via the Red River. Water quality in Lake Winnipeg has steadily deteriorated since the early 1900s, with pronounced increases in eutrophication after 2000, primarily due to phosphorus loading (Environment Canada and Manitoba Water Stewardship 2011). However, recent evidence suggests that external phosphorus loading may be lessening slightly (ECCC and Manitoba Agriculture and Resource Development 2020).

Natural System Modifications (Category 7): Threat impact Medium-Low

Dams & Water Management/Use (7.2): Threat impact Medium-Low

This threat is similar to that discussed above in relation to the Great Lakes / St. Lawrence DU. The Mudpuppy is sensitive to sudden fluctuations in water levels (after flooding events caused by storms or dam management). Rapid changes in water levels (flooding or drainage) along hydro-electric dams can cause massive kills, and water management has the potential to affect habitat connectivity and population viability. Such fluctuations can also reduce available bank retreats and flush eggs/larvae. Drought-proofing of smaller wetlands with dams is ongoing in Manitoba, and dredging around dams could also pose a threat.

Other Ecosystem Modifications (7.3): Threat impact Medium-Low

This threat includes habitat modification caused by invasive exotic species. The Zebra Mussel and Eurasian Watermilfoil have a potential impact on Mudpuppy habitat and the food web. In areas with high densities of Zebra Mussels (which recently spread rapidly from the south to the north basin of Lake Winnipeg), light penetration in the water column is deeper; this has a negative impact on the Mudpuppy, which has low tolerance to light. Erosion from housing and shoreline development and existing land uses (agriculture, forestry) are included here. Siltation may cause a loss of crevices and refuges on the bottom substrate. The scope (large-restricted) and severity (moderate) for this category are based primarily on erosion and on habitat degradation caused by the Rusty Crayfish, an invasive species that recently arrived in the Mudpuppy's range in Manitoba.

Biological Resource Use (Category 5) – Threat impact Low

Fishing & Harvesting Aquatic Resources (Category 5.4): Threat impact Low

Use of the Mudpuppy ("water dogs") as bait for anglers is permitted throughout Manitoba if they are native (Government of Manitoba 2023). Ice fishing is popular and widespread throughout the range of this DU. In fact, bycatch by anglers, particularly ice fishers, and chance observations are the only data available on Mudpuppy distribution in Manitoba. Interviews with ice fisherman on the Winnipeg River revealed captures of 1.7 individuals per fishing trip, although most were released.

Residential & Commercial Development (Category 1) – Threat impact Low

Housing & Urban Areas (1.1) - Threat impact Low

Most development is taking place south and southwest of Lake Winnipeg, around Winnipeg and Brandon. There are also large acreage developments along the Red River in high flood areas; these include extensive riprap to control erosion, which may eliminate habitat or possibly provide new refuges. Overall, scope is considered small and severity moderate-slight based on shoreline habitat alteration, but with considerable uncertainty. Most of the concern relates to the development of summer and vacation homes.

Number of Locations

The most imminent threats or those likely to affect the Mudpuppy in Canada—i.e., pollution, urban development, water management and the operation of dams, fishing, diseases, and aquatic invasive species—could potentially occur simultaneously over a great area. Some threats, such as water pollution, are widely distributed in the St. Lawrence River and Great Lakes basins, which represent the majority of the species' habitat in Canada. The possibility that a single threat will rapidly affect all individuals of the species is influenced by hydrological connectivity for several threats (e.g., the use of lampricides, sudden variations in water levels, diseases, or invasive alien species). At a bare minimum, locations within the area of occupancy could be delineated at the watershed scale (Figure 9), but that is likely too coarse. More realistically, each major river should be considered separately, and since many water-based threats produce impacts only downstream of point sources, the number of locations is likely even higher.

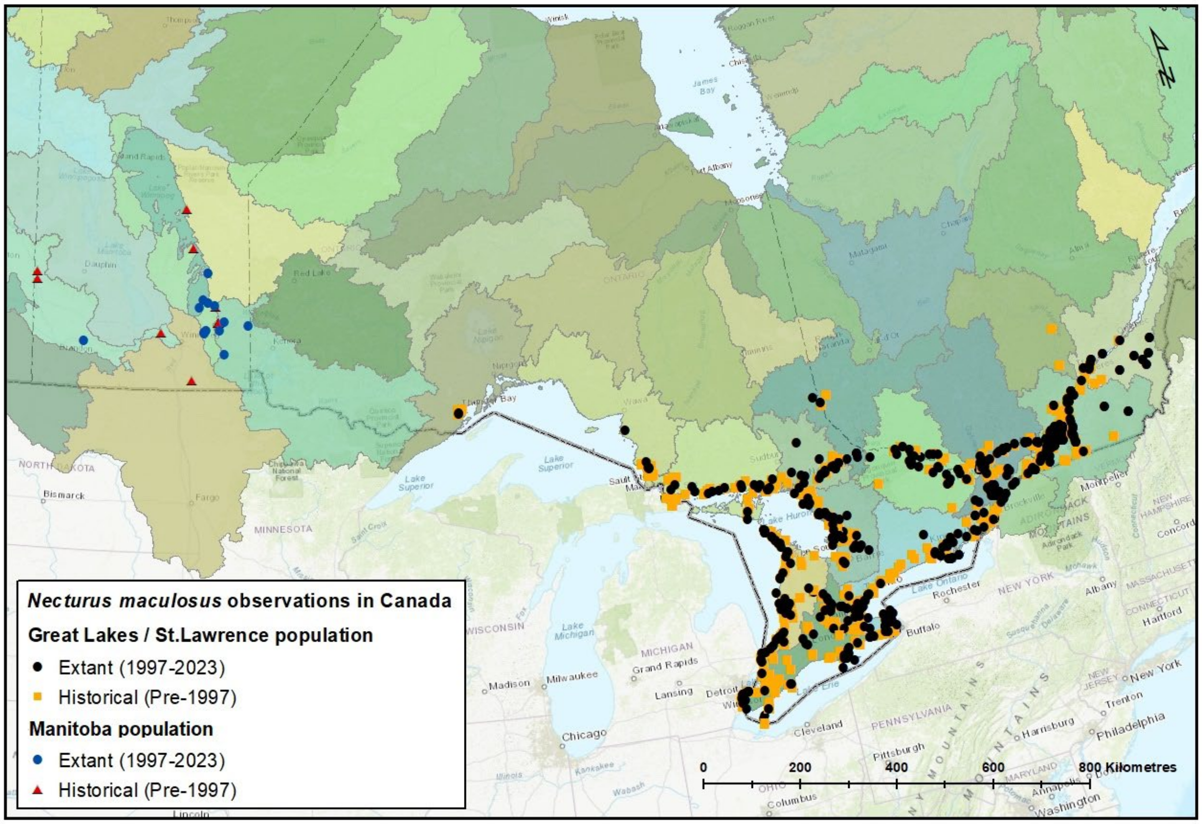


Figure 9. Mudpuppy (*Necturus maculosus*) observations in Canada, pre-1997 (historical) and extant (1997–2023), overlaid on watershed subdrainage areas.

Great Lakes / St. Lawrence DU

The number is unknown but likely greatly exceeds threshold values for application of B criteria (> 10).

