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Information in Support of an Updated Recovery Potential Assessment of Northern Madtom (*Noturus stigmosus*) in Canada, 2012–2021

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Foreword

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

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ABSTRACT

The Northern Madtom (*Noturus stigmosus*) is a small, ictalurid catfish species requiring medium to large streams or rivers with gravel, sand, or cobble substrates and moderate to swift current. In Canada, it is found in the Detroit, St. Clair, and Thames rivers, and Lake St. Clair. It is likely extirpated from the Sydenham River. In April 1993, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) placed Northern Madtom in the Data Deficient category. The species was re-examined in April 1998 and designated as Special Concern. Northern Madtom was re-assessed as Endangered in November 2002 (and again in May 2012) due to its restricted range, a deterioration in water quality, and interactions with invasive species. Subsequent to the 2002 COSEWIC designation, Northern Madtom was listed on Schedule 1 of the *Species at Risk Act* (SARA) in June 2003. The Recovery Potential Assessment (RPA) provides background information and scientific advice needed to fulfill various requirements of SARA including informing the development of recovery documents and for assessing SARA Section 73 permits. This research document describes the current state of knowledge of the biology, ecology, distribution, population trends, habitat requirements, and threats of Northern Madtom, with updated information from 2012 through 2021. A threat assessment identified the greatest threats to Northern Madtom in Canada as aquatic invasive species, various sources of pollution, climate change, and habitat modifications from shipping channel construction and maintenance. Mitigation measures and alternative activities related to the identified threats that can be used to protect the species are also presented. Knowledge gaps remain surrounding population status through time, the status of the species in the Sydenham River and Lake St. Clair, total habitat extent, and the mechanisms and impacts of major threats.

INTRODUCTION

Northern Madtom (*Noturus stigmosus*, Taylor 1969) was first assessed at a meeting of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in April 1993, which resulted in placement of the species in the Data Deficient category. The species was re-examined by COSEWIC in April 1998 and designated as Special Concern. In November 2002, Northern Madtom was re-assessed as Endangered based on the existing 1998 status report with an addendum. Subsequent to the COSEWIC designation, Northern Madtom was listed on Schedule 1 of the *Species at Risk Act* (SARA) when the Act was proclaimed in June 2003. The status was re-assessed and confirmed by COSEWIC in May 2012 (COSEWIC 2012). The reason given for this designation was that "this species is one of the rarest freshwater fish in Ontario, being found at only four locations in river systems in southwestern Ontario. Substantial and ongoing threats in these rivers include siltation, turbidity, exotic species and toxic compounds, which have all been assessed as high levels of concern. Although there may be some localized improvement in habitat, overall there is an inferred continuing decline in habitat quality and substantial ongoing threats throughout its range". A Recovery Potential Assessment (RPA) process has been developed by Fisheries and Oceans Canada (DFO) to provide information and scientific advice needed to fulfill SARA requirements, including the development of recovery strategies and authorizations to carry out activities that would otherwise violate SARA (DFO 2007a, b). A RPA was completed for Northern Madtom in March 2012 (DFO 2012). The RPA process has since been updated to include a standardized Terms of Reference (ToR) consisting of 22 recovery potential elements (DFO 2007a, DFO unpublished). Additionally, new information (2012–2021) from sampling efforts in Canada and adjacent populations in the United States of America (U.S.) are available to update the RPA advice. This document provides updates to background information on Northern Madtom found in McCulloch and Mandrak (2012) and, along with Fung and Koops (2024), informs the 22 elements of the RPA ToR.

BIOLOGY, ABUNDANCE, DISTRIBUTION AND LIFE HISTORY PARAMETERS

Element 1: *Summarize the biology of Northern Madtom*

SPECIES DESCRIPTION

Northern Madtom is a small, benthic ictalurid catfish species. The species possesses venom glands associated with the pectoral spines (Scott and Crossman 1973). Like all madtoms, Northern Madtom is negatively phototactic and seeks shelter during the day if light penetration reaches the substrate. As a result, foraging activity is nocturnal, with barbels and other sensory organs along the body used to locate prey (Keast 1985). The overall colour pattern is mottled with three irregular dark saddles on the back located at the front of the dorsal fin, behind the dorsal fin, and at the adipose fin. The dorsal and adipose fins of Northern Madtom have pale distal margins. There are three or four irregular crescent-shaped bars on the caudal fin; the middle bar usually extending across the upper and lower caudal rays and touching the caudal peduncle. Two pale spots about three-quarters the diameter of the eye are usually present just anterior to the dorsal fin. The adipose fin has a high rear edge, and it is nearly free from the caudal fin. The posterior edge of the pectoral spine is strongly serrated with 5–10 teeth (Page and Burr 2011). The distance from the notch between the adipose and caudal fins to the origin of the dorsal fin is 1.6–1.7 times greater than the distance from the notch to the end of the caudal fin (E. Holm, pers. comm.). In spawning males, the head flattens, dark pigment diffuses, and conspicuous swellings develop behind the eyes, on the nape, and on the lips and cheeks (Trautman 1981, Etnier and Starnes 1993, Holm et al. 2009, Page and Burr 2011).

Five madtom species occur in Canada. In Ontario, the distributions of three madtoms (Stonecat, *N. flavus*; Tadpole Madtom, *N. gyrinus*; and Brindled Madtom, *N. miurus*) overlap with that of Northern Madtom, although several distinctive characteristics can reduce the chance of errors in species identification. Stonecat and Tadpole Madtom are both unmottled and have weak serrations on the posterior edge of the pectoral fin spines. Brindled Madtom has a low adipose fin continuous with the caudal fin, a dark blotch at the tip of the dorsal fin, a dark bar that extends to the extreme upper edge of the adipose fin, and lacks pale margins on the dorsal and adipose fins. While rare, hybridization between madtom species can occur and has been reported for Brindled Madtom and Tadpole Madtom in the Great Lakes basin (Menzel and Ramey 1973, Welsh and Cincotta 2004).

A recent study compared the population structure of Northern Madtom sampled from the Detroit and St. Clair rivers and found that the two rivers exhibit significant genetic structure and may function as distinct populations (Utrup et al. 2023). Fin clips were taken from 34 individuals from the Detroit River, and 79 individuals from the St. Clair River in 2018 and 2019. Nine microsatellite loci were genotyped and mitochondrial DNA was analyzed. Results indicated population structure between the two rivers, and both datasets implied greater genetic diversity in the St. Clair River compared to the Detroit River. There was also evidence of recent population expansion in both rivers, which the authors hypothesized could be related to remedial activities and habitat improvements, and/or to Round Goby population sizes stabilizing where it co-occurs with Northern Madtom (Utrup et al. 2023). Genetic material from the Thames River was not available.

LIFE CYCLE

Northern Madtom likely lives to age 5 or 6 in the Great Lakes basin (Manny et al. 2014, Conard 2015). Age at maturity is 2–3 years (Taylor 1969, Manny et al. 2014, Conard 2015, Utrup et al. 2023), although Scheibly et al. (2008) provided evidence for early maturation of females at 13 months in Kentucky. Scheibly et al. (2008) stated that both sexes of Northern Madtom reach reproductive condition in early summer and exhibit secondary sexual dimorphism at this time. Breeding seems to occur in July in most parts of its range, including Ontario (Taylor 1969, MacInnis 1998, Scheibly et al. 2008, B. Utrup, Michigan Department of Natural Resources, pers. comm.). Spawning likely occurs at night in mid- to late-summer in Ontario when water temperatures range from 20–25°C (Goodchild 1992, MacInnis 1998, Scheibly et al. 2008, Johnson et al. 2021). Females lay eggs in a cavity nest that is guarded by a male. Nests may be excavated by the male, or natural or artificial cavities/containers may be used (MacInnis 1998, Scheibly et al. 2008). Current knowledge suggests that Northern Madtom produce only one clutch per year. However, MacInnis (1998) suggested that females may lay eggs in multiple nests. Eggs are thought to develop in approximately 10–13 days, and hatchlings develop for an additional 10 days until the yolk sac is absorbed. Males guard the young until they reach approximately 20 mm total length (TL) (Scheibly et al. 2008).

MacInnis (1998) observed and video-taped nesting of 21 adult Northern Madtom in Lake St. Clair near the Detroit River during the summer of 1996 while conducting research on the Round Goby. Eggs had a mean diameter of 3.0 mm (range: 2.4–3.7 mm) and clutch size was conservatively estimated to range from 32 to 160 eggs. The male guarded both the eggs and newly hatched fry and did not abandon the nest when disturbed. Larvae and juveniles measuring approximately 9 mm TL were observed being guarded by males on August 13th. The temperature during this period was 23°C. Gravid females were observed as late as mid-August, suggesting a reproduction season of at least one month (MacInnis 1998). SCUBA diving efforts in the St. Clair River in 2022 observed male Northern Madtom guarding nests with eggs as early as July 12 (20.0°C) through July 22 (20.8°C), but follow up surveys could not be completed to understand the end of the spawning period; no eggs or guarding males were observed on June 30 (18.1°C) (B. Utrup, pers. comm.). In Kentucky, ovaries of mature females contained 34–106 mature oocytes, which had a mean diameter of 2.2 mm (range 1.0–3.1 mm). Clutch sizes were estimated to be between 70–110 eggs. Eggs incubated in the laboratory hatched 13 days after fertilization. Hatchlings were 7.1–9.3 mm TL, and yolk sacs were absorbed within 10 days, at which time juveniles measured 15.4–15.7 mm TL. Young of the year (YOY) measuring 16–23 mm standard length (SL) were captured in a seine (i.e., out of the nest) shortly after spawning was observed (Scheibly et al. 2008). Clutch sizes in Michigan ranged from 61 to 141 eggs from older sources (Taylor 1969) and a mean of 177.9 eggs/fish (range: 115-288; n=10) was observed in samples from 2019 (Utrup et al. 2023). In Pennsylvania, mature female Northern Madtom collected in mid-June had an average oocyte diameter of 1.83 mm, and average clutch size of 98 eggs. Relative fecundity (expressed as number of oocytes/g of body weight) was 20.2 (Tzilkowski and Stauffer 2004).

Northern Madtom maximum length was previously reported as 132 mm TL, but recent detections revealed the species can reach 156 mm TL (Holm et al. 2009, Johnson et al. 2021, Utrup et al. 2023). It is unknown whether larger individuals were always present and were not detected, or whether the scope for growth has improved in the St. Clair – Detroit River System (SCDRS). MacInnis (1998) reported the average TL of Northern Madtom observed in Lake St. Clair to be 113.4 mm (female mean length of 101.3 mm and male mean length of 129.8 mm). The mean TL of 173 individuals captured in Ontario from 2003 through 2020 was 53.4 mm TL [(range 14 to 131 mm) (Fish Biodiversity Database)]. Manny et al. (2014) found a mean SL of 91 mm from 192 Northern Madtom captured in the Detroit River in 2008, with most captured individuals between 110–120 mm SL. Johnson et al. (2021) collected 141 Northern Madtom with a mean TL of 106 mm (range: 52–138 mm TL) in 2016-2018 through the SCDRS. A compiled data set of Northern Madtom captured in minnow traps in the SCDRS spanning 2010–2020 revealed a mean TL of 112 mm (range: 56–156 mm; n=781), noting a bias towards larger individuals in minnow traps (Utrup et al. 2023). The length-frequency distribution of Northern Madtom captured in the Detroit, St. Clair, and Thames rivers is presented in Figure 1.

Age assessments of Northern Madtom have been recently completed, although relatively few individuals were assessed due to their rarity and conservation status. Conard (2015) aged otoliths, pectoral, and dorsal spines from Northern Madtom ranging 32–140 mm SL (n= 21 caught + 30 preserved), and estimated ages to range from 1–5 years. Manny et al. (2014) estimated ages of 11 Northern Madtom in the Detroit River, ranging from 2–6 years. Both studies found that growth slowed after age 3 or 4, and found high agreement between assessments from otoliths and pectoral spines (compared to dorsal spines). Utrup et al. (2023) aged 27 Northern Madtom collected in 2019 in the SCDRS using 26 dorsal spines and 17 otoliths. Individuals ranged from 60–150 mm TL and were aged 2–5 years. Structure agreement was high between otoliths and dorsal spines (82%), as was agreement between readers for both structures. Additionally, 100% survival was observed after 7 days in the lab following dorsal spine removal. An additional 65 archived specimens were also aged to produce an age-length key, which would be applicable to Canadian specimens.

