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UPDATED RECOVERY POTENTIAL ASSESSMENT FOR NORTHERN MADTOM (*NOTURUS STIGMOSUS*) IN CANADA, 2012–2021

*Northern Madtom (*Noturus stigmosus*) captured in the Detroit River, 2012. Photo Credit: J. Barnucz, DFO.*

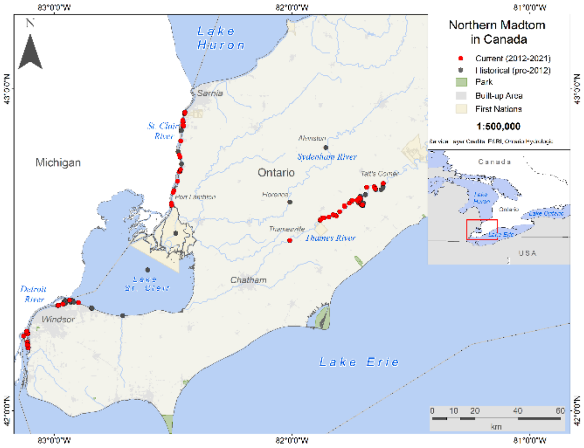

Figure 1. Current (2012–2021) and historical (pre–2012) distribution of Northern Madtom in Canada

Context:

*The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) first assessed the status of Northern Madtom (*Noturus stigmosus*) in April 1993. They considered the species Data Deficient. They re-examined the species in April 1998 and designated it as Special Concern. In November 2002, it was re-assessed and the status changed to Endangered. 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. Fisheries and Oceans Canada (DFO) Science conducted a Recovery Potential Assessment (RPA) held May 19, 2012 to gather scientific information to support decision-making with regards to SARA agreements and permits. The species was again assessed by COSEWIC in May 2012 and the status confirmed as Endangered. The reason given for this designation was that it is one of the rarest freshwater fish in Ontario, being found at only four localities that are under substantial and ongoing threat from siltation, turbidity, exotic species, and toxic compounds. There is an inferred continuing decline in habitat quality throughout its range.*

DFO Science was asked to update the RPA given substantial new information since the previous RPA, to inform both updates to recovery documents and the process of permit issuance.

*This Science Advisory Report is from the November 29-30, 2022 regional peer-review meeting on the Updated Recovery Potential Assessment for Northern Madtom (*Noturus stigmosus*), 2012–2012. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.*

February 2024

SUMMARY

- The current Northern Madtom (*Noturus stigmosus*) distribution (Figure 1) is limited to four distinct localities in Canada: St. Clair River, Lake St. Clair, Thames River, and Detroit River. The species is likely extirpated in the Sydenham River.
- Evidence of significant differences in population genetic structure between the Detroit and St. Clair rivers suggests that Lake St. Clair may represent a natural barrier to movement between these two riverine locations. The genetic structure of the Thames River has not been evaluated.
- Adults occupy a wide range of habitats with clear to turbid water in large rivers, with moderate to swift current, and occasionally lakes. Little is known about young-of-the-year (YOY) and juvenile habitat, but it is likely similar to adult habitat. Coarse woody debris, complex rocky substrates, or other overlaying objects have been used for cover and nesting.
- Northern Madtom occupies residences during the breeding and rearing parts of its life cycle. Spawning begins when water temperature reaches approximately 20 °C and takes place in cavity nests; males guard the eggs then young for approximately one month post-hatch (July to August) in Canada. It is uncertain when Northern Madtom start building nests.
- To achieve ~99% probability of persistence over 100 years, a minimum viable population (MVP) requires ~97,000 (CI: 29,000–230,000) adult and juvenile Northern Madtom (assuming age at maturity of 3 and maximum age of 5). Given evidence of population structure (reproductive isolation), each population needs an abundance consistent with the MVP to achieve long-term sustainability. Given current density estimates, an MVP abundance for each population would require ~1,900 ha of suitable habitat in the St. Clair River, ~1,600 ha in the Thames River, and ~1,700 ha in the Detroit River.
- Time to recovery was assessed with a simulation of an initial population at 10% of MVP. The median time to reach recovery (i.e., MVP) was 17 years, and 95% of populations reached MVP in 58 years or less.
- The greatest threats to the survival and recovery of Northern Madtom in Canada are invasive species, climate change, pollution, and shipping channel works.
- Population growth rate and abundance are most sensitive to perturbations in juvenile survival, followed by fertility and YOY survival, and are least sensitive to adult survival.
- There remain numerous sources of uncertainty related to Northern Madtom biology and life history, population abundance estimates and trends through time, status in the Sydenham River and Lake St. Clair, and total habitat extent. A thorough understanding of the mechanisms of impact of numerous threats affecting the Northern Madtom populations is also lacking.

