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Canadian Science Advisory Secretariat
Ontario and Prairie Region | Science Advisory Report 2025/033

RECOVERY POTENTIAL ASSESSMENT FOR KIDNEYSHELL (*PTYCHOBRANCHUS FASCIOLARIS*)

Photo of Kidneyshell from the Sydenham River (Photo credit: DFO).

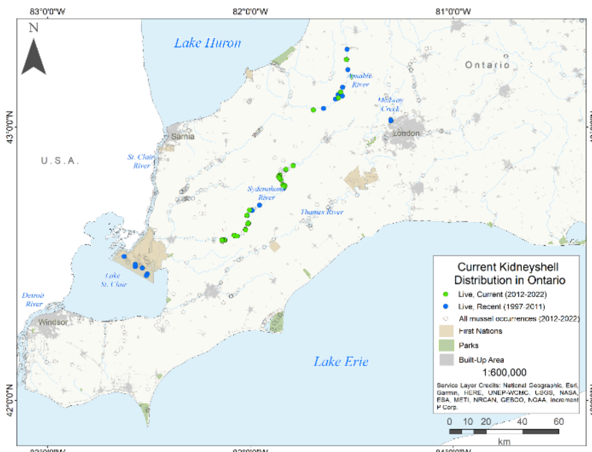

Figure 1. Recent (1997–2011; blue) and current (2012–2022; green) distribution of Kidneyshell in Canada. Empty circles depict all mussel occurrences from 2012–2022, including from formal surveys and incidental captures.

CONTEXT

Kidneyshell (*Ptychobranchus fasciolaris*) is a medium-sized, relatively long-lived freshwater mussel currently found in two watersheds in southwestern Ontario. It was assessed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in May 2003, and the status was re-assessed and confirmed in May 2013. This was due to a considerable loss in the species historical range from impacts of Zebra Mussel (*Dreissena polymorpha*) and agricultural land use practices. Kidneyshell was listed on schedule 1 of the *Species at Risk Act* (SARA) in 2005.

A Recovery Potential Assessment (RPA) process developed by Fisheries and Oceans Canada (DFO) was undertaken for Kidneyshell in October 2023. It summarizes information up to 2022 on the distribution, abundance, population trends, habitat requirements, threats, recovery targets and an allowable harm analysis for Kidneyshell in Canada. This information may be used to update the recovery strategy and action plan, and provide scientific advice needed to meet various requirements of SARA, including decisions related to the issuance of permits and authorizations.

This Science Advisory Report is from the October 24–26, 2023, regional peer review of the Recovery Potential Assessment of Kidneyshell (*Ptychobranchus fasciolaris*). Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.

SUMMARY

- In Canada, the current distribution of Kidneyshell is limited to the Ausable River (Lake Huron drainage) and the Sydenham River (Lake St. Clair drainage). Current evidence indicates that the species is extirpated from the Detroit, Grand, Niagara, St. Clair, and Thames rivers, Lake St. Clair, and Lake Erie.
- Kidneyshell is typically found in moderate to swift-flowing small- to medium-sized rivers or shallow lake areas in sand and gravel substrates. In Canada, Kidneyshell occupies medium rivers in relatively shallow depths (<1 m), moderate to swift currents, and a high proportion of gravel, sand, and cobble substrates.
- Kidneyshell larvae must encyst on the gills of a suitable host fish to survive and metamorphose into juveniles. The functional host fishes for Kidneyshell in Canada include Blackside Darter (*Percina maculata*), Johnny Darter (*Etheostoma nigrum*), and Logperch (*P. caprodes*), but may include other *Percina* spp. or *Etheostoma* spp. and Brook Stickleback (*Culaea inconstans*).
- Modeling projections indicate that achieving a 99% probability of persistence over 100 years requires ~5,250 (CI: 2,250–9,750) adult Kidneyshell. At current densities, this would require ~260 ha and ~50 ha of suitable habitat in the Ausable and Sydenham rivers, respectively. Habitat area is likely sufficient in both rivers, but with less certainty in the Ausable River.
- Positive population growth rates were observed in most sites in both rivers. On average, monitored sites in the Ausable River exhibited 7% growth per year (CI: 2–13%) based on five sample areas in each of three time periods between 2006 and 2019, while sites in the Sydenham River exhibited 13% growth per year (CI: 11–15%) based on 10 sampled areas in each of two or three time periods between 1999 and 2022. Overall, the abundances are interpreted to be stable in the Ausable River, and increasing in the Sydenham River.
- Kidneyshell populations are generally most sensitive to perturbations in adult survival. They may become more sensitive to perturbations to juvenile survival under higher population growth rate and later maturity. The Ausable River population is predicted to be more sensitive to perturbations in adult survival because of its current lower population growth rate.
- Dreissenid mussels are the likely cause of extirpation of Kidneyshell in the Great Lakes and connecting channels, including the St. Clair River, Lake St. Clair, Detroit River, and Lake Erie. Agricultural and urban land use, dams, and other historical habitat modifications likely contributed to extirpations in the Thames and Grand rivers.
- Presently, a number of threats, including agricultural and urban sources of pollution, aquatic invasive species, and climate change are contributing to habitat degradation. Current threats appear not to be causing population-level declines in extant localities, but localized impacts below the population level may be occurring. The cumulative effect of threats and their interactions are poorly understood. Recent research suggests greater impacts from certain combinations of threats than individual threats on their own.
- Key knowledge gaps remain regarding life history parameters (e.g., age at maturity, juvenile survival); larvae-host relationships; habitat preferences by life stage; population structure, abundance, and dynamics; and the magnitude, spatial extent, and impact of threats (individually and in combination).

INTRODUCTION

Kidneyshell (*Ptychobranchus fasciolaris*) was first assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in May 2003 as Endangered (COSEWIC 2003), and the status was re-assessed and confirmed in 2013 (COSEWIC 2013). The reason for this designation is that the species was lost from approximately 70% of its historical range due to impacts from Zebra Mussel (*Dreissena polymorpha*) as well as agricultural land use practices that resulted in heavily degraded habitat. The species was historically found in at least 10 localities in southwestern Ontario, but is presently only known from the Ausable and Sydenham rivers. Kidneyshell was listed on Schedule 1 of the *Species at Risk Act* (SARA) in 2005. A recovery strategy was first completed in 2006, and an amended final version was posted in 2013 (DFO 2013). Fisheries and Oceans Canada (DFO) developed the recovery potential assessment (RPA) process to provide information and science-based advice needed to inform listing decisions and to fulfill requirements of SARA, including the development (or updating/amending) of recovery strategies and action plans, and authorizations to carry out activities that would otherwise violate SARA. The process is based on DFO (2007) and updated guidelines (DFO unpublished) that assess 22 recovery potential elements. Supporting information is found in Colm and Morris (2025) and Fung et al. (2025).

ASSESSMENT

Biology, Abundance, Distribution, and Life History Parameters

Species Description and Biological Information

Kidneyshell is a medium-sized (125–150 mm maximum adult size) mussel (Unionidae) with an elliptical-elongate shell that is solid and relatively thick. The shell is typically rounded on the anterior end, pointed on the posterior end, and compressed; the ventral margin may be slightly curved. The periostracum ranges in colour from yellow to brown and has broad, interrupted green rays that resemble squares. The nacre is white. The beak sculpture is not developed, and the beak cavity is shallow. The pseudocardinal teeth are thick and triangular, and the lateral teeth are short, thick and may be serrated. The species is dioecious and not strongly sexually dimorphic.

Spawning in Ontario likely occurs late June through mid-August but could continue into October. Males release sperm that is filtered in by nearby females. After eggs are fertilized, the glochidia develop in the outer gills (marsupia) overwinter; Kidneyshell is a long-term brooder or bradytictic. Based on a relationship with adult female body length, females are predicted to have approximately 80,000 eggs (Fung et al. 2025), and three female Kidneyshell in the Sydenham River had a mean of 88,641 glochidia (McNichols 2007). The glochidia are released the following spring to summer (late April through August), beginning when temperatures reach approximately 14.5–17°C (Ortmann 1919, Gordon and Layzer 1989, Watters 1999, McNichols 2007). The sex ratio was 1.3:1 and 1.8:1 males to females in the Ausable and Sydenham rivers, respectively, in 2012–2014.