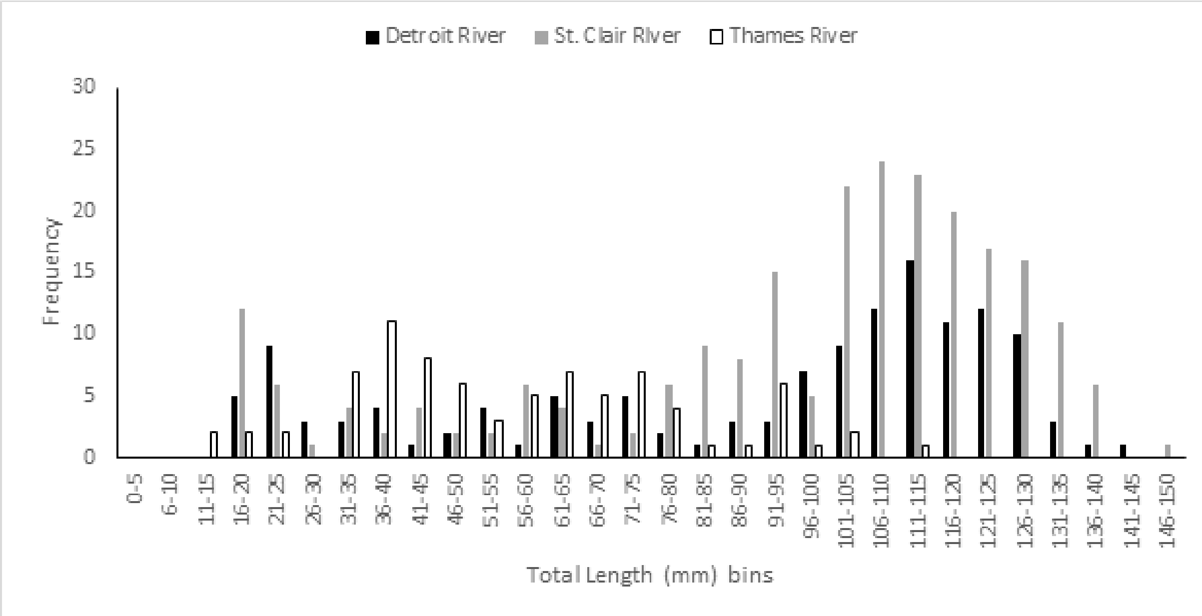

Figure 1. Length frequency distribution of Northern Madtom (n=450) captured in the Detroit, St. Clair, and Thames rivers from 2012-2021 using a combination of trawls, minnow traps and gill nets (Fish Biodiversity Database, MDNR unpublished).

FEEDING AND DIET

Northern Madtom feeds on aquatic macroinvertebrates, including mayflies, caddisflies, and chironomids. Small fishes and crustaceans are also eaten. While Northern Madtom is generally an opportunistic feeder, in Pennsylvania, Tzilkowski and Stauffer (2004) found that it preferentially selected blackflies and stoneflies, and avoided midges and riffle beetles. All other prey items were consumed in the same proportion to their relative abundance in the stream. In the St. Clair River, French and Jude (2001) found that at 3 m depth, Northern Madtom fed heavily on mayfly nymphs (Hexagenia; Ephemeridae and Baetisca; Baetiscidae). At 5 and 7 m depths, large Northern Madtom added brachycentrid caddisflies, amphipod crustaceans and fishes to their diet. Fish species that were consumed by Northern Madtom included Round Goby, an unidentified minnow, and other Northern Madtom (French and Jude 2001). In a follow up study in the St. Clair River, Northern Madtom diet varied with season and depth of capture (Burkett and Jude 2015). A large Northern Madtom (>75 mm) at 5 m depth collected in July 2011 had a total of seven different prey types in its stomach, including Hexagenia and other ephemeropterans, trichopterans, chironomid larvae and pupae, amphipods, and crayfish. Another individual collected in September 2011 had eaten a total of nine different prey items, with the addition of gastropods, fish, and unidentified insects. Additionally, fish eggs were found inside the stomach of a large Northern Madtom captured at 3 m depth in July 2011, and zooplankton was found inside the stomach of a small Northern Madtom captured at 7 m depth (Burkett and Jude 2015). In June 2019, 27 Northern Madtom stomachs from individuals captured in the St. Clair River were sampled, and Ephemeroptera and Trichoptera were the most abundant prey by volume (47% and 46%, respectively), followed by Amphipoda (33%) (Utrup et al. 2023).

ABUNDANCE

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

Abundance estimates are lacking for Northern Madtom populations in Canada. Fewer than 500 Northern Madtom have been captured in Canadian waters. Northern Madtom density was coarsely estimated (for evaluating the potential effects of lampricide on Northern Madtom) in the Detroit, St. Clair, and Thames rivers as 0.57 fish/100 m^2 (±0.30), 0.51 fish/100 m^2 (±0.29), and 0.60 fish/100 m^2 (±0.29), respectively, based on catch data where sample area was recorded (Smyth and Drake 2021); these estimates do not account for imperfect detection. Theoretical density estimates were generated based on an Area Per Individual length-weight relationship (Randall et al. 1995), corrected for each age class based on age-at-length estimates; this yielded density estimates ranging from 4.65 (at age 1) to 0.12 (at age 5) fish/m^2 for lake habitats, and 11.87 to 0.4 fish/m^2 for river habitats (Fung and Koops 2024). Additional capture data are presented for each occupied area in Table 1a. Sampling on the U.S. side of the SCDRS has allowed for catch per unit effort estimates of Northern Madtom across different time periods that used similar sampling protocols (Manny et al. 2014, Conard 2015, Johnson et al. 2021; Table 1b). Site fidelity of Northern Madtom is poorly known; therefore, there is uncertainty about the relevance of these estimates to Canadian populations. For comparison, density estimates for the Neosho Madtom (*N*oturus *placidus*; federally endangered in U.S.) ranged from 3.3–11.7 fish/100m^2, the lower end representing samples collected with kick seines during the daytime during a high-flow year, and the higher end representing electric kick-seines at night time (Moss 1983, Wenke et al. 1992, Fuselier and Edds 1994, Bulger and Edds 2001).

Table 1a. Summary of Northern Madtom (NMT) catch data from targeted trawling efforts in the Canadian range, 2012–2021 (Fish Biodiversity Database). [a] Density (fish/100 m^2) estimate from Smyth and Drake (2021). CPUE = catch per unit effort. Area occupied is coarsely estimated based on methods in Mandrak et al. (2014) and further details are provided in Table 6.

Waterbody	No. of sites with NMT	No. of sites sampled	Proportion of Trawls with NMT	Mean CPUE	Mean no. caught (when n>0)	Density [a] Fish/100 m^2 (±SD)	Estimated Area Occupied (m^2)
Detroit River	17	281	0.060	0.100	1.647	0.57 (±0.30)	13,874,641
Lake St. Clair	2	95	0.021	0.021	2.000	-	31,805,930
St. Clair River	36	420	0.086	0.115	1.528	0.51 (±0.29)	24,636,117
Thames River	50	192	0.260	0.283	1.480	0.60 (±0.29)	3,218,385

Table 1b. Summary of Northern Madtom catch data from targeted minnow trapping efforts in the St. Clair – Detroit River System. Sampling occurred in 2003, from 2005–2011 (Manny et al. 2014), from 2013–2014 (Conard 2015), and from 2016–2018 (Johnson et al. 2021). CPUE of Northern Madtom is presented as minnow trap-days (where effort is number of days a trap is fished multiplied by the number of traps per location); or minnow trap-hours (where effort is number of hours a trap was fished multiplied by the number of traps per location). Minnow traps were baited with cheese (Manny et al. 2014), or with worms, cheese, dog food or unbaited in Johnson et al. (2021).

Waterbody	Total Number Captured (Manny et al. 2014)	Mean CPUE (minnow trap-days) (range) (Manny et al. 2014)	Total Number Captured (Conard 2015)	Mean CPUE (minnow trap-days) (range) (Conard 2015)	Total Number Captured (Johnson et al. 2021)	CPUE (minnow trap-hours); (Johnson et al. 2021)
Detroit River	304	0.07 (0.0–0.59)	17	0.037 (0.0–0.062)	30	0.001
St. Clair River	-	-	19	0.009 (0.0–0.037)	141	0.007

Compiled minnow trapping data from U.S. agencies from the St. Clair River suggest an increase in Northern Madtom in the system since 2010 (Utrup et al. 2023). A total of 871 Northern Madtom were captured from 2010–2022. Minnow traps set in 2010–2015 baited with cheese resulted in a mean of 0.08 Northern Madtom/trap, and traps set in 2016–2022 baited with nightcrawlers captured a mean of 0.72 Northern Madtom/trap (Table 1c). Previous work comparing bait types identified that traps baited with nightcrawlers resulted in approximately 4.5 times more Northern Madtom compared to traps baited with cheese (Johnson et al. 2021). Catches from cheese-baited traps were corrected for bait type, suggesting a mean of 0.38 Northern Madtom/trap from 2010–2015 (Table 1c). Minnow traps used appear to bias towards larger individuals (>110 mm TL; Manny et al. 2014, Utrup et al. 2023), but it is unknown whether the gear itself is size selective, or if this is reflective of behavioural or habitat differences of smaller size classes (Utrup et al. 2023).

Table 1c. Summary of Northern Madtom catch per unit effort from minnow trapping in the St. Clair River, 2010–2022 (Utrup et al. 2023). Minnow traps in 2010–2015 were baited with cheese, and traps from 2016–2022 were baited with more effective nightcrawlers; thus a bait-type correction was applied to 2010–2015 catches.

	Mean Northern Madtom per Trap (range)	Mean Northern Madtom per Year (range)
2010–2015 (cheese-baited)	0.08 (0.04–0.14)	14.4 (7.0–24.0)
2010–2015 (bait-corrected)	0.38 (0.17–0.62)	65.5 (31.8–109.1)
2016–2022 (nightcrawler-baited)	0.72 (0.23–1.33)	133.1 (44.0–299.0)

DISTRIBUTION

Northern Madtom is rare with a disjunct distribution. It is known from the Mississippi River basin (Ohio and Tennessee rivers) and lower Great Lakes basin (lakes Erie and St. Clair) in Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania, West Virginia, and Ontario; (Page and Burr

2013). The U.S. distribution was revised following a taxonomic revision, in which Thomas and Burr (2004) determined that the allopatric populations occurring in the Coastal Plain streams of Mississippi and Tennessee were not Northern Madtom, but actually a new species, Piebald Madtom (*Noturus gladiator*). The Canadian distribution of Northern Madtom is restricted to Ontario, where it is known only from the Detroit River, St. Clair River, Lake St. Clair, and two tributaries of Lake St. Clair, the Thames River and the Sydenham River (Figure 2). It is likely extirpated from the Sydenham River.

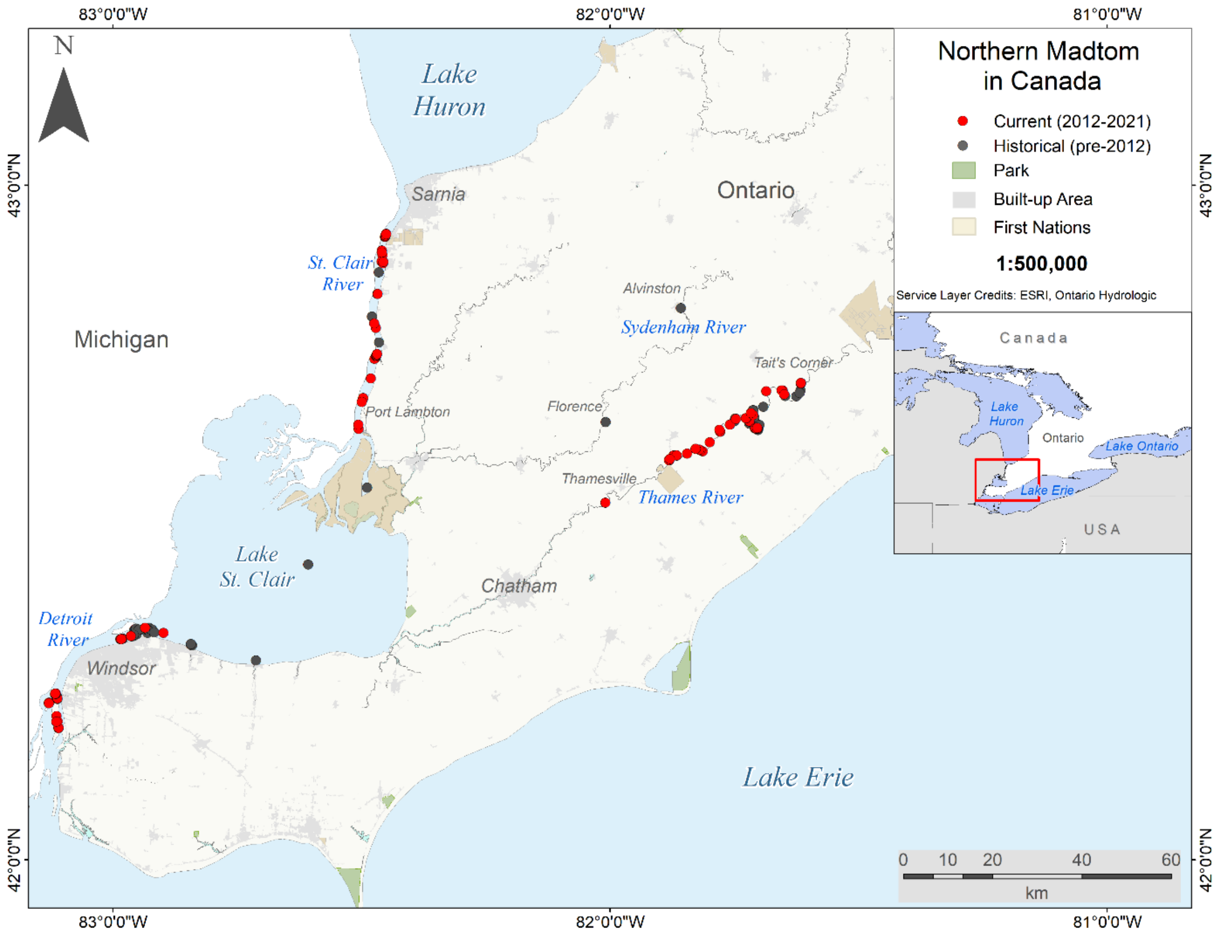

Figure 2. Current (2012–2021) and historical (pre–2012) distribution of Northern Madtom in Canada.