Manitoba DU

Treating records from separate watercourses as single locations and all records on Lake Winnipeg as a single location (assuming a lake-wide impact would affect all individuals), would yield six extant locations and eight historical locations (assuming all extant sites also supported historical populations) (Figure 10). If an even more conservative approach is adopted, by treating all records (except those sharing watercourses and separated by < 5 km and those on Lake Winnipeg) as single locations, the result would be only 9 locations.

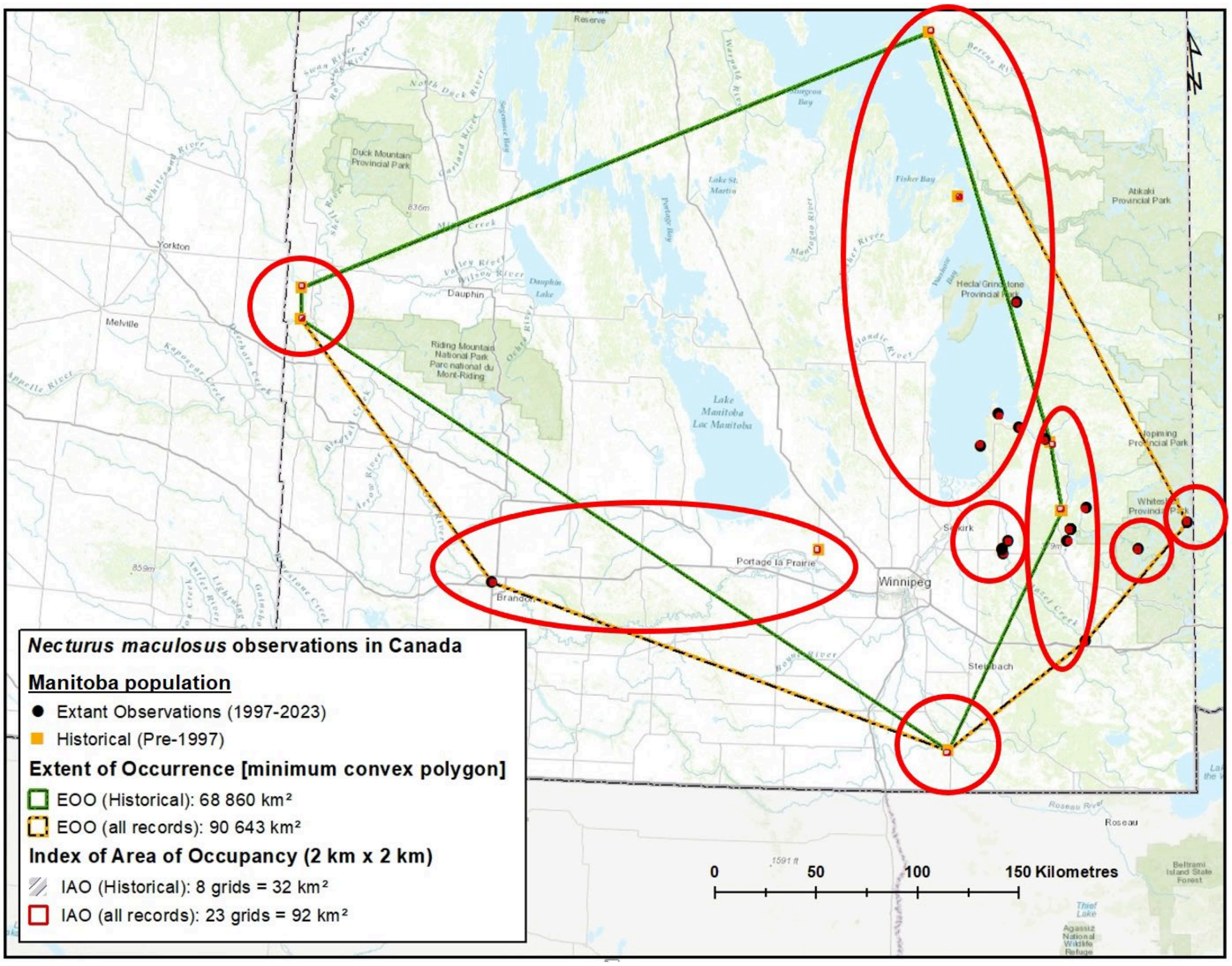


Figure 10. Estimated extant (1997–2023) and historical (pre-1997) locations* for the Mudpuppy (*Necturus maculosus*) – Manitoba population. Ellipses denote most likely locations based on threats from pollution, ecosystem modification and aquatic invasive species (see text for details). * Refer to Definitions and Abbreviations on COSEWIC website for more information on this term.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Because the Mudpuppy is designated "Not at Risk" in Canada, it does not benefit from any legal protection under the *Species at Risk Act* (SARA) (Government of Canada 2021c). However, since the Mudpuppy is the obligate host of the Salamander Mussel (which is federally listed as Endangered), threats to the Mudpuppy within the range of the Salamander Mussel are also considered threats to the mussel (DFO 2019). Such protections are therefore limited to one locality on the Sydenham River. No provincial legislation directly protects the Mudpuppy in Canada; the species is considered "Not at Risk" in Manitoba, Ontario, and Quebec.

Manitoba Conservation is responsible for management of all wildlife species, including Mudpuppy subpopulations (Government of Manitoba 2017). At present, native Mudpuppies can be used as bait by anglers across Manitoba (Government of Manitoba 2023). In Ontario, the Mudpuppy is not listed as a game species or as a specially protected species under the *Fish and Wildlife Conservation Act* 1997 (FWCA). However, it is included under the definition of *wildlife* and therefore receives general protections under the FWCA. For instance, a licence is required to hunt or trap wildlife, and wildlife may not be hunted or trapped for gain. Fishing regulations prohibit the import of salamanders into Ontario, and the use of native or non-native salamanders as bait (Government of Ontario 2021). The Mudpuppy is not listed as either Threatened or Vulnerable in Quebec under the *Act respecting threatened or vulnerable species*, nor is it included on the list of wildlife species likely to be designated as threatened or vulnerable (Gouvernment du Québec 2023).

The Mudpuppy may be kept in captivity without a licence under the Quebec *Regulation respecting animals in captivity* made under the *Act respecting the conservation and development of wildlife*. Using the Mudpuppy as live bait for fishing is not explicitly prohibited (Gouvernement du Québec 2017). Section 128.6 of this Act also indirectly protects the species' aquatic habitat in Quebec. Section 22 of the *Environment Quality Act* (LQE) provides general and specific protection for this species' aquatic habitat through the *Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains*. Under the LQE, a certificate of authorization must be obtained prior to undertaking any construction or industrial activity that negatively affects a river, stream, lake, pond, marsh, or peat bog. However, work is sometimes undertaken without prior authorization from the government.

Non-Legal Status and Ranks

NatureServe (2021b) ranks Mudpuppy as Globally Secure (rank G5 and rank G5T5 for the subspecies *N. m. maculosus*), owing to its extensive distribution in North America and its abundance in several regions. The species is ranked from Vulnerable to Apparently Secure (S3S4) in Manitoba, and is Apparently Secure in Quebec and Ontario (S4). The species is classified as Least Concern on the IUCN Red List (IUCN 2015).