Kidneyshell glochidia must attach to a vertebrate host to complete their life cycle. To appeal to host fishes, glochidia are packaged as conglutinates that resemble fish fry or insect larvae. These packages rupture when bitten, allowing glochidia to attach to the gills. Kidneyshell conglutinates all have “eyespots” with pigmented lines (weak spots in the conglutinate membrane), but some may be a “major” type, approximately 7–10 mm in length with additional lines resembling myomeres of fish fry, or a “minor” type, approximately 4–6 mm in length with a red disc around the “head” resembling insect larvae (Watters 1999). The conglutinate has an adhesive end that can attach to a variety of substrate types. Each conglutinate may contain 150–500 glochidia (Watters 1999, McNichols 2007).

When encysted, the glochidia feed on gill tissue fluids and develop their internal organs. This is also the main opportunity for dispersal. Successful transformation of Kidneyshell glochidia has been reported on darters, sculpins, and a stickleback in laboratory studies in the U.S.A. and Canada (White et al. 1996, Watters et al. 2005, McNichols 2007). Field studies in Ontario further support the use of several darter species, notably Blackside Darter (*Percina maculata*), Johnny Darter (*Etheostoma nigrum*), Logperch (*Percina caprodes*) and Greenside Darter (*Etheostoma blennioides*), with some evidence that primary hosts may differ slightly between watersheds (DFO unpublished data). Metamorphosis was completed within 22–35 days on host fishes in laboratory studies in Ontario (McNichols 2007, Van Tassel et al. 2021).

Once transformation is complete, juveniles drop off the host fish and settle into the substrate. Juveniles typically remain burrowed for the first few years of life until maturity is reached (estimated 3–5 years). The maximum age and length were predicted to be 32 years based on age estimations and 157.4 mm based on a Von Bertalanffy growth function, from Licking River, Kentucky specimens (Haag and Rypel 2011). Age assessments of 98 spent shells from the Ausable River ranged from 1–33 years (mean 11.2 years; Figure 2), and the largest specimen recorded in Ontario was 125 mm (DFO unpublished data). From recent quadrat sampling, the mean size in the Ausable and Sydenham rivers was 64.6 mm and 74.3 mm, respectively (Fung et al. 2025). Generation time of Kidneyshell was coarsely estimated as 11–14 years in the Ausable River, and 9–11 years in the Sydenham River (DFO unpublished data).

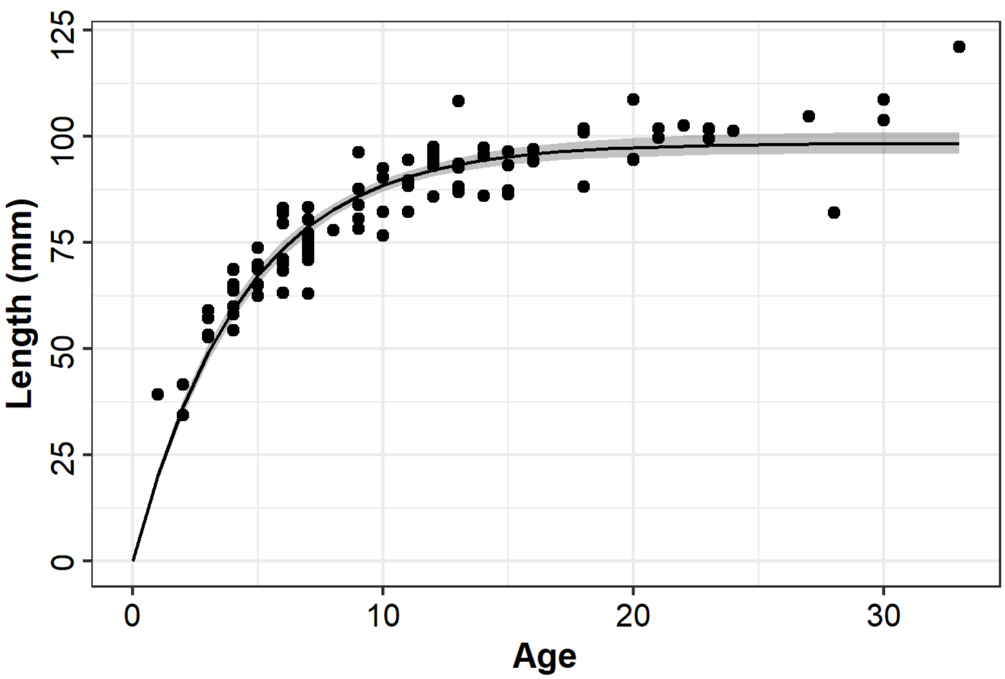

Figure 2. Length-at-age data of spent Kidneyshell shells collected in the Ausable River (n = 98). The solid line represents a fitted von Bertalanffy growth function ($L_t = 98.27(1 - e^{-0.23t})$) and the grey region represents the 95% credible intervals.

Adult unionid mussels are suspension feeders, generally consuming organic debris, algae and bacteria from the water column and sediment. Juveniles remain burrowed in the sediment for the first few years of life and feed on organic material available through interstitial pore water. Larval mussels (glochidia) feed on host fish tissue while encysted.

Abundance and Trend Analysis

There are no recent population-wide abundance estimates for Kidneyshell in Canada. Long-term monitoring data collected from the Ausable and Sydenham rivers through the Unionid Monitoring and Biodiversity Observation (UMBO) network was used to model population-specific estimates of population density and trajectory (Fung et al. 2025). Standardized quadrat surveys were conducted at five sites in the Ausable River across three time periods, and at ten sites in the Sydenham River with four sites surveyed for a third time. The Kidneyshell counts from the quadrat surveys were fit with separate statistical models per river to estimate quadrat site abundance, density, and population growth rates (Table 1; Fung et al. 2025). Generalized linear mixed models with a negative binomial distribution were constructed and fit using Integrated Nested Laplace Approximation (INLA), with habitat covariates included. The abundance pooled across all quadrat sites in the Ausable River was estimated to be 1,129 (95% CI: 933–1,360), and 6,949 (5,371–9,059) in the Sydenham River; these estimates likely represent a minimum population size for each river as Kidneyshell occupies areas beyond the quadrat sites, but information is lacking to project estimates across the entire distribution in each river. Mean density across time periods was 0.45 mussels/m^2 in the Ausable River, and 0.42 mussels/m^2 in the Sydenham River.

In terms of population trends through time, significant increases in quadrat count were estimated across years for both rivers (Figure 3). For the Sydenham River, from three (partial) sampling periods between 1999 and 2022, the estimated population growth rate was 1.13 (95% CI: 1.11–1.15). All quadrat site-specific estimates of population growth rate were > 1. For the Ausable River, from three sampling periods between 2006 and 2019, the estimated population growth rate was 1.07 (95% CI: 1.02–1.13). Three of the five quadrat site-specific estimates of population growth rate were > 1, one was stable (i.e., population growth rate = 1), and one site showed a significant decrease.

Table 1. Summary of length and area of occupied river length (based on contiguous segments of the Ontario Hydro Network watercourse layer and occurrence records from 2012–2022), and of mean density, quadrat sample site abundance estimate, and population growth rate from Fung et al. (2025).