CURRENT STATUS

In Canada, the current and historical distribution of Northern Madtom is limited to the SCDRS within the Lake Erie drainage (Figure 2). It is currently known from the St. Clair River, Lake St. Clair, the Thames River, and the Detroit River, and historical records exist for the Sydenham River. Records described below are thought to be complete for the Canadian side of the distribution.

ST. CLAIR RIVER

Northern Madtom distribution in the St. Clair River is relatively continuous from downstream of Sarnia to the outlet at Lake St. Clair. It was first collected on the Canadian side of the St. Clair River by DFO in 2003, downstream of the Lambton Generating Station at the confluence of Clay

Creek. In 2010, six individuals were collected between Stag Island and Clay Creek (Fish Biodiversity Database). Northern Madtom was captured during benthic trawl surveys by DFO in 2012 (summer and fall; n=27), 2013 (n=7), and 2014 (summer; n=16), overall amounting to detections at 14% of sites sampled with a detection probability of 0.160 (±0.017) (Kindree and Mandrak 2020, Lamothe et al. 2020).

LAKE ST. CLAIR

In Lake St. Clair, a historical record exists from 1963 close to the inlet of the Detroit River (Trautman 1981). In 1996, three juveniles were seined at the mouth of Belle River approximately 19 km east of the Detroit River (Holm and Mandrak 2001) and one individual was found dead on the south shore of Lake St. Clair near the outlet of Puce Creek (ROM 104215). Also in 1996, MacInnis (1998) observed 21 Northern Madtom guarding egg clutches near the source of the Detroit River. In 1999, a specimen was captured near the St. Clair River delta (ROM 72038). In 2010, DFO captured an individual in a trawl at the mouth of Pike Creek. In 2012 and 2013, DFO sampled 54 sites with a trawl along the south shore of Lake St. Clair between the mouth of the Thames River and the Detroit River, including major south shore tributaries: Pike and Puce creeks, and Belle, Ruscom and Thames rivers (Barnucz et al. 2015); three Northern Madtom were captured in 2012 at one site between the mouth of Pike Creek and the Detroit River (Fish Biodiversity Database).

It is unclear to what extent Lake St. Clair contributes to production of Northern Madtom. As detections have been relatively infrequent in the lake, it is possible that individuals have been flushed from riverine sources (i.e., St. Clair or Thames rivers), and new research suggests there is no evidence of recent gene flow between the St. Clair and Detroit rivers (Utrup et al. 2023).

SYDENHAM RIVER

Historical records exist from the Sydenham River from 1929 near Alvinston (ROM 6675) and 1975 near Florence (CMN 75-1623) (Edwards et al. 2012). Targeted sampling of infrequently sampled river reaches in the lower Sydenham River between Dawn Mills and Dresden was conducted in 2019 at 40 field sites spanning a gradient of lotic and lentic habitat (Barnucz and Drake 2021). Despite the presence of potentially suitable habitat at some sites and the detection of other madtom species (Stonecat and Brindled Madtom), Northern Madtom was not detected. The St. Clair Region Conservation Authority conducted sampling in 2019–2021 from Dawn Mills to Alvinston (electrofishing followed by seining) to understand expansion of Round Goby (follow-up to Poos et al. 2010), but did not detect Northern Madtom. Northern Madtom has not been collected from the Sydenham River since 1975, and it most likely has been extirpated.

THAMES RIVER[1]

Northern Madtom is known from an approximately 54 km stretch of the Thames River from Tait's Corners to just downstream of Thamesville; the majority of records are located near the Big Bend Conservation Area. It was first collected in the Thames River in 1991 near Wardsville. A juvenile specimen was captured in August 1997 at the same site. In 2003, an individual was captured by boat electrofishing near Big Bend Conservation Area. Between 2004 and 2010, 31 Northern Madtom were collected at 27 sites on the Thames River between Littlejohn Road and

[1] Lower Thames Valley Conservation Authority captured a 23 mm YOY Northern Madtom in a seine net in September 2022 at Tait's Corners. DFO captured 22 Northern Madtom from Tait's Corners through Big Bend Conservation Area in October 2022 while trawling; specimens ranged 37–103 mm TL.

Tait's Corners through seining and trawling efforts (Fish Biodiversity Database). Northern Madtom was collected in 2013 (n=19), 2014 (n=16), 2015 (n=18), 2016 (n=2), and 2020 (n=9) during various DFO targeted and non-targeted trawling efforts (Barnucz and Drake 2022, Fish Biodiversity Database). Detection probability of Northern Madtom calculated from 2012 to 2016 trawl efforts was 0.192 (±0.013 95% CI) (Lamothe et al. 2020). An additional specimen was captured in 2018 with backpack electrofishing near Big Bend (Ontario Ministry Natural Resources and Forestry unpublished data).

DETROIT RIVER

The first Canadian record from the Detroit River was a single specimen collected in 1994 (ROM 68328) on the northeast side of Peche Island (near the first capture site in Lake St. Clair); Northern Madtom was first collected in 1903 on the United States side of the river (University of Michigan Museum of Zoology; UMMZ 132009). It is found in two areas within the Detroit River in Canadian waters: at the inlet from Lake St. Clair around Peche Island and Belle Isle (U.S.), and in the middle of the river around Fighting Island; it appears to be more abundant at the former area (Manny et al. 2014, Conard 2015). Northern Madtom has been collected in the area around Peche Island in 1996 (n=11), 2003 (n=7), 2005 (n=15), 2006 (n=42), 2008 (n=183), 2009 (n=9), 2010 (n=2), 2011 (n=20), 2013 (n=5), and 2018 (n=1). Near Fighting Island, Northern Madtom was found in 2009 (n=7), 2010 (n=2), 2011 (n=1), 2012 (n=3), 2013 (n=2), 2015 (n=1), 2017 (n=7), 2018 (n=2), and 2019 (n=1) (Fish Biodiversity Database, USGS/USFWS data). Most Northern Madtom from the Detroit River were captured during benthic trawl surveys or in minnow traps (sometimes baited).

POPULATION ASSESSMENT

To assess the status of Northern Madtom populations in Ontario, each population was ranked in terms of its abundance (Relative Abundance Index) and trajectory (Population Trajectory) (Table 2).

The Relative Abundance Index was assigned as Extirpated, Low, Medium, High or Unknown. Sampling parameters such as gear used, area sampled, sampling effort, and whether the study was targeting Northern Madtom were considered. The number of individual Northern Madtom caught during each sampling period was then considered when assigning the Relative Abundance Index. The Relative Abundance Index is a relative parameter in that the values assigned to each population are relative to the most abundant population (assigned as High here by default; differs from assessment in McCulloch and Mandrak (2012)). The recent catch data from Canadian populations (Table 1a) suggests catches (and density) are similar in the Detroit, St. Clair, and Thames rivers; however, the total available habitat space is greater in the Detroit and St. Clair rivers (on both Canadian and U.S. side) compared to the Thames River, and it is likely that these larger systems support larger total population sizes.

The Population Trajectory was assessed as Decreasing, Stable, Increasing, or Unknown for each population based on the best available information about the current trajectory of the population. The number of individuals caught over time for each population was considered. Trends over time were classified as Increasing (an increase in abundance over time), Decreasing (a decrease in abundance over time), or Stable (no change in abundance over time). If insufficient information was available to identify the trajectory, the Population Trajectory was listed as Unknown. Certainty has been associated with the Relative Abundance Index, and Population Trajectory rankings and is listed as: 1=quantitative analysis; 2=CPUE or standardized sampling; 3=expert opinion (Table 2). Northern Madtom has been caught in very low numbers since its discovery in Canadian waters and, given a lack of repeat sampling, inferences about trajectory could not be made with available data.

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

Population	Relative Abundance Index	Certainty	Population Trajectory	Certainty
St. Clair River	High	2	Unknown	3
Lake St. Clair	Low	2	Unknown	3
Sydenham River	Likely Extirpated	3	Not Applicable	-
Thames River	Medium	2	Unknown	3
Detroit River	High	2	Unknown	3

The Relative Abundance Index and Population Trajectory values were then combined in the Population Status matrix (Table 3) to determine the Population Status for each area. Each Population Status was subsequently ranked as Poor, Fair, Good, Unknown or Not Applicable. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index, or Population Trajectory). Population status, as assessed in the original RPA (McCulloch and Mandrak (2012), is presented alongside the updated status (Table 4); however, these assessments are independent of one another and represent the relative population status at the time of assessment. The resulting Population Status being ranked as poor or fair for all areas is driven by the “unknown” Population Trajectory; as this assessment is based on limited data for both the Relative Abundance Index and Population Trajectory, additional data could result in a different Population Status.

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

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

Table 4. Population Status for all Northern Madtom populations in Canada, resulting from an analysis of both the Relative Abundance Index and Population Trajectory. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index, or Population Trajectory). Original Population Status assessment results from McCulloch and Mandrak (2012), but these assessments are independent.

Population	Original Population Status (Certainty)	Revised Population Status (Certainty)
St. Clair River	Poor (3)	Fair (3)
Lake St. Clair	Poor (3)	Poor (3)
Sydenham River	Likely Extirpated (3)	Likely Extirpated (3)
Thames River	Poor (3)	Poor (3)
Detroit River	Poor (3)	Fair (3)

HABITAT AND RESIDENCE REQUIREMENTS

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

ADULT

Northern Madtom occupies a wide range of habitats in Canada, including clear to turbid waters of large rivers with moderate to swift current, and occasionally lakes. The lentic environment is usually close to a lotic source, and has a noticeable current (J. Barnucz, pers. comm. 2010). In the Licking River, Kentucky, Scheibly (2003) found that moderate current, averaging 0.50 m/s, was preferred. Northern Madtom occurs in habitat areas composed of sand, gravel, and rocks, occasionally with silt, detritus, accumulated debris and fallen logs or other coarse woody debris, and is sometimes associated with macrophytes (Taylor 1969, Smith 1979, Trautman 1981, Cooper 1983, Burr and Warren 1986, Robison and Buchanan 1988, Carman 2001). Many madtom species seek out natural or artificial cover objects (Midway et al. 2010, Cope et al. 2019, B. Utrup pers. comm.). Occupancy models found gravel substrate to be an important habitat co-variate for Northern Madtom in the Thames and St. Clair rivers (Lamothe et al. 2020). Northern Madtom has been captured at depths ranging from less than 1 m in the Thames River to approximately 14 m in the St. Clair River (Fish Biodiversity Database, Johnson et al. 2021); preferred depth is thought to be 3–7 m in the SCDRS (Conard 2015). Recent studies have shown that Northern Madtom catches were positively associated with turbidity and water temperature (Johnson et al. 2021, Rodriguez et al. 2021). The thermal tolerance of Northern Madtom is not known. It has been captured in waters as warm as 26°C in Ontario (Fish Biodiversity Database), and the upper thermal tolerance for bullheads (*Ameiurus* spp.) has been reported as 35°C but depends on acclimation temperature (Scott and Crossman 1973).

In the St. Clair River, French and Jude (2001) collected Northern Madtom at depths of 3–7 m from the crest of the shipping channel and down along the slope of the channel. In 2016 through 2018 (May through October), Johnson et al. (2021) collected 141 Northern Madtom at natural and artificial reef sites on the U.S. side in the middle through lower reaches of the river. Average water depth ranged 10.6–14.8 m, water velocity ranged 0.47–1.22 m/s, secchi depth ranged 2.8–3.6 m, and the dominant substrate consisted of dreissenid shells, fine sediment, or cobble.

In the Detroit River, Northern Madtom was collected at sites with mean depths of 4.7–8.2 m, modelled water velocity of 0.4–0.7 m/s, over limestone with occasional muddy sand. The site with the greatest catches had a mean depth of 6.83 m, mean velocity of 0.55 m/s, and sand/coarse sand substrate (Manny et al. 2014). From 2016 through 2018, Johnson et al. (2021) collected 30 Northern Madtom at natural and artificial reef sites, where average water depth ranged 6.7–9.2 m, water velocity ranged 0.3–0.6 m/s, secchi depth ranged 2.1–2.8 m, and dominant substrate consisted of cobble, fine sediment, or dreissenid shells.

In the Thames River, Northern Madtom was captured in June through October at sites with a mean water temperature of 18.3°C (range: 8.3–25.9°C), mean conductivity of 650.9 µs/cm (range: 487.8–755.0 µs/cm), mean dissolved oxygen of 8.3 mg/L (range: 3.5–11.7 mg/L), mean pH of 8.7 (range: 8.1–9.3), and mean turbidity of 86.9 ntu (range: 19.6–187.7 ntu). The mean water depth at capture sites was 1.7 m (range: 0.3–3.2 m) and the mean velocity was 0.8 m/s (range: 0.2–1.2 m/s). The substrate was composed of a mean of 38% gravel, 31% sand, and 31% cobble. Sites where only adults (i.e., >65 mm TL) were captured had a mean water temperature of 20.4°C (range: 10.0–24.2°C), mean conductivity of 673.4 µs/cm (range: 593.6–755.0 µs/cm), mean dissolved oxygen of 7.8 mg/L (range: 7.1–11.03 mg/L), mean pH of 8.6 (range: 8.1–9.3), and mean turbidity of 106.8 ntu (range: 26.5–187.7 ntu). The mean water depth at capture sites was 1.6 m (range: 0.8–3.2 m) and the mean velocity was 0.8 m/s (range: 0.2–1.1 m/s). The mean substrate composition was 49% gravel, 34% sand, and 21% cobble (Fish Biodiversity Database).