The Mudpuppy is not listed under the *U.S. Endangered Species Act* and is considered nationally secure (N5) (NatureServe 2021b). However, it is considered possibly extirpated (SH) from South Dakota and Maryland; critically imperilled (S1) in Georgia and Illinois; and imperilled (S2) in Alabama, Iowa, Indiana, North Carolina, Virginia, and Vermont. The species is considered vulnerable (S3) in Connecticut, Kansas, Michigan, Minnesota, New York, and Pennsylvania; apparently secure (S4) in Mississippi, Missouri, North Dakota, and Iowa; secure (S5) in Tennessee; and exotic (introduced; SNA) in Maine, Massachusetts, and Rhode Island.

Habitat Protection and Ownership

In Canada, the Mudpuppy is present on at least 14 sites managed by Parks Canada: seven National Parks (Bruce Peninsula, Fathom Five, Georgian Bay Islands, Point Pelee, Pukaskwa, Rouge, Thousand Islands), six National Historic Sites (Chambly Canal, Fort St. Joseph, Rideau Canal, Sault Ste. Marie Canal, Trent-Severn Waterway, Sainte-Anne-de-Bellevue Canal), and one National Marine Conservation Area (Lake Superior) (Pruss pers. comm. 2018). In Manitoba, the parks and protected areas located near the border with Ontario, around Lake Winnipeg and in the Asessippi River basin may contribute to the preservation of habitats for the Mudpuppy (Government of Manitoba 2017). In Ontario, the species' habitat receives some degree of protection in the numerous provincial parks that border lakes Superior, Huron, Erie, and Ontario, and the Ottawa River (Government of Ontario 2017). In Quebec, protected natural areas support the conservation of certain Mudpuppy habitats in southern Quebec, along the Ottawa River, in the Montreal metropolitan area, and along the St. Lawrence River and its tributaries (Réseau de milieux naturels protégés 2017). Projects are being carried out in the Mudpuppy's range by various conservation organizations (e.g., the Nature Conservancy of Canada, Nature-Action Québec, and Éco-Nature), watershed organizations, Conseils régionaux de l'environnement (CRE) [regional environment councils], and ZIP [comités de zones d'intervention prioritaire - areas of prime concern] committees (A. Boutin, unpublished data). Protected areas can restrict development and provide some protection for shorelines and plant cover, which can be beneficial to the Mudpuppy. However, provincial park or national protected area status does not guarantee the maintenance of water quality or other essential elements of the species' habitat and does not necessarily prevent fishing- or persecution-related threats.

Ontario uses a nested coarse and fine filter approach to meet wildlife habitat needs and provide healthy forests. The *Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales* (Stand and Site Guide) builds upon this approach. While Ontario's Stand and Site Guide does not provide specific direction related to the Mudpuppy, the coarse filter direction outlined to protect water quality and maintain inputs of fine and coarse organic matter in lakes, ponds, rivers, streams, and wetlands may help to mitigate potentially negative impacts to the species. The Mudpuppy could also benefit from silvicultural practices adopted in Quebec to protect stream salamanders, which have been applied since 2006 on provincial public lands that are subject to forest management (Gouvernement du Québec 2008). In some areas, various organizations, particularly the Nature Conservancy of Canada (CNC) and the Société de conservation et d'aménagement du bassin versant de la rivière Châteauguay (SCABRIC), encourage private property owners to apply these measures on a voluntary basis. Several of the conservation organizations that are active in the Mudpuppy's range in Quebec are helping to improve water quality and restore the banks of numerous rivers, along with tributaries of the St. Lawrence River. They are also working to restore degraded habitats and protect habitats through stewardship or voluntary conservation.

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BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

Amanda Bennett is a Research Associate at the Council of Canadian Academies (CCA). Amanda's academic research has focused on the ecology and conservation of reptiles and amphibians. She holds a B.Sc. (Hons.) in Zoology and Studio Arts from the University of Guelph, an M.Sc. in Biology from Laurentian University, and a Ph.D. in Environmental and Life Sciences from Trent University. Amanda worked in applied conservation, as an intern with the Georgian Bay Biosphere Reserve and the Saving Turtles at Risk Today Project, before returning to Trent University as a postdoctoral fellow, working on stress physiology, species distribution modelling, and infectious diseases of amphibians. She is the Vice-President of the Canadian Herpetological Society.

Anaïs Boutin earned a master's degree in biology at the University of Montreal in 2006. Her master's thesis dealt with habitat selection within a community of stream salamanders in Covey Hill, Quebec, including five species and hybrids of the genus *Desmognathus*. Her research work also dealt with the development of molecular methods for identifying these hybrids and their parent species. Anaïs Boutin currently works as a biologist for the recovery of numerous species at risk. She is involved in the conservation of wildlife species and natural environments. She is coordinator of the Équipe de rétablissement des salamandres de ruisseaux [Quebec Stream Salamander Recovery Team], a member of the Ontario Dusky Salamander Recovery and Implementation Team, and is involved in several herpetofauna protection projects.

COLLECTIONS EXAMINED

No collections were examined during the preparation of this status report.

Appendix 1. Threats Assessment Worksheet - Manitoba population.

THREATS ASSESSMENT WORKSHEET				
Species or Ecosystem Scientific Name	*Necturus maculosus* (Mudpuppy) Manitoba population			
Element ID		**Elcode**		
Date (Ctrl + ";" for today's date):	2/22/2023			
Assessor(s):	Amanda Bennett (SSC, report writer), Nicholas Cairns (SSC), Carla Church (Manitoba Habitat Heritage Corporation), Chris Edge (SSC), Tom Herman (SSC Co-chair for this report), Thomas Hossie (SSC), Dwayne Lepitzki (facilitator), Bev McBride (Secretariat), Randy Mooi (Manitoba Museum), Njall Rollinson (SSC), Pamela Rutherford (SSC Co-chair), Bill Watkins (University of Winnipeg, retired), Katharine Yagi (SSC) (SSC means the COSEWIC Amphibians and Reptiles Specialist Subcommittee)			
References:	Draft COSEWIC status report (October 2018); draft single Canadian DU calculator with 26 April 2022 edits and 2021-11-08 draft status report with 2 DUs			
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	1	1
	D	Low	2	3
Calculated Overall Threat Impact:			High	High
Assigned Overall Threat Impact:	**B = High**			
Impact Adjustment Reasons:				
Overall, Threat Comments	Generation time: 15 yrs; therefore, timeframe for severity and timing is 45 years into the future. GLSL DU- EOO: 569,859 km²; IAO: 1,636 km²; Manitoba DU-EOO: 29,116 km², IAO: 60 km². Population trends unknown for each DU. In Manitoba DU, recent exposure to new invasive species, decline in EOO, and potential exposure to disruptive flooding of unknown severity were of particular concern, and are reflected in the High Overall Threat score.			

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development	D	Low	Small (1-10%)	Moderate - Slight (1-30%)	High (Continuing)	Removal of Mudpuppy habitat due to development.
1.1	Housing & urban areas	D	Low	Small (1-10%)	Moderate - Slight (1-30%)	High (Continuing)	Projected average annual growth is above the national average in only one of the six growth scenarios in Manitoba (StatCan 2015). Most development is S/SW of Lake Winnipeg, around Winnipeg and Brandon, as well as large acreage developments along Red River in high flood areas; these include extensive riprap to control erosion, which may eliminate habitat or provide new refuges. **Overall**, Scope is lower end of Small. Severity: moderate-slight based on shoreline habitat alteration, but with much uncertainty. Most of the concern is driven by the development of summer and vacation homes. [Water quality scored in 9. Siltation scored in 9.]