Habitat and Population Measure	Ausable River	Sydenham River
Approximate Occupied River Length (km)	57 (+ 3 km of Little Ausable River)	92
Approximate Occupied River Area (ha)	110	241
Mean Density (live/m^2)	0.450	0.417
Projected Abundance Pooled Across Sample Sites (95% CI)	1,129 (933–1,360)	6,949 (5,371–9,059)
Population Growth Rate (95% CI)	1.07 (1.02–1.13)	1.13 (1.11–1.15)

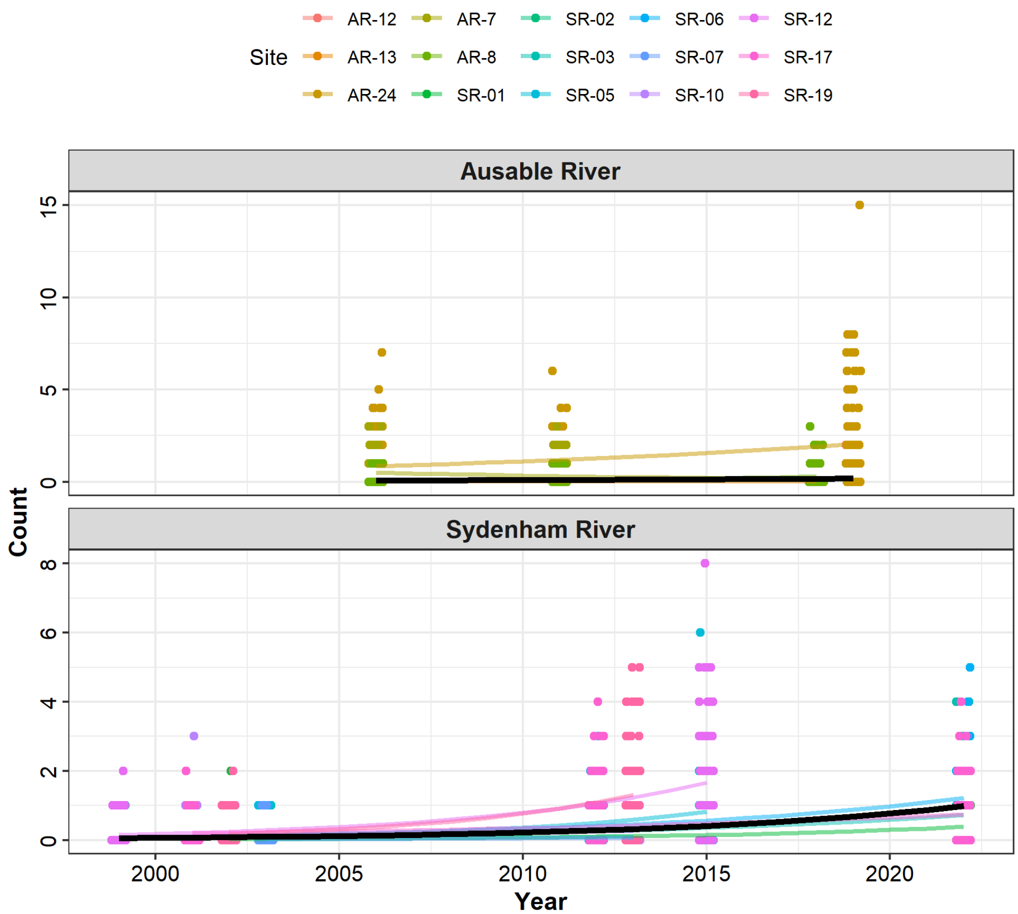

Figure 3. Quadrat count data (mussels/m²) of Kidneyshell collected at the UMBO sample sites in the Ausable and Sydenham rivers over time. Each dot represents a quadrat data point. Colour indicates the sampled site, and the lines represent the estimated trends through time with the black line indicating the site-combined trend and the coloured lines showing site-specific trends.

Distribution

Kidneyshell is found in eastern North America primarily in the Ohio River basin and lower Great Lakes basin. Its distribution is widespread but sporadic. It is known from 13 states in the U.S.A. and one Canadian province. In Ontario, it was historically known from the Ausable River, Lake St. Clair, Sydenham River, Thames River (and Medway Creek), Detroit River, Lake Erie, Grand River, and the Niagara and possibly Welland rivers. It is currently confirmed in the Ausable and Sydenham rivers (Figure 1).

Sampling efforts for Kidneyshell in Canada have been a combination of timed-search surveys and standardized quadrat surveys. Timed-search surveys (visual and tactile searching) are useful for understanding species distributions and can cover a large area relatively quickly. Quadrat surveys (excavations) are designed for evaluating trends through time and population demographics. A brief summary of the most recent sampling information at each locality is provided below, with complete records found in Colm and Morris (2025).

Ausable River

Kidneyshell was first found in the Ausable River in 1994. Since 1998, approximately 506 and 509 individuals have been found using timed-search and quadrat surveys, respectively. The historical distribution of the species is approximately 70 km from Crediton to Springbank, and it is currently found in approximately 57 km based on distribution records from 2012–2022.

Additionally, single live individuals were found in Nairn Creek (in 2010) and the Little Ausable River (in 2018) both records approximately 3 km upstream from where these tributaries meet the Ausable River.

St. Clair River

Kidneyshell (live or shells) has not been reported from the Canadian side of the river, but shells have been found on the American side. Most recently, dive surveys found six weathered shells in 2021 (Keretz 2022). Kidneyshell is likely extirpated from this location.

Lake St. Clair

Kidneyshell was first reported in Lake St. Clair in 1934. Live individuals were last found near the mouth of Puce River in 1990 (Gillis and Mackie 1994), and most recently, nine individuals were found at seven sites around the St. Clair River delta from 1998 to 2003 (note two were from the American side of the delta). Approximately 33 sites were surveyed in the lake from 2004–2021, including those sites where live individuals were last found, but no additional live specimens or shells were found. The historical distribution of the species in Lake St. Clair is from the St. Clair River delta towards Mitchell's Bay, and near the mouth of Puce River towards the inlet of the Detroit River. The species is likely extirpated from Lake St. Clair.

Sydenham River

Live Kidneyshell have been consistently found in the East Sydenham River since 1963. From 1997 through 2022, 1,036 live individuals were collected across 237 sites during timed-search surveys, and 925 live individuals were found during quadrat surveys of approximately 2,265 m^2. Kidneyshell is currently (and historically) known from an approximately 100 km stretch of the East Sydenham River from Napier to Dresden. A weathered valve was observed in 2018 in Bear Creek, a tributary of the North Sydenham River, but no live individuals or other shells have been found there despite extensive timed-search and quadrat surveys.

Thames River

Live Kidneyshell have not been detected in the main branches of the Thames River; however, shells have been periodically found dating back to 1894. From 1997–2022 approximately 141 sites were surveyed using timed-search methods, and quadrat surveys excavated approximately 855 m^2. Shell records exist from Big Bend to Chatham; however, it is not known if this accurately reflects the historical distribution of live individuals in the Thames River.

Four live individuals were found in Medway Creek, a tributary of the North Thames River in 2004 (n = 2) and 2006 (n = 2), but they were old and senescing. A handful of surveys were conducted in Medway Creek before and after this time, but no other evidence of the species has been found. Following the development of a subdivision surrounding the creek, the habitat conditions are no longer thought to be suitable, and the species is likely extirpated from this locality. In 2017, a weathered valve was found in the South Thames River approximately 12 km upstream of the Forks in London.

Detroit River

Live Kidneyshell were first collected in the Detroit River in 1982 and were consistently found until the mid-1990's. Most records of live individuals were from the American side of the river, including: 63 individuals found in 1992, two in 1994, and the last live individual in 1998. Only shells were found on the Canadian side of the river after 1984. Extensive diving surveys were conducted in the Detroit River (both Canadian and American waters) in 2019 to search for live unionids at potential refuge sites; no live Kidneyshell were found but 121 weathered shells were collected (Keretz et al. 2022). The species was historically distributed throughout the Detroit River, from the inlet at Lake St. Clair to the outlet at Lake Erie, but is considered extirpated from this system.

Lake Erie (subpopulations)

There are numerous historical records of Kidneyshell along the north shore of Lake Erie and around Pelee Island (and associated islands) from 1885–1993 (approximately 334 sampling events during this period); however, the condition or state of these specimens at the time of collection is largely unknown. Two live individuals were last found in 1992 in American waters. The species (mostly shells) has been detected sporadically along the north shore of the lake, including around the outlet of the Detroit River, towards the mouth of Cedar Creek, Pelee Island, Rondeau Bay, Long Point Bay, and between the mouth of the Grand River and the Niagara River. These likely represented multiple subpopulations when extant, but all are thought to be extirpated now.

