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# Information in Support of a Recovery Potential Assessment for Kidneyshell (*Ptychobranchus fasciolaris*)

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**Foreword**

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

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## ABSTRACT

Kidneyshell (*Ptychobranchus fasciolaris*, Rafinesque 1820) was first assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2003 as Endangered. The status was re-assessed and confirmed in 2013, owing to large declines in the historical range and declines in abundance at extant localities related to invasive dreissenid mussels and habitat degradation from agricultural land use practices. The species was listed under the *Species at Risk Act* (SARA) in 2005. The Recovery Potential Assessment provides background information and scientific advice needed to fulfill various requirements of the *Species at Risk Act* (SARA). This research document provides the current state of knowledge on the species including its biology, distribution, population trends, habitat requirements, and threats. Kidneyshell is a medium-sized, relatively long-lived, bradytictic species thought to use several darter species (*Etheostoma* spp., *Percina* spp.) as hosts. Historically, it was known from 10 localities in Canada, but is currently confirmed in two, the Ausable and Sydenham rivers. Kidneyshell occupies small- to medium-sized rivers and occasionally shallow lake environments with wave action over sand and gravel substrates. Many threats related to habitat loss and modification, and impacts from invasive dreissenid mussels are thought to be responsible for the extirpation of this species from much of its historical range. Persistent threats related to agricultural and urban sources of pollution, aquatic invasive species, and impacts from climate change are likely negatively impacting Kidneyshell currently; however, the impacts appear to be low at the population level. Important knowledge gaps remain surrounding the historical and current abundance and distribution in Ontario, many aspects of its reproductive biology including timing of spawning and glochidial release, habitat preferences by life stage, mussel-host interactions, physiological tolerances to environmental conditions, and the magnitude of impact and spatial extent of threats.

# INTRODUCTION

Kidneyshell (*Ptychobranchus fasciolaris*, Rafinesque 1820) is a medium-sized freshwater mussel (Unionidae) found in riffle and run habitats in rivers or embayments of lakes with wave action in sand and gravel substrates in the Ohio River and lower Great Lakes basins. Kidneyshell was assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2003 as Endangered, owing to the fact that it "has been lost from about 70% of its historical range in Canada due to impacts of Zebra Mussel (*Dreissena polymorpha*) and land use practices. Agricultural impacts, including siltation, have eliminated populations in the Grand and Thames rivers and threaten the continued existence of this species in Canada." The species was listed under Schedule 1 of the *Species at Risk Act* (SARA) in 2005. Kidneyshell was reassessed and the status confirmed in 2013, because "the population in Lake St. Clair is close to extirpation. Both Ausable and East Sydenham river populations appear to be reproducing, but populations in Medway Creek and Lake St. Clair are not reproducing. Populations are threatened by pollution from agriculture, urban and road runoff sources, and invasive species (dreissenids and Round Goby [*Neogobius melanostomus*])". A joint Recovery Strategy for Kidneyshell and Round Hickorynut (*Obovaria subrotunda*) was completed in 2006 and an amended Recovery Strategy was posted in 2013 (DFO 2013). A Critical Habitat Order was enacted in 2019 protecting habitat in the Ausable River, East Sydenham River, and lower Thames River and Medway Creek (DFO 2019).

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 fulfill requirements of SARA, including the development of recovery strategies 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. Although Kidneyshell is already listed under SARA, an RPA was requested to inform the development of an updated recovery strategy and action plan, and to support decision making with regards to issuance of permits. This document summarizes information about the biology, distribution, population parameters, habitat, and threats and applicable mitigation measures to support the RPA process for Kidneyshell. This research document accompanies a recovery potential modeling research document (Fung et al. 2025) and together these address the 22 elements outlined in the RPA process (DFO 2007, DFO unpublished).

# BIOLOGY, ABUNDANCE AND DISTRIBUTION

***Element 1:*** *Summarize the biology of Kidneyshell*

## DESCRIPTION

Kidneyshell is a medium-sized freshwater mussel (Unionidae) in the Lampsilini tribe. It has 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 and older individuals may develop a hump towards the posterior end. The periostracum can range from yellow to yellow-brown to brown, and has broad, interrupted green rays that resemble green squares. The green rays often fade on older individuals. The beak sculpture is not developed, but may have a few "indistinct wavy ridges" (Ortmann 1919). The nacre is typically white, but may be pinkish in younger individuals. The beak cavity is shallow, and females may have a groove from the beak cavity towards the ventral edge on the posterior side for marsupia. Additionally, males may be slightly more compressed than females but this is not reliable for distinguishing between the sexes (Ortmann 1919); otherwise, it is not strongly sexually dimorphic. Hinge teeth are complete. The pseudocardinal teeth are thick and triangular (two in the left valve, one in the right). The lateral teeth are short, thick, and can be serrated (COSEWIC 2003, Metcalfe-Smith et al. 2005). Adults can reach approximately 125–150 mm in length (Metcalfe-Smith et al. 2005, INHS 2023). Kidneyshell could be confused with Spike (*Eurynia dilatata*), Mucket (*Ortmanniana ligamentina*), and Rainbow (*Cambarunio iris*) (INHS 2023), with which it co-occurs in Ontario. Spike has thinner green rays that are not interrupted, beak sculpturing of three or four single loops (if visible) and is usually purple inside. Mucket has a slightly more oblong shell shape with beak sculpture slightly higher than the hinge line. Rainbow has a smaller adult size, has more prominent beak sculpturing (double looped after first ring), and a lure that resembles a crayfish.

## BIOLOGY AND LIFE CYCLE

Kidneyshell reproduction, like all unionids, starts with males releasing sperm (often many packaged into a ball) that is filtered in through the incurrent siphon of nearby females. Kidneyshell is a dioecious species, although hermaphrodism has been reported occasionally (van der Schalie 1970). Spawning occurs in August across much of its range, with glochidia being released the following spring through early summer (Ortmann 1919), making Kidneyshell bradytictic (long-term brooder). Between 2012–2014, a reproductive study was undertaken by DFO at two sites, one in the Sydenham River and one in the Ausable River. Weekly sampling of Kidneyshell at each of these sites found the highest proportion of females with eggs and males with sperm from late June to mid-August (mean water temperature 25.17 °C, range: 22.4–27.2 °C), suggesting that this is the main spawning period in Ontario. Males with sperm were also observed in August and early October; however, the amount of sperm present was low compared to the main spawning event (Figure 1 shows the results of the Sydenham River site; DFO unpublished data). Gravid females containing conglutinates were observed from August through January and none were observed in May to July (sampling was not possible February through April). Gordon and Layzer (1989) noted that gravid females have been reported in all months except July across its American range. The male to female sex ratios were 1.3:1 and 1.8:1 in the Ausable and Sydenham rivers, respectively (DFO unpublished data). Eggs are fertilized and glochidia develop in the entirety of the outer gills (marsupia) (Haag 2012). In the Sydenham River, female Kidneyshell had a mean of 88,641 (range: 18,750–184,375; n = 3) glochidia (McNichols 2007). The glochidia lack hooks, suggesting they are exclusively gill parasites and not able to attach to fins or other external body parts. Glochidia from southwestern Ontario had a mean shell length of 176.10 (± 14.38 SD) μm, mean shell height of 201.39 (± 17.12 SD) μm, and mean hinge length of 87.30 (± 7.60 SD) μm (Tremblay et al. 2015).

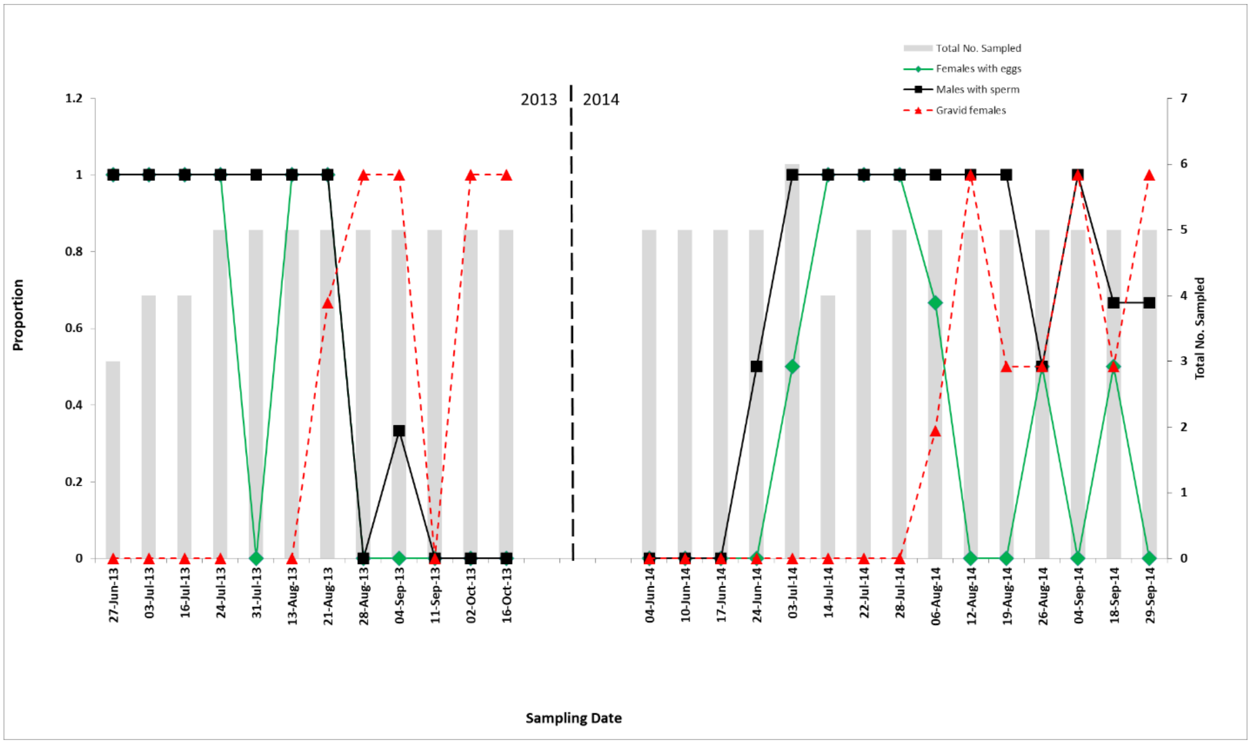


*Figure 1. Proportion of male and female Kidneyshell (*Ptychobranchus fasciolaris*) that contained sperm, eggs, and conglutinates in the Sydenham River in 2013 and 2014. The total numbers of Kidneyshell sampled are represented by the grey bars (DFO unpublished data).*

Like all unionids, Kidneyshell glochidia must encyst on a vertebrate host to complete development. Once the glochidia are mature, they are packaged as conglutinates to appeal to a host fish. All members of the *Ptychobranchus* genus produce prey-mimicking conglutinates consisting of glochidia encased in layers of acellular membrane, with an adhesive end that can anchor to the substrate when released, and pigmentation that resembles eyespots and lateral lines. This pigmentation is associated with weak spots in the membrane that will rupture on contact from the host (Haag 2012). The degree of detail in the appearance of conglutinates varies slightly by population and possibly by size of the female (Watters 1999, Haag 2012). Watters (1999) described female Kidneyshell in Ohio as having a “major” and “minor” type of conglutinate; these may appear simultaneously within a population but an individual female will display only one of the two in a given year; the minor type was more commonly associated with smaller females. Both conglutinate types had 2–5 “eyespots”, with pigmented lines extending out. The major type was typically 7–10 mm in length and had additional lines with the appearance of myomeres, resembling fish fry. The minor type, typically 4–6 mm in length, had a red disc around the “head” and resembled insect larvae (chironomid or simuliid). Most of the conglutinates observed in Ontario appear similar to the “minor” type described by Watters (1999) with the red disc (DFO unpublished data). There were approximately 150–500 glochidia per conglutinate (Watters 1999, McNichols 2007). In a lab setting, the adhesive end attached to a variety of substrate types (e.g., glass, wood, rock, metal) and remained adhesive even after multiple reattachments (Watters 1999). Although conglutinates easily rupture when pressed (especially weak at the eyespots), they remained intact under flowing conditions, and Watters (1999) noted that water current added to the mimicry of prey items (resembling movement).

Female Kidneyshell collected in April from Little Darby Creek, Ohio, released approximately twelve conglutinates daily (day and night) for a period of one month in a laboratory setting (water temperature of 17 °C; Watters 1999). The absence of gravid females in May from the Ausable and Sydenham rivers suggests that conglutinates are likely released in late April in Ontario as well; however, drift nets set weekly in the Ausable (July 2012 through February 2014) and Sydenham rivers (July 2013 through June 2014) found Kidneyshell glochidia in the water column from late June through late October with the greatest abundances throughout September (DFO unpublished data). Smodis (2021) found that Kidneyshell glochidia were released nocturnally in the Sydenham River, with the greatest abundances detected at 22:00–4:00 am local solar time. In this study, glochidia were sampled from late August through end of September, and the abundance of Kidneyshell glochidia was variable but generally declined over this period (Smodis 2021).

Host fishes are attracted to the prey-mimicking conglutinates of Kidneyshell, which will rupture when bitten and release glochidia that can then encyst in the host's gill tissue. Hosts for Kidneyshell have been reported to be darters, sculpins and a stickleback (White 1996, Watters 1999, Watters et al. 2005, McNichols 2007). In a laboratory study on specimens from the Sydenham River, McNichols (2007) found successful metamorphosis of Kidneyshell glochidia on: Blackside Darter (*Percina maculata*), Fantail Darter (*Etheostoma flabellare*), Johnny Darter (*E. nigrum*), Iowa Darter (*E. exile*), and Brook Stickleback (*Culaea inconstans*) out of a total of 12 species (representing four families) of fishes tested. Blackside Darter produced the most juveniles per host fish tested (51 ± 50 SE), followed by Johnny Darter (29 ± 21 SE), suggesting these species are primary hosts. A reproductive study conducted in the Ausable and Sydenham rivers in 2012–2014 found presumed[1] Kidneyshell glochidia on Blackside Darter, Johnny Darter, and Logperch (*P. caprodes*) in the Ausable River and Blackside Darter, Johnny Darter, Logperch, and Greenside Darter (*E. blennioides*) in the Sydenham River. Logperch had the highest infestation rates of Kidneyshell glochidia per fish in both rivers, followed by Blackside Darter in the Ausable River and Johnny Darter in the Sydenham River. The greatest number of individuals with Kidneyshell glochidia attached were Blackside Darter in the Ausable River, and Logperch in the Sydenham River (DFO unpublished data).

Encysted glochidia feed on the host's tissue and undergo metamorphosis, developing their internal organs; there is typically little change in size over this time. The length of this process depends on mussel species, host species, and water temperature. In a lab test, the duration of Kidneyshell glochidial metamorphosis ranged from 22–29 days across all host fishes tested (McNichols 2007). Glochidia collected from wild-caught females from the Sydenham River transformed on Blackside Darter and Johnny Darter from the Grand River after 25–35 days in the laboratory (Van Tassel et al. 2021). The success of metamorphosis also depends on the availability of host fishes at the time of glochidia release that are of sufficient quality and have not developed immunity.