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1.2	Commercial & industrial areas						Few developments likely in next 10 years, and large development buffers around rivers reduce risk in Manitoba. [Water quality related to industrial areas scored in 9.]
1.3	Tourism & recreation areas		Negligible	Negligible (<1%)	Unknown	High (Continuing)	Development of marinas, beach resorts, tent sites, and promotion of sportfishing may pose a threat, but likely only negligible. [Boats scored under 6.1.; impact of sports fishing scored under 5.4.]
2	Agriculture & aquaculture		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	
2.1	Annual & perennial non-timber crops		Negligible	Negligible (<1%)	Unknown	High (Continuing)	Southern Manitoba offers potential for annual and perennial non-timber crops. Expansion and intensification of agricultural activities adjacent to the species' habitat over the next 10 years may alter and reduce habitat quality (road construction, forest drainage, quality of shorelines). This could cause forest cover removal, habitat conversion, increase of water use and reduced water quality. However, farming is slowly moving towards practices that better protect soils and prevent erosion. [Impacts on water quality scored under 9.3]
2.2	Wood & pulp plantations						Not a threat
2.3	Livestock farming & ranching		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	Habitat quality and availability may be compromised by the growing trend towards larger, industrialized farms and in some areas an increase in livestock density, i.e., intensive practices. There may be trampling and habitat modification in the shallows; cattle don't go in deeper areas and are generally not present during spring breeding season, when there is still ice on lakes. [Pollution from livestock scored under 9.3.]
2.4	Marine & freshwater aquaculture						No aquaculture of any significance in this DU's range at present.
3	Energy production & mining						
3.1	Oil & gas drilling						Habitat loss/alteration from new infrastructure in this category is not considered a significant threat at present.
3.2	Mining & quarrying						Current and future extent of mining and quarrying in the Mudpuppy's habitat are likely very low. [Contamination scored under 9].
3.3	Renewable energy						No expansions likely in next 10 years in Mudpuppy range. [Impacts of hydro scored under 7.2 (water management)].
4	Transportation & service corridors		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4.1	Roads & railroads		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	This type of activity is carried out for numerous purposes (urban, commercial, industrial development as well as timber harvesting, agriculture, and wind farms) and has the potential to impact adjacent aquatic habitats throughout the species range. This includes maintenance of existing bridges, construction of new bridges and railways, refurbishing and widening of old bridges and road crossings across rivers (regulations exist in most of these cases). This threat also includes unpaved roads used for forest management, ATVs, etc, as well as culvert replacement. The main impacts would be associated with opening up of the forest canopy, siltation, embedding of infrastructure, and habitat contamination. New roads in the Mudpuppy's range are primarily associated with access to cottages, and relocation of ice roads associated with climate change. Scope negligible and Severity probably at low end of Slight.
4.2	Utility & service lines		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	Deforestation and access roads (and their impact) related to implementation and maintenance of utility and services lines represent the main threats adjacent to the species habitat. They are likely to increase with urbanization/industrialization and human population growth, but no new pipelines or hydro corridors are planned for next 10 years, only regular maintenance and upkeep of existing infrastructure.
4.3	Shipping lanes						Not a threat
4.4	Flight paths						Not a threat
5	Biological resource use	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						Not a threat
5.2	Gathering terrestrial plants						Not a threat
5.3	Logging & wood harvesting						Not a threat (indirect effects captured elsewhere, under 1 and 2). The threat would be primarily from logging of the remaining forest at the head of the watersheds which could affect drainage and water quality in the species habitat. Siltation resulting from logging roads is discussed under 4.1.
5.4	Fishing & harvesting aquatic resources	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	Bycatch by anglers, particularly ice fishers, and chance observations are the only data available on Mudpuppy distribution in Manitoba. Interviews with ice fisherman on the Winnipeg River revealed captures of 1.7 individuals per fishing trip, but most were released apparently unharmed.
6	Human intrusions & disturbance		Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
6.1	Recreational activities		Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	Recreational activities (boating, fishing, etc.) are ongoing on the water bodies where the Mudpuppy is found and could potentially cause habitat degradation and disturbance. The impact is likely negligible at the population level, but could include wave-induced erosion and siltation, introduction of invasive exotic species and decrease in water quality (all have been discussed elsewhere). Not considered a significant threat or research question at present.
6.2	War, civil unrest & military exercises						Not a threat
6.3	Work & other activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Non-lethal research on fish and other aquatic biota, including freshwater mussels, is a source of potential disturbance to the Mudpuppy, but scope and severity both considered negligible.
7	Natural System Modifications	CD	Medium - Low	Restricted (11-30%)	Serious - Moderate (11-70%)	High (Continuing)	
7.1	Fire & fire suppression						Not a threat.
7.2	Dams & water management/use	CD	Medium - Low	Restricted (11-30%)	Serious - Moderate (11-70%)	High (Continuing)	The Mudpuppy is sensitive to sudden fluctuations in water levels (after flooding events caused by storms or dam management). Rapid changes in water levels (flooding or drainage) along hydro dams have previously caused massive kills in the Great Lakes / St. Lawrence DU, and water management has the potential to affect habitat connectivity and population viability. Such fluctuations can also reduce available bank retreats, as well as flush eggs/larvae. Manitoba: drought-proofing of smaller wetlands with dams is ongoing, and dredging around dams could be a threat.
7.3	Other ecosystem modifications	CD	Medium - Low	Large - Restricted (11-70%)	Moderate (11-30%)	High (Continuing)	This threat discusses habitat modification caused by exotic species. Other impacts related to invasive exotic species and diseases are treated in 8.1. Zebra Mussel and Eurasian Watermilfoil have a potential impact on Mudpuppy habitat and the food web. In areas of high Zebra Mussel density , light penetration in water column is deeper; this negatively impacts the Mudpuppy, which has low tolerance to light. It also increases the species' visibility to fish predators. Erosion from housing, shoreline development and existing land uses (agriculture, forestry) are included here. Siltation may cause loss of crevices and refuges on the bottom substrate. Scope and severity for this category are based primarily on erosion and habitat degradation, including that caused by activities of the Rusty Crayfish, a novel and recent arrival to the Mudpuppy range in Manitoba. Considerable uncertainty about scope was noted.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8	Invasive & other problematic species & genes		Unknown	Large - Small (1-70%)	Unknown	High (Continuing)	
8.1	Invasive non-native/alien species		Unknown	Pervasive - Large (31-100%)	Unknown	Moderate (Possibly in the short term, < 10 yrs)	Chytrid fungus (Bd and Bsal) presents a potential threat, but it is not known to be present in this species in Canada. The sensitivity of the Mudpuppy to Bd is unknown, but it was recently classified as resistant to Bsal (SNAPS program). Although Bd is possibly native, introduced strains may be more virulent; hence it is scored here. Direct impact of the recently arrived Rusty Crayfish unknown.
8.2	Problematic native species		Unknown	Large - Small (1-70%)	Unknown	High (Continuing)	Massive die-offs of Mudpuppy caused by botulism have occurred in Lake Erie in Pennsylvania. However, prevalence in Canada is unknown, with no records from Manitoba. Ranavirus is a potential threat, but no cases of ranavirus infection have been reported for the species. However, the host species that act as vectors for Rv co-occur with the Mudpuppy. Harmful algae blooms are increasing in frequency, distribution, and severity, and are adversely impacting ecosystem health.
8.3	Introduced genetic material						
9	Pollution	BC	High - Medium	Large (31-70%)	Serious - Moderate (11-70%)	High (Continuing)	There was initial uncertainty in the scoring of scope and severity in the original unified threats calculator (2022.04.22), particularly for the subcategories under Pollution. Nonetheless, all participants agreed that pollution is the main issue for the species. Additional guidance/ review was sought from two experts in the field (Tana McDaniel, Shane de Solla) before finalizing the scores.
9.1	Domestic & urban wastewater	CD	Medium - Low	Restricted (11-30%)	Moderate - Slight (1-30%)	High (Continuing)	Considerable uncertainty about the population effects and average impact across the entire Canadian range. All or most water bodies probably have some level of contamination but the impacts on populations vary depending on contamination levels. Storm sewer overflows (due to excessive loads or system malfunction) into rivers and natural habitat when volumes of water to be treated exceed treatment plant capacity , with likely negative impacts on the Mudpuppy and its habitat. This causes contamination (fecal coliforms, nitrates, ammonia, heavy metals, etc. and reduced oxygen) and decreases water quality (ECCC 2020).