INTRODUCTION

Northern Madtom (*Noturus stigmosus,* Taylor 1969) was first assessed at an April 1993 meeting of the Committee On the Status of Endangered Wildlife In Canada (COSEWIC), where it was designated as Data Deficient. 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 this 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 of the species was re-assessed and confirmed by COSEWIC in May 2012 (COSEWIC 2012), as it “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 general RPA process has since been updated to include a standardized template 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. Updates to background information on Northern Madtom, and population recovery modeling, are found in Colm et al. (2024) and Fung and Koops (2024), respectively; both help inform the 22 elements of the current RPA for this species.

Biology, Distribution, and Life History Parameters

Northern Madtom is a small, benthic ictalurid catfish species. It is rare and has a disjunct distribution, known from the Mississippi River basin (Ohio and Tennessee rivers) and lower Great Lakes basin (lakes Erie and St. Clair) in seven U.S. states and the province of Ontario. In Ontario, it is known only from the Detroit River, St. Clair River, Lake St. Clair, and two tributaries of Lake St. Clair: the Sydenham River (from which it is likely extirpated) and the Thames River.

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; foraging activity is nocturnal. The overall colour pattern is mottled with three irregular dark saddles along the back. 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. The species is sexually dimorphic during spawning; in males, the head flattens, dark pigment diffuses, and conspicuous swellings develop around the face (Holm et al. 2009, Page and Burr 2011). Northern Madtom co-occurs with three other madtoms in Ontario. It is easily distinguished from Tadpole Madtom (*N. gyrinus*) and Stonecat (*N. flavus*), both of which are unmottled and have weak serrations on the pectoral spines, and from Brindled Madtom (*N. miurus*), which 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.

In the Great Lakes basin, Northern Madtom reaches maturity at age 2 or 3, and likely lives to age 5 or 6 (Manny et al. 2014, Conard 2015, Utrup et al. 2023). Spawning seems to occur in July in most parts of its range, including Ontario, when water temperatures range from 20–25 °C (MacInnis 1998, Scheibly et al. 2008, Johnson et al. 2021). 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); no eggs or guarding males were observed on June 30 (18.1 °C) (B. Utrup, Michigan Department of Natural Resources, pers. comm.). Females lay eggs in a cavity nest that is guarded by a male. Nests may be excavated by the male, though natural or artificial cavities/containers may also be used. Reported clutch sizes throughout its distribution range from approximately 30–300 eggs, with a mean of 178 eggs/fish (n=10) observed in the St. Clair – Detroit River System (SCDRS; Utrup et al. 2023). 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). Adult Northern Madtom maximum length was previously reported as 132 mm TL in Ontario, 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 but not detected, or if the scope for growth has improved in the SCDRS. The mean length of 173 individuals captured in Ontario from 2003 through 2020 was 53.4 mm TL (range 14 to 131 mm) (Fish Biodiversity Database). Recent age assessments from individuals captured in the SCDRS suggest Northern Madtom lives to age 5 or 6, and that pectoral or dorsal spines may be suitable aging structures for non-lethal sampling (Manny et al. 2014, Conard 2015, Utrup et al. 2023). Length-at-age and length-weight relationships predicted from the von Bertalanffy growth function are depicted in Figure 2 (refer to Fung and Koops 2024).