Once transformation is complete, the juveniles will drop off of the host fish and settle into the substrate. Large-scale dispersals happen through transport on the host, and juveniles have limited ability to select suitable habitats for settling; however, they appear able to use their foot (and possibly valve movements) to reduce settling velocity and perhaps aid in site selection. The smaller body size of Kidneyshell juveniles compared to other unionids tested also reduced the settling velocity (Schwalb and Ackerman 2011). Juveniles will burrow in the sediment and typically remain buried for the first few years of life, and will emerge once maturity is reached. Age of maturity is unknown for Kidneyshell, but is estimated to be 3–5 years (or earliest maturity

[1] It should be noted that the glochidia were identified using the discriminant function analysis in Tremblay et al. (2015), which was less reliable for Kidneyshell compared to other species.

at approximately 48 mm) (Fung et al. 2025). The maximum age and length were predicted to be 32 years and 157.4 mm based on observed ages and the Von Bertalanffy Growth Function calculated from Licking River, Kentucky specimens, respectively (Haag and Rypel 2011). A total of 99 spent Kidneyshell shells from the Ausable River, Ontario were assessed (DFO unpublished data). Ages were assessed from 1–33 years (mean: 11.2 years), and lengths ranged 27.7–121.1 mm (mean: 81.7 mm) (Figure 2). The largest specimen recorded in Ontario was 125 mm from the Sydenham River. The length-frequency distributions from all specimens collected in the Ausable and Sydenham rivers are presented in Figure 3 (LGLUD unpublished data). McNichols (2007) recaptured 16 Kidneyshell that had previously been marked at three sites on the Sydenham River and found that adults grew a mean of 0.25 (± 0.05 SE) cm per year (mean initial shell length was 8.43 ± 0.47 cm), and growth was not significantly different between individuals. Kidneyshell growth was significantly slower than the growth of Northern Riffleshell (*Epioblasma rangiana*), Snuffbox (*E. triquetra*), or Rayed Bean (*Paetulunio fabalis*) that were marked and recaptured at the same time. Ortmann (1919) noted that Kidneyshell from Lake Erie tended to reach a smaller size and have tighter growth rings compared to Ohio River drainage specimens; this could be indicative of slower growth in a less ideal lake habitat.


*Figure 2. Length-at-age of Kidneyshell (n = 99) collected from the Ausable River, ON. Ages estimated by two readers (DFO unpublished data).*

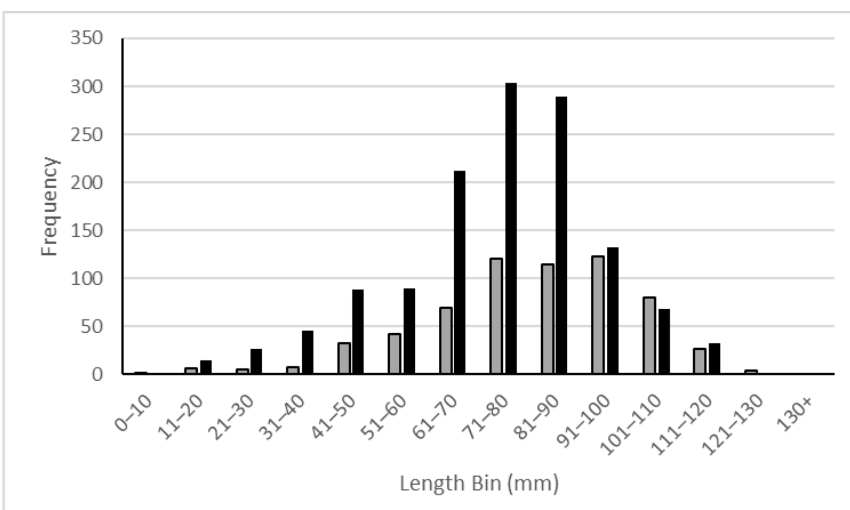


*Figure 3. Length frequency distribution of Kidneyshell collected during all surveys in the Ausable (gray) and Sydenham (black) rivers from 1997–2022.*

## DIET

Adult unionid mussels feed on bacteria, algae, organic detritus, and protozoans through suspension feeding. There is limited species-specific diet information available but there is some evidence to suggest different species may select different sized particles for feeding, which may reduce interspecific competition in diverse mussel beds (Tran and Ackerman 2019). Juveniles are thought to feed on organic material available in interstitial pore water through pedal feeding (Gatenby et al. 1997). Mussels in the glochidia stage feed on tissue fluids from their host fishes. Stable isotope analysis of the diet of Kidneyshell in Big Darby Creek, Ohio, suggested that the species is primarily a detritivore, consuming a low-protein diet of bacteria and/or microeukaryotes; this likely varies slightly seasonally, depending on availability of nutrients from fine particulate organic matter (Christian et al. 2004).

## POPULATION GENETICS

Population genetics of Kidneyshell were evaluated in the Ausable and Sydenham rivers using nine microsatellite loci. Other imperiled and common mussels were also evaluated (Galbraith et al. 2015). Evidence of population structuring was found at the river scale for all species; however, Kidneyshell displayed lower divergence among rivers compared to other species, despite using less mobile, small-bodied host fishes. Kidneyshell also displayed lower allelic richness, on average, compared to most other species. There was no evidence of population sub-structure (suggesting good historical connectivity within a waterbody or on-going gene flow) or of major population declines (e.g., bottleneck event) for any species. Understanding how population genetic structure of Canadian Kidneyshell populations compares to those across its American range would be useful. To help inform potential conservation translocation efforts for Kidneyshell, Van Tassel et al. (2021) evaluated the genetic diversity of first generation captive-reared individuals compared to wild caught ones. They found that genetic diversity was maintained with as few as seven females (and an unknown number of males) contributing to the brood, suggesting captive-rearing may be appropriate for conservation translocations.

## SPECIAL SIGNIFICANCE

Freshwater mussels historically make up a large proportion of benthic biomass in rivers and streams in North America, filtering large volumes of water. This improves water clarity, and cycles nutrients through the water column (Vaughn et al. 2004, Atkinson et al. 2014). The contribution of ecosystem services provided by mussels varies, depending on their density, species composition, the life history strategies of the species present, and on environmental factors (Vaugh et al. 2004 and 2008, Haag 2012). Mussel burrowing oxygenates the substrate, and their feeding activity cycles nutrients between the water and sediment making them available for other benthic invertebrates (Vaughn and Hakenkamp 2001, Vaughn et al. 2004, Howard and Cuffey 2006). Dense beds of burrowed mussels can increase the stability of the substrate under higher flows (Zimmerman and de Szalay 2007). Mussels may also be a food source to many fishes, as well as avian and terrestrial predators allowing energy to be transferred outside of the aquatic environment (Neves and Odom 1989). Spent shells can provide habitat structure for other benthic invertebrates and fishes, and these organisms may associate with living mussels for food supply as well (Beckett et al. 1996, Gutierrez et al. 2003, Spooner and Vaughn 2006, Eveleens et al. 2023). Members of the genus *Ptychobranchus* are considered sensitive species, and their presence is often associated with higher quality habitats (Haag 2012).

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

## ABUNDANCE

Kidneyshell has been reported to be rare to locally abundant. Christian et al. (2004) noted that Kidneyshell and Spike were “numerically dominant” at sites in Big Darby Creek, Ohio. COSEWIC (2003) summarizes the frequency of occurrence and percent composition of Kidneyshell in mussel surveys across several states and watersheds where it occurs in the U.S.A. The frequency of occurrence ranged from 4% of sites sampled in Duck River, Tennessee to 40% of sites surveyed in Paint Rock River, Alabama, and it represented a maximum of 8% of the total mussel community across all sites sampled in the Clinton River, Michigan (range of 1–30% relative abundance per site). Grabarkiewicz (2012) calculated the mean density of Kidneyshell in the Blanchard River (tributary of Lake Erie); estimates ranged from 0.18 (90% CI: 0.12–0.29) mussels/$m^2$ to 0.30 (CI: 0.20–0.43) mussels/$m^2$ in the middle reaches; and 0.13 (CI: 0.10–0.18) mussels/$m^2$ to 0.14 (CI: 0.07–0.026) mussels/$m^2$, in the upper reaches; sites were randomly selected within each reach. Habitat suitability models for imperiled unionids in Michigan rivers suggested that approximately 3.1% of statewide stream habitat was suitable for Kidneyshell (range:1.1–13.6% across all species), with only 0.3% being highly suitable (0.1–1.8% across all species) (Daniel et al. 2018).

Coarse estimates of Kidneyshell abundance exist for the Ausable and Sydenham rivers. COSEWIC (2003) estimated the abundance of Kidneyshell in the Ausable River as approximately 10,000–20,000 individuals, and in the Sydenham River as approximately 30,000–50,000, by multiplying the average density (0.1225 mussels/$m^2$) in suitable riffle/run habitat by the area of occupancy, assuming only 10–20% of that area contains suitable habitat.

Using quadrat survey data from the Ausable and Sydenham rivers spanning three time periods, Fung et al. (2025) projected quadrat site-specific abundances using a hierarchical Bayesian approach. The projected abundances at the quadrat sites were then pooled, resulting in estimates of 1,129 (95% CI: 933 – 1,360) for the Ausable River and 6,949 (CI: 5,371 – 9,059) for the Sydenham River; these estimates can be interpreted as a minimum population size in each river, as many areas beyond the quadrat sites are also occupied but data are lacking to project beyond. In the absence of total population size estimates, density estimates and estimated occupied area (based on occurrence records of live individuals from 2012–2022 in continuous segments of the Ontario Hydro Network data layers) are presented for the Ausable and Sydenham rivers (Table 1).

*Table 1. Catch per unit effort (CPUE) calculated from quadrat surveys, and approximate area occupied based on occurrence records from 2013-2022 in continuous segments of the Ontario Hydro Network (OHN). Mean and median density and population growth rate are reported from Fung et al. (2025) with 95% credible intervals (CI). Growth rates represent annual growth, with 1 meaning a population in steady state.*

| Locality | Approximate occupied river length (km) | Mean Density (live/m$^2$) | Abundance pooled at quadrat sites (95% CI) | Population Growth Rate (95% CI) |
|---|---|---|---|---|
| Ausable River | 57 km (+3 km of Little Ausable River)<br>(area: 110 ha) | 0.450 | 1,129<br>(933 – 1,360) | 1.069<br>(1.02–1.126) |
| Sydenham River | 92 km<br>(area: 241.4 ha) | 0.417 | 6,949<br>(5,371 – 9,059) | 1.13<br>(1.11–1.15) |

## DISTRIBUTION

Kidneyshell is found in eastern North America primarily in the Ohio River drainage basin and lower Great Lakes basin. Its distribution is widespread but sporadic. It is known from Alabama (S2; Imperiled), Georgia (S1; Critically Imperiled), Illinois (S1), Indiana (S2), Kentucky (S4; Apparently Secure), Michigan (S2), Mississippi (S1), New York (S2), Ohio (S3; Vulnerable), Pennsylvania (S4), Virginia (S4), West Virginia (S3), and Tennessee (S4), and is thought to be extirpated in North Carolina (NatureServe 2023). It is considered Near Threatened globally as it appears to be decreasing in many of its historically occupied localities (Bogan and Woolnough 2017).

In Canada, Kidneyshell is found only in southwestern Ontario (S1). Historically, it was found in the Ausable River, Lake St. Clair, Sydenham River, Thames River (and Medway Creek), Detroit River, Lake Erie, Grand River, and the Niagara and Welland rivers. Although many issues related to urban and industrial pollution likely contributed to the decline of Kidneyshell in the Great Lakes and connecting channels, the invasion of Zebra Mussel is thought to be the cause of their ultimate extirpation from the St. Clair River, Lake St. Clair, the Detroit River, Lake Erie, and the Niagara River. A combination of intensive agricultural land use with some urban and industrial development and large dams likely resulted in the extirpation of the species from the Grand and Thames rivers. Kidneyshell is currently confirmed in the Ausable and Sydenham rivers. It was recently known from Lake St. Clair (St. Clair River Delta), and Medway Creek (tributary of the Thames River) but recent records of live individuals are limited and reproduction is not thought to be possible (Figure 4).

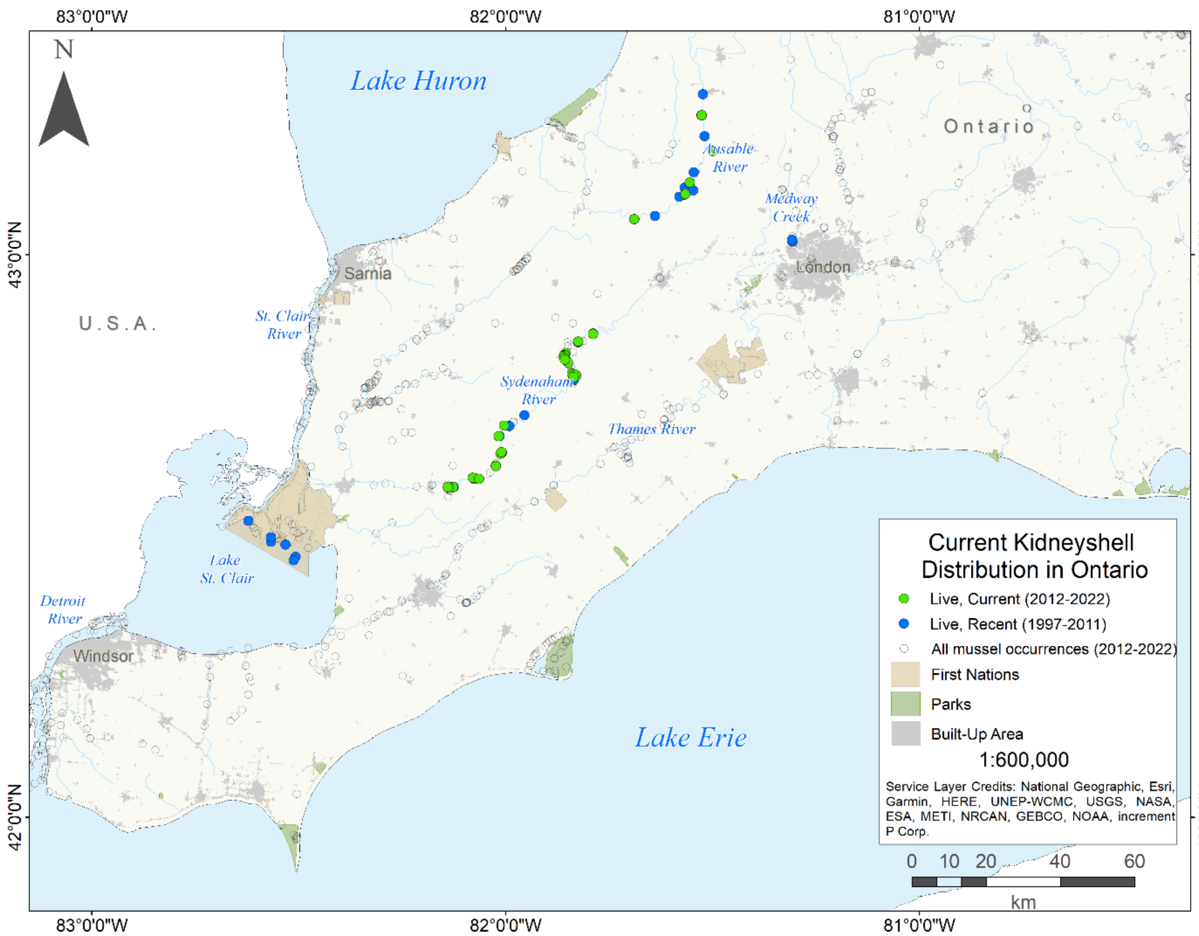


*Figure 4. Recent (1997–2011; blue) and current (2012–2022; green) distribution of Kidneyshell in Canada. Empty circles depict all mussel occurrences from 2012–2022, including from formal surveys and incidental captures.*

## Current Status

Sampling efforts for Kidneyshell in Canada include a combination of timed-search surveys and standardized quadrat (Unionid Monitoring and Biodiversity Observation [UMBO] network) surveys. Timed-search surveys are generally used for broadly understanding species distributions. They use a combination of visual and tactile methods (e.g., viewers, racooning, snorkeling), which can cover a large area relatively quickly making them effective for detecting rare species, but tend to bias towards larger individuals. UMBO quadrat surveys are designed for evaluating trends through time and population demographics. Quadrat surveys are typically conducted by a stratified random design with 20% coverage. Generally, the survey methodology takes a 400 $m^2$ site divided into 15 $m^2$ blocks whereby three 1 $m^2$ quadrats are excavated to 15 cm below the substrate surface within each block. Juveniles are better represented in quadrat samples as they tend to burrow more deeply than adults and may not be visible on the surface during timed-search efforts. Reid and Morris (2017) intensively sampled one site on the Sydenham River and found that 98.8% of live individuals were found during excavations, compared to 1.2% detected visually on the surface. Both methods contribute different information towards understanding population parameters.