Grand River

Live Kidneyshell have not been verified in the Grand River. Historical accounts exist from 1934–1969 but the status of these specimens at the time of collection is unknown. From 1997–2022, approximately 294 sites were surveyed using timed-search methods, and approximately 984 m^2 of quadrats have been excavated, but no live individuals were found. Shells were most recently found in 2020 and 2021. Shell records from the main stem of the Grand River exist from Caledonia to the mouth at Port Maitland; however, it is not known if this reflects the historical distribution of live individuals. Additionally, there is a record from the Nith River from 1997, but no indication of shell condition or sampling effort is available. Approximately 21 sampling events occurred in the Nith River from 1997–2021 using timed-search methods, but no live specimens or other shells were found.

Niagara River (upper)

Kidneyshell has not been collected live from the Canadian side of the Niagara River. A fresh shell was first observed in 1934 above the falls (i.e., Lake Erie drainage). A small number of historical records exist from the American side of the river. A dive survey was conducted in 2001 to search for live unionids, but only three individuals were found. The historical distribution in the Niagara River is not well understood given the difficult sampling conditions and the species is presumed extirpated from this system. Historical records exist from the Welland River (formerly Chippawa Creek). There were at least 15 shells found prior to 1926, likely near the mouth where it drains into the Niagara River. A shell was discovered adjacent to a Feeder Canal that fills the Welland Canal in 2015, but it is possible this was deposited along with fill material during construction or maintenance of the canals.

Population Status Assessment

To assess the population status, Kidneyshell populations were ranked in terms of abundance (Relative Abundance Index: Extirpated, Low, Medium, High, or Unknown) and trajectory (Population Trajectory: Increasing, Decreasing, Stable, or Unknown). The Relative Abundance Index considers the mean density estimates along with the coarse estimates of occupied river length, and the Population Trajectory is based on the estimates of population growth rate (Table 1; Fung et al. 2025). A certainty value was assigned based on the type of information used to assess the population (1 = quantitative analysis, 2 = catch per unit effort, 3 = expert opinion). The Relative Abundance Index and Population Trajectory were combined to yield a Population Status (Table 2). Refer to Colm and Morris (2025) for detailed methods.

Table 2. Population Status of all Kidneyshell 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).

Population	Population Status
Ausable River	Fair (2)
Lake St. Clair	Presumed Extirpated
Sydenham River	Good (2)
Medway Creek	Presumed Extirpated
Detroit River	Extirpated
Lake Erie (subpopulations)	Extirpated

Habitat Requirements

Kidneyshell typically occupies small to medium rivers in riffle/run habitats with moderate to swift current in stable gravel and sand substrates. It occasionally occupies lake areas that are shallow (< 1 m in depth), and have sand or gravel shoals with wave action (Ortmann 1919, COSEWIC 2003). The species is thought to prefer clear water (Watters et al. 2009), and has been reported at the edges of Water Willow (*Justicia americana*) beds with strong current (Ortmann 1919). Grabarkiewicz (2012) found that Kidneyshell in the Blanchard River, Ohio was more common in gravel substrates. Among the 35 quadrats where the species was found, the mean substrate composition was 53.9% small gravel, 20.3% sand, and 10.1% large gravel. From an analysis of quadrat survey data in Ontario, Kidneyshell abundance increased with increasing proportions of sand and gravel substrates in the Sydenham River, and in the Ausable River along with depth (from 0.02–0.52 m) (Fung et al. 2025). Habitat is thought to be the same for adults and juveniles.

The habitat for the glochidial stage is considered to be the habitat required by the hosts (Blackside Darter, Johnny Darter, Logperch, Greenside Darter, and possibly others). These are typically riverine species, preferring riffles/runs with slow to moderate flow and coarser substrates, but there are microhabitat differences among the darter species. Several of the host species are common and widely distributed throughout both the Ausable and Sydenham rivers (particularly Blackside Darter and Johnny Darter), and are not thought to be limiting Kidneyshell at this time.

Functions, Features, Attributes

A description of the essential functions, features, and attributes associated with the habitat of Kidneyshell in Canada are described to inform identification of or refine critical habitat for this species (Table 3). The habitat required for each life stage has been assigned a life-history function that corresponds to a biological requirement of Kidneyshell. 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 to complete its life cycle. Habitat attributes have also been provided, which are measurable components describing how the habitat features support the life history function for each life stage. Habitat attributes described across the species' range from the literature have been combined with attributes from recent records to show the range of habitat values that Kidneyshell may be found in (note that the species may be currently occupying areas where habitat is not optimal). Additional guidance on identifying critical habitat for freshwater mussels can be found in DFO (2011).

Table 3. Summary of the essential functions, features, and attributes for each life stage of Kidneyshell in Canada. Table is modified from DFO (2013) to include habitat information from current sampling events (2012–2022). Habitat attributes from the published literature and those recorded during recent sampling events can be used to support or refine delineations of critical habitat. Note that habitat as described in "Recent Knowledge" may reflect sub-optimal habitat.

Life Stage	Function	Feature	Attribute		Critical Habitat
			Scientific Literature	Recent Knowledge	
Spawning and fertilization (mid-June through August)	Reproduction	Reaches of rivers and streams with riffle and/or run habitats (or nearshore lake habitats with wave action) with gravel and sand substrates present	-	• assumed to be same as adult habitat with sufficient summer depths to avoid desiccation or predation while on sediment surface • highest proportion of females with eggs and males with sperm observed when daily water temperature was a mean of 25.2°C (range 22.4–27.2°C) in the Sydenham River	• moderate to strong currents or wave action (if in lakes) for distribution of sperm • daily water temperatures of approximately 25°C (at least 14.5°C) • shallow (0.4–1.0 m), clear, well-oxygenated water • gravel, sand and cobble substrates
Encysted glochidia (release in spring, encystment for 22–35 days on host)	Feeding Cover Nursery	Same as above with host fishes present (presumed hosts: Blackside Darter, Brook Stickleback, Fantail Darter, Greenside Darter, Iowa Darter, Johnny Darter, Logperch)	• spring (April) water temperatures of 17°C for females to release conglutinates (Watters 1999)	Blackside Darter and Johnny Darter in the Ausable and Sydenham rivers (Fish Biodiversity Database) were found at sites with: • mean summer water temperature 22.1°C (range: 8.6–28.6°C) • mean water velocity 0.134 m/s (0.00–0.59 m/s) • mean depth 0.85 m (0.15–4.40 m) • mean turbidity 46.0 NTU (8.6–229.9 NTU); • mean conductivity 534.9 µs/cm (229–735 µs/cm) • mean dissolved oxygen 4.85 mg/L (0.70–12.25 mg/L) • mean percent composition of substrates: 24.5% gravel, 24.2% sand, 19.8% cobble, silt 12.0%	• spring water temperatures of approximately 17°C for females to begin releasing conglutinates • clear water (high visibility of conglutinates) • presence of host fishes (Blackside and Johnny darters and Logperch likely primary hosts)
Juvenile	Feeding Cover	Reaches of rivers and streams with riffle and/or run habitats (or nearshore lake habitats with wave action) with gravel and sand substrates present	• moderate to strong currents in riffles or wave action (in lakes) (Ortmann 1919) • shallow water (< 1 m) • firmly packed small gravel (54%), sand (20%) and large gravel (10%) or cobble with sufficient pore water availability (Ortmann 1919, Grabarkiewicz 2012)	-	• same as adult with well-oxygenated substrates
Adult	Feeding Cover	Same as above	• moderate to strong currents in riffles or wave action (in lakes) (Ortmann 1919) • shallow water (<1 m) • firmly packed small gravel (54%), sand (20%) and large gravel (10%) or cobble (Ortmann 1919, Grabarkiewicz 2012) • clear water (Watters et al. 2009) • presence of Water Willow (*Justicia americana*) beds nearby (Ortmann 1919)	Adults in the Ausable and Sydenham rivers (LGLUD): • mean summer water temperature 22.2°C (range: 11.5–28.0°C) • mean water velocity 0.302 m/s (0.03–0.61 m/s) • mean depth 0.41 m (0.13–0.95 m) • mean turbidity 3.4 NTU (0.0–51.9 NTU); mean water clarity 0.23 m (0.06–0.60 m) • mean percent composition of substrates: 34.4% gravel, 20.9% sand, 18.4% cobble	• moderate to strong currents in riffles or wave action (if in lakes) • stable gravel, sand and cobble substrates • adequate supply of food (plankton, bacteria, algae, organic detritus, protozoans)

Threats and Limiting Factors to the Survival and Recovery of Kidneyshell

Freshwater mussels are among the most imperiled taxa in the world, owing to historical harvest, widespread habitat alteration, pollution, and aquatic invasive species (AIS; most notably dreissenid mussels). Furthermore, as obligate parasites at the larval stage, mussels are impacted by threats to host species as well. In Ontario, threats to Kidneyshell are considered to be pollution from agricultural and urban sources, impacts of climate change (droughts and temperature extremes), invasive species (Round Goby [*Neogobius melanostomus*] and dreissenid mussels), and habitat modifications through impoundments. Some of these threats in combination are thought to be responsible for the extirpation of Kidneyshell from across much of its historical range in Ontario. Kidneyshell is an equilibrium life history strategist with a relatively long life span, slow growth, and late maturity, meaning recovery of populations following disturbances or catastrophes is likely to be slow (Haag and Warren 2008, Haag 2012).