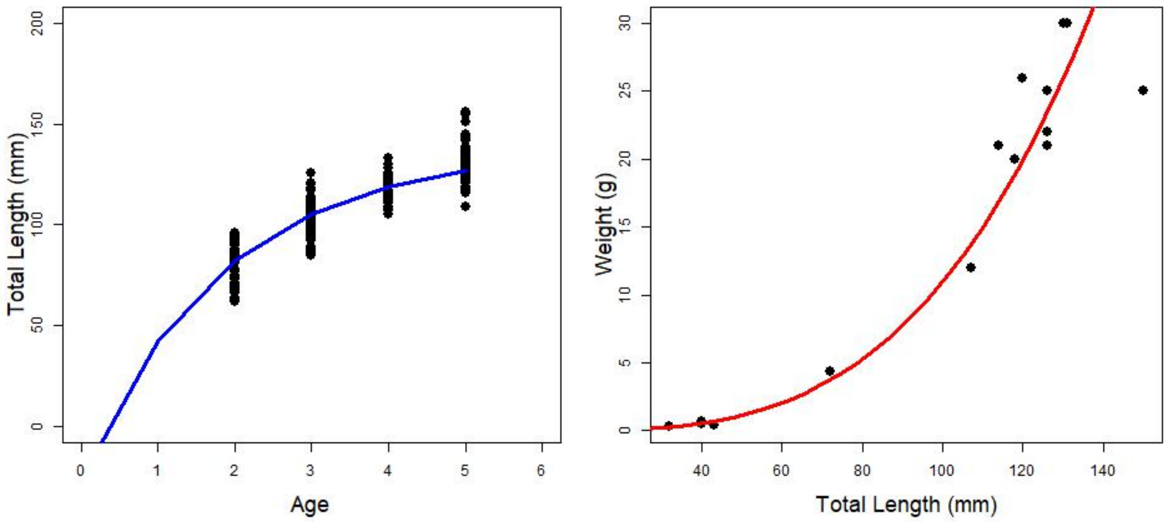

Figure 2. The left panel depicts the fitted von Bertalanffy growth curve for Northern Madtom based on data and parameter values from Michigan Department of Natural Resources (MDNR; n=690). The right panel depicts the length-weight relationship using data from MDNR and DFO (n=15).

Northern Madtom feed on aquatic macroinvertebrates such as mayflies, caddisflies, chironomids, blackflies, and stoneflies, but small fishes and amphipod crustaceans are also eaten. Northern Madtom is generally an opportunistic feeder, and its diet may vary with time of year (related to benthic macroinvertebrate emergence times), body size, and depth/flow (French and Jude 2001, Burkett and Jude 2015, Utrup et al. 2023).

A recent study compared the population structure of Northern Madtom sampled from the U.S. side of 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). 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 stabilization of Round Goby (*Neogobius melanostomus*) populations where they co-occur with Northern Madtom (Utrup et al. 2023). Genetic material from the Thames River was not available.

ASSESSMENT

Current Species Status

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

Lake St. Clair

Records of Northern Madtom in Lake St. Clair have been infrequent and disjunct. Most records (including observed spawning activities) come from the extreme southwest end of the lake, at 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); recent genetic work 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). Despite several targeted sampling efforts in recent years, Northern Madtom has not been collected from the Sydenham River since 1975, and has most likely been extirpated.

Thames River

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 through seining and trawling efforts on the Thames River between Littlejohn Road and Tait’s Corners. 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 (Fish Biodiversity Database, Barnucz and Drake 2021). 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). 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 (sometimes baited) minnow traps.

Abundance

Abundance estimates are lacking for Northern Madtom populations in Canada. Fewer than 500 Northern Madtom have been captured in Canadian waters. Population densities were 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 0.12 (at age 5) to 4.65 (at age 1) fish/m^2 for lake habitats, and 0.4 to 11.87 to fish/m^2 for river habitats (Fung and Koops 2024). Additional capture data are presented for each occupied area in Table 1. For comparison, density estimates for the Neosho Madtom (*N. placidus*; federally endangered in U.S.) ranged from 3.3–11.7 fish/100m^2, with the lower end representing samples collected with kick seines during the daytime during a high-flow year, and the higher end representing captures using electric kick-seines at night (Wenke et al. 1992, Bulger and Edds 2001, Fuselier and Edds 1994).

Table 1. 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) estimates from Smyth and Drake (2021). CPUE = catch per unit effort. Estimated Area Occupied is coarsely estimated based on methods in Mandrak et al. (2014).