SPAWN TO HATCH

Northern Madtom is a cavity nester, with nests constructed in depressions under large rocks, logs or other woody debris, inside crayfish burrows, and in anthropogenic debris such as bottles, cans, and boxes (Taylor 1969, Cochran 1996, B. Utrup pers. comm.). Other madtoms have been observed using artificial nests constructed from terracotta pot saucers (Midway et al. 2010, Cope et al. 2019). It also uses mud, sand, gravel, and rock substrates for spawning, and may prefer softer substrates under larger objects for excavating nests (Scheibly et al. 2008, Manny et al. 2014, Johnson et al. 2021). MacInnis (1998) observed and video-taped nesting of 21 adult Northern Madtom in Lake St. Clair during the summer of 1996 while conducting research on the Round Goby. Northern Madtom did not use the artificial goby nests constructed for that research, but excavated 5 cm deep cavities in sand substrates beneath the nests (MacInnis 1998). The nests were set in moderate current on a sandy and/or cobble bottom surrounded by a thick bed of aquatic macrophytes – primarily stonewort (*Chara* spp.), wild celery (*Vallisenaria americana*), and *Cladophora* spp. Water depth at the nests ranged from 1.5–1.8 m (MacInnis 1998). In Kentucky, Scheibly et al. (2008) observed Northern Madtom nesting in cavities 4–7 cm deep under slab rocks in a raceway upstream of a large riffle in mid-July. Water temperatures were 23–25°C and velocities were 0.36–0.69 m/s. Water depth at the nests ranged from 0.26 to 0.46 m. The raceway contained patches of *Potamogeton* spp., one of which contained an egg mass. Site fidelity for nest cavities is unknown in Northern Madtom, but given the dynamic nature (i.e., high flows) of all three riverine locations, it seems unlikely the same nest cavities would be available for use each year.

YOUNG OF THE YEAR AND JUVENILE

There is very limited information on larval and juvenile Northern Madtom habitat requirements. MacInnis (1998) observed YOY Northern Madtom (with and without yolk sacs attached) in nests being guarded by adult males approximately one month after occupation of nests was first observed. When nests were removed, YOY were observed taking shelter in the surrounding macrophytes. In Kentucky, 20 mm SL young had moved upstream from a spawning raceway to the head of a large riffle also about one month after hatching, and were found distributed throughout the raceway and riffle (like adults) by late September (Scheibly et al. 2008). Comparably, the YOY of Brindled and Tadpole madtoms are usually found in the shallow waters (0–2 m) of protected nearshore areas, marshes, and tributaries over substrates of sand, mud, and silt, with aquatic vegetation (Mandrak et al. 2014), and Schiebly (2003) notes that YOY madtoms, in general, are thought to aggregate in schools and associate with cover like leaf litter.

There is limited information regarding the juvenile (i.e., up to age 2 or approximately 65 mm TL) habitat of Northern Madtom or other closely related madtoms. From DFO sampling in 2009 through 2020, there were 29 trawling sites in the St. Clair and Thames rivers where more than one Northern Madtom was captured, and 10 of these sites contained multiple age/size classes ranging from 19–114 mm TL, suggesting that YOY, juveniles and adults may occupy the same or similar habitats at times. Scheibly (2003) noted that juveniles occupy a “narrow niche” within preferred adult habitats, and vegetative cover was more important at the juvenile stage.

HABITAT FUNCTIONS, FEATURES, ATTRIBUTES

A description of the functions, features, and attributes associated with the habitat of Northern Madtom in Canada can be found in Table 5. The habitat required for each life stage has been assigned a life history function that corresponds to a biological requirement of Northern Madtom. In addition to the life history function, a habitat feature has been assigned to each life stage. A feature is considered to be the structural component of the habitat necessary for the species. Habitat attributes have also been provided; these are measurable components describing how the habitat features support the life history function for each life stage. The habitat functions, features, and attributes outlined in Table 5 were adapted from the Critical Habitat order for Northern Madtom (DFO 2016), supplemented with additional, recent information to guide any future identification of critical habitat for this species.

Table 5. Summary of the essential habitat functions, features, and attributes for each life stage of Northern Madtom in Canada. Habitat attributes from published literature (see McCulloch and Mandrak 2012) were used to identify Critical Habitat (Edwards et al. 2012, DFO 2016), and those recorded during recent (2012–2022, May through October) Northern Madtom sampling events have been used to support further delineations of critical habitat. Current knowledge reflects mean habitat values at all sites where young-of-year (YOY; i.e., < 45 mm TL), juvenile (i.e., age 1 to 2, 45–65 mm TL) and adult (i.e., ≥ age 2 or 3, or > 66 mm TL) Northern Madtom were captured across Ontario (Fish Biodiversity Database).

Life Stage	Function	Feature	Attributes		
			Literature	Current Knowledge	For Identification of Critical Habitat
Spawn to Hatch	Spawning Cover Nursery	River reaches with variable substrates suitable for cavity nesting	Water temperature of ~ 20–23°C and moderate current (~0.50 m/s); larger substrates (i.e., cobble, small boulders, fallen logs, bottles, cans) overlaying softer substrates (i.e., mud, sand, fine gravel) suitable for excavating cavities (MacInnis 1998, Scheibly 2003, Scheibly et al. 2008)	Use of woody debris for nesting sites observed in St. Clair River (B. Utrup, pers. comm.); eggs observed once water temperatures reach 20°C	•Warm water (spawning initiated ≥20°C) •Complex substrates where natural (or artificial) cavities exist or can be excavated •Moderate current
Young of Year (<45 mm TL)	Feeding Cover Nursery	River reaches with variable substrates suitable for cavity nesting, and aquatic macrophytes nearby	Same as above; YOY may remain close to the nest, especially if aquatic macrophyte beds are nearby, or move to slightly slower flowing areas (e.g., head of riffles) (Scheibly 2003)	mean water temperature: 16.255°C (range: 8.75–25.92); mean conductivity: 377.20 µs/cm (175.0–755.0); mean dissolved oxygen: 9.41 mg/L (3.76–11.94); mean pH: 8.65 (8.12–9.23); mean turbidity: 27.42 ntu (0–165.3); mean stream depth: 3.12 m (0.97–8.00); mean stream velocity: 0.477 m/s (0.067–1.24) mean substrate composition: 47% sand (0–100), 42% gravel (0–90), 10% clay (0–80)	•Complex substrates where natural (or artificial) cavities exist or can be excavated •Moderate current •Aquatic macrophytes (e.g., *Chara* spp., *Vallisneria americana*, *Cladophora* spp.) or other instream cover
Juvenile (age 1 to 2; or ~45 to ~ 65 mm TL)	Feeding Cover	Medium to large rivers (or lakes) with moderate to swift currents and variable substrates of cobble, gravel, sand	-	mean water temperature: 18.639°C (range: 8.75–24.09); mean conductivity: 510.99 µs/cm (176.0–755.0); mean dissolved oxygen: 8.41 mg/L (3.48–11.68); mean pH: 8.58 (8.09–9.28); mean turbidity: 73.86 ntu (0.70–167.31); mean stream depth: 2.32 m (1.07–5.63); mean stream velocity: 0.604 m/s (0.077–1.233) mean substrate composition: 34% gravel (0–90), 34% cobble (0–100), 32% sand (0–80), 21% clay (0–80)	Same as adult

Life Stage	Function	Feature	Attributes		
			Literature	Current Knowledge	For Identification of Critical Habitat
Adult (≥ age 2 or 3)	Feeding Cover	Medium to large rivers (or lakes) with moderate to swift currents and variable substrates of cobble, gravel, sand	Detroit River: average depth 6.7–9.23 m; average water velocity 0.3–0.6 m/s; average secchi depth 2.12–2.77 m; temperature range 7.71–27.73°C; dominant substrates dreissenids (n=1), cobble (n=1), fines (n=2) (Johnson et al. 2021); greatest catches at Peche Island with mean depth 6.83 m, mean velocity of 0.55 m/s, sand/coarse sand; at all occupied sites water depth from 4.73-8.23 m; 0.35 to 0.70 m/s modeled water velocity, mostly rocky substrate (ranged mud/muddy sand to hard (limestone with rocks/rubble) bottom) (Manny et al. 2014) St. Clair River: average depth 10.6–14.83 m; average water velocity 0.47–1.22 m/s; average secchi depth 2.82–3.64 m; temperature range 10.10–24.15°C; dominant substrates dreissenids (n=3), cobble (n=1), fines (n=2) (Johnson et al. 2021)	mean water temperature: 18.321°C (range: 9.98–25.20); mean conductivity: 441.36 µs/cm (range: 176.0–755.0); mean dissolved oxygen: 9.48 mg/L (range: 7.10–16.86); mean pH: 8.61 (range: 8.07–9.27); mean turbidity: 61.95 ntu (range: 0–187.69); mean stream depth: 2.21 m (range: 0.30–5.50); mean stream velocity: 0.468 m/s (range: 0.063–1.12) mean substrate composition: 42% sand (range: 0–100%), 30% gravel (range: 0–100%), 26% cobble (range: 0–90%), 16% clay (range: 0–100%)	• Relatively deep (usually >1 m, with 3–8 m preferred), flowing (~0.50 m/s) water • Mixed substrates; predominantly cobble, gravel and sand • Adequate supply of prey species (e.g., chironomids, mayflies, caddisflies, small fishes, crustaceans)

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

The spatial extent of areas likely to contain habitat properties required by Northern Madtom has not been explicitly quantified, but has been approximated for each occupied area. Critical Habitat has been identified in the Detroit River and the Thames River (Edwards et al. 2012, DFO 2016). Mandrak et al. (2014) developed a conceptual framework for delineating critical habitat for Northern Madtom based on the functional habitat requirements for each life-stage. Estimates of range sizes for each population were made based on available information about waterbody size and shape, and occurrence records. Since this framework was developed, additional sampling has been conducted, resulting in an expanded distribution at each area; revised estimates are provided in Table 6. Additional areas warrant consideration for critical habitat, including the St. Clair River from north of Froomfield to the top of the St. Clair Delta, and expanded envelopes surrounding Peche Island and Fighting Island in the Detroit River. It is unlikely that the habitat attributes required by Northern Madtom are found consistently throughout each of the identified areas, and it is also possible they exist beyond the identified areas. Bathymetry data are available for the Detroit and St. Clair rivers, but should be considered with substrate and flow data to quantify suitable habitat.

*Table 6. Conservative estimates of area of occupancy population range for each Northern Madtom locality in Canada. Estimates following methods in Mandrak et al. (2014); * indicates area was revised from original estimate because of expanded occurrence records at that location.*

Waterbody	Approximate Area (m^2)	Estimation Approach
Detroit River*	13,874,641	Area of Occupancy - population range envelope
	40,257,881	Area of Occupancy - whole waterbody
Lake St. Clair (4)	**31,805,930**	Home Range buffered occurrence points
	(35,839,865; 35,912,562; 31,804,596)	Home Range buffered occurrence points
St. Clair River*	24,636,117	Area of Occupancy - whole waterbody
Thames River	3,218,385	Ecological Classification - ALIS

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

There appear to be few spatial configuration constraints impacting Northern Madtom in Canada. The Detroit and St. Clair rivers may represent potential barriers to upstream movement for many fishes due to flow conditions, but this is likely not the case for Northern Madtom. There are no obvious constraints in the lower Detroit River, but Northern Madtom has not been detected there in Canadian or U.S. waters; this could be related to sampling difficulties or unsuitable habitat (i.e., presence of soft, contaminated sediments (Manny et al. 2014)). A mark-recapture study showed that two adult Northern Madtom moved across the Fleming Channel from Belle Isle to Peche Island (Manny et al. 2014), suggesting these shipping channels do not represent a complete barrier to movement. On the Thames River, Northern Madtom is known from a fairly continuous stretch from Tait's Corner to downstream of Thamesville; the upstream end is approximately 100 km downstream from Hunt Dam on the South Thames River and approximately 115 km downstream of Fanshawe dam on the North Thames River. Northern Madtom dispersal through Lake St. Clair may be limited by the species' small size. Lake St. Clair is unlikely to be used by Northern Madtom for completing all stages of its life cycle. Occasional detections of the species throughout the lake could indicate that it does not represent a complete barrier to movement between occupied riverine habitats, or that individuals are occasionally flushed from adjoining riverine sources. Recent genetic analyses found strong evidence of population structure between the Detroit River and St. Clair River, suggesting Lake St. Clair may, in fact, represent a barrier (Utrup et al. 2023). Inclusion of genetic data from the Thames River would be beneficial in resolving the degree of movement among occupied habitats.

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

Residence is defined in SARA as "a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating". Residence is interpreted by DFO as having been constructed, created, or at least modified, by the organism. In the context of the above narrative description of habitat requirements, Northern Madtom may occupy residences during the breeding and rearing parts of its life cycle. It is a cavity nester, with nests located in depressions under large rocks, logs and inside crayfish burrows, and in anthropogenic debris such as bottles, cans, and boxes (Taylor 1969, Cochran 1996). Northern Madtom was observed to excavate 5 cm deep crevices beneath artificial Round Goby nests in Lake St. Clair (MacInnis 1998). Parental guarding is conducted by males until YOY are approximately one month of age, at which time both males and young leave the nest (MacInnis 1998, Scheibly et al. 2008).