Pollution

As sedentary filter-feeders, freshwater mussels are generally vulnerable to the effects of pollution both in the water column and in the sediment (through pore water). Contaminants from industrial and urban sources that peaked in the 1970's likely contributed to the decline and loss of many freshwater mussels in Ontario, and these legacy contaminants and current land use practices continue to result in poor habitat quality. The two remaining watersheds with Kidneyshell populations in Ontario have intensive agricultural land use, ranging from ~70–80%, with a high proportion of watercourses being channelized, tiled, or buried drains (ABCA 2018a,b, SCRCA 2018). Siltation/sedimentation can arise from many of these watercourse modifications, or from livestock access to rivers, poor soil retention practices, and a lack of riparian buffers. Suspended sediments can clog incurrent siphons and gills, interrupting feeding, respiration, growth, and reproduction, and filtering out large quantities of sediment can be energetically costly. High turbidity may also reduce visibility of prey-mimicking conglutinates for host fishes. When sediments settle out of suspension, they can smother individuals. Nutrient loads may also negatively affect mussels or host fishes, as increased primary productivity can reduce dissolved oxygen during periods of the day or seasonally. Additionally, fertilizers contain potassium and other nitrogenous compounds, the latter of which can result in increased ammonia levels. Freshwater mussels are highly sensitive to potassium and ammonia, particularly at early life stages. Pesticides can also be toxic or have sublethal effects to freshwater mussels, but recently measured concentrations in some Ontario rivers suggest they are not at high enough levels to have these effects. Granular Bayluscide is a targeted pesticide applied in the Great Lakes basin for assessing and controlling invasive Sea Lamprey (*Petromyzon marinus*) and can pose a mortality risk to Kidneyshell at typical application concentrations (Newton et al. 2017); however, recent applications have not occurred within the known distribution of Kidneyshell (Andrews et al. 2021).

The majority of land use surrounding the Ausable and Sydenham rivers is agricultural, but these systems are not immune from the effects of urbanization. Urban wastewater and runoff can result in numerous point and non-point sources of pollutants that are of concern to freshwater mussels and their hosts. Road salts applied for winter de-icing are a major concern, as chloride is among the most toxic substances to unionids particularly at the glochidial stage, and pulses associated with spring melt may occasionally be high enough to impact viability of glochidia. Other contaminants associated with roadways (e.g., polycyclic aromatic hydrocarbons [PAHs] and heavy metals) could negatively affect feeding, behaviour, reproduction, and growth, and may be especially problematic for individuals in downstream reaches of watersheds where these contaminants may accumulate (Archambault et al. 2018). Wastewater or other sewage treatment plants may also contribute nutrients and other toxic compounds to stream ecosystems. There are three and two larger wastewater treatment facilities immediately upstream of the Kidneyshell distribution on the Ausable and Sydenham rivers, respectively, as well as a number of septic systems that could contribute contaminants if old and leaching. In the Grand River, high nitrite and ammonia, and low dissolved oxygen resulted in highly unsuitable habitat devoid of mussels for a stretch immediately downstream of a large wastewater treatment plant (Gillis et al. 2017), and estrogenic compounds found in wastewater have led to reproductive consequences for Rainbow Darter (*Etheostoma caeruleum*) (Fuzzen et al. 2016, Hodgson et al. 2020).

Invasive and Other Problematic Species, Genes, and Diseases

The invasion of dreissenid mussels (Zebra Mussel and Quagga Mussel *Dreissena rostriformis*) in the Great Lakes basin resulted in the near eradication of native unionid mussels in the lakes, connecting channels, and lower reaches of tributaries by the mid 1990's. Dreissenids attach to native mussels via byssal threads and can accumulate on their shells in extremely large numbers, which can smother the siphon (reducing feeding, respiration and reproduction), prevent or inhibit valve movements, interfere with burrowing activities, and impair shell formation. Dreissenid mussels may also outcompete native mussels for food. Dreissenids are typically found in low abundances in riverine habitats as they have poor attachment abilities under flowing conditions. They were likely the primary driver in the extirpation of Kidneyshell from several of its historically occupied localities in the Great Lakes and connecting channels, but they are unlikely to have a great impact on the extant populations in the Ausable and Sydenham rivers, where they are only found near the mouths where flows are slow and substrates unsuitable for Kidneyshell.

Round Goby is an invasive benthic fish that is now widespread through the lower Great Lakes and is expanding its range upstream into many major tributaries, including the lower reaches of the Ausable River, and the entirety of the known Kidneyshell distribution in the Sydenham River. Round Goby is unlikely to consume Kidneyshell due to its small gape size, but may act as a sink for glochidia where attachment occurs but transformation is unsuccessful (Tremblay et al. 2016). Impacts of Round Goby on Kidneyshell may be indirect, as it is an aggressive and territorial species thought to be responsible for declines of many native benthic fishes, especially darters, in lakes St. Clair and Erie and many tributaries of the Great Lakes through increased diet overlap, predation of early life stages (egg/larval/young of year), and habitat displacement. Black Carp (*Mylopharyngodon piceus*) is a large-gaped molluscivore that has established in the Mississippi River that could pose significant threats to native unionids should it arrive in the Great Lakes basin (Nico et al. 2005); however, it is unlikely to arrive within the 10-year timeframe considered here.

Climate Change and Severe Weather

Freshwater mussels are generally considered vulnerable to impacts of climate change, owing to their reliance on host fishes to complete their life cycle and a limited ability to disperse to new habitats if conditions become unfavourable (Brinker et al. 2018). Ontario is expected to see increases in mean annual temperatures and winter precipitation, and a decrease in summer precipitation (McDermid et al. 2015). The most significant impact of climate change for Kidneyshell is expected to be a reduction of habitat quantity and quality due to increasing frequency and severity of droughts. Droughts will result in a loss of habitat space, increased risk of desiccation, increased predation risk from terrestrial and avian predators, and density-dependent effects like reduced food supply through competition, increased risk of disease transfer due to crowding, and reduced dissolved oxygen through consumption. Low flows during droughts can also lead to increased temperatures, decreased dissolved oxygen, and higher turbidity. Losses of mussels and fishes are anticipated in the Great Lakes drainage and across North America under some climate change scenarios resulting from declines in discharge (Spooner et al. 2011).

Additionally, extreme temperatures may arise during droughts or other low water periods, or during heat waves, which are also expected to increase in frequency and intensity with climate change. Critical thermal maxima (or other thermal endpoints) have not been assessed for Kidneyshell specifically, but a review of thermal tolerance studies for unionids in North America found an overall grand mean lethal thermal tolerance (LC50) of 34.6° C for acute (<4 days) exposures, and 32.0 °C for medium-chronic exposures (7–10 days) across all species tested, with some variability by life stage (Fogelman et al. 2023). Host thermal tolerances may also be limiting, with some reported values of darters in the Great Lakes ranging 30.5–36.0° C, depending on species, season, and acclimation temperature (Hlohowskyj and Wissing 1984, Ingersoll and Claussen 1984, Pandolfo et al. 2012).