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

Population Assessment

To assess the Population Status of Northern Madtom in Canada, each population was ranked in terms of its abundance (Relative Abundance Index) and trajectory (Population Trajectory), and a level of certainty was associated with each parameter (1=quantitative analysis; 2=CPUE or standardized sampling; 3=expert opinion). The Relative Abundance Index and Population Trajectory values were combined in the Population Status matrix to determine the Population Status for each population, ranked as Poor, Fair, Good, Unknown or Extirpated (Table 2). The Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter. Original Population Status was from McCulloch and Mandrak (2012); however, these assessments are independent of one another and represent the relative population status at the time of assessment. Refer to Colm et al. (2024) for detailed methods used in the Population Status assessment.

The recent catch data from Canadian populations (Table 1) 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. sides) compared to the Thames River, and it is therefore likely that these larger systems support larger total population sizes. As this assessment is based on limited data for assessing both the Relative Abundance Index and Population Trajectory, additional data could result in a different Population Status.

Table 2. Population Status for all Northern Madtom populations in Canada, resulting from an analysis of 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. 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

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. Velocity typically ranges from 0.1–1.1 m/s with a mean of approximately 0.5 m/s (Sheibly et al. 2008, Manny et al. 2014, Johnson et al. 2021, Fish Biodiversity Database). 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. 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 upper thermal tolerance of Northern Madtom is not known.

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; or in anthropogenic debris such as bottles, cans, and boxes, or in cavities excavated approximately 5 cm beneath these objects (Taylor 1969, MacInnis 1998, B. Utrup pers. comm.). Nests are typically set in moderate current with sandy and/or cobble bottoms surrounded by macrophyte beds. Depths at nest sites in the Detroit River ranged from 1.5 to 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.

Young-of-the-year and Juvenile

There is very limited information on larval and juvenile Northern Madtom habitat requirements. MacInnis (1998) observed young-of-the-year (YOY) Northern Madtom (with and without yolk sacs attached) in nests being guarded by adult males approximately one month after occupation of these nests was first observed. When nests were removed, YOY were observed taking shelter in the surrounding macrophytes. In Kentucky, 20 mm standard length YOY 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). From 2009 through 2020, 10 sites sampled by DFO contained multiple age/size classes of Northern Madtom, 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.

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 3. 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 3 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 3. Summary of the essential habitat functions, features, and attributes for each life stage of Northern Madtom in Canada.

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
YOY (<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: 16.26 °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 ~ 67 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: 18.64 °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)	Presumed 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: 18.32 °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)

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. 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).

Habitat Extent and Spatial Constraints

The spatial extent of Northern Madtom was quantified in Mandrak et al. (2014) using several methods (refer to Table 1); however, the spatial extent of habitat attributes identified in Table 3 has not been quantified. Bathymetry data could be considered with substrate and flow data to quantify the extent of suitable habitat in all occupied locations.

Lake St. Clair may represent a barrier to movement for this small-bodied species between the Detroit, St. Clair, and likely Thames rivers. Recent genetic analyses found strong evidence of population genetic structure between the Detroit and St. Clair rivers, suggesting reproductive isolation between the two rivers (Utrup et al. 2023); genetic samples from the Thames River were unavailable.

Threats and Limiting Factors

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, 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 unified classification of direct threats and Salafsky et al. (2008).

Invasive and other Problematic Species and Genes

Round Goby was first detected in the St. Clair River in 1990, and has been implicated in the decline of several other benthic species in the Great Lakes. It overlaps with Northern Madtom throughout its Canadian distribution, being found at 57% of sites where Northern Madtom was captured during DFO trawling efforts (2012–2021). Using recent 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). Round Goby may compete with Northern Madtom for food and for nesting sites. Significant diet overlap was found between the two species in the St. Clair River at depths of 3 m, but not at deeper depths (French and Jude 2001). Competition for food is lessened when dreissenid mussels are abundant (Burkett and

Jude 2015, Carman et al. 2006), likely as a result of different foraging behaviours (e.g., nocturnal foraging by Northern Madtom), but Round Goby has been shown to increase diet overlap among fishes in native benthic communities, creating indirect competitive interactions (Firth et al. 2021). Round Goby is known to be fiercely territorial and an aggressive nest defender. Male Round Goby may outcompete male Northern Madtom for nesting sites, particularly over gravel substrates, but Northern Madtom may be better able to compete at sandier sites, especially if cover (e.g., coarse woody debris) is available (MacInnis 1998, Utrup et al. 2023). Round Goby may consume the eggs and larvae of Northern Madtom, but this has not been directly observed.