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.2	Industrial & military effluents		Negligible	Negligible (<1%)	Moderate (11-30%)	High (Continuing)	Heavy metal contamination (e.g., mercury, cadmium, lead) from industries has been observed in Manitoba. Mudpuppies accumulate contaminants, potentially causing differing levels of stress including hormonal disruption and limb deformities; these contaminants potentially explain the species absence and disappearance in some heavily contaminated water bodies but are probably not limiting in most subpopulations. Spills related to oil and gas drilling also have the potential to contaminate water. Many chemicals associated with industry are released primarily through municipal wastewater or through agricultural use. Scope likely negligible.
9.3	Agricultural & forestry effluents	BC	High - Medium	Large (31-70%)	Serious - Moderate (11-70%)	High (Continuing)	Pesticides and fertilizers are commonly used in the agricultural watersheds inhabited by the species. Legacy contaminants include DDT, DDE, and other persistent compounds, but these have generally declined substantially and are likely not currently a major issue. Recent estimates indicate that toxicity in surface waters to aquatic animals in Great Lakes tributaries are mostly due to non-persistent compounds in surface waters, such as current use pesticides (e.g., metolachlor, atrazine); likely also true in this DU. Nutrients such as nitrates, ammonia, and phosphates are likely also (directly or indirectly) important sources of toxicity or chemical stress. Agricultural effluent and runoff can also intensify siltation rates by an increase in suspended sediments, which is hypothesized to be detrimental to the Mudpuppy. Nutrient loading, including nitrates, is a threat across the Mudpuppy range (both DUs). Nitrates, which can be highly toxic, increase from the conversion of forest cover to pasture and to crops, and their effects on amphibian species can be significant. Impacts of runoff from agricultural and forestry operations include pollutants and sedimentation that can decrease available habitat and reproductive success. Long term impact of effluents on the species is unknown but potentially severe, especially when combined with other stressors. Siltation and runoff from forestry activity are potentially significant in this DU. Although there is no exposure to lampricide in this DU, there is potential for pollutants from the US to enter the area.
9.4	Garbage & solid waste		Unknown	Small (1-10%)	Unknown	High (Continuing)	Garbage and solid waste are dumped along water bodies where the species is found. If chemical wastes were dumped, contamination could be severe.
9.5	Air-borne pollutants		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Atmospheric deposition of pollutants has caused *D. fuscus* (a stream salamander) population to decline in the U.S. in sites where bedrock had low buffer capacity, but no data on this in Canada. Threat is unknown.
9.6	Excess energy						Not a threat
10	Geological events						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
10.1	Volcanoes						Not a threat
10.2	Earthquakes/tsunamis						Not a threat
10.3	Avalanches/landslides						Landslides can occur in watersheds inhabited by the species. This threat is probably localized and restricted. No increase in this threat anticipated.
11	Climate change & severe weather		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
11.1	Habitat shifting & alteration						
11.2	Droughts		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	Forecasts for longer periods of drought in summer (concern for habitat availability, connectivity, and water temperature). The severity of change in water levels of streams, rivers and lakes is uncertain. Seasonal droughts may become more severe and/or more frequent in the short term. Timing of precipitation is important; increased precipitation predicted in general. Small, shallow streams were included in the scope, because they are likely to be most affected by seasonal droughts. Impacts less or non-existent for Mudpuppy in large water bodies.
11.3	Temperature extremes						Not a threat. Maximum critical temperature appears to be 33 to 34°C.
11.4	Storms & flooding		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Projections show an increase in heavy precipitation events (potentially increasing flooding events and reducing water quality through siltation and pollution). See discussion under Dams & water management/use [7.2]. Across the range, effects are most pronounced in collection basins; "century" flooding events are occurring more frequently. Impacts in both breeding and overwintering areas include erosion and habitat alteration, and direct mortality events associated with storms (past report of a die-off of >1000 individuals in Sarnia (Lake Huron) after an intense storm). Storm surges and flooding events, particularly in winter or spring, might displace Mudpuppy downstream or push them into unsuitable floodplain habitat. Massive Red River flooding is likely to increase in time and frequency due to land use practices & channelization, with huge volume of water from runoff from USA and poor wetland protection in Saskatchewan. Flushing effect from Assiniboine R. is increasingly frequent, with potential effects on reproduction and mortality.

Appendix 2. Threats Assessment Worksheet - Great Lakes / St. Lawrence population.