A summary of recent (1997–2022) Kidneyshell records is found in Appendix 1 (Table A1.1 for timed search and Table A1.2 for quadrat surveys); these tables include all recent sampling where the species was historically known. Historical records (i.e., before 1997) are also summarized in Appendix 1 (Table A1.3); these often have incomplete sampling information and details of specimen condition at the time of collection or even numbers collected were sometimes unavailable. Note that sampling events prior to 1997 described below may also include incidental observations.

### Ausable River

Kidneyshell was first reported live in the Ausable River in 1994, where six individuals were found at two sites (Morris and Di Maio 1998). Twenty-seven live individuals (+17 fresh shells and/or valves, and eight weathered shells and/or valves) were found during timed-search surveys (four sites with 4.5 p-h and one site with 0.75 p-h) in 1998 (Metcalfe-Smith et al. 1999). In 2002, 32 live individuals were collected at four sites (4.5 p-h each). In 2004, four individuals (+ one weathered valve) were collected at three sites (4.5 p-h each). Eighty-eight individuals were collected in 2008 (four sites). One individual was observed in 2010 (no details available). As part of a behavioural study, 265 individuals were collected in 2012. An additional 73 individuals in 2013, and four in 2014, and two weathered valves in 2016, were also found during timed-search surveys. In 2019, 12 live individuals were observed and genetic samples taken. Quadrat surveys yielded 138 individuals in 2006 (506 $m^2$ surveyed), four individuals in 2008 (199 $m^2$), 102 individuals in 2011 (534 $m^2$), 37 individuals in 2018 (226 $m^2$), and 229 individuals in 2019 (229 $m^2$). Quadrat surveys were also conducted in 2007 (66 $m^2$), 2009 (146 $m^2$), 2013 (75 $m^2$), and 2022 (75 $m^2$), but no Kidneyshell were detected (Ausable Bayfield Conservation Authority [ABCA] and DFO unpublished data). Brail sampling was conducted in the lower Ausable River in the summer of 2022 at 23 sites from Kennedy Line to the mouth at Port Franks (i.e., downstream of the known Kidneyshell distribution), and did not detect any Kidneyshell (LeBaron et al. 2023). The historical distribution of Kidneyshell is approximately 70 km in the main stem of the Ausable River from Crediton to Springbank, and, based on current distribution records (2012–2022), is approximately 57 km (plus three km in the lower Little Ausable River).

Additionally, one live Kidneyshell was found in 2010 in Nairn Creek near where it enters the Ausable River following 15 person-hours of tactile searching (University of Guelph, Ackerman Lab, unpublished data). A live individual was found in the Little Ausable River in 2018 during quadrat surveys (ABCA unpublished data).

### St. Clair River

Although not reported from the Canadian side of the St. Clair River, Kidneyshell shells have been observed on the American side of the river during dive surveys. Six weathered shells were observed in 2021 at three sites near Recors Point and Algonac State Park (Keretz 2022).

### Lake St. Clair

Kidneyshell shells were first reported in Lake St. Clair in 1934. Approximately 48 sampling events occurred in Lake St. Clair from 1928–1990, yielding only shells. Gillis and Mackie (1994) surveyed sites near the mouth of Puce River in 1990 and reported a density of 0.01 Kidneyshell/$m^2$. The most recent live records were from 1999 when six live individuals were recorded at five sites near the Delta (Zanatta et al. 2002), one specimen from 2001 (on the American side), and two more individuals (one on the American side) were found in 2003 using stake and rope surveys (Metcalfe-Smith et al. 2004). Approximately 33 sites were surveyed from 2004–2021, including at the sites where live individuals were observed in 1999–2003, but no evidence of Kidneyshell (live or shells) was found. Historically, specimens and shells were found in the St. Clair River Delta, along the east shore to Mitchell’s Bay, and near the mouth of the Puce River towards the inlet at the Detroit River. This population is presumed to be extirpated.

### Sydenham River

Live Kidneyshell were reported in the East Sydenham River in 1963 (n = 1), 1965 (n = 2), 1967 (n = 13), 1971 (n = 3), 1973 (n = 5 + 5 fresh shells), and 1991 (n = 14; Clarke 1992). Shells were also reported in 1985 and 1992 in unknown condition. From 1997 (when more standardized sampling efforts began) to 2022, a total of 1,036 live Kidneyshell (+116 fresh shells and valves and 10 weathered shells and valves) were collected across 240 sites with at least 1304 person-hours of timed-search efforts. Quadrat surveys in the Sydenham River yielded 20 Kidneyshell in 1999 (147 $m^2$), 17 in 2001 (156 $m^2$), 23 in 2002 (306 $m^2$), 11 in 2003 (312 $m^2$), 243 in 2012 (591 $m^2$) 139 in 2013 (300 $m^2$), 216 in 2015 (150 $m^2$), 13 in 2017 (50 $m^2$), six in 2020 (50 $m^2$), 19 in 2021 (50 $m^2$), and 218 in 2022 (300 $m^2$). In 2022, brail sampling was conducted at 37 sites in the Sydenham River from Dawn Mills to Wallaceburg (East Sydenham River) and from Wilkesport to Wallaceburg (North Sydenham River), which yielded one live Kidneyshell downstream of Dawn Mills (LeBaron et al. 2023). 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, following 4.5 p-h of timed search effort. Standardized quadrat surveys have been undertaken there in 2001–03, 2012–13, 2015, and 2022 but no other specimens have been found.

### Thames River

Live Kidneyshell have not been detected in the main branches of the Thames River. Historical shell records exist from 1894 and 1933, and more recently, one fresh shell (at one of 30 sites sampled) was found in 1995 (Morris 1996), and two fresh shells and four weathered shells (at four of 16 sites sampled) were found in 1997 (Metcalfe-Smith et al. 1998) and one weathered shell in 1998; all of these shells were reported near Chatham. Two shells were found downstream of Big Bend in 2005 (Morris and Edwards 2007), a fresh and a weathered shell were found near Tait's Corner in 2011, and a weathered valve was found near Thamesville in 2021 (Goguen et al. 2023), and another in 2022. Approximately 173 sites were sampled using visual/tactile timed-search surveys from 1984 to 2022 but no live individuals or other shells were found. Additionally, quadrat surveys were completed in 2004 (66 $m^2$), 2005 (69 $m^2$), 2010 (270 $m^2$), 2015 (150 $m^2$), 2016 (150 $m^2$), and 2017 (150 $m^2$). Brail sampling at 34 sites in the lower Thames River (Thamesville to the confluence with Jeannette's Creek) in the summer of 2022 did not detect Kidneyshell (LeBaron et al. 2023).

In 2017, a weathered valve was found in the South Thames River approximately 12 km upstream of the Forks in London.

Two live individuals (old adults) were found in Medway Creek (a tributary of the North Thames River) in 2004. Two more individuals, believed to be different based on photo vouchers, were found in 2006 (and confirmed to still be there in 2007 and 2008) during mussel relocations for a housing development project. All four individuals were large and senescent. Thirteen sites were sampled prior to the 2004 record, and 25 sites were sampled from 2010–2021 using visual/tactile survey methods, but no other live individuals or shells were found. Standardized quadrat surveys have not been undertaken in Medway Creek. There has been limited recent sampling in Medway Creek, but the habitat conditions are no longer thought to be consistent with suitable Kidneyshell habitat and the species is likely extirpated from this locality.

### Detroit River

Many mussel surveys undertaken in the Detroit River occurred across the Canadian and U.S.A sides of the river; combined survey efforts are reported with specimens from Canada reported where possible. Kidneyshell was first collected in the Detroit River in 1982, when 16 live individuals (+ nine fresh valves) were collected (one live and one fresh shell from the Canadian side). Diver surveys in 1983 and 1984 yielded 17 live individuals (+30 weathered valves) at 13 sites with 11.2 p-h of dive time, and six individuals (+27 weathered valves) at 11 sites with 10.9 p-h of dive time (one live and eight weathered valves from the Canadian side). In 1992, 63 individuals were collected (+70 fresh valves) from 16 sites surveyed (40 fresh shells from the Canadian side). In 1994, one individual was collected (+54 fresh valves) from nine sites surveyed (none on the Canadian side). The last live Kidneyshell was observed in the Detroit River in 1998 at the top of Belle Isle, U.S.A.. Extensive diving surveys were conducted in the Detroit River in 2019 to search for live unionids at 56 sites (17 historically occupied, 27 randomly selected, 10 potential refuge sites, and two additional selected sites); no live Kidneyshell were found but 121 weathered shells were collected (43 from the Canadian side) (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

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). The condition or state of these specimens at the time of collection is not known. A weathered shell was found at each of four sites during snorkeling efforts (totaling 6.0 person-hours) in 2005. Sampling also occurred in 2001, 2004, 2006, 2013, 2014, and 2021 but no additional Kidneyshell (live or shells) were found. A record of Kidneyshell exists from Long Point Inner Bay in 1963, but the condition of the specimen at the time of collection is unknown. Weathered shells or valves were found in Rondeau Bay in 2001 (LGLUD unpublished data) and 2014 (n = 12); additional sampling in 2015 did not result in more shells (Reid et al. 2016). Overall in Lake Erie, the species has been detected sporadically along the north shore of the lake, including around the outlet of the Detroit River, near the mouth of Cedar Creek, in Rondeau Bay, Long Point Bay, and between the mouth of the Grand River and the Niagara River. These likely represented multiple subpopulations when extant.

### Grand River

Historical accounts of Kidneyshell exist sporadically from 1934–1966; however, these were not formal surveys and few details are available including the status of the specimens (i.e., live vs. shells). Historical surveys were conducted by Kidd (1973) who reported Kidneyshell shells in 1972, and a follow up survey revisiting those sites in 1995, 1997–1998 also found shells in 1997 (Metcalfe-Smith et al. 2000). Approximately 217 sites (at least 607 person-hours) were sampled in the Grand River from 2001–2021 using visual/tactile timed-search methods. This covered reaches of the main stem in the Kitchener to Glenn Morris area (Gillis et al. 2017a), and the Caledonia to Cayuga area (Hayward et al. 2022). No live Kidneyshell were found, but three shells were found near Caledonia in 2020. A number of quadrat surveys have also been conducted on the Grand River, including 234 $m^2$ excavated in 2007, 225 $m^2$ in 2010, 300 $m^2$ in 2017, and 225 $m^2$ in 2018. Brail surveys were conducted in 2019 from Brantford (Cockshutt bridge) to the mouth at Port Maitland (excluding the reach from Caledonia to Cayuga) with 48 sites sampled in each summer and fall but Kidneyshell was not detected (LeBaron et al. 2023). There have been no verified live Kidneyshell from the Grand River. Overall, shell records exist on the main stem of the Grand River from Caledonia to the mouth at Port Maitland; however, it is not known if this accurately reflects the historical distribution of live individuals.

Additionally, there is a record from the Nith River from 1997, but no indication of shell condition at the time of collection or sampling effort is available. Approximately 39 sampling events occurred from 1894–2021 using visual/tactile timed-search methods, but no live specimens or other shells were found. Timed-search sampling (4.0 person-hours/site) also occurred on two tributaries, at six sites on the Speed River (Gillis et al. 2017a) and three sites on Boston Creek (Hayward et al. 2022).

### Niagara River (upper)

Kidneyshell has not been collected live from the Canadian side of the Niagara River; however, a fresh shell was observed in 1934 above the falls (i.e., Lake Erie drainage). Three sites were surveyed with 4.5 p-h of search time in 2001, and one site in 2002. On the American side of the river, historical records of live individuals exist from around Beaver Island, and shells from the north side of Grand Island (1935, 2001 (+two weathered shells), and 2002; LGLUD) and from Buckhorn Island (NYDEC 2015). A diver survey in New York waters in 2001 reported only 13 live unionids (representing three species), and an abundance of Zebra Mussels (COSEWIC 2003). The historical distribution in the Niagara River is not well understood given the difficult sampling conditions.

Historical records exists 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 (Buffalo Museum of Science catalogue no. M 1467 and M 1468; I. Porto-Hannes, University of Buffalo pers. comm.). A shell was discovered adjacent to a Feeder Canal (that historically connected the Lower Grand River and the Welland Canal) in 2015 (Wright et al. 2017), but it is possible this was deposited along with fill material during construction or maintenance of the canals.

## POPULATION ASSESSMENT

To assess the Population Status of Kidneyshell in Canada, each population was ranked in terms of its abundance (Relative Abundance Index) and trajectory (Population Trajectory; Table 2). This is a relative assessment intended to help prioritize populations. The Relative Abundance Index (Extirpated, Low, Medium, High, or Unknown) considers the number of Kidneyshell found and amount and type of sampling effort. The Sydenham River is the best studied and thought to be the largest population in Canada, so the other populations are assessed relative to it. This benchmark population receives a ranking of High by default, bearing in mind that the species is considered imperiled in Canada (COSEWIC 2013) and across its global range (Bogan and Woolnough 2017). This ranking does not necessarily mean the population is abundant relative to historical levels or to healthy populations elsewhere (as historical data are lacking, and ideal or normal densities elsewhere are unknown). The Population Trajectory (Declining, Stable, Increasing, Unknown), is based on mean population growth rates from a trend analysis of the quadrat survey data (Fung et al. 2025).

*Table 2. Relative Abundance Index and Population Trajectory of each Kidneyshell population in Canada. Certainty has been associated with each Relative Abundance Index and Population Trajectory ranking based on 1 = quantitative analysis; 2 = CPUE or standardized sampling; 3 = expert opinion. * indicates localities where only shells of Kidneyshell have been found (no live individuals) and, thus, do not constitute a population.*

| Population | Relative Abundance Index | Population Trajectory |
|---|---|---|
| Ausable River | Medium (2) | Stable (1) |
| St. Clair River* | NA | NA |
| Lake St. Clair | Presumed Extirpated | NA |
| Sydenham River | High (2) | Increasing (1) |
| Thames River* | NA | NA |
| Medway Creek | Presumed Extirpated | NA |
| Detroit River | Presumed Extirpated | NA |
| Lake Erie (subpopulations) | Presumed Extirpated | NA |
| Grand River* | NA | NA |
| Niagara River* | NA | NA |

The Relative Abundance Index and Population Trajectory rankings were then combined in the Population Status Matrix (Table 3) to determine the status for each population. Population Status was assigned as Poor, Fair, Good, or Unknown (Table 4) and the lowest level of certainty associated with either initial parameter was retained.