THREATS AND LIMITING FACTORS TO SURVIVAL AND RECOVERY

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

A wide variety of threats negatively impact Northern Madtom across its range. The greatest threats to its survival and persistence are related to competition from aquatic invasive species (AIS), climate change, toxic compounds, siltation and excessive turbidity, nutrient loading, and the degradation and/or loss of habitat through dredging. Many of these are directly tied to the agricultural and urban land uses that dominate the surrounding landscape. It is important to note that most Northern Madtom populations are facing more than one threat, and that the cumulative impacts of multiple threats may exacerbate their decline. It is difficult to quantify these interactions and, therefore, each threat is discussed independently. Threats have been classified based on the International Union for the Conservation of Nature (IUCN) unified classification of direct threats and Salafsky et al. (2008), and are assessed based on DFO (2014).

THREAT CATEGORIES

Invasive and Other Problematic Species and Genes

The Great Lakes have a long history of invasion by exotic species and introductions of non-native aquatic organisms. Of these, the Round Goby is thought to represent the greatest threat to Northern Madtom due to the potential for diet overlap, competition for nesting sites, and predation. Since its first detection in the St. Clair River in 1990, Round Goby has been implicated in the decline of two other benthic species, Mottled Sculpin (*Cottus bairdii*) and Logperch (*Percina caprodes*) in the St. Clair River (French and Jude 2001) and similar declines of Johnny Darter (*Etheostoma nigrum*), Logperch, and Trout-perch (*Percopsis omiscomaycus*) have been observed in Lake St. Clair (Thomas and Haas 2004). Round Goby is now abundant and ubiquitous throughout the Great Lakes and many of its tributaries.

Round Goby overlaps with Northern Madtom throughout its Canadian distribution. During recent (i.e., since 2012) targeted trawling efforts by DFO, Round Goby was captured at 57% of sites where Northern Madtom was captured. Of the 727 sites where Northern Madtom was targeted or likely to be captured, Northern Madtom (n=120) was captured at 74 (10%) sites, and Round Goby (n=19,345) was captured at 495 (68%) sites. At the 74 sites with Northern Madtom, 3,269 Round Goby were captured. Sampling between 2012 and 2016 detected both Northern Madtom and Round Goby in the Thames and St. Clair rivers, with 39 Northern Madtom captured at 21% of sites and 3,748 Round Goby captured at 35% of sites in the Thames River, while in the St. Clair River, 44 Northern Madtom were captured at 14% of sites and 9,956 Round Goby at 95% of sites (Lamothe et al. 2020). Using this sampling data and two-species occupancy modelling, Lamothe et al. (2020) determined that the probability of detecting Northern Madtom in both the Thames (0.192 ± 0.013 95% CI) and St. Clair (0.160 ± 0.017 95% CI) rivers was substantially lower than the probability of detecting Round Goby (0.833 ± 0.020 95% CI and 0.826 ± 0.005 95% CI, respectively). Northern Madtom was negatively associated with Round Goby in the St. Clair River, and occupancy estimates were lower for Northern Madtom overall when Round Goby was present (Lamothe et al. 2020). Conversely, Johnson et al. (2021) did not find Round Goby CPUE to be a significant factor predicting the number of Northern Madtom captured in the SCDRS. However, all sites were at depths greater than 5 m, where Round Goby may overlap minimally with Northern Madtom. In the Detroit River, Manny et al. (2014) found that Round Goby was the most abundant species in minnow traps from 2003–2011, but Northern Madtom was the second most abundant. In the Sydenham River, Round Goby has been detected as far upstream as the Head Street Dam in Strathroy, well above the recorded occurrence of Northern Madtom at the town of Alvinston (Poos et al. 2010, Firth et al. 2021, C. Paterson, pers. comm.). In a 2019 trawling survey targeting Northern Madtom habitat in the Sydenham River, Round Goby was the second most abundant species captured, and was caught at 97% of sites sampled (Barnucz and Drake 2021).

Round Goby may compete with Northern Madtom for food. French and Jude (2001) found significant diet overlap between Round Goby and Northern Madtom at 3 m depth (but not at 5–7 m) in the St. Clair River in 1994, with both species feeding heavily on *Hexagenia*. However, in a follow-up study in 2011, Burkett and Jude (2015) found no significant diet overlap as large (>75 mm) Northern Madtom ate mainly ephemeropterans and trichopterans, while Round Goby of all sizes ate almost exclusively Quagga Mussels (*Dreissena rostriformis bugensis*). Diet overlap could be a greater concern in systems where dreissenid mussels are not abundant, like the Thames River. While the Round Goby is a mussel specialist, Carman et al. (2006) showed that diet is similar to native benthic fishes when mussels are absent from a waterbody. In this study in a Lake Michigan tributary, Round Goby diet was found to vary throughout the day, consisting of benthic invertebrates during the daytime and drifting prey at night. Differences in foraging behaviours, namely nocturnal benthic foraging by Northern Madtom, may have resulted in resource partitioning in areas where these species overlap (French and Jude 2001, Carman et al. 2006, Burkett and Jude 2015). In addition to direct competition for food resources, Round Goby has been shown to increase diet overlap among fishes in native benthic communities, creating indirect competitive interactions (Firth et al. 2021).

As both Northern Madtom and Round Goby are cavity nesters, competition for nest sites might exist. Round Goby is known to be fiercely territorial and aggressive with other species, even approaching, chasing or hitting fish nearing their nests (Wickett and Corkum 1998, Bergstrom and Mensinger 2009). At spawning sites in Lake St. Clair, MacInnis (1998) noted that one of four study areas had the highest occurrence of Northern Madtom and the lowest occurrence of Round Goby, but male Round Goby appear to have outcompeted male Northern Madtom for nest sites at the other study areas. There may be subtle microhabitat differences driving nest site selection, with male Northern Madtom better able to compete at sandy sites that are less preferred than cobble for Round Goby, especially if coarse woody debris is available (MacInnis 1998, Ray and Corkum 2001, Poos et al. 2010, B. Utrup pers. comm.). MacInnis and Corkum (2000) found that Round Goby generally spawns earlier in the year (late spring through mid-summer) than Northern Madtom with only a few weeks of overlap observed in the upper Detroit River; thus, timing of spawning may reduce interactions (although Round Goby may spawn multiple times per year). Predation is another possible interaction with Round Goby that may negatively affect Northern Madtom, but most likely at the egg and/or larval stages. French and Jude (2001) found that large Northern Madtom preyed on Round Goby YOY, but that the reverse was not observed. The presence of dorsal and pectoral spines that possess venom (Scott and Crossman 1973) likely afford larger Northern Madtom some protection from predation by Round Goby.

In addition to Round Goby, the invasive Tubenose Goby (*Proterorhinus marmoratus*), which also entered the Great Lakes in the 1990s via ballast water (Jude et al. 1992), has been identified as a potential competitor to Northern Madtom for food and other habitat resources (Burkett and Jude 2015, French and Jude 2001, Kocovsky et al. 2011). Like the Round Goby, the Tubenose Goby has a small maximum size, rapid growth, and early maturation; however, vegetated corridors may be required for dispersal, which may explain its limited distribution (relative to the Round Goby) through the Great Lakes (Dawson et al. 2020). It does not consume dreissenid mussels, and exhibits dietary overlap with native benthic fishes (e.g., Tadpole Madtom in a Lake Superior tributary) (Dawson et al. 2020). Sampling efforts between 2012 and 2016 detected both Northern Madtom and Tubenose Goby in the St. Clair River, with 44 Northern Madtom captured at 14% of sites and 640 Tubenose Goby captured at 35% of sites (Lamothe et al. 2020). Using two-species occupancy models, Lamothe et al. (2020) determined that the probability of detecting Tubenose Goby in the St. Clair River (0.294 ± 0.028 95% CI) was higher than the probability of detecting Northern Madtom (0.166 ± 0.012 95% CI). Tubenose Goby is currently found throughout the SCDRS, and has been detected in the mouth of the Thames River (i.e., lower 4 km), and in the lower Sydenham River to just upstream of the confluence between the North and East branches (Fish Biodiversity Database).

Potential negative impacts of Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*D. bugensis*) on Northern Madtom include reduction in the colonization of potential nesting cavities, as well as alteration of food web dynamics and surrounding water quality (Edwards et al. 2012). Increased populations of these mussels could, however, reduce diet overlap between Round Goby and Northern Madtom (Burkett and Jude 2015).

Climate Change and Severe Weather

Climate change models predict that several aquatic species like Northern Madtom potentially will be affected. In the Great Lakes basin, it is expected that air and water temperatures will increase; duration of ice cover will shorten; frequency of extreme weather events will increase, diseases will spread, and predator-prey dynamics will shift (Lemmen and Warren 2004). Like many species at risk in southern Ontario, Northern Madtom is at the northern edge of its global range. While coldwater species may be extirpated from much of their present range if water temperatures increase, warmwater species like Northern Madtom may expand northwards (Chu et al. 2005). However, this supposed benefit might be offset by several factors, including decreased summer lake and stream water levels, changes in evaporation patterns and vegetation communities, and increased intensity and frequency of storms (EERT 2008). Northern Madtom was found to be moderately vulnerable to impacts of climate change by Doka et al. (2006) because of its restricted distribution. Brinker et al. (2018) assessed Northern Madtom as moderately vulnerable to impacts from climate change, largely due to changes to its physiological hydrological niche (predicted changes in flow regimes beyond its known range of occupied flows) and presence of natural barriers (large geographic area of open lake habitat lacking suitable flow conditions).

Increased frequency and severity of droughts is the most immediate concern for Northern Madtom resulting from climate change, especially in the Thames River. The Thames River is predominantly surface-fed with minimal baseflow (UTRCA 1998). In extreme drought conditions, the river discharge can decline quickly and remain low, reducing both quantity and quality of habitat. The potential for multiple stressor effects during drought conditions from decreased water volume/ flow, increased temperature, decreased dissolved oxygen, increased sedimentation and contaminant impacts is high (Lake 2003, Murdoch et al. 2020, Beermann et al. 2018, Luck and Ackerman 2022).

Pollution

Agricultural and Forestry Effluents

Pesticides

Granular Bayluscide (gB) is a chemical lampricide, applied in the Great Lakes basin by both Canadian and U.S. government agencies, that has been highly successful in assessing and controlling invasive Sea Lamprey (*Petromyzon marinus*) populations. However, gB applications have also been identified as a potential threat to many at-risk fishes and mussels, including Northern Madtom. A laboratory study by Boogaard et al. (2016) indicated that Tadpole Madtom displayed avoidance behaviour (defined as vertical migration greater than 15 cm from the bottom of a confined column) when exposed to gB (3.2%), with initial avoidance occurring after an average of 6.6 minutes. High mortality (67%) of Tadpole Madtom was also observed from gB exposure in the experimental columns, suggesting that significant gB-induced mortality may occur if it is unable to escape the application areas (Boogaard et al. 2016). Smyth and Drake (2021) evaluated the risk of gB-induced mortality on fishes and mussels of conservation concern in focal rivers of the Great Lakes basin, based on simulated species responses. It was found that, generally, there was very low risk of gB-induced mortality for Northern Madtom (due to low probability of occurrence and low density at targeted sites), but 5% of the time, application cycles could result in impactful mortalities (~3 individuals) in the Detroit, St. Clair and Thames rivers. When looking at population effects of gB applications in a worst-case scenario (i.e., no recovery between applications), Northern Madtom populations in the Detroit and Thames rivers nearly collapsed after 100 years when applications occurred every 5 years or less, assuming a small amount of habitat is occupied (Smyth and Drake 2021). In a relative risk assessment of gB on at-risk fishes and mussels, Northern Madtom had one of the highest risks of mortality of freshwater fishes evaluated (i.e., 87th percentile), owing to a high exposure score (high spatial and temporal overlap of gB applications) and a high toxicity score (inferred from Channel Catfish as a surrogate) (Andrews et al. 2021). From 2011 through 2017, approximately 22% of Northern Madtom distribution in Canada experienced gB applications, including five that occurred within critical habitat (Andrews et al. 2021). Bayluscide has not been applied in Lake St. Clair but could be applied in any of the locations in the future. In addition to direct effects of gB applications on Northern Madtom, the macroinvertebrate prey base may also decline following gB applications leading to indirect effects on Northern Madtom (Andrews et al. 2021).

Glyphosate and associated surfactants applied around the Great Lakes basin for control of European Common Reed (*Phragmites australis australis*) could potentially negatively impact Northern Madtom, most likely in the Thames River. Glyphosate applied to crops could also enter waterways through runoff. Although species-specific data are lacking, bullheads were found to experience the greatest mortality in Lake Erie wetlands following glyphosate applications (Reid et al. 2023).

Additionally, runoff from agricultural fields is also likely to contain pesticides and other agrichemicals, which may negatively affect benthic invertebrate structure and macrophyte growth (Barton 1996, Bartlett et al. 2016, Marrocchi et al. 2021). Concentrations of pesticides in Ontario streams are often highest in the summer months coinciding with peak applications and low flows (and Northern Madtom spawning), and may exceed Canadian Water Quality Guidelines for the protection of aquatic life during these periods (Bartlett et al. 2016). This may be of particular concern in the Thames River given that the system is predominantly surface-fed by runoff from surrounding agricultural fields (UTRCA 1998, Collins et al. 2019).