Tubenose Goby (*Proterorhinus marmoratus*) may also compete with Northern Madtom for food or other resources. It does not consume dreissenid mussels so may compete with Northern Madtom to a greater extent for food, but prefers more heavily vegetated habitats so spatial overlap with Northern Madtom may be less of a concern than it is for Round Goby. 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). Potential negative impacts of Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena 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).

Climate Change and Severe Weather

Northern Madtom was found to be moderately vulnerable to impacts of climate change because of its restricted distribution, 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) (Doka et al. 2006, Brinker et al. 2018). Of particular concern are changes in flow regimes (notably droughts) that are likely to be most substantial in the Thames River, a predominantly surface-fed system. Additional ecosystem impacts, such as increased air and water temperatures, shortened duration of ice cover, increased frequency of extreme weather events, increased disease prevalence, and shifting predator-prey dynamics, are likely to impact Northern Madtom, as well as co-occurring species (Lemmen and Warren 2004).

Pollution

Several sources of pollution are of concern to Northern Madtom, including those from agricultural practices (i.e., pesticides, sedimentation, nutrient loading), industrial effluents (petroleum and chemical processing), and domestic and urban wastewater (i.e., road runoff and wastewater effluent).

Granular Bayluscide (gB) is a chemical lampricide applied strategically around tributaries of the Great Lakes basin for control of invasive Sea Lamprey (*Petromyzon marinus*) that may pose a threat to Northern Madtom. It was found to elicit an avoidance response and high mortality rates (67%) in lab trials using Tadpole Madtom (*Noturus gyrinus*) (Boogaard et al. 2016). Although Northern Madtom is not likely to be found in habitats used by larval Sea Lamprey, applications have occurred within the known distribution of Northern Madtom and this, combined with the high toxicity, resulted in a high relative risk for Northern Madtom (Andrews et al. 2021). Smyth and Drake (2021) found that the risk of granular Bayluscide-induced mortality is relatively low for Northern Madtom, but 5% of the time, applications could result in impactful mortalities in the Detroit, St. Clair, and Thames rivers, and a worst-case scenario resulted when applications occurred every five years or less. In addition, pesticides from agricultural field runoff may negatively impact benthic invertebrate prey availability (Bartlett et al. 2016).

Nutrient and sediment loading resulting from agricultural land uses (e.g., manure and fertilizer use, cattle access to streams, overland transport of sediments, tile drainage) have led to generalized ecosystem impacts. Nutrient loads lead to increased primary productivity, which can cause decreased dissolved oxygen, particularly during periods of decomposition. Sedimentation may lead to decreased macrophyte growth, which is important cover for YOY Northern Madtom, and deposition of sediment can cover coarse substrates. This has the potential to reduce prey availability, as well as the species' ability to nest in cavities, which could lead to reduced egg survival (Dextrase et al. 2003, Beermann et al. 2018).

Industrial effluents in the Detroit and St. Clair rivers resulting from petroleum and chemical processing facilities have resulted in these systems being designated as Areas of Concern. Toxic compounds including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and dichlorodiphenyltrichloroethane (DDT) and their derivatives, as well as metals, oils, and greases, have declined in fish tissue since the 1970s (though the rate of decline has slowed since the mid-90s) resulting from remedial activities in these areas (Gewurtz et al. 2010). Impacts to Northern Madtom are not known, but some studies have evaluated other benthic invertivores and found that, although tissue concentrations remain above guidelines for human consumption, they do not appear to be at a level of concern for fish health (Muttray et al. 2020, Muttray et al. 2021).