*Table 3. The Population Status matrix combines the Relative Abundance Index and Population Trajectory rankings to establish the Population Status for each Kidneyshell population in Canada.*

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

*Table 4. Population Status of 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 |

The density of Kidneyshell appears to be greater in the Ausable River than the Sydenham River at some sites (Fung et al. 2025); however, the estimated occupied area is greater in the Sydenham River, thus the abundance is likely greater overall (similar conclusions were drawn by COSEWIC (2003)). Analysis of the quadrat survey data resulted in positive population growth rates at all sites in the Sydenham River and at most sites in the Ausable River. Given that there were fewer sites sampled and a lower mean population growth rate in the Ausable River with more variability between sites compared to the Sydenham River, we consider it to be stable overall (Fung et al. 2025). If the Population Trajectory was ranked as increasing, the overall population status would remain Fair (see Table 3). There remains uncertainty around whether population growth rates calculated at quadrat survey sites are representative of trends in the overall population in each river. Additionally, Kidneyshell is considered an equilibrium life history strategist (Haag 2012), where later maturity and lower fecundity mean population growth rates are expected to be low, even under ideal conditions.

## HABITAT AND RESIDENCE REQUIREMENTS

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

### ADULT HABITAT

Kidneyshell typically occupies small to medium rivers in riffle/run habitats with moderate to swift current, in gravel and sand substrates[2]. It occasionally occupies lake areas (or dammed reaches of rivers) that are shallow (< 1 m in depth), and have sand or gravel shoals with wave action (Ortmann 1919, COSEWIC 2003). Gordon and Layzer (1989) stated that Lake Erie is the only truly lentic environment from which it has been reported (although it was known from Lake St. Clair as well), and it is less abundant and possibly smaller in lentic habitats (Ortman 1919, Strayer and Jirka 1997). All members of the genus *Ptyochobranchus* are typically riverine specialists; however, Haag (2012) described Kidneyshell as being marginally tolerant of impounded areas, despite being a host-specialist on riverine fishes. The species is thought to

[2] Substrates where Kidneyshell is found have been described as “firmly packed” (Ortmann 1919) and “unshifting” (van den Schalie 1988); these descriptions may represent a preference for stable substrates.

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. Kidneyshell had a strong negative relationship with discharge and with urban land use in a habitat suitability model from Michigan (Daniel et al. 2018).

Habitat where live Kidneyshell were collected in the Ausable River from 1997 to 2022 consisted of a mean of 39.6% gravel, 21.5% cobble, 13.3% silt, and 12.7% sand. The mean water temperature was 22.53 °C (range: 18.6–28.0 °C), mean water clarity was 0.26 m (0.06–0.60 m), mean velocity was 0.38 m/s (0.17–0.50 m/s) and mean depth was 0.57 m (0.40–0.75 m). Habitat where live Kidneyshell was collected in the Sydenham River from 1997 to 2022 consisted of a mean of 33.3% gravel, 22.8% sand, 17.6% cobble, and 15.7% boulder. The mean water temperature was 22.0 °C (range: 11.5–27.0 °C), mean water clarity was 0.21 m (0.10–0.60 m), mean velocity was 0.29 m/s (0.03–0.61 m/s), and the mean depth was 0.38 m (0.13–0.95) (LGLUD unpublished data).

## JUVENILE HABITAT

There is limited information available on habitat requirements or associations of juvenile Kidneyshell. Habitat is assumed to be the same as adult, but juveniles will bury deep in the substrate (van der Schalie 1988, COSEWIC 2003). Grabarkiewicz (2012) found a general trend that smaller individuals tended to be more common in subsurface compared to surface samples than larger individuals in the Blanchard River, Ohio, but all life stages of Kidneyshell were generally associated with subsurface samples.

## GLOCHIDIAL HABITAT

Once conglutinates are released by the female, they must be encountered by a host fish, successfully attach to and encyst in gill tissue. The habitat for this life-stage is considered to be the habitat required by the hosts. Host fishes in Canada could include Blackside Darter, Fantail Darter, Greenside Darter, Johnny Darter, Iowa Darter, Logperch and Brook Stickleback. These host fishes are generally riverine species but have microhabitat differences. Blackside Darter is often found in calmer waters of rivers over gravel bars. Fantail Darter prefers smaller streams to medium rivers with gravel or rock bottoms with slow to moderate currents. Greenside Darter prefers well vegetated areas with coarse substrates in small and medium rivers. Johnny Darter is a habitat generalist, but is most common in slow to no flow waters in lakes and rivers with sand, gravel or mud substrates; it avoids heavy aquatic vegetation and riffles. Iowa Darter inhabits slow to no flow waters in lakes and rivers with aquatic vegetation and a mix of sand and organic debris; it is not tolerant of turbidity. Logperch is typically found in sand or gravel beaches of lakes or deep pools with similar substrates in large rivers with moderate to fast currents. Brook Stickleback is also found in a variety of habitats, but it prefers clear, cool water, and dense aquatic vegetation in small streams or spring-fed wetlands (Scott and Crossman 1973, Holm et al. 2009). Darters are most active during their spring spawning seasons when temperatures reach 10° C for Johnny Darter and up to 17° C for Fantail Darter (Ingersoll et al. 1984, Holm et al. 2009, Hicks and Servos 2017), which overlaps with the beginning of the presumed glochidial release period for Kidneyshell. The conservation status of these fishes are considered Secure (S5; Brook Stickleback, Iowa Darter, Jonny Darter, Logperch) or Apparently Secure (S4; Blackside Darter, Fantail Darter, Greenside Darter) in Ontario (NatureServe 2023). Blackside and Johnny darters are widely distributed throughout the current range of Kidneyshell (Figure 5), and most likely serve as the primary hosts (McNichols 2007, DFO unpublished data).

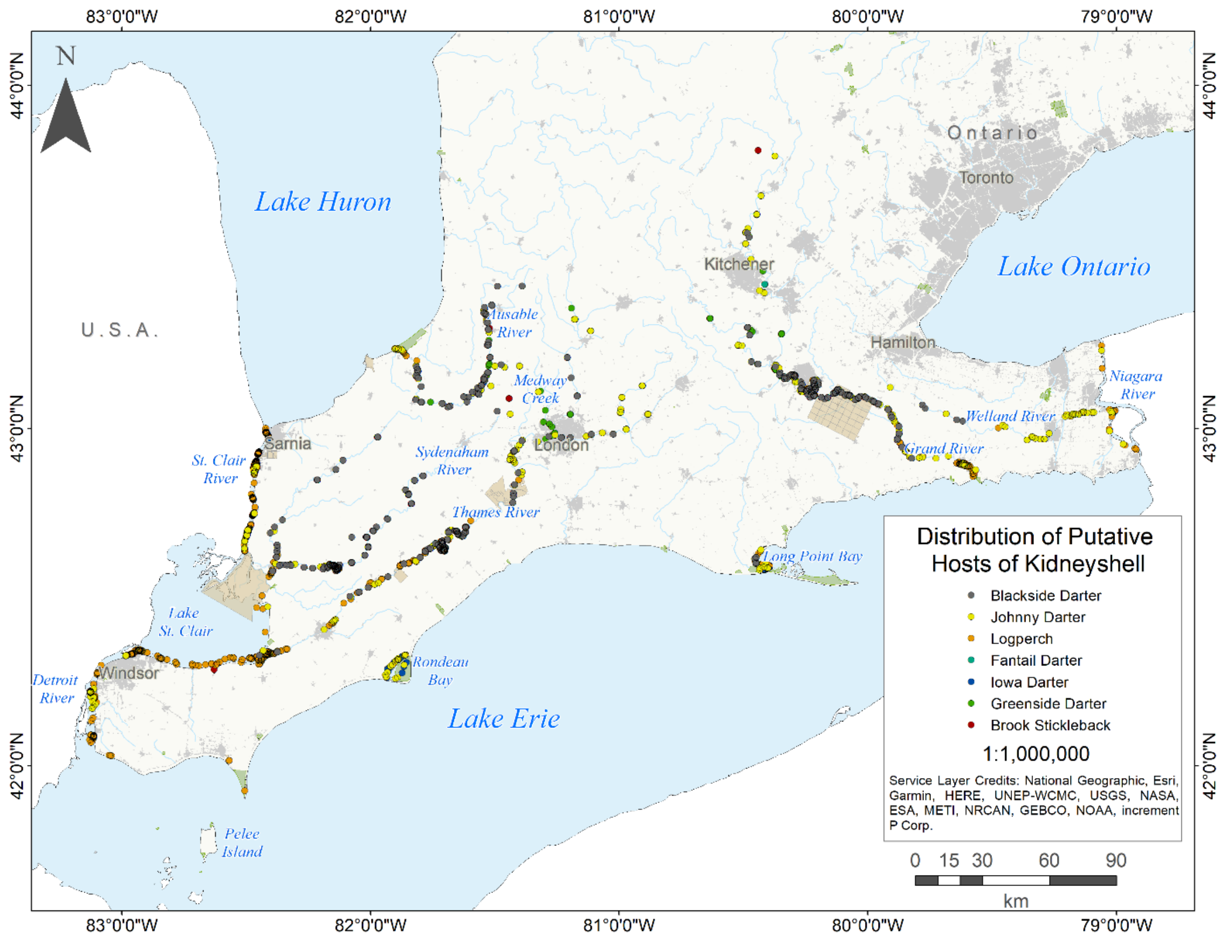


*Figure 5. Distribution records of presumed host fishes (Blackside Darter, Brook Stickleback, Fantail Darter, Greenside Darter, Iowa Darter, Johnny Darter, Logperch) in the historical distribution of Kidneyshell from various DFO sampling efforts (2003–2022; Fish Biodiversity Database). Note these records do not reflect the full distribution of the species in southwestern Ontario.*

From fish sampling in the Ausable River where Blackside and/or Johnny darters were captured, the mean water temperature was 21.8 °C (range: 11.0–26.6 °C), mean dissolved oxygen was 6.0 mg/L (0.2–12.3 mg/L), mean pH was 8.34 (7.34–8.69), mean turbidity was 27.16 ntu (8.60–229.87 ntu), mean depth was 0.80 m (0.15–2.8 m), and mean water velocity was 0.09 m/s (0.00–0.34 m/s). The mean substrate composition was 28.2% sand, 25.0% gravel, and 16.3% cobble. From fish sampling in the Sydenham River where Blackside and/or Johnny darters were captured, the mean water temperature was 21.5 °C (range: 8.6–28.6 °C), mean dissolved oxygen was 4.13 mg/L (0.10–11.3 mg/L), mean pH was 8.32 (7.25–8.71), mean turbidity was 58.46 ntu (14.52–200.0 ntu), mean depth was 0.94 m (0.16–4.4 m), and mean water velocity was 0.19 m/s (0.00–0.59 m/s). The mean substrate composition was 32.5% cobble, 27.8% gravel, and 16.9% sand (Fish Biodiversity Database).

## 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 5). 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, these 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 5. 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<br>• 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<br>• daily water temperatures of approximately 25 °C (at least 14.5°C)<br>• shallow (0.4–1.0 m), clear, well-oxygenated water<br>• gravel, sand and cobble substrates |
| Encysted glochidia (release in spring, encystment for 22-35 days on host) | Feeding<br>Cover<br>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:<br>• mean summer water temperature 22.1°C (range: 8.6–28.6°C)<br>• mean water velocity 0.134 m/s (0.00–0.59 m/s)<br>• mean depth 0.85 m (0.15–4.40 m)<br>• mean turbidity 46.0 NTU (8.6–229.9 NTU);<br>• mean conductivity 534.9 μs/cm (229–735 μs/cm)<br>• mean dissolved oxygen 4.85 mg/L (0.70– 12.25 mg/L)<br>• 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<br>• clear water (high visibility of conglutinates)<br>• presence of host fishes (Blackside Darter, Johnny Darter, and Logperch likely primary hosts) |
| Juvenile | Feeding<br>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)<br>• shallow water (< 1 m)<br>• 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<br>Cover | Same as above | • moderate to strong currents in riffles or wave action (in lakes) (Ortmann 1919)<br>• shallow water (< 1 m)<br>• firmly packed small gravel (54%), sand (20%) and large gravel (10%) or cobble (Ortmann 1919, Grabarkiewicz 2012)<br>• clear water (Watters et al. 2009)<br>• presence of Water Willow (*Justicia americana*) beds nearby (Ortmann 1919) | Adults in the Ausable and Sydenham rivers (LGLUD):<br>• mean summer water temperature 22.2°C (range: 11.5–28.0°C)<br>• mean water velocity 0.302 m/s (0.03–0.61 m/s)<br>• mean depth 0.41 m (0.13–0.95 m)<br>• mean turbidity 3.4 NTU (0.0–51.9 NTU); mean water clarity 0.23 m (0.06–0.60 m)<br>• 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)<br>• stable gravel, sand, and cobble substrates<br>• adequate supply of food (plankton, bacteria, algae, organic detritus, protozoans) |

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

Most of the rivers currently and historically occupied by Kidneyshell are likely to contain patches or reaches of suitable habitat; however, habitat attributes have not been quantified. Critical habitat was identified in DFO (2013) using a bounding box (a rectangle that encapsulates all contiguous river valley segments in the Ontario Ministry of Natural Resources and Forestry (MNRF) Aquatic Landscape Inventory System (ALIS) with occurrence records), as the entire bankfull channel of:

- 120 km of the Sydenham River (from Murphy Drive in Alvinston to County Road 21 in Dresden), below this downstream point, the river is thought to be too flat with insufficient flows to be suitable habitat; lower ~3 km in each of Fansher, Brown and Spring creeks;
- 70 km of the Ausable River (Crediton Road to just past Centre Road); lower ~2 km of Nairn Creek;
- 3 km of Medway Creek surrounding Fanshawe Park Road West; and,
- 55 km of the lower Thames River from Tate's Corner to 5 km southwest of Thamesville.

It is unlikely that the entirety of these stretches is suitable, and likely that other suitable habitat exists beyond these known river segments. Suitable (or marginal) habitat likely still exists in some of the historically occupied localities; however, further assessments would be needed to confirm the availability of habitat and whether threats that led to extirpation have been abated.

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

There are several physical barriers that could prevent Kidneyshell and its host fishes from dispersing or accessing new habitats. There are two major dams, Exeter Dam and Morrison Dam, on the Ausable River located approximately 13 km upstream of the known Kidneyshell distribution (COSEWIC 2021). There are two dams located upstream of Napier on the Sydenham River, at Head Street in Strathroy and Coldstream Dam in Greystead, and an additional 11 smaller dams and barriers throughout the distribution of Kidneyshell. No physical barriers are present on the St. Clair River and through Lake St. Clair that would prevent Kidneyshell or its host fishes from moving between occupied localities; however, these areas are unlikely to be traversed by the small-bodied, short-dispersing host fishes.

In addition to physical barriers preventing access, the absence of suitable habitat may also present a constraint to the distribution of Kidneyshell. The lower reaches of the Sydenham River (i.e., below County Road 21 in Dresden, On) are thought to have too low of a slope, creating low velocities that are unsuitable for the species (DFO 2013). Additionally the substrate through this lower stretch is predominantly silt, clay, and organics (LeBaron et al. 2023). Similarly, the lower reaches of the Ausable River (i.e., downstream of Kennedy Line to the mouth) have predominantly silt and clay substrates that are likely unsuitable (excluding some patches of sand) (LeBaron et al. 2023). Presence of invasive species may also constrain the distribution of Kidneyshell or its hosts. Dreissenid mussels are still abundant within the Great Lakes and connecting channels, which may make recolonization of historically occupied habitats unlikely. Round Goby (*Neogobius melanostomus*), a competitor of many native benthic species, may impact the abundance, movement behaviours, timing (i.e., presence of hosts during the glochidial release period of Kidneyshell), or health (diet) of host fishes (Burkett and Jude 2015, Raab et al. 2018, Firth et al. 2021, McAllister et al. 2022), and areas of high Round Goby abundance may be less likely to support sufficient and healthy populations of host fishes leading to reduced Kidneyshell recruitment.