Nutrient Loads

Nutrient loading has been identified as a primary threat affecting species at risk in the Sydenham and Thames rivers (Staton et al. 2003, Taylor et al. 2004, Nelson 2006), and in Lake St. Clair (EERT 2008). Phosphorus and nitrogen levels can increase due to agricultural fertilization and manure use practices, or cattle access to waterways may contribute and/or re-suspend nutrients. Water quality monitoring within the Detroit, St. Clair, and Thames watersheds indicate total phosphorous levels generally exceed provincial guidelines (SCRCA 2018, LTVCA 2018). Generalized adverse effects to the aquatic ecosystem include increased frequency of algal blooms, increased growth of macrophytes, increased turbidity, and disruption of food webs (Bailey and Yates 2003). Specific impacts to Northern Madtom are not known, but the species is considered sensitive to dissolved oxygen (Tang et al. 2020), which may be greatly reduced as a consequence of increased primary production and subsequent decomposition (Ziegler et al. 2021).

Sedimentation

Siltation and turbidity are also potential threats to Northern Madtom in Canada. This is likely of greatest concern in the Thames River where the majority of the surrounding land use is agricultural. Bailey and Yates (2003) stated that agricultural tile drains and overland transport through runoff are the greatest contributors of direct soil inputs, but that channelization and loss of riparian zones can lead to erosion and sediment inputs, as well. Increases in turbidity might not affect feeding activity patterns, as Northern Madtom is nocturnally active and so does not require light to forage. In fact, catches of Northern Madtom have been positively correlated with turbidity (Johnson et al. 2021, Rodriguez et al. 2021). Wildhaber et al. (2000) found significantly higher turbidity at sites with Neosho Madtom than sites without, suggesting low visibility may afford madtoms some protection from predation and/or offer an advantage over competitors that rely on sight. Alternatively, turbidity may reduce the ability of Northern Madtom to evade capture gear. However, decreased primary productivity due to reduction in light penetration might reduce available food sources, and deposition of sediment can cover coarse substrates, which might affect benthic prey availability, as well as the species' ability to nest in cavities; it could also lead to reduced egg survival (Dextrase et al. 2003, Beermann et al. 2018).

Industrial and Military Effluents

The Detroit and St. Clair rivers have both been designated Areas of Concern (AOC) due to the presence of toxic compounds including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), Dichlorodiphenyltrichloroethane (DDT), and their derivatives, metals, oils, and greases largely from petroleum and chemical processing (ECCC 2022). Gewurtz et al. (2010) looked at long-term spatial and temporal trends in concentrations of contaminants (heavy metals, PCBs, DDT, etc.) in tissues of sport fishes (based on provincial monitoring data) in the SCDRS and found generally decreasing trends of contaminants through time. Contaminant concentrations in fish tissues declined steeply from the 1970's through mid-1980's, and then a slower rate of decline towards stabilization was observed through to 2007 (Gewurtz et al. 2010). Similarly, studies evaluating trends in tissue concentrations of metals/metalloids (Muttray et al.

2021), and PCBs and chlorinated pesticides and derivatives (Muttray et al. 2020) in select fish species in the St. Clair River found general declines between the 2002/2003 samples and 2014 samples, including in the benthic invertivore Shorthead Redhorse (*Moxostoma macrolepidotum*); however, concentrations remained slightly higher at the most industrialized site (Stag Island) compared to upstream or downstream sites. These studies reported contaminant levels (notably mercury and PCBs) to generally exceed Canadian guidelines for the Protection of Wildlife Consumers of Aquatic Biota, but noted that the concentrations were unlikely to impair fish health. Muttray et al. (2020, 2021) evaluated several fish health indices (e.g., body condition, gonadosomatic index, liver-somatic index, fecundity, etc.) and, although they noted some correlations with tissue concentrations of specific contaminants, relationships were inconsistent, thus precluding inferences about impacts.

In all cases, trends differed slightly across contaminants, trophic levels, species, and (occasionally) individuals. Visha et al. (2018) reported a slower decrease of mercury contamination through time in benthic species compared to pelagic species. Most contaminants in the St. Clair River are found in the sediment, meaning the benthic-dwelling Northern Madtom is likely at a slightly greater risk of exposure, but given that it is a low-level trophic feeder that is relatively small-bodied and short-lived, it is unlikely to bioaccumulate contaminants to a similar degree as longer-lived piscivorous fishes (Muttray et al. 2020, 2021). In the midwestern United States, Wildhaber et al. (2000) suggested that the closely related Neosho Madtom is limited by the presence of heavy metals such as cadmium, lead, and zinc, particularly in benthic food sources.

It is believed that remediation activities (e.g., contaminated substrate removals, substrate caps), upgrades and improvements to petrochemical plants, and closures of certain facilities (e.g., chlor-alkali plants) are likely the cause for the steep declines in these contaminants early on (1970's through 1990's), but the consistently higher levels of certain contaminants (particularly mercury) around Stag Island in the St. Clair River suggest legacy contaminants are persisting and bioaccumulating (Gewurtz et al. 2010, Muttray et al. 2020, Muttray et al. 2021). Environmental factors such as atmospheric deposition, altered food webs (primarily related to AIS), and climatic factors likely also play a role in spatial and temporal trends, but to a lesser degree than point-source inputs and remedial activities (Gewurtz et al. 2010, Visha et al. 2018, Muttray et al. 2020, Muttray et al. 2021). The St. Clair River has seen a 75% reduction in contaminant loads from petroleum and chemical plants in the last 30 years; however, further remediation of substrates is needed to improve habitat quality for benthic organisms (ECCC 2022).

Domestic and Urban Wastewater

Pollutants such as chloride (from road de-icing salt and water softeners), heavy metals, and other inorganic compounds (from road run-off) are likely to enter the aquatic environment (TRERT 2004). Chloride levels have been generally increasing in surface and ground water across Ontario over the last several decades, with the highest levels reported in the lakes Erie and Ontario watersheds, corresponding to urban development and high road density (Sorichetti et al. 2022). The Thames River had relatively high chloride concentrations (median range: 68–95 mg/L) from 2016 through 2019, while the rest of Lake St. Clair and the SCDRS had median values of approximately 10 mg/L over this period, with noticeable spikes in the spring (Sorichetti et al. 2022). While below the Canadian Water Quality Guidelines for the protection of aquatic life (120 mg/L for long-term exposure; CCME 2011), the increasing trends are of concern. Chloride may negatively impact Northern Madtom through changes in benthic invertebrate community structure. Beermann et al. (2018) found that salinity caused declines in Ephemeroptera and Trichoptera abundance as well as overall species richness, and resulted in drift responses from several taxa that may decrease foraging success for Northern Madtom. Contaminants associated with rubber tire wear (e.g., hexamethoxymethylmelamine and derivative 6PPD-quinone) that have recently been identified as a concern for aquatic species, notably causing mortalities in salmonids (Tian et al. 2021, Brinkmann et al. 2022, French et al. 2022), have been reported in high levels in urban areas of Ontario (Johannessen et al. 2021); the impacts to other freshwater fishes are not yet known.

Despite recent improvements to municipal wastewater treatment systems in Windsor and Sarnia (ECCC 2022), wastewater effluent often contains pharmaceuticals and derivatives from personal care products. Estrogenic compounds, in particular, can lead to feminization and other neuroendocrine disruptions in fishes and invertebrates, resulting in reproductive consequences (Gagné et al. 2004, Gagné et al. 2011, Tetreault et al. 2011), but levels of these compounds can be reduced with improved effluent treatment with denitrification processes (Nikel et al. 2023). Domestic and urban wastewater can also contribute nutrient loads through effluents from sewage treatment plants and faulty septic systems (Edwards et al. 2012). Sewage overflows and bypasses of treatment facilities have been reported in the Thames River, typically during years of high precipitation (City of London 2020). Additionally, contaminants found in urban runoff (e.g., heavy metals) may interact with those found in wastewater effluent leading to reduced body condition and longevity in organisms found downstream of these inputs (Gillis 2012, Gillis et al. 2014).

Transportation and Service Corridors

Shipping Lanes

Habitat loss resulting from dredging and channelization for agricultural or shipping purposes has been implicated in the decline of numerous madtom species in North America, likely because of substantial alterations to stream substrates (Angermeier 1995, Piller et al. 2004, Simon 2006). Shipping corridors dredged from the St. Clair River through the SCDRS to Lake Erie, as well as lake and river shoreline modifications for shipping infrastructure (e.g., shoreline stabilization projects, docks, marinas) along the Detroit River and Lake St. Clair may negatively impact Northern Madtom (Edwards et al. 2012). Larson (1981) stated that dredging of the shipping channels in the Detroit River has altered large areas of substrate from a complex limestone environment to homogeneous bedrock and clay habitats. Loss of habitat heterogeneity may increase predation risk, decrease availability of prey (and, therefore, foraging success), and remove cover objects for nesting. A trawling survey was conducted by DFO betwen 2012 and 2013 in areas of Lake St. Clair regularly affected by maintenance dredging, to assess the impacts of both dredging (the removal of substrate) and dredgeate disposal (the disposal of the removed substrate within the waterbody) on fish species at risk, community composition and habitat quality (Barnucz et al. 2015). Impact sites (locations of maintenance dredging and nearby dredgeate disposal) were sampled and compared to corresponding reference sites (non-dredged locations of similar depths and substrate types to impacted sites); however, no Northern Madtom and only one fish species at risk (an Eastern Sand Darter, *Ammocrypta pellucida*, at a reference site) were detected across all sampling efforts. Fish species at risk abundances may be very low in Lake St. Clair and, as a result, the direct impacts of maintenance dredging on them are also potentially low (Barnucz et al. 2015); however, limited sampling has occurred in the lake. Maintenance dredging occurs periodically in the Detroit and St. Clair rivers to ensure vessels drawing a draft of 7.78 m can pass (USACE 2022); these activities are likely of greater consequence as abundances of Northern Madtom are higher than in Lake St. Clair.

THREAT ASSESSMENT

Threats were assessed following guidelines in DFO (2014). Each threat was ranked in terms of the threat Likelihood of Occurrence (LO), threat Level of Impact (LI) and Causal Certainty (CC). Threats were considered over a 10 year timeframe. The Likelihood of Occurrence was assigned as Known, Likely, Unlikely, Remote, or Unknown, and refers to the probability of a specific threat occurring for a given population over 10 years. The Level of Impact was assigned as Extreme, High, Medium, Low, or Unknown and refers to the magnitude of the impact caused by a given threat, and the level to which it affects the survival or recovery of the population (Table 7). The level of certainty associated with each threat was assessed and classified as: 1 = very high, 2 = high, 3 = medium, 4 = low, 5 = very low. The Population-Level Threat Occurrence (PTO), Threat Frequency (PTF) and Threat Extent (PTE) were also evaluated and assigned a status based on the definitions outlined in Table 6 with rankings in Table 8. The LO and LI for each population were subsequently combined in the population-level Threat Risk Matrix (Table 9; rankings in Table 10). The species-level Threat Assessment in Table 10 is a roll-up of the population-level threats identified in Table 11.

Table 7. Definition and terms used to describe Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF) and Population-level Threat Extent (PTE) reproduced from DFO (2014).

Term	Definition
Likelihood of Occurrence (LO)	
Known or very likely to occur (K)	This threat has been recorded to occur 91-100%
Likely to occur (L)	There is a 51-90% chance that this threat is or will be occurring
Unlikely (UL)	There is 11-50% chance that this threat is or will be occurring
Remote (R)	There is 1-10% or less chance that this threat is or will be occurring
Unknown (U)	There are no data or prior knowledge of this threat occurring or known to occur in the future
Level of Impact (LI)	
Extreme (E)	Severe population decline (e.g., 71-100%) with the potential for extirpation
High (H)	Substantial loss of population (31-70%) or threat **would jeopardize** the survival or recovery of the population
Medium (M)	Moderate loss of population (11-30%) or threat is **likely to jeopardize** the survival or recovery of the population
Low (L)	Little change in population (1-10%) or threat is **unlikely to jeopardize** the survival or recovery of the population
Unknown (U)	No prior knowledge, literature or data to guide the assessment of threat severity on population
Causal Certainty (CC)	
Very high (1)	Very strong evidence that threat is occurring and the magnitude of the impact to the population can be quantified
High (2)	Substantial evidence of a causal link between threat and population decline or jeopardy to survival or recovery
Medium (3)	There is some evidence linking the threat to population decline or jeopardy to survival or recovery
Low (4)	There is a theoretical link with limited evidence that threat is leading to a population decline or jeopardy to survival or recovery
Very low (5)	There is a plausible link with no evidence that the threat is leading to a population decline or jeopardy to survival or recovery
Population-Level Threat Occurrence (PTO)	
Historical (H)	A threat that is known to have occurred in the past and negatively impacted the population.
Current (C)	A threat that is ongoing, and is currently negatively impacting the population.
Anticipatory (A)	A threat that is anticipated to occur in the future, and will negatively impact the population.
Population-Level Threat Frequency (PTF)	
Single (S)	The threat occurs once.
Recurrent (R)	The threat occurs periodically, or repeatedly.
Continuous (C)	The threat occurs without interruption.
Population- Level Threat Extent (PTE)	
Extensive (E)	71-100% of the population is affected by the threat.
Broad (B)	31-70% of the population is affected by the threat.
Narrow (N)	11-30% of the population is affected by the threat.
Restricted (R)	1-10% of the population is affected by the threat.