Climate change may have other indirect impacts on mussels and mussel habitat, including: increases in nutrient and turbidity loads, altered flow regimes and changes to water velocity, increased disease prevalence, and changes in distribution of host fishes, competitors, and/or predators. Additionally, the glochidial-host relationship can be precarious under ideal conditions, and climate change could result in mismatches in timing of mussel spawning and host site occupancy, host feeding behaviours, host health and susceptibility to infestation.

Natural Systems Modifications

Dams, although impacts vary by type and size, typically result in lentic (i.e., slow to no flow) environments with heavy sediment loads settling out upstream, and can reduce water volume, alter temperature profiles and result in bed scouring downstream, eliminating the preferred habitat of Kidneyshell (and its hosts) on either side of the dam. This may also make habitat more favourable for dreissenid mussels, and prevent movement of host fishes. Kidneyshell is not found approximately 15–30 km downstream of the dams on the Ausable and Sydenham rivers; however, due to the lack of complete historical distribution data, it is unknown to what degree those existing dams impact(ed) Kidneyshell. Large dams on the Grand River and North Thames River may have played a role in the loss of the species in those systems.

Other Threat Considerations

Other minor threats identified by COSEWIC (2013) could cause mortalities to individuals or otherwise harm or impair productivity of Kidneyshell locally, but are unlikely to cause population-level impacts at current levels or rates of occurrence. Human population growth in Ontario may intensify threats over the next decade. Furthermore, Kidneyshell is experiencing a large number of threats simultaneously, and stressors may interact with each other in complex and unpredictable ways. Multiple threat effects and threat interactions was the greatest source of uncertainty in understanding and quantifying the current threat landscape for Kidneyshell.

Threat Assessment

Threats were assessed following guidelines in DFO (2014) using definitions found in Table 4. Given the generation time of Kidneyshell in Ontario of approximately 9–14 years, the threats were assessed over a 10 year timeframe (Table 5). Extant Kidneyshell populations are currently thought to be stable or increasing slightly, thus the level of impact of threats appears to be low (no measurable population-level decline). However, the threat assessment framework does not allow for the evaluation of cumulative threat effects or threat interactions, nor does it allow for evaluation of impacts below the population level (e.g., sub-lethal effects, impacts to vital rates). Threats could also have extreme impacts at small spatial scales (e.g., immediately downstream of a point source impact), at certain times of the year, or to certain life stages. Any of these circumstances individually may not result in a population-level decline, but given the relatively small distribution at only two remaining localities (and uncertainties in meta-population structure), combinations of these scenarios could be cause for concern. Furthermore, the threats are ranked low individually, but there are a large number of threats occurring simultaneously resulting in generally poor habitat conditions and any change in intensity of existing threats or any new threats may greatly increase the risk to these populations. This is of concern given projected human activities in Ontario.

Table 4. Definition and terms used to describe likelihood of occurrence (LO), level of impact (LI), causal certainty (CC), population-level threat occurrence (PTO), threat frequency (PTF) and 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.

Term	Definition
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 5. Roll up of population-level threat assessment for Kidneyshell 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). Threats received a Causal Certainty score of 5 if a plausible link is made between the threat and a decline, but direct evidence of impacts is lacking; a 4 if there is strong evidence of impacts from laboratory studies, but weaker evidence of impacts in the natural environment or evidence that the stressor is not at impactful levels in the natural environment in Ontario; and a 3 if there is strong evidence from laboratory studies and in the natural environment that the stressor is leading to population-level impacts in freshwater mussels somewhere.

IUCN Threat Category	Sub-category	Details	Kidneyshell in Canada
Pollution	Agricultural and Forestry Effluents	Sedimentation (field runoff, upstream drain maintenance)	Low (3)
		Nutrient Loading (+ ammonia and potassium)	Low (4)
		Pesticides (+ granular Bayluscide)	Low (4)
	Domestic and Urban Wastewater (incl. urban runoff)	Nutrient Loading (+ ammonia)	Low (4)
		Pharmaceuticals and estrogenic compounds	Low (5)
		Chloride	Low (4)
		Heavy Metals / PAHs	Low (4)
Invasive and other Problematic Species and Genes	-	Round Goby, Dreissenid mussels	Low (5)
Climate Change and Severe Weather	-	Frequent and severe droughts and extreme temperatures	Low (3)

Limiting Factors

There are natural factors that could be limiting to Kidneyshell, most of which relate to the obligate parasitic larval stage requiring encounter with host fishes and a period of encystment. Hosts must be present in sufficient quantity (and of good health) and at the right time to be suitable hosts. Host-mediated transport is the main opportunity for dispersal for Kidneyshell, but host darters are small-bodied and typically have limited dispersal capabilities. Darters may make more and longer distance movements during the spring spawning period, which likely partly overlaps with the glochidial release period. Predation is a potential risk to all life stages of Kidneyshell from molluscivorous fishes, and avian and terrestrial predators. Adults are medium-sized with relatively robust shells affording them protection, and juveniles remain buried and are likely not readily available to predators. Most encounters with predators are likely opportunistic and unlikely to limit Kidneyshell populations, particularly when found in a diverse mussel community with smaller, thinner-shelled species.

Recovery Targets and Allowable Harm

Recovery potential modelling to identify potential recovery targets and evaluate harm was completed in three main steps. Firstly, information on vital rates was compiled to build projection matrices that incorporate parameter uncertainty, environmental stochasticity and density-dependence acting on the first year of life (specifically, following detachment from host fish during settling). The impact of anthropogenic harm to populations was then quantified with the use of elasticity and simulation analyses. Lastly, estimates of recovery targets for abundance and habitat were made with estimation of the minimum viable population (MVP) and the minimum area for population viability (MAPV). As many uncertainties around Kidneyshell life-history remain, some parameters were drawn from ranges of plausible values. Estimates of harm and recovery targets can be refined as more research is conducted on the species to fill in knowledge gaps. Refer to Fung et al. (2025) for complete methods.

Modelling Impacts of Harm

The impact of anthropogenic harm to Kidneyshell populations was analyzed with deterministic elasticity analysis on the population growth rate and through the use of population simulations.

The elasticity of the population growth rate to perturbations in vital rates gives an indication of how the population may respond to small (< 30%), permanent changes in vital rates. In most instances, Kidneyshell populations were most sensitive to changes in adult survival rate. As a population grows, however, it becomes less sensitive to adult survival and more sensitive to juvenile survival. When the population growth rate is greater than about ~1.05, the elasticity value for juvenile survival can overlap or surpass that of adult survival depending on other life-history parameters. Since the Ausable River population has a lower current rate of growth, it is more sensitive to adult survival perturbations and less sensitive to perturbations in age-1+ juvenile survival or recruitment compared to the Sydenham River population, which has a greater population growth rate. Age-at-maturity produced negative elasticities indicating that later maturity would cause a decrease in population growth rate. Under most conditions, recruitment, which encompasses all aspects of reproduction, from egg production through first year survival, had small elasticities relative to adult survival. The elasticity of recruitment from old adults was small and less than that of young adults, thus the population was more sensitive to changes in reproductive contributions from young adults compared to old adults.

Simulation analysis was used to investigate the impact of harm from periodic perturbations occurring annually (for comparison to elasticity analysis), every second year, fifth year, and tenth year. Harm was applied at regular intervals to either the recruitment stage, the juvenile stage, the adult stage, or to all three stages. In the simulations, harm had the strongest impact when applied to all life-stages. When harm was applied to only a single life-stage, perturbations to the adult stage produced the strongest impact on density. For example, increased annual mortality rates of 3% applied to adults resulted in a 25% decrease in population size, whereas a mortality rate increase of 10% applied to the age 1+ juvenile stage was required for the same reduction in total population size. Kidneyshell populations were least impacted by harm to recruitment, representing interruptions to reproduction or harm to glochidia/post-settlement age-0 mussels. The simulations results are consistent with the results from the elasticity analysis.