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

Residence is defined in SARA as a "dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating". Residence is interpreted by DFO as being constructed by the organism (DFO 2010). In the context of the above narrative description of habitat requirements during glochidial, juvenile and adult life stages, Kidneyshell does not construct or occupy a residence during its life cycle.

## THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF KIDNEYSHELL

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

Freshwater mussels are among the most imperiled taxa in the world. Approximately 72% of species in North America are of conservation concern, due to historical harvests (pearl and button industries), widespread habitat alteration, pollution, and AIS (particularly dreissenid mussels) (Bogan 1993, Williams et al. 1993, Metcalfe-Smith et al. 1998, Ricciardi and Rasmussen 1999, Anthony and Downing 2001). Given the relatively long life span, slow growth, and late maturity of many unionids, recovery of populations following disturbance events is slow (Haag and Warren 2008, Atkinson et al. 2014).

A number of threats may limit the survival and recovery of Kidneyshell in Canada. Pollution from agricultural and urban sources, impacts of climate change (e.g., droughts and extreme temperatures), biotic interactions from AIS, and habitat modifications through impoundments are considered the greatest threats to this species (COSEWIC 2003, 2013, DFO 2013). Although Kidneyshell is dependent on host fishes for completing its life cycle, threats to host species are briefly discussed below but are not assessed. Threats are categorized following Salafsky et al. (2008), and are assessed based on DFO (2014) over a 10 year timeframe.

### 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). All life stages of freshwater mussels are highly sensitive to contaminant effects, but adults are better able to withstand acute exposures with behavioural avoidance (valve closure/burrowing) with fewer metabolic consequences (Byrne et al. 1990, Cope et al. 2008). Kidneyshell glochidia may be afforded protection against some contaminants (e.g., copper and chloride) while still encased in conglutinates (Gillis et al. 2008, Gillis 2011).

Air and water pollution, primarily from industrial sources, reached a peak in Ontario (and much of North America) in the 1970's, when impacts to wildlife became a concern. Historically, several large rivers where Kidneyshell was found supported heavy industrial operations related to petrol and chemical processing (e.g., the Niagara, Detroit, and St. Clair rivers) resulting in their designation as Areas of Concern (ECCC 2022). Policies and remediation efforts were implemented starting in the 1970's (ECCC 2023), and, although these have generally resulted in improved conditions in those systems, legacy contaminants persist and may impact the recovery of benthic species (Gewurtz et al. 2010, Richman et al. 2011, Visha et al. 2018, Muttray et al. 2021, ECCC 2022). Mussel surveys in Ontario began in a more systematic way in the late 1990's, and the lack of historical data prevents a thorough evaluation of the impacts to freshwater mussels of this heavy industrial period, or of the implemented policies and remediation efforts.

## Agricultural and Forestry Effluents

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). Approximately 4,700 km of watercourses in the Sydenham River watershed are classified as drains (60% of watercourses). Nutrient levels in these watersheds often exceed provincial guidelines (ABCA 2018a,b, SCRCA 2018). Impacts of some of these agricultural pollutants may be mitigated by riparian buffer zones. In the Sydenham River, intact riparian buffer zones resulted in improved water quality, where ammonia (ionized and unionized) concentrations were lower, and dissolved oxygen in the surface water was higher, compared to sites with fragmented buffer zones. A higher proportion of mussels were found at the intact riparian sites as well, including Kidneyshell, which was more frequently observed at sites with intact riparian buffers (Lu 2023).

Siltation/sedimentation of water courses is a widespread threat facing aquatic life in southwestern Ontario, and can arise from many agricultural sources including livestock access to rivers, poor soil retention practices, erosion/bank stability issues, and is made worse by a lack of riparian buffers. Sediments may be suspended leading to high turbidity, or settle out and deposit on coarser substrates and live animals. Suspended sediments can clog incurrent siphons and gills, interrupting feeding, respiration, growth, and reproduction (Tuttle-Raycraft et al. 2017, Goldsmith et al. 2021, Luck and Ackerman 2022). As mussels filter water, they remove non-food items for expulsion, and in highly turbid areas, sorting sediments out may become too energetically costly compared to the food coming in (Madon et al. 1998, Tokumen et al. 2016, Tuttle-Raycraft and Ackerman 2019). Sediments can clog the gills, resulting in reduced respiration rates and oxygen uptake (Aldridge et al. 1987, Madon et al. 1998). The outer gills are non-functional for respiration in females for most of the year, possibly making them more sensitive to reduced oxygen conditions (Watters 1999). For burrowed mussels, deposited silt and other fines can clog interstitial spaces, reducing feeding (for juveniles) and respiration success, and may impact burrowing activity or lead to death (Brim Box and Mossa 1999, Osterling et al. 2010). High loads of total suspended solids (TSS) can reduce fertilization success in females as increased production of pseudofeces can result in sperm being expelled before being captured. In Swedish streams, Osterling et al. (2010) found reduced recruitment of juvenile Pearl Mussel (*Margaritifera margaritifera*), and reduced adult growth in stream systems with 3–4 times the turbidity (mean of 4.1 ± 1.4 NTU at sites without recent recruitment compared to 0.96 ± 0.14 NTU at sites with recent recruitment). High suspended sediment loads may decrease mussel-host fish interactions, particularly when lures, mantle displays, and prey-mimicking conglutinates are used to attract host fishes (Goldsmith et al. 2021). Heavy sediment loads may also make host fishes less susceptible to infestation as fish gill tissue may become damaged from abrasive sediments, or mucous secreted to protect gill tissue from abrasion may reduce attachment and metamorphosis rates (Goldsmith et al. 2021 from Beussink 2007).

Nutrient loading is another consequence of agricultural land use that can negatively affect mussels and host fishes. Nutrients can come from a number of agricultural sources, including fertilizers and manure, and may become resuspended during upstream drain maintenance activities or when cattle access streams. Nutrients increase primary productivity, particularly algal growth, which can lead to reduced dissolved oxygen both daily and seasonally (i.e., during periods of decomposition). This can impact respiration and potentially lead to mortality at extreme levels of hypoxia (Sparks and Strayer 1998). Kidneyshell may be particularly sensitive to low dissolved oxygen concentrations. Following an agricultural spill in Big Darby Creek, Ohio, dissolved oxygen levels dropped to just above 0 mg/L and Kidneyshell and Wavyrayed Lampmussel (*Lampsilis fasciola*), two of the most abundant species present before the spill, quickly died off and it was estimated that less than 5% survived at the spill site (Tetzloff 2001).

Fertilizers and other nitrogenous compounds can result in increased ammonia levels in the aquatic environment, and freshwater mussels are among the most sensitive taxa to ammonia, particularly at early life stages (Augspurger et al. 2003, Wang et al. 2007). Potassium, often found in fertilizers, is also toxic to early life stage mussels (Gillis et al. 2021). Ammonia and potassium in Ontario rivers may occasionally exceed concentrations where survival and/or viability of lab-exposed glochidia of Rainbow (*Cambarunio iris*), another mussel of conservation concern, was impaired (Salerno et al. 2020).

Lastly, pesticides applied to farm fields or occasionally in or near water for aquatic invasive species control (e.g., glyphosate for *Phragmites australis australis*) may be toxic to freshwater mussels, depending on exposure concentration (Keller and Ruessler 1997, Bringolf et al. 2007), and genotoxic effects have also been reported in a lab study (Conners and Black 2004). However, toxicity tests of widely used pesticides (neonicotinoids, fungicides, carbamates, organophosphates and butenolides) in Ontario revealed that the mussels tested (*Lampsilis siliquoidea, L. fasciola*, and *C. iris*) were not sensitive to the pesticides at current environmental levels during acute or medium-term exposures (Prosser et al. 2016a, Salerno et al. 2018). Granular Bayluscide (niclosamide ethanolamine salt), applied for control of invasive Sea Lamprey (*Petromyzon marinus*)[3], is highly toxic to Kidneyshell at typical application concentrations (Newton et al. 2017). The risk to Kidneyshell is thought to be relatively low as there was limited spatial overlap of recent applications with Kidneyshell occurrence records in Ontario (Andrews et al. 2021). The mortality risk to Kidneyshell could be high when applications occur in areas with moderate to high densities of Kidneyshell, but these are likely sub-optimal substrates for larval Sea Lamprey (Smyth and Drake 2021).

### Domestic and Urban Waste Water

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 for freshwater mussels, as chloride is among the most toxic substances to unionids particularly at the glochidial stage (Gillis 2011, Pandolfo et al. 2012b). Chloride was negatively associated with mussel species richness in the Sydenham River (Metcalfe-Smith et al. 2003). Todd and Kaltenecker (2012) reported that maximum chloride values measured in Ontario rivers (including the Ausable and Thames) exceeded specific tolerances ($EC_{20}$) of glochidia reported during lab tests (Gillis 2011), and peaks in chloride were not exclusively associated with the winter season. Reduced viability of glochidia is the most likely effect of current road salt applications in Ontario but more extreme impacts may occur during peaks, which are not always measured (Prosser et al. 2016b, Gillis et al. 2022).

Other contaminants associated with roadways (e.g., polycyclic aromatic hydrocarbons [PAHs] and heavy metals) are likely to negatively affect feeding, behaviour, reproduction, and growth, can also have toxic and mutagenic effects on freshwater mussels (Keller and Zam 1991, Marvin et al. 1994, Naimo 1995, Jaruga et al. 2017, Archambault et al. 2018), and were correlated with a “zone of mussel decline” in the Clinch River, Tennessee (Cope et al. 2021), but these contaminants are likely present at low levels in the Ausable and Sydenham rivers.

[3] Note that lampricide is applied to control AIS, and although not used for agriculture or forestry purposes, its function as a pesticide with impacts to non-target organisms is best captured in this category.

There are numerous wastewater or sewage treatment plants found in the Ausable (n = 14; three of which are upstream of Kidneyshell) and Sydenham (n = 18; two of which are upstream of Kidneyshell) watersheds that could negatively affect Kidneyshell (Figure 6; ABCA 2018a,b, SCRCA 2018). Most wastewater is treated prior to being released into rivers, but not all contaminants are removed. Gillis et al. (2017b) reported a complete absence of mussels for an approximately 7 km stretch downstream of a large (> 200,000 households serviced) wastewater treatment plant on the Grand River, Ontario, in contrast to a healthy mussel community immediately upstream, likely related to high nitrite and ammonia and low dissolved oxygen. Municipal wastewater effluent often contains toxic compounds from pharmaceuticals and personal care products. Although dozens of these chemicals have been detected in the tissues of wild mussels (de Solla et al. 2016), lab toxicity assessments of individual pharmaceuticals revealed that none of the contaminants of concern were toxic to mussels at the levels found in the environment; however, some behavioural effects were observed (Gilroy et al. 2014, 2017). Estrogenic compounds can lead to feminization and other neuroendocrine disruptions in mussels and fishes, resulting in reproductive consequences (Gagné et al. 2004, Gagné et al. 2011, Tetreault et al. 2011). Host fishes could be impacted: delayed sperm development, increased frequency and severity of intersex development in males, increased metabolic rates, and changes to gill morphology were observed in Rainbow Darter downstream of municipal wastewater treatment plants on the Grand River (Fuzzen et al. 2016, Hodgson et al. 2020). Additionally, contaminants found in urban runoff (e.g., heavy metals) may interact with those found in wastewater effluent leading to reduced body condition and longevity in mussels found downstream of these inputs (Gillis 2012, Gillis et al. 2014).

Faulty or leaching septic systems have also been identified as an issue in the Ausable and Sydenham watersheds (SCRCA 2018, COSEWIC 2021). These can contribute nutrients leading to increased algal blooms and decreased dissolved oxygen.

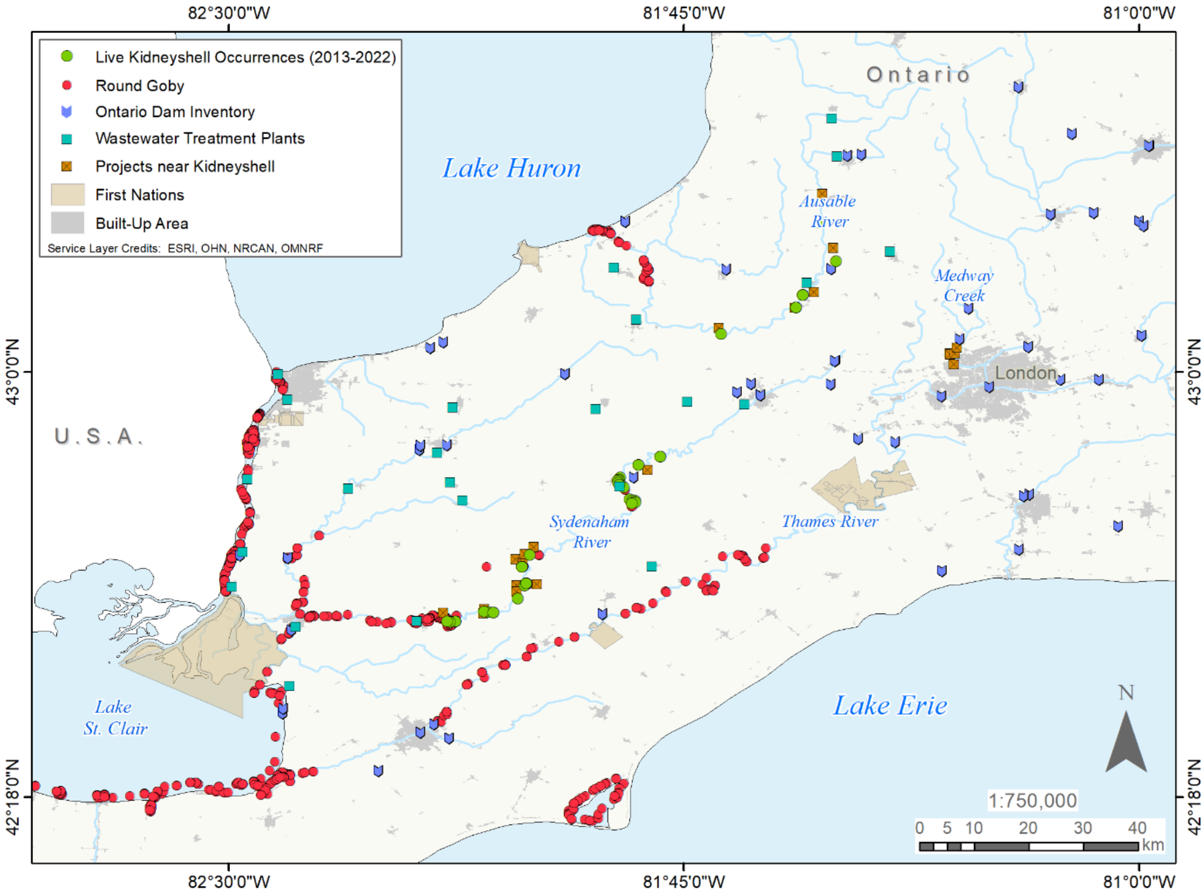


*Figure 6. Spatial location of specific threats within the Kidneyshell distribution, where data was available. Round Goby distribution data is from the Fish Biodiversity Database. Dam locations are found in the Ontario Ministry of Natural Resources and Forestry's Ontario Dam Inventory layer. Wastewater treatment plant spatial data was provided by the Ausable-Bayfield Conservation Authority, Lower Thames Valley Conservation Authority, and St. Clair Region Conservation Authority. Projects that occurred within 2 km of Kidneyshell occurrence records were queried from the DFO Project Activity Tracking for Habitat (PATH) database.*