A variety of pollutants from domestic and urban wastewater are present throughout the distribution of Northern Madtom, but direct effects of these are unknown. Chloride from road-deicing salt is likely to result in decreased benthic invertebrate diversity and abundance of sensitive taxa, and may be concerning to all aquatic taxa during peaks at spring melt (Beermann et al. 2018, Sorichetti et al. 2022). Heavy metals and other inorganic compounds (e.g., 6PPD-quinone) from road runoff may also negatively affect benthic invertebrates, aquatic macrophytes, and/or fishes. Urban wastewater effluent can contain estrogenic compounds from pharmaceuticals that may lead to feminization and/or other neuroendocrine disruptions in fishes and invertebrates, resulting in reproductive consequences (Gagné et al. 2004, Gagné et al. 2011, Tetreault et al. 2011). Wastewater can also contain salts from water softeners, and nutrients, particularly when there are sewage overflows or faulty septic systems (Edwards et al. 2012).

Transportation and Service Corridors

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 and flows. Shipping corridors dredged from the St. Clair River through 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). These activities homogenize habitat (i.e., substrate and flows), which may increase predation risk, and/or decrease availability of both prey (and, therefore, foraging success) and suitable nesting sites.

Threat Assessment

A threat assessment was completed for Northern Madtom following guidelines provided in DFO (2014). Each threat was ranked in terms of the Likelihood of Occurrence, Level of Impact, and Causal Certainty. The Likelihood of Occurrence and Level of Impact for each population were subsequently combined in a Threat Risk Matrix resulting in the population-level threat assessment (Table 4). Terms used to describe threat categories are described in Table 5. Threats were then rolled-up to create a species-level threat assessment, presented in Table 6. Refer to Colm et al. (2024) for detailed methods.

Table 4. 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 (gB, 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 5. 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 6. 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. 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	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 (gB, 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

Recovery Modelling (Recovery Targets and Allowable Harm)

Recovery potential modelling was completed in three main steps. First, information on vital rates was compiled to build projection matrices that incorporate parameter uncertainty, stochasticity and density-dependence. Next, the impact of anthropogenic harm to populations was quantified with the use of elasticity and simulation analyses. Lastly, recovery targets for abundance and habitat were proposed with estimation of the minimum viable population and the minimum area for population viability. Refer to Fung and Koops (2024) for complete methods.

Allowable Harm

The impact of anthropogenic harm to Northern Madtom populations was analyzed with deterministic elasticity analysis on the population growth rate and on life-stage densities, and via the use of population simulations. This combination of methods allowed for the impact of changes to vital rates on a population's growth rate to be evaluated under situations of permanent changes (elasticity) and transient/periodic harm (simulations).

Northern Madtom populations are most sensitive to changes in juvenile survival, followed by fertility and YOY survival; adult survival had the least impact. The patterns of these results do not change under scenarios of different population growth rates, although the degree of sensitivity to changing vital rates (i.e., the elasticity values) differs slightly. When the influence of density is considered, juvenile survival again had the greatest influence on adult abundance followed by YOY survival; YOY survival followed by egg carrying capacity had the greatest influence on juvenile abundance. Based on the median elasticity value of juvenile survival on the adult population, a reduction in the juvenile survival rate by ~9% would cause the adult population to decline by 25% from its initial carrying capacity. Simulation results evaluating impacts of periodic perturbations similarly found the juvenile stage to be most sensitive, followed again by harm to the YOY stage and finally harm to the adult stage. Relationships between specific anthropogenic activities and changes in vital rates have not yet been established for Northern Madtom, but elasticity analyses may be useful for guiding decisions based on known (or estimated) population size and expected level of harm.

Recovery Targets

Abundance (Minimum Viable Population)

The concept of demographic sustainability was used to identify potential recovery targets for Northern Madtom using the concept of a minimum viable population (MVP) size. MVP was assessed using stochastic, density-dependent population simulations. Simulations ran over a 100 year timeframe with initial abundances ranging from 100 to 10,000 adult females, incorporating different frequencies (from 5 to 20% per generation) and severities (50 to 100% decline in population size) of catastrophic events to account for uncertainties in nature, and used a quasi-extinction threshold of 25 adult females, below which a population is likely unviable.