THREATS ASSESSMENT WORKSHEET				
Species or Ecosystem Scientific Name	*Necturus maculosus* (Mudpuppy) Great Lakes / St. Lawrence population			
Element ID			Elcode	
Date (Ctrl + ";" for today's date):	2/22/2023			
Assessor(s):	Amanda Bennett (SSC, report writer), Nicholas Cairns (SSC), Carla Church (Manitoba Habitat Heritage Corporation), Chris Edge (SSC), Tom Herman (SSC Co-chair for this report), Thomas Hossie (SSC), Dwayne Lepitzki (facilitator), Bev McBride (Secretariat), Randy Mooi (Manitoba Museum), Njall Rollinson (SSC), Pamela Rutherford (SSC Co-chair), Bill Watkins (University of Winnipeg, retired), Katharine Yagi (SSC) (SSC means the COSEWIC Amphibians and Reptiles Specialist Subcommittee) [original Calculator, based on a single Canadian DU, was completed on 2019-01-09 - assessors: Amanda Bennett, Sara Ashpole, Joe Crowley, Anais Boutin, Christina Davy, Isabelle Gauthier, Stephen Hecnar, Andrée Gendron, Yohann Dubois, William Watkins, Burke Korol, Andrew Didiuk, Philippe Lamarre, Kristiina Ovaska (facilitator)]			
References:	Draft COSEWIC status report (October 2018); draft single Canadian DU calculator with 26 April 2022 edits & 2021-11-08 draft status report with 2 DUs			
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	1	1
	D	Low	2	3
Calculated Overall Threat Impact:			High	High
Assigned Overall Threat Impact:			**B = High**	
Impact Adjustment Reasons:				
Overall, Threat Comments			Generation time: 15 yrs; therefore, timeframe for severity and timing is 45 years into the future. GLSL DU- EOO: 569,859 km²; IAO: 1,636 km²; Manitoba DU- EOO: 29,116 km², IAO: 60 km². Population trends unknown for each DU. Projected decline in GLSL DU (10%-70% based on overall threat impact) likely closer to median value.	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential & Commercial Development	D	Low	Small (1-10%)	Moderate - Slight (1-30%)	High (Continuing)	Removal of Mudpuppy habitat due to development.
1.1	Housing & urban areas	D	Low	Small (1-10%)	Moderate - Slight (1-30%)	High (Continuing)	Maps of ground cover from 2000 show that the species is mostly found in agricultural and forested areas but also occurs to a smaller extent in urbanised areas. Conversion of forest habitat to housing and urban areas is likely in the next 10 years. In Quebec, the law protecting agricultural lands prevents urban development at some point. In the US and in Ontario Canada, reports reveal that urban areas have significantly reduced the coastal wetlands and caused shorelines to become highly modified. Population growth and urban development are projected to be 4 times the current rate in Ontario over the next 30 years. In projections from 2009 to 2036 under six growth scenarios, Ontario will see average annual growth exceeding that of the Canadian population as a whole in all six. Conversely, all scenarios suggest average annual growth below that of Canada in Quebec. For the rest, the picture is more varied. Quebec: Most development localized around existing cities (Montreal, Quebec, Trois-Rivière, Sorel); Ontario: probably limited changes in the next 10 years. Shoreline modification is an issue if breeding or overwintering habitat is affected. The proportion of shoreline constituting habitat may be large in shallow water bodies/rivers in contrast to lakes. Erosion control, e.g. concrete walls, may lead to losses of habitat. **Overall**, Scope is lower end of Small. Severity: moderate-slight based on shoreline habitat alteration, but with much uncertainty. [Water quality scored in 9. Siltation scored in 9.]
1.2	Commercial & industrial areas		Negligible	Negligible (<1%)	Serious - Moderate (11-70%)	High (Continuing)	Additional industrial or commercial development as well as intensification of commercial and industrial activities in southern Quebec (incl. construction of new port in Montreal) and Ontario are likely, albeit to a limited extent, over the next 10 years. Because the areas currently used for these purposes are relatively restricted, scope is uncertain but probably negligible and severity has the potential to be serious. Shoreline habitats have already been altered or destroyed by existing industrial development, particularly in Montreal and southern ON. [Water quality related to industrial areas scored in 9.]
1.3	Tourism & recreation areas		Negligible	Negligible (<1%)	Unknown	High (Continuing)	The Great Lakes represent an important tourism and recreational destination but there is some uncertainty as to what extent if any of these will affect Mudpuppy sites either directly or indirectly. Campgrounds, marinas and docks are included in this threat. Small cottage docks can be used by the species as shelter, however large marina docks with significant boat traffic will have a greater impact. ON: scope negligible but no data on severity (likely to be negligible unless concentrations of animals are affected); this assumes that displaced animals are surviving and reproducing, as these developments usually constitute a small proportion of habitat. [Boats scored under 6.1.; impact of sports fishing scored under 5.4.]

Threat		Impact (calculated)	Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
2	Agriculture & Aquaculture	Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	
2.1	Annual & perennial non-timber crops	Negligible	Negligible (<1%)	Unknown	High (Continuing)	Southern Quebec and Ontario offer the potential for annual and perennial non-timber crops. Expansion and intensification of agricultural activities adjacent to the species' habitat over the next 10 years may alter and reduce habitat quality (road construction, forest drainage, quality of shorelines). This could cause forest cover removal, habitat conversion, increase of water use and reduced water quality. However, farming practices are slowly moving towards practices that better protect soils and prevent erosion. [Impacts on water quality scored under 9.3]
2.2	Wood & pulp plantations					Not a threat
2.3	Livestock farming & ranching	Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Habitat quality and availability may be compromised by the growing trend towards larger, industrialized farms and in some areas an increase in livestock density, i.e., intensive practices. There may be trampling and habitat modification in the shallows; cattle don't go in deeper areas and are generally not present during spring breeding season, when there is still ice on lakes. [Pollution from livestock scored under 9.3.]
2.4	Marine & freshwater aquaculture	Unknown	Unknown	Unknown	Unknown	Although freshwater aquaculture has a potential impact on the species through habitat use, introduction of parasites or diseases, competition for food, shelter and predation, scope is unknown but probably very limited.
3	Energy Production & Mining	Unknown	Unknown	Unknown	High (Continuing)	
3.1	Oil & gas drilling					Habitat loss/alteration from new infrastucture in this category not considered a significant threat at present. Water use and water contamination are threats associated with this type of activity. Spills related to oil and gas drilling also have the potential to contaminate groundwater and surface water. In Quebec, the law on hydrocarbons prevents the exploitation of shale gas in the St. Lawrence Valley. The most important threat is from oil and gas transportation through pipelines, railroads and ground transportation (ordered in decreasing risk of habitat contamination). Examples in Quebec include Lac-Mégantic rail disaster in 2013, and a high potential for habitat contamination through leakage of pipelines found in the species habitat and passing through streams and rivers, with the potential to contaminate large water bodies. See map of pipelines (CER n.d.) [Contamination, including spills, scored under 9 (Pollution)].
3.2	Mining & quarrying	Unknown	Unknown	Unknown	High (Continuing)	The current and future extent of mining and quarrying in the Mudpuppy's habitat are unknown. The severity is unknown but has the potential to be high where it occurs (water contamination, dewatering channels); the scope is unknown but likely to be small. Quarrying is likely to increase to support high projected population growth and urban development in Ontario over the next 30 years. In Ontario, quarries exist near Mudpuppy habitat, but not in aquatic habitats, where new quarries are unlikely to be permitted. Alteration of shoreline would pose a potential threat. [Contamination scored under 9].