Table 8. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent of each Northern Madtom population in Canada. Definitions and terms used to describe the threat ratings are found in Table 6.

			Detroit River						**Lake St. Clair**						**St. Clair River**						**Thames River**					
IUCN Threat Category	**Sub-category**	**Details**	LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE
Invasive and other Problematic Species and Genes	-	Round Goby, Tubenose Goby, dreissenid mussels	K	M	4	H/C/A	C	E	K	M	4	H/C/A	C	E	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	E
Climate Change and Severe Weather	-	Changes in flow conditions (droughts, severe storms), generalized food web changes	K	L	4	H/C/A	R	B	K	L	4	H/C/A	R	B	K	L	4	H/C/A	R	B	K	M	4	H/C/A	R	B
Pollution	Agricultural and Forestry Effluents	Pesticides (Bayluscide, glyphosate)	K	H	2	H/C/A	R	B	UL	H	4	H/C/A	R	B	K	H	2	H/C/A	R	B	K	H	2	H/C/A	R	B
		Nutrient loads	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B
		Sedimentation	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B	K	M	5	H/C/A	C	B
	Industrial and Military Effluents	Petroleum and chemical industry (PCBs, PAHs, metals, oils, greases)	K	M	5	H/C/A	C	B	K	M	5	H/C/A	C	B	K	M	5	H/C/A	C	B	R	M	5	H/C/A	na	R
	Domestic and Urban Wastewater	Chloride, metals, and inorganic compounds from roadways; nutrients and estrogenic compounds from wastewater	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B
Transportation and Service Corridors	Shipping Lanes	Dredged canals	K	M	4	H/C/A	R	B	K	L	2	H/C/A	R	N	K	M	4	H/C/A	R	B	UL	M	4	H/C/A	na	N

Table 9. The Threat Level Matrix combines the Likelihood of Occurrence and Level of Impact rankings to establish the Threat Level for each Northern Madtom population in Canada. The resulting Threat Level has been categorized as low, medium, high, or unknown. Reproduced from DFO (2014).

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

Table 10. Threat Level assessment of all Northern Madtom populations in Canada, resulting from an analysis of both the Threat Likelihood of Occurrence and Threat Level of Impact. The number in brackets refers to the Causal Certainty associated with the threat impact (1 = Very High; 2 = High; 3 = Medium; 4 = Low; 5 = Very Low).

Threat Category	Sub-category	Details	Detroit River	Lake St. Clair	St. Clair River	Thames River
Invasive and other Problematic Species and Genes	-	Round Goby, Tubenose Goby, dreissenid mussels	Medium (4)	Medium (4)	Medium (4)	Medium (4)
Climate Change and Severe Weather	-	Changes in flow conditions (droughts, severe storms), generalized food web changes	Low (4)	Low (4)	Low (4)	Medium (4)
Pollution	Agricultural and Forestry Effluents	Pesticides (Bayluscide, glyphosate)	High (2)	Medium (4)	High (2)	High (2)
		Nutrient loads	Low (5)	Low (5)	Low (5)	Low (5)
		Sedimentation	Low (5)	Low (5)	Low (5)	Medium (5)
	Industrial and Military Effluents	Petroleum and chemical industry (PCBs, PAHs, metals, oils, greases)	Medium (5)	Medium (5)	Medium (5)	Low (5)
	Domestic and Urban Wastewater	Chloride, metals, and inorganic compounds from roadways; nutrients and estrogenic compounds from wastewater	Low (5)	Low (5)	Low (5)	Low (5)
Transportation and Service Corridors	Shipping Lanes	Dredged canals	Medium (4)	Low (2)	Medium (4)	Medium (4)

Table 11. Species-level Threat Assessment for Northern Madtom in Canada, resulting from a roll-up of the population-level Threat Assessment. The species-level Threat Assessment retains the highest level of risk for any population, all categories of Threat Occurrence and Threat Frequency are retained, and the species-level Threat Extent is the mode of the population-level Threat Extent.

Threat Category	Sub-category	Details	Species-level Threat Risk	Species-level Threat Occurrence	Species-Level Threat Frequency	Species-level Threat Extent
Invasive and other Problematic Species and Genes	-	Round Goby, Tubenose Goby, dreissenid mussels	Medium (4)	H/C/A	C	E
Climate Change and Severe Weather	-	Changes in flow conditions (droughts, severe storms), generalized food web changes	Medium (4)	H/C/A	R	B
Pollution	Agricultural and Forestry Effluents	Pesticides (Bayluscide, glyphosate)	High (2)	H/C/A	R	B
		Nutrient loads	Low (5)	H/C/A	C	B
		Sedimentation	Medium (5)	H/C/A	C	B
	Industrial and Military Effluents	Petroleum and chemical industry (PCBs, PAHs, metals, oils, greases)	Medium (5)	H/C/A	C	B
	Domestic and Urban Wastewater	Chloride, metals, and inorganic compounds from roadways; nutrients and estrogenic compounds from wastewater	Low (5)	H/C/A	C	B
Transportation and Service Corridors	Shipping Lanes	Dredged canals	Medium (2)	H/C/A	R	B

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

Important habitat properties for Northern Madtom are clear to turbid waters with a moderate to swift current, depths greater than 1 m where sand, gravel, and rock are the dominant substrates, access to macrophytes (particularly *Chara* spp.) or other cover (notably at the YOY stage), and structure suitable for cavity nesting. Activities that occur in Northern Madtom habitat that are likely to damage or destroy these properties are described in the Critical Habitat Order (DFO 2016) and modified below.

- Accidental or intentional introductions of AIS that may result in habitat changes that affect Northern Madtom for food resources or cavity nesting sites.
- Dredging (for shipping channel maintenance or sediment remediation), grading, excavation, structure removals and the placement of material (e.g., dredgeate disposal) or structures in water that can change water depths, change flow patterns (which potentially affects turbidity), and impact nutrient levels and water temperatures. Most importantly, these activities can result in decreased heterogeneous rocky substrates needed for spawning and foraging. This can result in direct mortalities, or habitat becoming unsuitable for the species.
- Construction of dams/barriers, and water level management or water extraction activities that can result in habitat fragmentation, altered flow patterns, increased sediment deposition (e.g., changing preferred substrates), change in water temperatures, change in aquatic plant growth and change in prey abundance.
- Shoreline hardening for bank stabilization or boating infrastructure can alter substrate type, flow conditions, and aquatic vegetation growth, and damage or destroy riparian zones important for buffering runoff (Fischer et al. 2018). This can result in decreased suitability for Northern Madtom spawning, nursery and feeding habitat, as well as lead to decreased water quality overall.
- Work in or around water with improper sediment and erosion control causing increased turbidity, which potentially reduces feeding success or prey availability, growth of aquatic vegetation, impacts the availability of small cavities for nesting, and possibly excludes fish from habitat due to physiological impacts of sediment in the water (e.g., gill irritation).
- Over application of pesticides/herbicides affecting water chemistry, prey availability and spawning/recruitment success.
- Application of gB for Sea Lamprey control may result in direct mortalities and changes in food supply.
- Over application of fertilizer and improper nutrient management causing nutrient loading of nearby waterbodies. This can lead to increased primary productivity, decreased dissolved oxygen, and changes in the benthic invertebrate prey base.

Limiting Factors

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

The availability of suitable spawning/nesting cavities may limit the survival and recovery of Northern Madtom. Areas of sand, gravel, and cobble substrates with large overlaying objects (e.g., boulders, slab rocks, debris) with suitable flow conditions and nearby macrophytes have not been quantified through its distribution, but competition from Round Goby and possibly other madtoms may further reduce spawning site availability (MacInnis 1998, Edwards et al. 2012). Northern Madtom is a short-lived species, typically living to age 5 or 6 in the Great Lakes basin where individuals are likely to participate in only 1–3 spawning events in their life time. Given the relatively small population sizes in Canada, stochastic events (e.g., extreme weather, disease outbreaks) that result in mortalities of even a small number of individuals can substantially decrease the long-term stability of the population.

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

Aquatic invasive species (particularly benthic organisms) would likely compete with Northern Madtom and may alter food web structure or habitat leading to cascading impacts on co-occurring species. Dredging for channel maintenance disturbs sediments and often results in the removal of rocky (or other large-particle) substrates that native benthic fishes rely on for foraging and completing their life cycle. Agricultural land use practices often result in increased nutrient loading and sedimentation of water courses which can lead to decreased dissolved oxygen, increased algal blooms, and increased turbidity (which may be especially detrimental to co-occurring species that rely on sight for foraging or mating success). Reduced or absent riparian buffer zones and access to streams by livestock can increase overland transport or direct inputs of sediments and nutrients, resulting in impaired water quality for all aquatic taxa.

Northern Madtom co-occurs with numerous SARA-listed fishes and mussels throughout its Canadian distribution, most of which face similar threats and would benefit from these threats being abated. This may be especially true for mussels of conservation concern that share rocky benthic habitats with Northern Madtom and are reliant on healthy host fish populations for completing their life cycles, and for Eastern Sand Darter (in the Thames River) that relies on clean sand substrate for completing its life cycle.

Populations of Northern Madtom in the Detroit and St. Clair rivers are monitored by U.S. agencies as part of a long-term monitoring project evaluating success of constructed reefs for native fish spawning, and incidentally captured during AIS sampling (Manny et al. 2014, Johnson et al. 2021). There is no long-term monitoring for Northern Madtom in Canada, but targeted surveys are periodically conducted. It has been incidentally captured during sampling associated with the Great Lakes Action Plan, and when targeting other Species at Risk (e.g., Eastern Sand Darter in the Thames River). DFO's Asian Carp Program conducts routine surveillance in the rivers occupied by Northern Madtom that, although unlikely to detect Northern Madtom, may detect AIS of concern. Water quality monitoring is also routinely conducted by federal, provincial and municipal agencies on both sides of the border throughout the SCDRS and Thames River watershed.

SCENARIOS FOR MITIGATION OF THREATS OF THREATS AND ALTERNATIVES TO ACTIVITIES

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

Threats to species survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects that could result from works, undertakings, or activities (w/u/a) associated with projects in Northern Madtom habitat. A review has been completed summarizing the types of w/u/a that have been undertaken in habitat known to be occupied by Northern Madtom. The DFO Program Activity Tracking for Habitat database was reviewed to estimate the number of w/u/a that have occurred during the period from November 2013 through August 2022 within 1 km of occurrence records of Northern Madtom in Canada (Table 11). There were 50 projects identified, mostly related to shoreline protection, boating/marina infrastructure (e.g., boat houses, boat launches/ramps, breakwaters, docks, piers, etc.), other infrastructure (bridges/culverts), and dredging/excavation. Many additional projects were undertaken along the shoreline of Lake St. Clair where detections of Northern Madtom have been sporadic and population status is poorly understood; these were not included. Additionally, eleven projects in the Detroit River and three in the Thames River occurred in Northern Madtom Critical Habitat, but occurred more than 1 km from occurrence records. Some projects occurring in proximity to, but not in the known area of, Northern Madtom habitat may also have impacts, but were not included. Some projects may not have been reported to DFO as they may have met self-assessment requirements and were, thus, not reported. The review did not include the Sydenham River, from where the species is probably extirpated.

There were two projects authorized under the *Fisheries Act* within the habitat of Northern Madtom. Both projects occurred near Windsor in the Detroit River; one was an infilling project for boating infrastructure, and the other was a shoreline erosion project on Peche Island. Most other projects were deemed low risk to fishes and fish habitat and were addressed through letters of advice with standard mitigations. Without appropriate mitigation, projects or activities occurring adjacent or close to areas inhabited by Northern Madtom could have impacted the species (e.g., through increased sedimentation, and/or nutrient loading).

The most frequent project types were shoreline protection and boat launches/ramps in the Detroit River; shoreline protection and dredging/excavation in Lake St. Clair and the St. Clair River; and bridge construction/repair in the Thames River. Based on the assumption that historical and anticipated development pressures are likely to be similar, it is expected that similar types of projects will likely occur in or near Northern Madtom habitat in the future. The primary project proponents were adjacent land owners, municipalities, and private corporations.

Numerous threats affecting Northern Madtom populations are related to habitat loss or degradation. Habitat-related threats to Northern Madtom have been linked to Pathways of Effects developed by DFO’s Fish and Fish Habitat Protection Program (formerly Fish Habitat Management) (Table 12). Guidance has been developed on mitigation measures for 18 Pathways of Effects for the protection of aquatic species at risk in Ontario and Prairie Region (formerly Central and Arctic Region) (Coker et al. 2010). This guidance should be referred to when considering mitigation and alternative strategies for habitat-related threats. DFO has also developed a Code of Practice for routine maintenance dredging for navigation that should be referred to for dredging projects within the Detroit and St. Clair rivers (DFO 2022). Northern Madtom appear to use any cover objects available (e.g., large slab rocks, boulders, logs and other coarse woody debris, cans, bottles, artificial nests) for protection and nesting, and ensuring such cover objects are available for the species following habitat modifications, particularly during the spawning season, is an important consideration. Additional mitigation and alternative measures related to lampricide applications for controlling Sea Lamprey, and other invasive species concerns are listed below.