The estimated MVP size was ~2,400 (CI: 700–5,600) adult females at a 5% extinction risk and ~7,900 adult females (CI: 2,400–18,600) at a 1% extinction risk. Given the stable age distribution for Northern Madtom of 84% juveniles (age 1–2), and 16% adults (age 3–5) and a 1:1 sex ratio, the number of adult females can be converted to a total population size of ~29,000 (CI: 8,900–68,000) under a 95% chance of persistence over 100 years and ~97,000 (CI: 29,000–230,000) under a 99% chance of persistence over 100 years. These MVP values were estimated for an isolated population. If Northern Madtom in occupied localities are reproductively isolated from each other, then the MVP value should be applied to each individual population.

This analysis assumed age at maturity was 3 and maximum age was 5; however, Northern Madtom may mature at age 2 and live to a maximum of age 6. Should one of these alternative life-history scenarios be true, the revised MVP sizes are presented in Table 7.

Table 7. MVP and 95% CI values for two alternative life-history scenarios (age 2 maturity and age 6 longevity) compared with the standard scenario. MVP values were estimated for a 99% chance of persistence over 100 years. Values are presented for adult females and for all age-1 and older individuals.

Scenarios	MVP – Adult Females	MVP – Age 1+ individuals
Age 3 maturity, Age 5 longevity (standard scenario)	7,900 (2,400–18,600)	97,000 (29,000–230,000)
Age 2 maturity	9,400 (2,500–24,000)	52,000 (14,000–133,000)
Age 6 longevity	7,000 (2,100–17,000)	80,000 (24,000–193,000)

Habitat (Minimum Area for Population Viability)

The minimum area for population viability (MAPV) is the quantity of habitat required to support a population of MVP size, and is estimated as the MVP divided by mean population density. Densities were estimated to be 0.57 (±0.30), 0.51 (±0.29) and 0.60 (±0.29) individuals per 100 m^2 for the Detroit, St. Clair, and Thames rivers, respectively. These estimates were calculated from trawl data where sampling area was available (Smyth and Drake 2021; Table 1). The MAPV for a total population of 97,000 Northern Madtom (i.e., MVP at 1% extinction risk) would be ~1,700 hectares for the Detroit River, ~1,900 ha for the St. Clair River and ~1,600 ha for the Thames River.

Additionally, theoretical density estimates were generated based on Area Per Individual length-weight relationships for lake and river habitats (Randall et al. 1995), corrected for the stable age distribution. 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. This resulted in an MAPV of ~13.9 ha for lacustrine habitats and ~4.5 ha for riverine habitats. The large discrepancy in MAPV results is driven by the differences in empirical density estimates and theoretical ones.

Recovery Time

As abundances are unknown for Northern Madtom populations in Ontario, time to recovery was estimated with simulations that began with an initial population size set at 10% of the MVP. This approach results in the longest times for recovery for a viable population. These simulations reflect a situation where there is sufficiently available habitat or a removal of threats or competitors such that vital rates return to a state that permits population growth towards carrying capacity. Simulations incorporated stochasticity, density-dependence, and catastrophes in the same manner as MVP simulations. Recovery simulations resulted in a distribution of recovery times, but the median time to recovery was 17 years, and 95% percent of populations reached recovery in 58 years or less.

Mitigations and Alternatives

Threats to species survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects that could result from projects in Northern Madtom habitat. A review has been completed summarizing the types of works, undertakings and activities that have been conducted in habitat known to be occupied by Northern Madtom in Canada during the period of November 2013 through August 2022 (Table 8). Complete details are found in Colm et al. (2024). The most frequent project types were 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. 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.