## INVASIVE AND OTHER PROBLEMATIC SPECIES, GENES, AND DISEASES

The invasion of dreissenid mussels (Zebra Mussel and Quagga Mussel) 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 (Gillis and Mackie 1994, Schloesser and Nalepa 1994, Nalepa et al. 1996, Ricciardi et al. 1996, Schloesser et al. 2006). Dreissenids attach to native mussels via byssal threads and can accumulate on their shells in extremely large numbers (e.g., a few dozen up to 3,366 Zebra Mussel per unionid (Zanatta et al. 2002)). This can smother the siphon (reducing feeding, respiration and reproduction), prevent or inhibit valve movements, interfere with burrowing activities, and impair shell formation (Gillis and Mackie 1994, Nalepa et al. 1996, Schloesser et al. 2006). Dreissenid mussels also appear to outcompete native unionids for food resources, having a filtering capacity 12 times greater than that of the native mussel community prior to invasion in the Detroit River despite a lower mean biomass (Nalepa et al. 1996). Dreissenid mussels are, however, lentic species, typically found in low abundances in riverine habitats as they have poor attachment abilities under flowing conditions (Horvath et al. 1996, Stoeckel et al. 1997). Mackie (1995) suggested water velocities of less than 0.00006 m/s are required for dreissenids to hold their position. Although Zebra Mussel is the likely cause of the extirpation of Kidneyshell from Lake St. Clair, the Detroit River, Lake Erie, and the Niagara River, remaining populations found in the Ausable and Sydenham rivers may be at a relatively low risk of impacts. Zebra Mussel has been detected in the lower reaches of both rivers where flows are slow and affected by the lake, but this habitat is thought to be unsuitable for Kidneyshell. The St. Clair River Delta and associated wetlands appeared to offer a refuge for some native unionids (2,356 live unionids representing 22 species at 33 of 95 sites sampled in 1998 and 2001), attributed to the shallow depth (with wave action), high connectivity to the lake (i.e., access to host fishes), and softer substrates where they can burrow to depths that smother dreissenids (Nichols and Wilcox 1997, Zanatta et al. 2002). However, sampling in the St. Clair River delta in 2011 and 2016 did not result in any Kidneyshell, and sampling on the American side in 2021 found only 14 live unionids (11 species) at 7 of the 51 sites sampled (Keretz 2022).

Round Goby (*Neogobius melanostomus*) 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 Ausable, Sydenham and Thames rivers (Poos et al. 2010). Round Goby is currently found throughout the distribution of Kidneyshell in the Sydenham River up to at least Napier, but may only extend as far as Sylvan on the Ausable River (Figure 6, DFO unpublished data and K. Jean, ABCA, pers. comm.). Round Goby is unlikely to threaten Kidneyshell directly, given its relatively small gape size; however, it may serve as a sink for glochidia where attachment occurs but transformation is unsuccessful (Tremblay et al. 2016). Round Goby is more likely to indirectly impact Kidneyshell through negative interactions with host fishes. 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 (French and Jude 2001, Reid and Mandrak 2008) and many tributaries of the Great Lakes (Raab et al. 2018, McAllister et al. 2022), through increased diet overlap, predation of early life stages (egg/larval/young of year), and habitat displacement (French and Jude 2001, Poos et al. 2009, Abbett et al. 2013, Reid 2019, Firth et al. 2021).

Other invasive species that are not yet on the landscape could pose a threat to Kidneyshell or its host fishes in the future. For example, 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). Considerable changes in temperature and precipitation are expected across Ontario by 2100, with mean annual temperatures expected to increase, summers to see a decrease in total precipitation and winters an increase compared to previous decades (McDermid et al. 2015). Climate change may also have 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 (Lemmen and Warren 2004, COSEWIC 2021). 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.

The two rivers inhabited by Kidneyshell in Canada are considered flashy due to the high degree of semi-impervious surfaces in the watersheds (ABCA 2018a,b, SCRCA 2018), and thus prone to impacts from extreme water levels or temperatures. Kidneyshell is thought to prefer shallower waters (< 1 m in depth; Ortmann 1919), which may make them more susceptible to desiccation or exposure during drought or extreme heat.

### Droughts

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. Effects of drought are likely to be greater in smaller streams than larger rivers (Haag and Warren 2008).

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) predicted species losses to be greater for mussels (5–60%, depending on region) than fishes as they rely on hosts, and greatest for host-specialist mussels. Shifts in mussel community composition, and declines in mussel abundance and biomass have been observed following severe drought events in the southern U.S.A. (Golladay et al. 2004, Haag and Warren 2008, Galbraith et al. 2010, Lopez et al. 2022), with significant corresponding loss of function of nutrient cycling (e.g., an approximately 30% decline in both nitrogen and phosphorous storage in the system, and a 22% decline in nitrogen remineralization) one year post-drought compared to surveys from one year pre-drought (Atkinson et al. 2014). Golladay et al. (2004) found that drought-impacted river reaches with coarse woody debris where shallow depressions formed appeared to offer some refuge to mussels.

The Province of Ontario monitors surface water metrics to provide low water warnings through the Ontario Low Water Program. Precipitation and discharge data are combined to indicate a Level 1 (early indication of a potential drought), Level 2 (increased likelihood of drought conditions), and Level 3 (high likelihood of drought conditions) warnings. The annual frequency of these low water levels are summarized in Figure 7 for the Ausable-Bayfield (Ausable River) and St. Clair Region (Sydenham River) watersheds (Ontario Low Water Program, unpublished data).

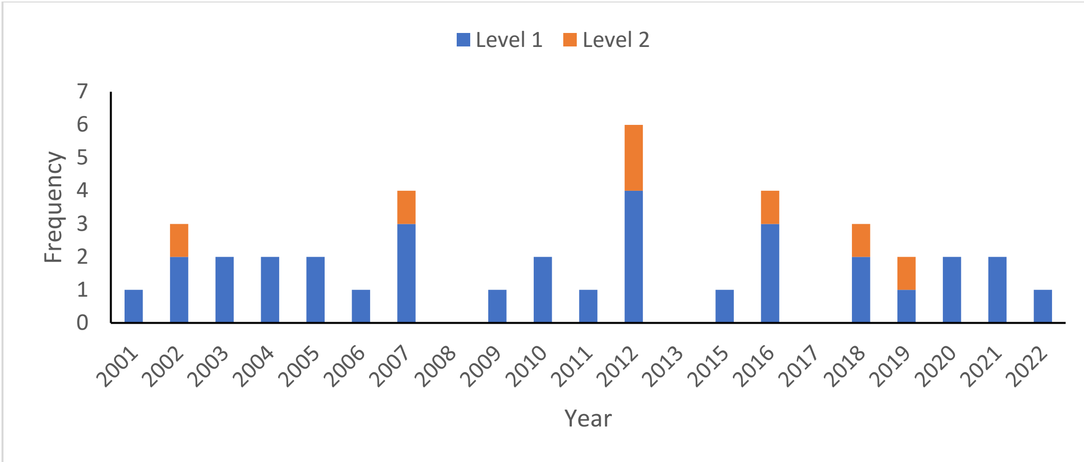


*Figure 7. Annual frequency of low water level designations for the Ausable-Bayfield, and St. Clair Region watersheds from 2001–2022 based on precipitation and discharge metrics (Ontario Low Water Program, unpublished data).*

In addition to droughts, extreme flood events could potentially flush mussels to less ideal habitats, and scour stream beds, changing substrate composition in suitable patches. If floods occur during spawning season, the uptake of sperm by females could be limited, resulting in reduced fertilization success, or conglutinates could be flushed out, preventing larval development.

### Temperature Extremes

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. This is likely to be more pronounced for populations in smaller or predominantly surface-fed systems. The lethal thermal tolerance and thermal optimum of Kidneyshell are not known; however, a review of literature on thermal tolerances of 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 (Fogelman et al. 2023). Thermal tolerances varied slightly by life stage, and depending on exposure duration: the mean lethal temperature was 32.8° C (range: 21.4–42.6° C; acute exposures) for glochidia; 35.0° C (29.9–44.4° C) and 30.1° C (30.5–35.6° C) for juveniles during acute and chronic exposures, respectively; and 36.4° C (33.7–38.7° C) and 35.9° C (32.4–37.5° C) for adults during acute and chronic exposures, respectively. Critical thermal maxima were identified for adults during ramping exposure trials as a mean of 39.5° C (range: 32.1–42.7° C). Species in the Lampsillini tribe (to which Kidneyshell belongs) tended to be intermediate in thermal tolerances across life stages (Fogelman et al. 2023). Pandolfo et al. (2012a) found that host fish thermal tolerance may be more limiting in some cases. Critical thermal maxima of Johnny and Fantail darters in the Great Lakes basin have been reported as 30.5–36.0° C, depending on species, season, and acclimation temperature (Hlohowskyj and Wissing 1984, Ingersoll and Claussen 1984) and is probably a similar range for other darter hosts.

## NATURAL SYSTEM MODIFICATIONS

### Dams and Water Management/Use

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 on either side of the dam (COSEWIC 2013). Dams can also prevent movement of host fishes, potentially disrupting recruitment. Lastly, but perhaps most significantly, dams can create habitat suitable for dreissenid mussels that would otherwise be excluded from flowing systems (Mackie 1995, Smith et al. 2015). Kidneyshell is typically a riverine species that uses riverine fishes as hosts; however, Haag (2012) considered Kidneyshell marginally tolerant of impoundments, and some of its putative host species (e.g., Johnny Darter) prefer slow to no flow areas. Impoundments in the U.S.A. have contributed to the decline and/or loss of other *Ptychobranchus* species. Historical mussel shell surveys in the Holston River in Tennessee suggest that Kidneyshell and Fluted Kidneyshell (*P. subtentum*) were common or abundant prior to impoundment, but the mussel community is now dominated by lentic species like Giant Floater (*Pyganodon grandis*) and Paper Pondshell (*Utterbackia imbecillis*) (Parmalee and Polhemus 2004).

Several impoundments exist within the current distribution of Kidneyshell that may negatively impact it or its host fishes. There are two major dams upstream of the Kidneyshell distribution on each of the Ausable and Sydenham rivers (Figure 6). Additionally, COSEWIC (2021) estimated 21 smaller dams and weirs on the Ausable River, and 11 on the Sydenham River. Most of these are private structures and the degree to which they limit or prevent movement of species or disrupt habitat is unknown, but may be small if substrate composition, and thermal and oxygen regimes remain relatively unchanged (Haag 2012, Hornbach et al. 2014). Large dams on the Grand River (Wilkesport, Cayuga, Caledonia, and Dunnville dams) may have fragmented populations of Kidneyshell and hindered reproduction through changes to flow and limitations to hosts. Due to the lack of complete historical distribution data on both the Ausable and Sydenham rivers, it is unknown to what degree the existing dams impacted the species.

## OTHER

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. These include (but are not limited to): new housing developments within the vicinity of the Kidneyshell distribution resulting in increased turbidity, changes to flow regimes, and increased impervious surfaces; livestock farming and cattle access to streams that occurs in upstream tributaries resulting in increased turbidity and nutrients downstream; agricultural drain maintenance activities may also occur in upstream tributaries, resulting in homogenization of habitat (i.e., substrate, flows) locally and increased turbidity downstream; agricultural spills of organic or inorganic substances resulting in depleted dissolved oxygen concentrations could result in mass mortality of Kidneyshell as occurred in Big Darby Creek, Ohio (Tetzloff 2001); oil drilling projects within the watershed, which could lead to inputs of toxic substances; recreational vehicle use in streams causing mortalities of individuals and impairing in-stream and riparian habitat at points of contact; maintenance dredging of shipping canals/corridors through Lake St. Clair (and the St. Clair and Detroit rivers), causing mortalities of individuals, increased turbidity and homogenization of substrates; and, baitfish harvest that could remove host darters, reducing transformation success and recruitment – all of the putative darter hosts are no longer legal baitfish in Ontario, and prior to the regulation change, were not commonly sold or used as bait in Ontario (Drake and Mandrak 2014).

## MULTIPLE THREAT EFFECTS

Threats can interact in complex and context-dependent ways and it is likely that Kidneyshell is experiencing many of these threats/stressors simultaneously. These interactions could result in additive effects, or stressors could be amplified or dampened in combination compared to each on its own. As such, the magnitude and direction of impacts are difficult to predict, but research on multiple threat effects is growing, particularly related to climate change and changes in land use. Luck and Ackerman (2022) evaluated the interactive effects of water temperature, water velocity, and total dissolved solids on three measures of mussel physiology and found that, in several cases, combining stressors resulted in multiplicative effects. A worst case scenario was identified of high summer temperatures combined with heavy turbidity and either above- or below-average velocity, which are likely conditions under most climate change scenarios where droughts or intense rain events are expected to increase (Luck and Ackerman 2022). Beermann et al. (2021) generally found negative synergistic effects on benthic invertebrate communities when suspended sediments increased and flow velocity decreased; sensitive taxa were further impacted when salinity increased as well. Contaminants ammonia, chloride, copper, and potassium are known to be among the most toxic to freshwater mussels in isolation, but likely co-occur (along with other stressors) in the natural environment. Salerno et al. (2020) investigated mixture toxicity of pairings of these contaminants on early life-stage mussels, and found that they typically resulted in synergistic effects (depending on exposure level) in combination compared to individual exposures. Drought events may be worsened by land-use changes. Atkinson et al. (2014) found that reductions in mussel biomass and abundance following a drought were greater in areas with high agricultural land use (and lower forest cover). Smaller headwater streams that are more drought prone may be less likely to rebound when land use changes further fragment river habitats for host fishes thus reducing recolonization potential (Haag and Warren 2008), while larger rivers are often subject to water extraction for human uses (e.g., irrigation), demands for which are likely to increase during drought events further exacerbating low water levels and associated increased temperatures and decreased dissolved oxygen (Galbraith et al. 2010). Further investigation of multiple stressors on mussel vital rates is warranted.

## THREAT ASSESSMENT

Threats were assessed following guidelines in DFO (2014). Each threat was ranked in terms of the threat Likelihood of Occurrence (LO), threat Level of Impact (LI) and Causal Certainty (CC). The Likelihood of Occurrence refers to the probability of a specific threat occurring for a given population over 10 years or three generations, whichever is shorter. Given the generation time for Kidneyshell (coarsely estimated as 9–11 years in the Sydenham and 11–14 in the Ausable; DFO unpublished data) this threat assessment was evaluated over a 10-year time frame. The Level of Impact refers to the magnitude of the impact caused by a given threat, and the level to which it affects the survival or recovery of the population. Threats received a Causal Certainty score of 5 if a plausible link is made 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 occurring 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 declines in freshwater mussels somewhere. The Population-Level Threat Occurrence (PTO), Threat Frequency (PTF) and Threat Extent (PTE) were also evaluated and assigned a status based on the definitions outlined in Table 6 (rankings in Tables 7–8). The Likelihood of Occurrence and Level of Impact for each population were subsequently combined in the population-level Threat Risk Matrix (Table 9; rankings in Table 10). Additional justifications for threat scores are found in Appendix 2.