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

Work/Undertaking/Activity	**Threats (associated with work/undertaking/activity)**						**Watercourse/Waterbody (number of projects between 2013 and 2022)**			
-	Pollution: Pesticides	Pollution: Nutrient Loads	Pollution: Sedimentation	Pollution: Industrial Effluents	Pollution: Domestic and Urban Wastewater	Transportation and Service Corridors	St. Clair River	Lake St. Clair	Thames River	Detroit River
Applicable Pathways of Effects (Coker et al. 2010) for threat mitigation	1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18	1, 4, 7, 8, 11, 12, 13, 14, 15, 16	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18	1, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 16, 18	1, 5, 6, 7, 11, 12, 13, 14, 15, 16, 18	1, 2, 3, 4, 5, 7, 9, 10, 11, 12, 13, 15, 17, 18	-			
Water crossings (bridges, culverts, open cut crossings)	✓	-	✓	✓	✓	✓	-	-	1	1
Shoreline, streambank work (stabilization, infilling, retaining walls, riparian vegetation management)	✓	-	✓	✓	✓	✓	4	9	-	8
Instream works (channel maintenance, restoration, modifications, realignments, dredging, aquatic vegetation removal)	✓	✓	✓	✓	✓	✓	5	4	-	4
Water management (stormwater management, water withdrawal)	✓	✓	✓	✓	✓	✓	-	-	-	-

Work/Undertaking/Activity	Threats (associated with work/undertaking/activity)						Watercourse/Waterbody (number of projects between 2013 and 2022)			
-	Pollution: Pesticides	Pollution: Nutrient Loads	Pollution: Sedimentation	Pollution: Industrial Effluents	Pollution: Domestic and Urban Wastewater	Transportation and Service Corridors	St. Clair River	Lake St. Clair	Thames River	Detroit River
Applicable Pathways of Effects (Coker et al. 2010) for threat mitigation	1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18	1, 4, 7, 8, 11, 12, 13, 14, 15, 16	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18	1, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 16, 18	1, 5, 6, 7, 11, 12, 13, 14, 15, 16, 18	1, 2, 3, 4, 5, 7, 9, 10, 11, 12, 13, 15, 17, 18	-			
Structures in water (boat launches, docks, effluent outfalls, water intakes, dams)	-	✓	✓	✓	✓	✓	5	6	-	3
Invasive species introductions (accidental and intentional)	-	-	-	-	-	-	-	-	-	-

GRANULAR BAYLUSCIDE APPLICATION

Granular Bayluscide is a chemical lampricide applied at numerous locations around the Great Lakes basin, focusing on tributaries where soft substrate types are found, to assess and control the invasive Sea Lamprey. Concerns were raised over the impacts that lampricide application may have on non-target species, notably fish and mussel species of conservation concern. Science advice was developed to quantify and mitigate impacts and is summarized below (DFO 2021).

Mitigations

- Decreasing the number or size of application sites reduces the range of mortality outcomes (i.e., average outcome unlikely to change, but reduces likelihood of catastrophic events).
- Decreasing frequency of applications (from once every year to once every 10 years) reduces the likelihood of population collapse for Northern Madtom. Generally, small populations experienced greater proportional declines in abundance following mortality events, leading to greater population-level consequences.
- Other mitigation measures exist, such as reducing target concentrations of gB, applying gB to areas outside of critical habitat or outside of high-density patches of SAR, salvage or exclusion of fishes and mussels of conservation concern prior to application, and seasonal application of gB outside of reproductive periods. Mitigation measures, if pursued, should be empirically tested to ensure intended benefits for species of conservation concern are realized.

INVASIVE SPECIES

Round Goby (and possibly Tubenose Goby) is likely already impacting Northern Madtom through competition for food and nesting sites. Other AIS, notably benthic fishes or crayfishes, may outcompete Northern Madtom for resources, or may prey upon them.

Mitigation

- Establish exclusion zones of AIS in areas known to have suitable Northern Madtom habitat
- Develop public awareness campaigns and encourage the use of existing invasive species reporting systems (e.g., Ontario Invading Species Awareness Program hotline, EDDMapS).
- Physically remove non-native species from areas known to be inhabited by Northern Madtom.
- Conduct early detection surveillance or monitoring for invasive species that may negatively affect Northern Madtom populations directly, or negatively affect Northern Madtom preferred habitat.
- Develop a response plan to address potential risks, impacts, and proposed actions if monitoring detects the arrival or establishment of an exotic species.

Alternatives

- Unauthorized introductions
  - None
- Authorized introductions

- Do not stock non-native species in areas inhabited by Northern Madtom.
- Do not enhance habitat for non-native species in areas inhabited by Northern Madtom.
- Follow the National Code on Introductions and Transfers of Aquatic Organisms for all aquatic organism introductions (DFO 2017).

SOURCES OF UNCERTAINTY

Despite recent (i.e., since 2012) targeted sampling for Northern Madtom in Canada and the U.S. side of its Great Lakes distribution, the species has been captured in relatively low numbers and there remain key uncertainties for this species. Sources of uncertainty have been organized into research themes based on Drake et al. (2021) to create consistency across RPAs and to aid in planning and prioritization of research objectives.

POPULATION ECOLOGY

Life History

Information on Northern Madtom life history is limited across its range. Knowledge of spawning through early development comes from relatively few studies, only one of which was conducted in Canada near the beginning of the Round Goby invasion (MacInnis 1998, Scheibly et al. 2008). It is unknown to what extent these studies represent current conditions for Canadian populations. Furthermore, there is very limited age and growth information available in the Great Lakes, particularly from Canadian specimens. Although sample sizes were small, dorsal spines may be a suitable non-lethal aging structure for completing age assessments (Utrup et al. 2023).

Abundance

Abundance estimates of Northern Madtom are lacking at all occupied locations in Canada. Information on population trajectory and trends through time is also unavailable. There has been increased sampling effort over the last 20 years, but repeated, standardized sampling is necessary to estimate abundance and trajectory through time for all occupied areas. This will help to determine occurrence, status, range, abundance, and population demographics and contribute to the identification of critical habitat. Northern Madtom is a cryptic species that is difficult to detect, and methods to improve detection probability should be investigated.

Distribution

Knowledge of the distribution of Northern Madtom in the Detroit, St. Clair, and Thames rivers has improved since the first RPA due to targeted (and/or suitable) sampling in those systems. Recent (i.e., since 2012) sampling at other locations (e.g., lower Thames River near its mouth, Sydenham River, and river mouths around Lake St. Clair) has been undertaken but resulted in few if any Northern Madtom detections. Populations with low certainty identified in the population status analysis (e.g., Lake St. Clair, Sydenham River) should be sampled further. These baseline data are required to monitor changes in Northern Madtom distribution and population trends as well as the success of any recovery measures. It remains unknown to what extent Lake St. Clair contributes to Northern Madtom production. Detections of Northern Madtom environmental DNA (eDNA) have been reported in the Thames River at Melbourne Road, approximately 30 km upstream of its known distribution (V. McKay, Lower Thames Valley Conservation Authority, pers. comm.), and in the Sydenham River at four sites and a single site in the Grand River (Balasingham et al. 2018). Follow-up sampling using conventional sampling methods occurred in both the Sydenham and Grand rivers at eDNA sites but no Northern

Madtom were detected. Environmental DNA may be useful in identifying areas to sample further, but does not replace a physical specimen when considering a species distribution (or changes to it). The current distribution and extent of suitable Northern Madtom habitat should be investigated and mapped, and targeted sampling in areas lacking Northern Madtom records but possessing potentially suitable habitat should be conducted. New occurrences of Northern Madtom may be detected. As above, a standardized index population and habitat monitoring program should be implemented, enabling an assessment of changes in range, abundance, key demographic characters and changes in habitat features, extent and health (Edwards et al. 2012).

Population Genetics

Recently, tissue samples from Northern Madtom from the Detroit and St. Clair rivers were analyzed, and evidence of significant population genetic structure was found (Utrup et al. 2023). Additionally, the St. Clair River showed greater genetic diversity than the Detroit River, but both populations showed evidence of recent expansion. Including the Thames River in future genetic analyses could help resolve meta-population dynamics and aid in understanding how Lake St. Clair is being used by Northern Madtom (i.e., for dispersal and genetic exchange, for production, or acts as a sink). Including genetic samples from across the species range would also be useful to distinguish populations, and contribute necessary information should population enhancement through relocations or captive rearing be required (Edwards et al. 2012, Lamothe et al. 2019).

HABITAT

Species-Habitat Associations by Life Stage and Habitat Supply

Seasonal habitat needs, including home range and species movement, of all life-stages of Northern Madtom should be determined. The current understanding of habitat requirements is based on a limited number of studies. Robust analyses will allow for a full identification of critical habitat for Northern Madtom, and will assist with the development of a habitat model and estimates of habitat supply. Further understanding of physiological tolerances to environmental stressors across life-stages would improve understanding of habitat use; for example, adult Northern Madtom appear to have some affinity for, or at least tolerance to, high turbidity (Rodriguez et al. 2021), but the thresholds are not known. Further information on tolerances may help explain its apparent extirpation from the Sydenham River.

THREATS

Like most imperiled freshwater fishes in the Great Lakes – St. Lawrence River basin, research progress has been slower for threats and recovery topics for Northern Madtom, as more basic information on population ecology is needed before work on these advanced topics can proceed (Drake et al. 2021).

Mechanism of Impact

Numerous threats have been identified for Northern Madtom populations in Ontario, although the mechanism and severity of most of these threats is currently unknown. There is a need to investigate the impacts of Round Goby, Tubenose Goby, and dreissenid mussels on Northern Madtom. Studies should include impacts of these invaders on Northern Madtom spawning success, as well as diet overlap and the interaction between dreissenid density and diet overlap with gobies across locations. Generally, the relationship between water quality and life history is poorly understood for Northern Madtom. The impacts of physical habitat changes (e.g., dredging, sedimentation and shoreline hardening) on Northern Madtom should also be investigated (Edwards et al. 2012). Investigating the impacts (lethal/sub-lethal) of pollutants from urban and industrial sources in the SCDRS, and nutrient loading and sedimentation from agricultural practices in the Sydenham and Thames rivers, on Northern Madtom will enable an assessment of risks and the identification of contaminants of concern for Northern Madtom (Edwards et al. 2012). Additionally, climate change could have both broad positive (e.g., increased temperatures leading to range expansion, increased growth/production) and negative (e.g., decreased flow leading to reduced habitat quantity and quality) effects on Northern Madtom, and it is unknown how these effects will interact.

Probability, Extent, and Magnitude of Impact

There are many uncertainties related to the probability, extent, and magnitude of impacts from various threats affecting Northern Madtom. Quantifying the frequency and extent of catastrophic events related to climate change, notably severe droughts and floods that alter flow regimes, across locations where Northern Madtom occurs would help understand the impacts of climate change. Further research on impacts of gB applications in the field (e.g., environmentally realized concentrations and actual spatial overlap of applications with Northern Madtom) would help resolve the risk to the species. Turbidity and nutrient loads from agricultural sources cause broad ecosystem impacts through reduced water quality and changes in food webs, but to what extent Northern Madtom is affected, directly or indirectly, is unknown. The impact of channel maintenance dredging appears to be low in Lake St. Clair (Barnucz et al. 2015), but further research should be undertaken in the Detroit and St. Clair rivers where density of Northern Madtom is much higher.

RECOVERY

Threat Mitigation

There has been some effort to mitigate threats related to toxic substances and habitat loss where Northern Madtom occurs, but the response of Northern Madtom in the short- and long-term remains poorly understood. Work has been done on the U.S. side of the Detroit and St. Clair rivers to restore heterogeneous rocky habitat for native fishes following channelization for shipping canals. Northern Madtom has been captured and observed on this rocky habitat; however, it is unknown to what extent they are using these areas to complete their life cycle (Manny et al. 2014, Vaccarro et al. 2016, Johnson et al. 2021). Similarly, legislative changes and remedial activities have been undertaken in the Detroit and St. Clair rivers to improve habitat conditions related to toxic substances and contaminated substrate, but with the absence of long-term monitoring data or an understanding of the specific contaminant effects on the species, it is unclear what the response of Northern Madtom has been to these improvements. Furthermore, remediation efforts that remove contaminated substrates could have direct and indirect short-term consequences for the species. Best management practices that can mitigate threats related to agricultural land uses (e.g., sedimentation, nutrient loading, loss of riparian buffers) should be implemented if well supported as these are likely to benefit all aquatic organisms.

Re-introductions

Supplementation of Northern Madtom in Canada was proposed as a potential recovery option (Edwards et al. 2012), noting relocation and captive rearing techniques should be developed and incorporated into population specific action plans as required. In a review of translocation progress for SARA-listed fishes in Canada, Lamothe et al. (2019) highlighted research needs and considerations for Northern Madtom in advance of reintroduction attempts. The authors note that the upper Detroit River and possibly St. Clair River might be suitable source populations, but understanding genetic structure and harm to the source population(s) from removals is needed first. Although there are no known efforts to breed Northern Madtom in North America currently, successful reintroductions of captive-bred Smoky Madtom *(Noturus baileyi*) and Yellowfin Madtom (*Noturus flavipinnis*) have occurred in the southeastern U.S.A (Shute et al. 2005, Lamothe et al. 2019), and Piebald Madtom is being reared successfully in a Mississippi hatchery (M. Wagner pers. comm.).

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