Recovery Targets

Minimum Viable Population (MVP)

Demographic sustainability was assessed using population simulations which incorporated parameter uncertainty, environmental stochasticity and density-dependence. Simulation outputs of binomial quasi-extinction were fitted using a logistic regression as a function of adult female abundance (randomly drawn from an initial population size ranging 100–10,000), generational catastrophe rate (randomly drawn from 5%–20%), and maximum population growth rates (randomly drawn from 1.1–1.4). The mean MVP estimate of adult females, which corresponds to a 5% extinction risk over 100 years, was ~600 (95% CI: 260–1,150) and to a 1% extinction risk over 100 years was ~2,100 (95% CI: 900–3,900). If a 1:1.5 female-to-male sex ratio was assumed, then the MVP values for all adult Kidneyshell would be ~1,500 (95% CI: 650–2,875) and ~5,250 (95% CI: 2,250–9,750) for 5% and 1% extinction risks over 100 years respectively (Figure 4).

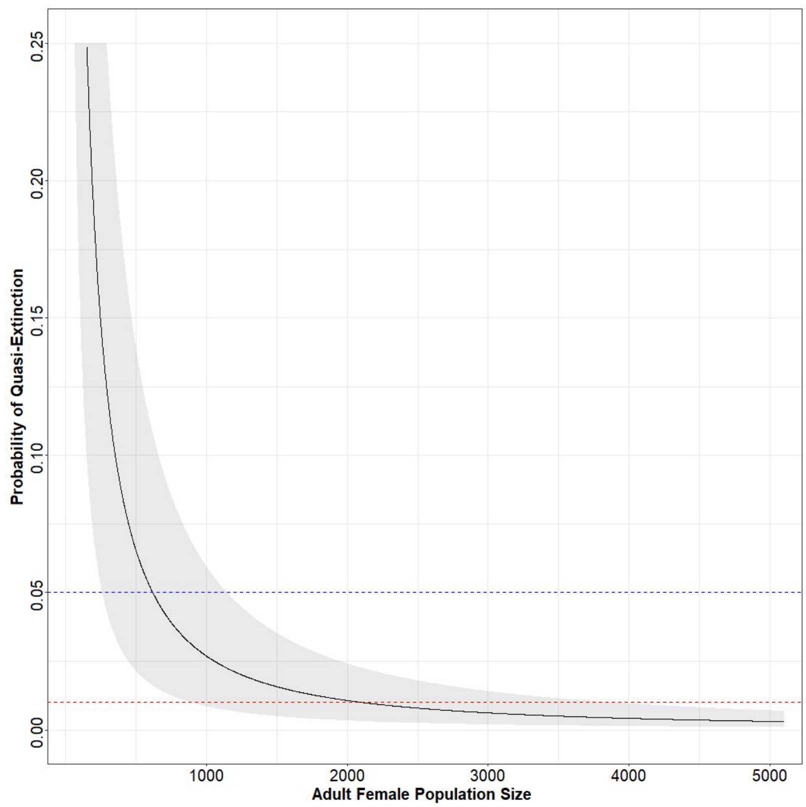

Figure 4. The probability of quasi-extinction within 100 years as a function of adult female population size. The solid black line represents the logistic regression trend with the grey region representing the confidence intervals (for catastrophe rates ranging from 5% to 20% per generation and maximum population growth rate ranging from 1.1 to 1.4). The blue and red horizontal dashed lines represent the 5% and 1% threshold for quasi-extinction respectively.

Minimum Area for Population Viability (MAPV)

The habitat quantity required to support an MVP-sized population of Kidneyshell was estimated using two methods based on either the current densities or the extrapolated densities in a stable population (Figure 5). The current density (based only on the most recent sampling period) of adult females in the quadrat sites on the Ausable River was estimated as 0.072 mussels/m^2 (95% CI: 0.044–0.099) and for the Sydenham River was 0.369 mussels/m^2 (95% CI: 0.291–

0.449). This corresponds to median MAPV estimates of ~260 ha (95% CI: 105–680) for the Ausable River and ~50 ha (95% CI: 22–113) for the Sydenham River.

The extrapolated adult female densities in a stable population (i.e., where the population growth rate is 1.0) was based on the estimate of current population density, population growth rate, and the population projection matrix with the assumed density-dependence relationship. The expected density of adult females in a stable population was 0.17 mussels/m^2 (95% CI: 0.004–3.10) for the Ausable River and 1.71 mussels/m^2 (95% CI: 0.19–24.70) for the Sydenham River. This corresponds to median MAPV estimates of ~108 ha (95% CI: 4.7–5,100) for the Ausable River and ~10 ha (95% CI: 0.62–109) for the Sydenham River.

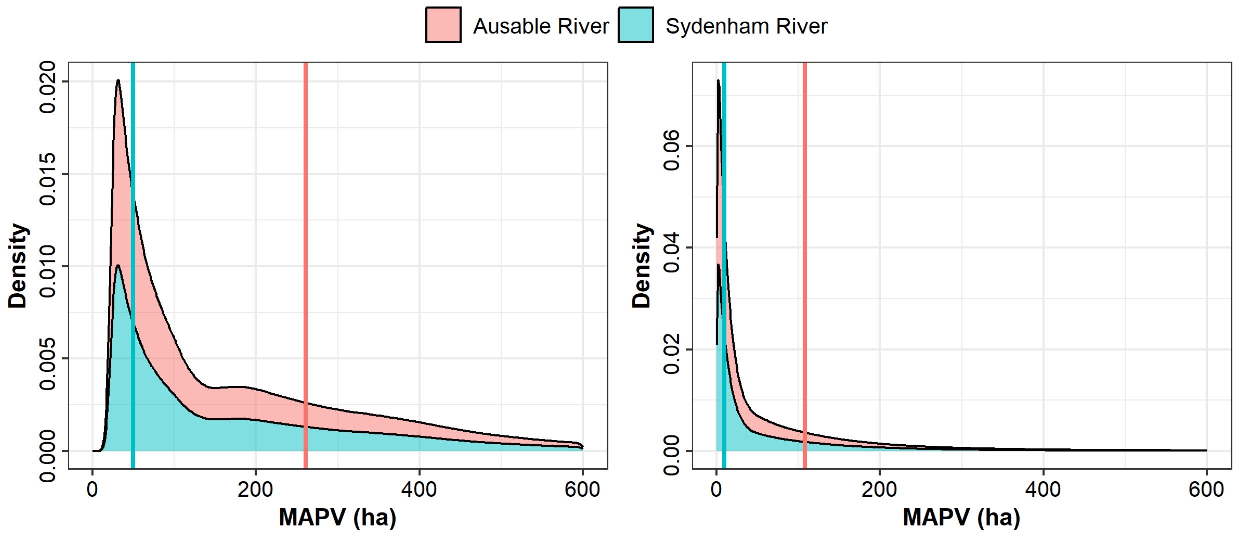

Figure 5. Density plot of the estimated minimum area for population viability (MAPV) for Kidneyshell populations based on current densities (left panel) or expected densities at a stable population growth rate (right panel). The colours represent the population in the Ausable River (red) and Sydenham River (blue). The vertical lines indicate the median estimates.

Population Projections

Projected time for Kidneyshell populations to reach MVP was estimated through model simulations. This was done for the Ausable River only, as the Kidneyshell population in the Sydenham River within the quadrat sites already exceed the estimated MVP. For simulated populations with initial population sizes within the credible range of projected abundances in the quadrat-sampled portion of the Ausable River in 2019 (95% CI: 933–1,360), 87% of the simulated populations reach MVP within 100 years and the median time to reach MVP was 52 years (95% CI: 22–167) if the carrying capacity was the same as the MVP. If the carrying capacity was twice the MVP value, the median time is reduced to 16 years (95% CI: 11–42). This only considers the proportion of the population found within the quadrat sites, assumes there is sufficient habitat among the quadrat sites to support a population of MVP size, and that the habitat through the river is connected and contains a single biological population.