Extant Kidneyshell populations are currently thought to be stable or increasing slightly in Ontario, 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 multiple threats simultaneously (i.e., cumulative threat effects, threat interactions), nor does it allow for evaluation of impacts below the population level (e.g., sub-lethal effects, impacts to vital rates). The former would not change the interpretation of level of impact, given positive population growth rates. Some threats may have extreme impacts locally, at certain times of the year, or to more sensitive life stages. The threat assessment also lacks a component of exposure (or intensity/magnitude).The threat may be present in the watershed (‘Known’ likelihood of occurrence), and can have a High level of impact at certain intensities (or under some circumstances), but is not at harmful levels presently. This level of exposure (or intensity/magnitude) of the threat may vary across locations based on landscape features, degree of human interference, or invasion status. Even though the threats are ranked low individually, there are a large number of threats occurring simultaneously resulting in generally poor habitat conditions. Other freshwater mussel species appear to be declining at the same sites where Kidneyshell is found (T. Morris, DFO, pers. comm.), suggesting these threats are having negative impacts on the mussel community. Any change in intensity of existing threats or any new threats may greatly increase the risk to Kidneyshell populations. The human population in southwestern Ontario[4] is projected to grow by 40.9% by 2046 (*Ontario Ministry of Finance 2023*), which will lead to greater habitat loss and/or degradation, urban runoff, and domestic wastewater inputs, thus, intensifying the threat landscape.

[4] Specifically, Middlesex County (majority of the Ausable River) is projected to increase by 53.7% (mostly associated with the City of London), and Chatham-Kent and Lambton counties (Sydenham River) are projected to increase by 14.9 and 18.6%, respectively.

*Table 6. 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 |
| 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 7. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent of Kidneyshell in the Ausable River. Definitions and terms used to describe the threat ratings are found in Table 6.*

| IUCN Threat Category | Sub-category | Details | Likelihood of Occurrence | Level of Impact | Causal Certainty | Threat Occurrence | Threat Frequency | Threat Extent |
|---|---|---|---|---|---|---|---|---|
| Pollution | Agricultural and Forestry Effluents | Sedimentation (field runoff, upstream drain maintenance) | K | L | 3 | H/C/A | C | E |
| | | Nutrient Loading (+ ammonia and potassium) | K | L | 4 | H/C/A | C | E |
| | | Pesticides (+ granular Bayluscide) | K | L | 4 | H/C/A | C | E |
| | Domestic and Urban Wastewater (incl. urban runoff) | Nutrient Loading (+ ammonia) | K | L | 4 | H/C/A | C | B |
| | | Pharmaceuticals and estrogenic compounds | K | L | 5 | H/C/A | C | B |
| | | Chloride | K | L | 4 | H/C/A | R | B |
| | | Heavy Metals/ PAHs | K | L | 4 | H/C/A | C | B |
| Invasive and other Problematic Species and Genes | - | Round Goby, Dreissenid mussels | K | L | 5 | H/C/A | C | B |
| Climate Change and Severe Weather | - | Frequent and severe droughts and extreme temperatures | K | L | 3 | H/C/A | R | E |

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

| IUCN Threat Category | Sub-category | Details | Likelihood of Occurrence | Level of Impact | Causal Certainty | Threat Occurrence | Threat Frequency | Threat Extent |
|---|---|---|---|---|---|---|---|---|
| Pollution | Agricultural and Forestry Effluents | Sedimentation (field runoff, upstream drain maintenance) | K | L | 3 | H/C/A | C | E |
| | | Nutrient Loading (+ ammonia and potassium) | K | L | 4 | H/C/A | C | E |
| | | Pesticides (+ granular Bayluscide) | K | L | 4 | H/C/A | C | E |
| | Domestic and Urban Wastewater (incl. urban runoff) | Nutrient Loading (+ ammonia) | K | L | 4 | H/C/A | C | B |
| | | Pharmaceuticals and estrogenic compounds | K | L | 5 | H/C/A | C | B |
| | | Chloride | K | L | 4 | H/C/A | R | B |
| | | Heavy Metals / PHAs | K | L | 4 | H/C/A | C | B |
| Invasive and other Problematic Species and Genes | - | Round Goby, Dreissenid mussels | K | L | 5 | H/C/A | C | E |
| Climate Change and Severe Weather | - | Frequent and severe droughts and extreme temperatures | K | L | 3 | H/C/A | R | E |

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

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

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

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

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

Small to medium rivers with moderate to swift currents, or nearshore lake habitats with wave action over stable sand, gravel, and cobble substrates that support darter hosts are the most important habitat features for Kidneyshell. There are several activities that take place in Kidneyshell habitat that are likely to damage or destroy these properties, directly or indirectly. These activities may include, but are not limited to:

- Physical habitat loss or modification through grading, dredging (for boating infrastructure or agricultural drain maintenance upstream of the Kidneyshell distribution), excavation, channelization, infilling, or riparian vegetation clearing that results in changes in the quantity and quality of habitat, changes to thermal, flow, and sediment transport regimes, and homogenization of substrates.
- Overapplication, misuse, and/or intensive use of pesticides, fertilizers, or road salts may result in effects ranging from behavioural (e.g., valve closure, burrowing) up to mortality, depending on exposure concentration and duration.
- Bridge and culvert construction or maintenance activities that involve instream works. This is likely to alter substrate at the site, and may impact water velocity and sediment transport leading to increased turbidity. These projects can fragment river reaches either temporarily during work, or permanently if undersized or perched.
- Impoundments (e.g., dams and weirs) that result in fragmentation of habitat can impact host fishes and the Kidneyshell reproductive cycle, lead to a loss of lotic habitat upstream, and changes to thermal, flow, and sediment transport regimes both upstream and downstream.
- Recreational vehicle (e.g., ATV) use in streams can increase turbidity and pollutants (e.g., gas, oil, heavy metals), disrupt the substrate (i.e., compaction, which can impact burrowing), and can also be a vector for AIS.
- Cattle access to streams (upstream of the Kidneyshell distribution) can lead to increased turbidity, bank instability, erosion, and nutrient inputs or resuspension.

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

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. Some of the putative hosts are rare in the systems inhabited by Kidneyshell in Ontario (e.g., Fantail Darter, Iowa Darter, Brook Stickleback), and if those happen to be preferred hosts, then reproductive success could be limited (COSEWIC 2003, McNichols 2007). Most darters have relatively limited dispersal capabilities, which could also present a limitation as host-mediated transport is the only opportunity for large-scale dispersal of unionids. In an Ohio stream in the fall, Johnny and Fantail darters travelled an average distance of 55 m (maximum of 109.3 m) and 62 m (maximum of 185.1 m), respectively (Mundahl and Ingersoll 1983). Only 3.2% of the Johnny Darter moved to a different pool or riffle from where they were initially captured (out of 91% recaptured), while 12.8% of the Fantail Darter moved (out of 39% recaptured). A study on Rainbow Darter in the Grand River found that median movement distance was 5 m (from four sampling events spanning two summers), except during May, the presumed spawning season, when a small number of movements exceeded 100 m (including one fish moving almost a kilometer). Overall, approximately 85% of tagged individuals remained within the riffle where they were initially captured (Hicks and Servos 2017).

Predation is also a potential risk to all life stages of Kidneyshell from a number of fish species (e.g., Lake Sturgeon [*Acipenser fulvescens*], Freshwater Drum [*Aplodinotus grunniens*], Pumpkinseed [*Lepomis gibbosus*], redhorses [*Moxostoma* spp.], catfishes), birds (e.g., diving ducks), and mammals (e.g., mink/fisher, muskrat, raccoon) (Custer and Custer 1996, Mulcrone 2005). Owen et al. (2011) found that Kidneyshell was one of several larger, thick-shelled mussel species generally avoided by muskrats. 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.

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

Reduced habitat quality through agricultural and urban land use practices that result in heavy nutrient loads, siltation/sedimentation of watercourses, and contaminant inputs from road or field run-off or wastewater is the biggest threat to most extant Kidneyshell populations in Canada. Nutrient loading can result in increased algal growth and decreased dissolved oxygen, which can negatively impact productivity of fishes and mussels. Increased sedimentation can clog siphons and/or gills, decrease feeding, respiration and reproduction, and turbidity may reduce visibility of prey-mimicking conglutinates leading to reduced host encounters and recruitment success. Mussels may experience toxic impacts from short- or long-term exposure to contaminants. Acutely toxic contaminant levels can negatively affect mussel survival, and chronic exposure can affect growth, reproduction, and survival. Climate change is likely to have wide ranging impacts that will affect species differently, but generally will exacerbate habitat degradation from anthropogenic disturbances.

Unionids are all sensitive to water quality, and thus any efforts to reduce pollution inputs or sedimentation from agricultural and urban sources would benefit all mussel species co-occurring with Kidneyshell. Kidneyshell occurs with many other SARA-listed mussels in the Ausable and Sydenham rivers, which contain 26 (including 7 SAR), and 34 (14 SAR) mussel species, respectively (McNichols-O'Rourke et al. 2012). Improved agricultural practices and use of appropriate mitigations (e.g., sediment screens, adequate riparian buffers, cattle fencing, etc.), as well as improvements to wastewater treatment plants that input into these rivers (Nikel et al. 2023) would benefit Kidneyshell and all aquatic species occupying its habitat. Notably, critical habitat identified for Kidneyshell (DFO 2013, DFO 2016) overlaps with critical habitat identified for several other species at risk, including Fawnsfoot (*Truncilla donaciformis*), Northern Riffleshell (*Epioblasma rangiana*), Rayed Bean (*Paetulunio fabalis*), Round Hickorynut (*Obovaria subrotunda*), Round Pigtoe (*Pleurobema sintoxia*), Salamander Mussel (*Simpsonaias ambigua*), Snuffbox (*E. triquetra*), Threehorn Wartyback (*Obliquaria reflexa*), as well as benthic fishes Eastern Sand Darter (*Ammocrypta pellucida*) and Northern Madtom (*Noturus stigmosus*); all of which would benefit from abatement of threats to Kidneyshell.

Standardized monitoring for mussels and fishes recurs periodically in the Ausable and Sydenham rivers through DFO's Unionid Monitoring and Biodiversity Observation (UMBO) network in partnership with the ABCA and the St. Clair Region Conservation Authority. As Kidneyshell is a long-lived species, long-term monitoring data is required to properly evaluate impacts of threats or mitigation measures and threat abatement. A variety of fisheries surveys, notably for SARA-listed fishes periodically and invasive Asian carps annually (e.g., Barnucz et al. 2020, Barnucz and Drake 2021a,b, Aguiar et al. 2021), are conducted in the Ausable and Sydenham rivers that could provide an indication of host fish population status and trends, and would likely detect invasive fishes and possibly other aquatic invasive taxa, should they occur. Water quality monitoring also occurs in the watersheds with Kidneyshell. The Provincial Water Quality Monitoring Network samples numerous sites (on a rotating basis) annually and measures nutrients (total and dissolved), metals, and chloride (see Appendix 3 of Colm and Morris 2023). Additional water quality monitoring aimed largely at nutrient management (including total phosphorous, *E. coli*, and benthic invertebrate biomonitoring) is conducted by Ontario Conservation Authorities (ABCA 2018a,b, SCRCA 2018). Monitoring contaminants of concern through time at sites where Kidneyshell is found would be helpful to understand levels of exposure.

## SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

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

Threats to species survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects that could result from works, undertakings, or activities (w/u/a) associated with projects in Kidneyshell habitat.

Within Kidneyshell habitat, a variety of w/u/a have occurred in the last several years. 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 (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. The review did not include areas with historical records where the species is thought to be extirpated (i.e., Lake St. Clair, Thames River watershed, Detroit River, north shore of Lake Erie, Grand River, Niagara River). Project types in the PATH database found on tributaries near Kidneyshell records included: bridge and culvert construction and maintenance (n = 4 on Sydenham River tributaries), and dredging for agricultural drain maintenance (n = 4 on Ausable River tributaries; n = 8 on Sydenham River tributaries). Additionally, there were two (including the one above), three, three, and zero projects that occurred within critical habitat on the Ausable, Sydenham, 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; Table 11). 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). Additionally, the benefits of intact riparian vegetation buffers to freshwater mussels (including Kidneyshell) was recently evaluated in the Sydenham River, where improved water quality (decreased ammonia concentrations and increased dissolved oxygen in the surface water) was found at sites with intact buffers 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 and other problematic species and genes) 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.

## INVASIVE AND OTHER PROBLEMATIC SPECIES AND GENES

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.

## Alternatives

- Unauthorized introductions
  - None
- Authorized introductions
  - Do not stock non-native species in areas inhabited by Kidneyshell.
  - Do not enhance habitat for non-native species in areas inhabited by Kidneyshell
  - Follow the National Code on Introductions and Transfers of Aquatic Organisms for all aquatic organism introductions (DFO 2017).

# SOURCES OF UNCERTAINTY

Sources of uncertainty have been organized into research themes based on Drake et al. (2021) to create consistency across RPAs and to aid in planning and prioritization of research objectives.

## Population Ecology

### Abundance and Distribution

The historical abundance and distribution of Kidneyshell in Ontario is poorly understood, making it difficult to identify appropriate abundance and distribution targets. In some localities, only shells have been found (e.g., Thames and Grand rivers) so the full extent of the distribution cannot be known. It is also unknown if the sparse records in Lake St. Clair and Lake Erie actually represented populations, or if these were individuals that had flushed down from nearby rivers (e.g., St. Clair, Detroit, Grand rivers). Historical observations of the species were often incidental and do not include information about sampling effort; standardized sampling efforts were not conducted in most locations prior to 1997. Additionally, standardized sampling efforts can be difficult in some locations (i.e., where scuba diving is required) or not feasible (e.g., upper Niagara River due to flows). All of these gaps make inferences about changes in abundance and distribution through time difficult. Although these gaps cannot be filled, it highlights the importance of long-term standardized monitoring continuing into the future.

Current abundance estimates are also lacking. Coarse estimates have been made for the Ausable and Sydenham rivers, but additional data are needed to refine these. There have been no observations of the species in Lake St. Clair or Medway Creek since 2003 or 2008, respectively, and there was no evidence of reproduction at those times. These populations are likely extirpated.

### Species Interactions

There is limited information available on the relationships between Kidneyshell and its host fishes (e.g., ideal host density, exact timing and rates of infestation, movement of hosts, etc.). There is some evidence from a reproductive study in the Ausable and Sydenham rivers that host use may differ between localities. Watershed specificity of hosts could have implications if translocations were to be undertaken.

Round Goby is negatively affecting many darters in the Great Lakes basin. The putative darter hosts of Kidneyshell still persist in the Ausable and Sydenham rivers despite overlap with Round Goby, but it is unknown to what extent Round Goby may be indirectly impacting Kidneyshell through other limitations to host fishes, or to what extent the benthic fish community will be impacted in the Ausable River should Round Goby extend further upstream.

Freshwater mussels often occur in multi-species beds where species at risk are usually found in amongst these complex species aggregations rather than individually (Eveleens et al. 2023) although the mechanisms of interactions within these beds and how they impact population dynamics are poorly understood. Although quantitative analyses have not been undertaken for most other co-occurring mussels, qualitatively, populations of some species seem to be declining while others (including Kidneyshell) appear to be stable or increasing.

### Life History

There remain many unknowns around the life history of Kidneyshell (see Fung et al. 2025). The exact timing of spawning and conglutinate release in Ontario is unknown as there are differences between timing reported in the literature (primarily in the American range), and field observations from Ontario. This is important for identifying suitable timing windows for in water works.

## Habitat

### Species-habitat Associations by Life Stage

General habitat characteristics for Kidneyshell have been described in the literature, and likely sufficiently describe suitable habitat. However, optimal habitat for Kidneyshell is poorly understood. Literature suggests Kidneyshell prefers clear water, yet it persists in extremely turbid environments in Ontario. The preferred temperature, flow, depth, and dissolved oxygen concentration are not known. These parameters are important for considering possible causes of extirpation, susceptibility to threats, and habitat restoration targets.