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), which 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 8. 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	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	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

The presence of 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(s).
- 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

- There is uncertainty in life history parameters used in the modeling, including: age at maturity (i.e., 2 or 3), fecundity (currently based on small sample size), rate and severity of catastrophes, YOY survival, age structure, and mortality estimates (based on aggregated data and generated from specimens aged with an age-length key). Most parameters were estimated from individuals collected from the St. Clair River and were applied to the other two rivers.
- Abundance and density estimates, and their trends through time, are lacking. Empirical density estimates were based on sampling data from unrelated trawling projects where sampled area was measured and do not account for imperfect detection, while theoretical estimates assume the population is at full productive capacity, which may not be true. Standardized sampling through time would allow for more reliable estimates of abundance and trajectory. Sampling designed for estimating density would be helpful in understanding which of the empirical or theoretical estimates used are more appropriate, and could refine the MAPV calculations.
- Gaps in the distribution remain. It is unknown to what extent the species uses Lake St. Clair; detections are sporadic, except in the southwest end near the inlet of the Detroit River, and genetic evidence suggests this system is a barrier to movement. The species has not been detected in the Sydenham River since 1975, and is thought to be extirpated, but could be persisting in low abundance. Northern Madtom environmental DNA was detected in the Grand River and Thames River (upstream of the known range), but live specimens are needed to confirm these results.
- Population genetic structure of the Thames River and how it relates to population structure in the Detroit and St. Clair rivers are unknown. This could impact interpretation of MVP and MAVP estimates.
- Habitat extent throughout all four localities where suitable depth, flow, and substrates exist is unknown, as are seasonal habitat needs by life-stage, especially for YOY and juveniles.
- Mechanism of impact, and extent and magnitude of threats including: interactions with invasive species, climate change, impacts of various pollutants (gB, toxic substances in SCDRS), and environmental tolerances (e.g., to turbidity), are unknown.

OTHER CONSIDERATIONS

Sampling Considerations

Northern Madtom is a small, cryptic species that occupies habitats that are difficult to sample, and may hide in crevices or under cover objects. It is most active at night, which can present logistical challenges for sampling. Field observations during sampling suggested that Northern Madtom occupies transition zones between shallower banks and inner deep channels of rivers, which can make it difficult to keep gear angled appropriately and to locate those spots without considerable side scanning first (Lamothe et al. 2020). Seining has been effective for sampling other rare madtom species when habitat is wadeable, especially when combined with kick-sweeping and/or backpack electrofishing (Fuselier and Edds 1994, Bulger and Edds 2001, Tiemann and Tiemann 2004). Wagner et al. (2019) found that ten 100 m transects would need to be seined to have 95% confidence that Piebald Madtom (*N. gladiator*; closely related and occupies similar habitats to Northern Madtom) is truly absent; and seining was 6.7 times more effective for detecting this species than the next best gear (backpack electrofishing). This study also found seines to be less size selective than minnow traps or backpack electrofishing, both of which selected for larger individuals. Benthic trawls have been effective at capturing YOY, juvenile and adult (19–130 mm TL) Northern Madtom in Ontario, but many repeat tows are needed (11–16 repeated non-detections) for 95% confidence of true absence, depending on the river (Lamothe et al. 2020). Gee-style minnow traps have captured over 800 Northern Madtom in the SCDRS from 2010–2022 (Utrup et al. 2023). A bait evaluation study found that traps baited with worms (nightcrawlers) were approximately 4.5 times more effective than traps baited with cheese, and even greater than those baited with dog food or unbaited (Johnson et al. 2021). These minnow traps may bounce off the bottom if set in high flows and not weighted properly (Manny et al. 2014), and may be size-selective; generally catching adults >110 mm TL (Manny et al. 2014, Utrup et al. 2023). Terracotta pot saucers stacked together as artificial nest structures placed along transects and searched by divers worked for sampling other rare madtoms; this is likely most effective during the spawning season, but these nest structures were attractive to madtoms as cover outside of the spawning season, as well (Midway et al. 2010a. Cope et al. 2019).

In addition to being a useful sampling strategy, these artificial nests appeared to be a good habitat enhancement. Some of the original nests were located by Cope et al. (2019) nearly 10 years after they were first placed by Midway et al. (2010a), and were occupied by madtoms. These terracotta nests were preferentially selected by Carolina Madtom (*N. furiosus*) over natural cover objects in a lab study (Midway et al. 2010b), and are used in rearing projects for Piebald Madtom at a Mississippi hatchery (M. Wagner, USWFS, pers. comm.).

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SOURCES OF INFORMATION

This Science Advisory Report is from the November 29-30, 2022 regional peer-review meeting on the Updated Recovery Potential Assessment for Northern Madtom (*Noturus stigmosus*), 2012–2012. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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