Scenarios for Mitigation of Threats and Alternatives to Activities

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 Kidneyshell habitat. The DFO Program Activity Tracking for Habitat (PATH) database was reviewed to estimate the number of w/u/a that have occurred during the period from November 2013 through August 2023 within the known distribution of Kidneyshell. There was one w/u/a identified within 2 km of live Kidneyshell occurrence records (a bridge replacement on the Ausable River), and 16 w/u/a that occurred within 2 km of occurrence records on smaller tributaries of the Ausable and Sydenham rivers. This is likely not a complete list, as some w/u/a may occur in proximity to (but beyond 2 km of) Kidneyshell records that may also have impacts; and, some w/u/a may not have been reported to DFO if the risk of harmful alteration, disruption, or destruction (HADD) to habitat was unlikely and measures to protect fish and fish habitat were taken. Additionally, there were two (including one above), three, three, and zero projects that occurred within critical habitat on the Ausable, Sydenham, and Thames rivers, and Medway Creek, respectively. Mitigation measures for drain maintenance projects that occurred upstream of Kidneyshell occurrence records included installing erosion and sediment control measures, working in low/no flow periods, and following timing windows. There were no projects authorized under the *Fisheries Act.* Based on the assumption that historical and anticipated development pressures are likely to be similar, it is expected that similar types of w/u/a will likely occur in or near Kidneyshell habitat in the future.

Numerous threats affecting Kidneyshell populations in Canada are related to habitat loss, degradation or fragmentation. Habitat-related threats to Kidneyshell have been linked to the Pathways of Effects developed by the Fish and Fish Habitat Protection Program (FFHPP). DFO FFHPP has developed guidance on mitigation measures for 18 Pathways of Effects for the protection of aquatic species at risk in the Ontario and Prairie Region (formerly part of Central and Arctic Region) (Coker et al. 2010). This guidance should be referred to when considering mitigation and alternative strategies for habitat-related threats.

In addition to the Pathways of Effects guidance, DFO has developed Codes of Practice for common project types in and around water, including for clear span bridges and culvert maintenance, which should be consulted when these activities occur within the habitat of Kidneyshell. Similarly, the Ontario Ministry of Agriculture, Food, and Rural Affairs has a number of Best Management Practices relevant for reducing sedimentation, nutrient loads, and other agricultural pollution sources around aquatic environments, some of which are outlined in DFO (2013). The benefit of intact riparian vegetation buffers to freshwater mussels (including Kidneyshell) was recently evaluated in the Sydenham River, where improved water quality (i.e., decreased ammonia concentrations and increased dissolved oxygen in the surface water) was found at sites with intact buffer zones compared to sites with fragmented buffer zones (Lu 2023). Advice has also been developed by DFO for relocating mussels during instream works (Mackie et al. 2008). This advice is summarized below. Additional mitigation and alternative measures for non-habitat related threats (e.g., invasive species) are also provided.

Mussel Relocation Protocol

Guidance for conducting surveys to detect the presence of SAR mussels, relocating mussels during w/u/a, and conducting post-relocation monitoring is provided in Mackie et al. (2008). This guidance is intended for projects planned in and around water, such as bridge or culvert construction, pipeline crossings, and dredging activities where SAR mussels may be affected. After determining that SAR mussels are present, that a relocation is deemed feasible, and appropriate permits have been obtained, the relocation may begin. See Mackie et al. (2008) for detailed methodology and note that this guidance is being updated.

Mitigations

- Identify a suitable control and relocation site, typically upstream of the w/u/a, that has similar habitat properties (area, water depth, substrate types, water velocity), and biotic structure (fish and mussel communities, absence of AIS);

- Conduct relocation at least one month before water temperature is likely to drop below 16°C (usually mid to late August in Ontario);
- Ensure all juvenile and adult mussels are removed from impacted area;
- Keep mussels moist or in water, avoid overcrowding, and minimize transit time to reduce stress on mussels;
- Aim to replace mussels in the same orientation and in similar substrate as they were found in;
- Conduct follow-up monitoring one month, one year, and two years after the relocation. Monitoring must be conducted when water temperatures are > 16° C to ensure mussels can rebury themselves.

Alternatives

- If project is planned around a mussel bed or near a high-density patch of SAR mussels, consider relocating project downstream or redesigning the project to avoid instream effects.

Aquatic Invasive Species

Several aquatic invasive taxa threaten Kidneyshell directly (through competition/ predation) and indirectly (through habitat modifications, attachment/ biofouling, or impacts to hosts).

Mitigations

- Develop public awareness campaigns and encourage the use of existing invasive species reporting systems (e.g., Ontario Invading Species Awareness Program hotline, EDDMapS).
- Conduct early detection surveillance or monitoring for invasive species that may negatively affect Kidneyshell populations directly, or negatively affect its habitat.
- Develop a response plan to address potential risks, impacts, and proposed actions if monitoring detects the arrival or establishment of an invasive species.

Sources of Uncertainty

- Many of the life history parameters required for the population model were unknown (e.g., age-at-maturity, maximum population growth rate, juvenile survival, etc.). To address these unknowns, a range of potential values were used, based on probability distributions. These uncertainties could impact interpretation of the model results. As one example, modelled Kidneyshell populations are usually most sensitive to harm to the adult stage, but when some of the uncertain parameters were changed (e.g., age of maturity increased) harm to the juvenile stage became more important. This could have consequences for permitting decisions or recovery actions if activities are likely to impact life stages differently.
- The historical abundance and distribution of Kidneyshell in Ontario is poorly understood, making it difficult to identify appropriate abundance and distribution targets. Standardized surveys have only been conducted for the last 25 years (i.e., starting in 1997–98). Patchy and often incomplete historical records prevent identification of an appropriate baseline. There have been numerous events over the last 100 years that have likely resulted in major changes in distribution and abundance (e.g., human settlement/ land clearing, peak industrial pollution in the 1970’s, legislative changes and remediation efforts, urban development), but it is difficult to quantify the impacts of these changes. Furthermore, shell records suggest several populations existed but were extirpated prior to surveys. Without knowledge of when viable populations last existed, understanding why they were extirpated

is speculative, and without knowledge of where live individuals were located, reintroduction planning is challenging. These unknowns cannot be resolved, but caution is warranted when considering extirpated populations and potential reintroductions.

- Estimates of abundance were developed for both extant populations, but represent an estimate of the number of individuals at the quadrat sites only. These estimates likely represent a minimum population size as Kidneyshell is found beyond the quadrat sites. These quadrat sites were chosen to evaluate status and trends through time for several SARA-listed mussels simultaneously, but since they are not randomly distributed, it is uncertain whether density estimates and growth trends are representative of the entire population. In the Sydenham River, there are enough individuals just within the quadrat sites to meet the minimum viable population size threshold; this is not the case for the Ausable River. Similarly, there is sufficient habitat within the Sydenham River quadrat sites to support a viable population, but it is uncertain whether this is true in the Ausable River; these estimates of habitat requirements rely heavily on the density estimate used, and the true density is unknown.
- Alternative interpretations of population status exist for both populations, which can only be resolved with additional data. The population trajectory for the Ausable River was interpreted as being stable out of precaution. The mean population growth rate was positive, indicating it is likely increasing; however, there were fewer sites surveyed compared to the Sydenham River, there was variability in the trends across those sites. For the Sydenham River, the site-specific population growth rates were lower when the partial third sampling period was included compared to when it was left out, which could mean that the population is stabilizing. However, incorporating a different Population Trajectory for either population would not change the overall population status.
- The population modelling assumes that each river represents a biological population, but a more complex population structure is possible. This could impact all of the recovery targets, such as MVP, MAPV, and time to recovery, as well as the probability of persistence for the population.
- There are many unknowns related to Kidneyshell and their interactions with host fishes. Some aspects of host interactions are likely to impact its survival and recovery but are not understood and so cannot be accounted for in the models. For example, uncertainties include how fluctuations (natural stochasticity or anthropogenic harm) in host population dynamics impact Kidneyshell, or how threats (direct or indirect) to hosts impact Kidneyshell.
- There is a generally poor understanding of the mechanism of impact of most threats on freshwater taxa, and even greater uncertainty in the extent or magnitude of threat impacts. Most importantly, data are lacking to relate habitat changes and other threat impacts to changes in vital rates. Fully incorporating environmental effects into the population model to analyze threat impacts or potential mitigation measures will require more information on the relationship between those factors and Kidneyshell vital rates.
- Both extant Kidneyshell populations in Ontario are facing multiple threats simultaneously, but how these threat effects interact to impact Kidneyshell (or its host fishes) is unknown. The existing threat assessment framework considers threats individually, and only assesses impacts at the population level. This likely under-represents the true threat landscape that the species is facing, and was among the greatest uncertainty and concern identified.

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