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
3.3	Renewable energy		Unknown	Unknown	Unknown	High (Continuing)	Expanding locally around the Great Lakes (Erie, Ontario, Huron). Wind farms in the US are located a few km from the Canadian border where the species occurs. They might expand over the next 10 years potentially on higher grounds representing the top of the watershed or in open (agricultural) areas next to the species habitat. The impact would be through road access, deforestation, alteration of water quality. The greatest impact is due to forest removal. There is also a problem of oil discharge from operating windmills. Uncertain how these would affect the Canadian population. In the long term, if renewable energy reduces the need for hydro dams and coal plants, there could be a net positive effect on reduction of acid rain and habitat contamination. Vibrations and low frequency sounds (shown to have an impact on anurans) from wind farms could pose a potential threat in Canada, but severity is unknown. ON: some 75% of current windfarms in Ontario are along lakes Erie and Huron; currently moratorium on offshore wind farms, which may change. [Impacts of hydro scored under 7.2 (water management)].
4	Transportation & Service Corridors		Unknown	Small (1-10%)	Unknown	High (Continuing)	
4.1	Roads & railroads		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	This type of activity for numerous purposes (urban, commercial, industrial development as well as timber harvesting, agriculture, and wind farms), has the potential to impact adjacent aquatic habitats throughout the species range. This includes maintenance of existing bridges, construction of new bridges and railways, refurbishing and widening of old bridges & road crossings across rivers (for most of which regulations exist). This threat also includes the unpaved roads used for forest management, ATVs, etc, as well as culvert replacement. The main impact would be through the effects of canopy opening, siltation, embedding of infrastructure, and habitat contamination. Severity probably at low end of Slight.
4.2	Utility & service lines		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	Deforestation and access roads (and their impact) associated with implementation and maintenance of utility and services lines represent the main threats adjacent to the species habitat. They are likely to increase with urbanization/industrialization and human population growth. Clearing of vegetation along a 10–20 m wide opening is also occurring along the US-Canada border, with potential impacts on adjacent aquatic habitats. Not a significant issue for the species.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4.3	Shipping lanes		Unknown	Small (1-10%)	Unknown	High (Continuing)	The Great Lakes basin and tributaries contain important shipping lanes. Other than the construction of harbours, human modification of shorelines and urban/industrial/road or railway development (all are discussed and scored elsewhere). The scope is likely small, but the severity is unknown. Maintenance of shipping lanes has a potential impact, and occurs in ON (Lake Erie) as well as QC, but the effect of shipping lane use on the species is unknown. In Quebec, projects to build new port facilities are planned in Montreal and Quebec City and could have major impacts on the species and cause habitat loss. Projects to widen and refurbish bridges in southern Quebec and Ontario are also ongoing and likely in future. There is a potential issue in the western basin of Lake Erie, where dredging occurs (small % of lake), and Mudpuppies are present to depths of about 30 m. Additional potential impacts from pressure effects of ships on underlying water column, but there are no data on impacts on the Mudpuppy. Scope is likely > 1% in Quebec and in Ontario taking into account shipping lanes (rather than dredging, which would be smaller).
4.4	Flight paths						Not a threat
5	Biological Resource Use	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						Not a threat
5.2	Gathering terrestrial plants						Not a threat
5.3	Logging & wood harvesting						Not a threat (indirect effects captured elsewhere, under 1 and 2). The threat would be primarily from logging of the remaining forest at the head of watersheds which could affect drainage and water quality in the species habitat. Siltation resulting from logging is discussed under 9.3. The threat is increased if forest habitat is converted into urban, industrial, commercial habitat or farmlands. Logging is ongoing in Ontario, but buffers are maintained, so water crossings would be the main threat from logging roads [scored under 4.1]

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.4	Fishing & harvesting aquatic resources	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	Recreational and commercial fishing of Mudpuppy has been occurring since the 1900s over a large extent of the range; current status of this exploitation is uncertain but could potentially be locally severe if occurring repeatedly at the same sites. Some declines have previously been observed at sites where large numbers of specimens were collected annually. Fishing bycatch (both recreational, particularly ice fishers, and commercial) causing mortality can lead to local declines. Quebec: most records for the species come from fishing bycatch; Ontario: large numbers caught as bycatch, although the impact probably varies considerably across the species range. Bycatch requires more research because long-lived species are particularly vulnerable to its impacts. These would be exacerbated by targeted collection for biological specimens, pet trade, fishing bait, and human consumption, although the extent of these is unknown. Additionally, the importance of commercial fishing and the gamefish industry in the species range increases the need for lampricide use and other pest control approaches which may negatively impact the Mudpuppy [scored in 9.3].
6	Human Intrusions & Disturbance		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	Numerous recreational activities (boating, fishing, etc.) are carried out on most water bodies where the species is found and could potentially cause habitat degradation and disturbance. Severity is likely negligible, but impacts could include wave-induced erosion and siltation, introduction of invasive exotic species, and decrease in water quality (all have been discussed elsewhere). Not considered a significant threat or research question at present.
6.2	War, civil unrest & military exercises						Not a threat
6.3	Work & other activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Non-lethal research on the Mudpuppy, fish, and other aquatic biota, including freshwater mussels, is a source of potential disturbance to the species., Scope and severity are both considered negligible.
7	Natural System Modifications	CD	Medium - Low	Restricted (11-30%)	Serious - Moderate (11-70%)	High (Continuing)	
7.1	Fire & fire suppression						Not a threat.
7.2	Dams & water management/use	CD	Medium - Low	Restricted (11-30%)	Serious - Moderate (11-70%)	High (Continuing)	The Mudpuppy is sensitive to sudden fluctuations in water levels (after flooding events caused by storms or dam management). Rapid changes in water levels (flooding or drainage) along hydro dams have previously caused massive kills, and water management has the potential to affect habitat connectivity and population viability. Such fluctuations can also reduce available bank retreats as well as flush eggs/larvae. Ontario: Very large numbers of dams exist in river habitats, and most rivers/tributaries draining into the Great Lakes are dammed; however, many on the Shield are not. Few new dams are planned, but existing dams continue to impact populations. Quebec: probably 70% of species habitat is dammed.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7.3	Other ecosystem modifications	CD	Medium - Low	Large - Restricted (11-70%)	Moderate - Slight (1-30%)	High (Continuing)	This threat discusses habitat modification caused by exotic species. Other impacts related to invasive exotic species and diseases are treated in 8.1. Quagga Mussel, Zebra Mussel, and Eurasian Watermilfoil have a potential impact on the Mudpuppy habitat and the food web. In areas of high Zebra Mussel density, light penetration in water column is deeper; this negatively impacts the species, which has low tolerance to light. Round Goby is thought to be a potentially serious threat to the Mudpuppy although currently unknown. Erosion from housing, shoreline development and existing land uses (agriculture, forestry) are included here. Siltation is a big issue in Ontario; impacts are primarily from loss of crevices and refuges on the bottom substrate rather than from turbidity. Scope and severity scores for this category are based primarily on erosion; the latitude in scores reflects uncertainty about population effects.
8	Invasive & Other Problematic Species & Genes		Unknown	Large - Small (1-70%)	Unknown	High (Continuing)	
8.1	Invasive non-native/alien species		Unknown	Pervasive - Large (31-100%)	Unknown	Moderate (Possibly in the short term, < 10 yrs)	Chytrid fungus (Bd and Bsal) presents a potential threat, but it is not known to be present in the Mudpuppy in Canada. The species' sensitivity to Bd is unknown; it was recently classified as resistant to Bsal (SNAPS program). Although Bd may be native, introduced strains may be more virulent, hence it is scored here. The lamprey represents a serious threat to the species because of lampricide treatments, which have caused and continue to cause mass kills of Mudpuppy [scored under 9.3]. Various invasive species, including Round Goby, Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena rostriformis bugensis*), were found in Mudpuppy stomach contents. Mussels are consumed more infrequently, probably owing to their hard shells (Beattie et al. 2017).
8.2	Problematic native species		Unknown	Large - Small (1-70%)	Unknown	High (Continuing)	*Diplostomum* sp. parasites affect Mudpuppy in parts of the range in Quebec (unknown elsewhere), sometimes in high numbers. If their impact is similar to that on fish, they can cause blindness, emaciation, and death. Prevalence may be increasing with pollution, water level changes, or changes in prevalence in other hosts (normal background levels would not be scored here). Massive die-offs of Mudpuppy caused by botulism have occurred in Lake Erie in Pennsylvania, but prevalence in Canada is unknown. Ranavirus is a potential threat to the species. No cases of ranavirus infection have been reported for the species; however, the host species that act as vectors for Rv co-occur with Mudpuppy. Harmful algal blooms are increasing in frequency, distribution, and severity, and are adversely impacting general ecosystem health.
8.3	Introduced genetic material						
9	Pollution	BC	High - Medium	Large (31-70%)	Serious - Moderate (11-70%)	High (Continuing)	There was initial uncertainty in the scoring of scope and severity in the original unified threats calculator (2022.04.22), in particular, for the subcategories under Pollution, although all participants agreed that pollution is the main issue for the species. Additional guidance/ review was sought from two experts in the field (Tana McDaniel, Shane de Solla) before finalizing the scores.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.1	Domestic & urban wastewater	CD	Medium - Low	Large (31-70%)	Moderate - Slight (1-30%)	High (Continuing)	The Great Lakes and their tributaries, the St. Lawrence River and other streams and water bodies inhabited by Mudpuppy are highly contaminated by pollutants. Water runoff in urbanized watersheds is a source of contamination and causes siltation that reduces available habitat and reproductive success. For example, in urban areas of southern Quebec, untreated household sewage and urban wastewater overflow into rivers and natural habitat when volumes of water to be treated exceed capacity of treatment plants, due to excessive loads or system malfunction. This causes contamination (fecal coliforms, nitrates, ammonia, heavy metals, etc. and reduced oxygen) and decreases water quality. Scope can be localized but also large considering that many watersheds are located in urban areas that receive significant amounts of urban runoff and wastewater. Despite increasing human populations, and hence increasing volume of wastewater generated, in general, quality of municipal effluents have improved due to a move towards more secondary and tertiary waste water treatment plants, and evidence indicates a reduction of toxicity of municipal effluents to aquatic organisms. In Ontario, from 2002 to 2018, water quality in rivers has not changed at across southern Canada in 69% of tributaries, deteriorated in 14%, and improved in 19%. Recent estimates indicated that toxicity in surface waters to aquatic animals in Great Lakes tributaries come mostly from non-persistent compounds in surface waters. Of these, municipal effluent releases compounds such as organophosphate flame retardants, plasticizers, and pharmaceuticals. Some chemicals associated with industry are released primarily through municipal wastewater. Some water quality parameters have gotten worse, such as increasing chloride levels, partially from effluent but more from road salt use. Salinization from chloride in tributaries in the Great lakes, especially urban areas, have an increasing potential to negatively affect amphibians. This is an existing threat that will continue in the future. Considerable uncertainty about the population effects and average impact across the entire Canadian range. All or most water bodies probably have some level of contamination but the impacts on populations vary depending on contamination levels. Ontario: the problem occurs in most waterways and is not restricted only to urban areas. (ECCC 2020.)

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.2	Industrial & military effluents	D	Low	Small (1-10%)	Moderate (11-30%)	High (Continuing)	The Great Lakes and their tributaries, the St. Lawrence River and other streams and water bodies inhabited by Mudpuppy are highly contaminated by pollutants from industrial sources. Legacy contaminants include PCBs and organochlorine pesticides, although exposures have generally dropped substantially from the 1990s to 2020. PAH emissions continue, but they too are dropping, and the most important sources are non-point sources such as airborne deposition and roads. Recent estimates indicated that toxicity in surface waters to aquatic animals in Great Lakes tributaries are mostly due to non-persistent compounds in surface waters. Of these, industrial effluents include nonylphenols and their ethoxylates. Heavy metal contamination (e.g., mercury, cadmium, lead) from industries has been observed in Manitoba, Ontario, and Quebec. Mudpuppy accumulates contaminants in their bodies, potentially causing differing levels of stress including hormonal disruption and limb deformities; these contaminants potentially explain the species absence and disappearance in some heavily contaminated water bodies but are probably not limiting in most populations. Spills related to oil and gas drilling also have the potential to contaminate water. Many chemicals associated with industry are released primarily through municipal wastewater or through agricultural use.
9.3	Agricultural & forestry effluents	BC	High - Medium	Large (31-70%)	Serious - Moderate (11-70%)	High (Continuing)	The Great Lakes and their tributaries, the St. Lawrence River and other streams and water bodies inhabited by Mudpuppies are highly contaminated by pollutants from agricultural sources. Pesticides and fertilizers are commonly used in the agricultural watersheds inhabited by the species. Legacy contaminants include DDT, DDE, and other persistent compounds; however, their levels have generally declined substantially throughout the Great lakes, including in Areas of Concern, and are likely not currently a major issue. Recent estimates indicate that aquatic animals in Great Lakes tributaries are mainly exposed to non-persistent compounds in surface waters, such as current use pesticides (e.g., metolachlor, atrazine). Nutrients such as nitrates, ammonia and phosphates, are likely also (directly or indirectly) important sources of toxicity or chemical stress. Agricultural effluent and runoff can also intensify siltation rates by increasing inputs of suspended sediments, which are hypothesized to be detrimental to the Mudpuppy. Loading of nutrients, including nitrates, is a threat across the Mudpuppy's range. Nitrates, which can be highly toxic, increase following the conversion of forest cover to pasture and to crops, and the associated effects on amphibian species can be significant. Impacts of runoff from agricultural and forestry operations include pollutants and sedimentation that can decrease available habitat and reproductive success. The long term impact of effluents on the species is potentially severe, especially when combined with other stressors. The wide range of scores, particularly for severity, reflects uncertainty about population effects. Water sampling to date shows high levels of contamination in the species range. Products used for fish management such as liquid rotenone impact salamanders and their invertebrate prey. Lampricides (TFM) have been widely used in the Great Lakes basin since the 1950s. Although these chemicals degrade quickly, they have caused local mass die-offs of Mudpuppies in lakes Superior, Michigan, Champlain, Erie, and their tributaries. In Ohio, an estimated population decrease of at least 29% in a one-year period was attributed to TFM.
9.4	Garbage & solid waste		Unknown	Small (1-10%)	Unknown	High (Continuing)	Garbage and solid waste are dumped along water bodies where the species is found. If chemical wastes are dumped, contamination could be severe.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.5	Air-borne pollutants		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Atmospheric deposition of pollutants has caused *D. fuscus* (a stream salamander) population to decline in the U.S. at sites where the bedrock had low buffer capacity. However, there are no similar data for Canada. Threat severity is unknown.
9.6	Excess energy						Not a threat
10	Geological Events						
10.1	Volcanoes						Not a threat
10.2	Earthquakes/tsunamis						Not a threat
10.3	Avalanches/landslides						Landslides can occur in watersheds inhabited by the species. This threat is probably localized and restricted. No increase in this threat anticipated.
11	Climate Change & Severe Weather		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
11.1	Habitat shifting & alteration						
11.2	Droughts		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	Forecasts for longer periods of drought in summer (concern for habitat availability, connectivity and water temperature). The severity of change in water levels of streams, rivers, and lakes is uncertain. Seasonal droughts may become more severe and/or more frequent in the short term. Timing of precipitation is important; an increase in precipitation is predicted in general. Small, shallow streams were included in the scope, because they are likely to be most affected by seasonal droughts. Impacts less or non-existent for the Mudpuppy in large water bodies.
11.3	Temperature extremes						Not a threat. Maximum critical temperature appears to be 33–34°C.
11.4	Storms & flooding		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Projections show an increase in heavy precipitation events (potentially increasing flooding events and reducing water quality through siltation and pollution). See discussion under Dams & Water Management/Use [7.2]. Across the range, effects are most pronounced in collection basins; "100-year" flooding events are occurring more frequently. Impacts in both breeding and overwintering areas include erosion and habitat alteration, and direct mortality events associated with storms (past report of a die-off of > 1,000 individuals in Sarnia [Lake Huron]) after an intense storm). Storm surges and flooding events, particularly in winter or spring, might displace Mudpuppies downstream or push them into unsuitable floodplain habitat

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