### Habitat Supply

The availability of suitable habitat in extant localities is also not known. Long stretches (70–100 km) in the Ausable and Sydenham rivers over which the species has been detected have been identified as likely habitat, but it is unlikely that the entirety of these reaches is suitable. The presumed functional host fishes of Kidneyshell are widespread throughout these identified stretches and it is assumed that habitat is sufficient for them as well, but this may not be true if hosts are not at optimal density.

## Threats

There is substantial literature evaluating direct impacts of many stressors (particularly pollutants) on freshwater mussels; however, the degree to which these stressors are impacting populations of Kidneyshell in Canada is unclear. The Ausable and Sydenham river populations appear stable or to be increasing, but pervasive threats in these localities, largely related to agricultural land use, are likely slowing recovery. Physiological thresholds for the species are not known and may help understand the mechanism or magnitude of impact of threats. For example, a rapid mass die-off event following an agricultural spill in an Ohio river suggested that Kidneyshell may be especially sensitive to low dissolved oxygen, but this has not been tested. Additionally, there is limited information available on the relationships between Kidneyshell and host fishes in general, so how threats to Kidneyshell or its hosts impact these relationships, and how threats to the hosts indirectly impact Kidneyshell are also unknowns.

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# APPENDIX 1

*Table A1.1. Summary of all timed-search sampling completed in waterbodies where Kidneyshell was historically known (live or shells) from 1997–2023. Specimens from the American side of the waterbody are presented in brackets, where applicable, from survey efforts that spanned the border. Effort, if reported, was typically reported as person-hours (PH) of searching, but was occasionally reported as an area covered ($m^2$). Data are summarized from the Lower Great Lakes Unionid Database.*

| Waterbody | Year | Number of Live Kidneyshell | Number of Fresh Shells or Valves | Number of Weathered Shells or Valves | Number of Sites Sampled | Number of Sites with Live Kidneyshell | Effort (when reported) |
|---|---|---|---|---|---|---|---|
| Ausable River | 1998 | 27 | 17 | 8 | 9 | 3 | 34.5 PH |
| Ausable River | 1999 | 0 | 0 | 0 | 2 | 0 | - |
| Ausable River | 2000 | 0 | 0 | 0 | 1 | 0 | - |
| Ausable River | 2001 | 0 | 0 | 0 | 1 | 0 | - |
| Ausable River | 2002 | 32 | 0 | 0 | 4 | 4 | 18.0 PH |
| Ausable River | 2003 | 0 | 0 | 0 | 1 | 0 | |
| Ausable River | 2004 | 4 | 0 | 1 | 8 | 2 | 36.0 PH |
| Ausable River | 2007 | 0 | 0 | 0 | 1 | 0 | 4.5 PH |
| Ausable River | 2008 | 88 | 0 | 0 | 9 | 4 | 18.0 PH |
| Ausable River | 2009 | 0 | 0 | 0 | 3 | 0 | 9.0 PH |
| Ausable River | 2010 | 1 | 0 | 0 | - | 1 | - |
| Ausable River | 2012 | 265 | 0 | 0 | 1 | 1 | - |
| Ausable River | 2013 | 73 | 0 | 0 | 6 | 2 | 0.8 PH; 300 $m^2$ |
| Ausable River | 2014 | 4 | 0 | 0 | 1 | 1 | - |
| Ausable River | 2015 | 0 | 0 | 0 | 1 | 0 | - |
| Ausable River | 2016 | 0 | 0 | 2 | 1 | 0 | - |
| Ausable River | 2018 | 0 | 0 | 0 | 2 | 0 | - |
| Ausable River | 2019 | 12 | 0 | 0 | 0 | 1 | - |
| Ausable River | 2022 | 0 | 0 | 0 | 23 | 0 | 11,100 m brail |
| Bear Creek (North Sydenham River) | 1997 | 0 | 0 | 0 | 1 | 0 | 4.5 PH |

| Waterbody | Year | Number of Live Kidneyshell | Number of Fresh Shells or Valves | Number of Weathered Shells or Valves | Number of Sites Sampled | Number of Sites with Live Kidneyshell | Effort (when reported) |
|---|---|---|---|---|---|---|---|
| Bear Creek (North Sydenham River) | 1998 | 0 | 0 | 0 | 3 | 0 | 13.5 PH |
| Bear Creek (North Sydenham River) | 2011 | 0 | 0 | 0 | 1 | 0 | - |
| Bear Creek (North Sydenham River) | 2013 | 0 | 0 | 0 | 1 | 0 | - |
| Bear Creek (North Sydenham River) | 2016 | 0 | 0 | 0 | 3 | 0 | 455 $m^2$ |
| Bear Creek (North Sydenham River) | 2017 | 0 | 0 | 0 | 15 | 0 | 63.0 PH; 10 $m^2$ |
| Bear Creek (North Sydenham River) | 2018 | 0 | 0 | 1 | 21 | 0 | 94.6 PH |
| Bear Creek (North Sydenham River) | 2020 | 0 | 0 | 0 | 4 | 0 | 9.0 PH; 10 $m^2$ |
| Bear Creek (North Sydenham River) | 2022 | 0 | 0 | 0 | 7 | 0 | 18 PH |
| Detroit River | 1998 | 0 (1) | 0 | 0 | 11 | 1 | - |
| Detroit River | 2019 | 0 | 0 | 43(78) | 56 | 0 | 64.0 PH |
| Detroit River | 2022 | 0 | 0 | 0 | 4 | 0 | 4 PH |
| Feeder Canal (Niagara River) | 2008 | 0 | 0 | 0 | 2 | 0 | - |
| Feeder Canal (Niagara River) | 2012 | 0 | 0 | 0 | 1 | 0 | - |
| Feeder Canal (Niagara River) | 2015 | 0 | 0 | 1 | 4 | 0 | 7.5 PH |
| Grand River | 1997 | 0 | 0 | 4 | 13 | 0 | 54.5 PH |
| Grand River | 1998 | 0 | 0 | 0 | 10 | 0 | 22.5 PH |
| Grand River | 2001 | 0 | 0 | 0 | 2 | 0 | - |
| Grand River | 2004 | 0 | 0 | 0 | 9 | 0 | 22.5 PH |
| Grand River | 2005 | 0 | 0 | 0 | 2 | 0 | 2.5 PH |
| Grand River | 2006 | 0 | 0 | 0 | 8 | 0 | - |

| Waterbody | Year | Number of Live Kidneyshell | Number of Fresh Shells or Valves | Number of Weathered Shells or Valves | Number of Sites Sampled | Number of Sites with Live Kidneyshell | Effort (when reported) |
|---|---|---|---|---|---|---|---|
| Grand River | 2007 | 0 | 0 | 0 | 9 | 0 | 8.7 PH |
| Grand River | 2008 | 0 | 0 | 0 | 15 | 0 | 825 $m^2$ |
| Grand River | 2009 | 0 | 0 | 0 | 9 | 0 | 37.2 PH |
| Grand River | 2010 | 0 | 0 | 0 | 8 | 0 | 39.6 PH |
| Grand River | 2011 | 0 | 0 | 0 | 21 | 0 | 84.8 PH; 441.2 $m^2$ |
| Grand River | 2012 | 0 | 0 | 0 | 33 | 0 | 98 PH |
| Grand River | 2013 | 0 | 0 | 0 | 15 | 0 | 44.5 PH; 30 $m^2$ |
| Grand River | 2014 | 0 | 0 | 0 | 6 | 0 | 51.3 PH |
| Grand River | 2015 | 0 | 0 | 0 | 4 | 0 | 17.5 PH |
| Grand River | 2016 | 0 | 0 | 0 | 1 | 0 | - |
| Grand River | 2017 | 0 | 0 | 0 | 7 | 0 | 27.2 PH |
| Grand River | 2018 | 0 | 0 | 0 | 7 | 0 | 36.0 PH |
| Grand River | 2019 | 0 | 0 | 0 | 107 | 0 | 54.5 PH; 72,000 m brail |
| Grand River | 2020 | 0 | 1 | 2 | 5 | 0 | 1.5 PH; 15,814 $m^2$ |
| Grand River | 2021 | 0 | 0 | 0 | 18 | 0 | 81.0 PH |
| Lake Erie (Rondeau Bay) | 2001 | 0 | 0 | > 0 | 6 | 0 | - |
| Lake Erie (Pelee Island) | 2005 | 0 | 0 | 4 | 17 | 0 | 17.3 PH |
| Lake Erie | 2006 | 0 | 0 | 0 | 1 | 0 | 1.2 PH |
| Lake Erie | 2013 | 0 | 0 | 0 | 4 | 0 | - |
| Lake Erie (Rondeau Bay) | 2014 | 0 | 0 | 12 | 12 | 0 | 54.0 PH |
| Lake Erie (Rondeau Bay) | 2015 | 0 | 0 | 0 | 15 | 0 | 67.5 PH |
| Lake Erie | 2021 | 0 | 0 | 0 | 1 | 0 | - |
| Lake St. Clair | 1998 | 0 | 0 | 0 | 19 | 0 | - |
| Lake St. Clair | 1999 | 6 | 0 | 0 | 71 | 5 | - |
| Lake St. Clair | 2000 | 0 | 0 | 0 | 10 | 0 | - |
| Lake St. Clair | 2001 | 0(1) | 0 | 0 | 10 | 1 | - |
| Lake St. Clair | 2003 | 1(1) | 0 | 0 | 28 | 2 | 10.7 PH |

| Waterbody | Year | Number of Live Kidneyshell | Number of Fresh Shells or Valves | Number of Weathered Shells or Valves | Number of Sites Sampled | Number of Sites with Live Kidneyshell | Effort (when reported) |
|---|---|---|---|---|---|---|---|
| Lake St. Clair | 2004 | 0 | 0 | 0 | 5 | 0 | - |
| Lake St. Clair | 2005 | 0 | 0 | 0 | 4 | 0 | 14.5 PH |
| Lake St. Clair | 2006 | 0 | 0 | 0 | 2 | 0 | - |
| Lake St. Clair | 2011 | 0 | 0 | 0 | 11 | 0 | 27.0 PH |
| Lake St. Clair | 2015 | 0 | 0 | 0 | 1 | 0 | - |
| Lake St. Clair | 2016 | 0 | 0 | 0 | 8 | 0 | 1.0 PH |
| Lake St. Clair | 2017 | 0 | 0 | 0 | 2 | 0 | - |
| Medway Creek (Thames River) | 1998 | 0 | 0 | 0 | 1 | 0 | - |
| Medway Creek (Thames River) | 2001 | 0 | 0 | 0 | 1 | 0 | - |
| Medway Creek (Thames River) | 2003 | 0 | 0 | 0 | 2 | 0 | 1.0 PH |
| Medway Creek (Thames River) | 2004 | 2 | 0 | 0 | 3 | 1 | 9.0 PH |
| Medway Creek (Thames River) | 2005 | 0 | 0 | 0 | 1 | 0 | 4.5 PH |
| Medway Creek (Thames River) | 2006 | 2 | 0 | 0 | 1 | 1 | - |
| Medway Creek (Thames River) | 2007 | 0 | 0 | 0 | 1 | 0 | - |
| Medway Creek (Thames River) | 2008 | 2 | 0 | 0 | 2 | 1 | - |
| Medway Creek (Thames River) | 2010 | 0 | 0 | 0 | 4 | 0 | 6 $m^2$ |
| Medway Creek (Thames River) | 2012 | 0 | 0 | 0 | 3 | 0 | 40.0 PH |
| Medway Creek (Thames River) | 2013 | 0 | 0 | 0 | 6 | 0 | 50.0 PH; 60 $m^2$ |
| Medway Creek (Thames River) | 2014 | 0 | 0 | 0 | 3 | 0 | 14.0 PH |

| Waterbody | Year | Number of Live Kidneyshell | Number of Fresh Shells or Valves | Number of Weathered Shells or Valves | Number of Sites Sampled | Number of Sites with Live Kidneyshell | Effort (when reported) |
|---|---|---|---|---|---|---|---|
| Medway Creek (Thames River) | 2015 | 0 | 0 | 0 | 5 | 0 | 14 PH |
| Medway Creek (Thames River) | 2018 | 0 | 0 | 0 | 1 | 0 | - |
| Medway Creek (Thames River) | 2021 | 0 | 0 | 0 | 3 | 0 | 8.5 PH |
| Nairn Creek (Ausable River) | 2002 | 0 | 0 | 0 | 1 | 0 | 4.5 PH |
| Nairn Creek (Ausable River) | 2010 | 1 | 0 | 0 | 2 | 1 | 30 PH |
| Nairn Creek (Ausable River) | 2014 | 0 | 0 | 0 | 9 | 0 | - |
| Niagara River | 2001 | 0 | 0(1) | 0(2) | 7 | 0 | 31.5 PH |
| Niagara River | 2002 | 0 | 0(1) | 0 | 5 | 0 | 22.5 PH |
| Nith River (Grand River) | 1997 | unk | unk | unk | 11 | 0 | 9.0 PH |
| Nith River (Grand River) | 1998 | 0 | 0 | 0 | 4 | 0 | 4.5 PH |
| Nith River (Grand River) | 2006 | 0 | 0 | 0 | 1 | 0 | - |
| Nith River (Grand River) | 2007 | 0 | 0 | 0 | 3 | 0 | - |
| Nith River (Grand River) | 2019 | 0 | 0 | 0 | 1 | 0 | 4.5 PH |
| Nith River (Grand River) | 2021 | 0 | 0 | 0 | 1 | 0 | 4.5 PH |
| Sydenham River | 1997 | 11 | 45 | 2 | 8 | 5 | 36.0 PH |
| Sydenham River | 1998 | 16 | 8 | 7 | 5 | 4 | 18.5 PH |
| Sydenham River | 1999 | 0 | 0 | 0 | 6 | 0 | - |
| Sydenham River | 2000 | 0 | 0 | 0 | 1 | 0 | - |
| Sydenham River | 2001 | 0 | 0 | 0 | 15 | 0 | - |
| Sydenham River | 2002 | 75 | 0 | 0 | 34 | 22 | 4.5 PH |
| Sydenham River | 2003 | 51 | 0 | 0 | 9 | 4 | 39.3 PH |
| Sydenham River | 2004 | 0 | 0 | 0 | 2 | 0 | 46.0 PH |
| Sydenham River | 2005 | 37 | 0 | 0 | 9 | 4 | 40.0 PH |

| Waterbody | Year | Number of Live Kidneyshell | Number of Fresh Shells or Valves | Number of Weathered Shells or Valves | Number of Sites Sampled | Number of Sites with Live Kidneyshell | Effort (when reported) |
|---|---|---|---|---|---|---|---|
| Sydenham River | 2006 | 21 | 0 | 0 | 6 | 2 | 20.5 PH |
| Sydenham River | 2007 | 0 | 0 | 0 | 2 | 0 | 16.0 PH |
| Sydenham River | 2008 | 241 | 0 | 0 | 19 | 18 | 34.45 PH; 168 $m^2$ |
| Sydenham River | 2009 | 59 | 0 | 0 | 14 | 7 | 45.9 PH |
| Sydenham River | 2010 | 19 | 1 | 0 | 2 | 2 | 37.5 PH |
| Sydenham River | 2011 | 18 | 0 | 0 | 6 | 3 | 96.0 PH |
| Sydenham River | 2012 | 27 | 0 | 0 | 5 | 4 | 230.0 PH |
| Sydenham River | 2013 | 96 | 0 | 0 | 6 | 5 | 120.5 PH |
| Sydenham River | 2014 | 43 | 0 | 0 | 4 | 4 | 60.0 PH |
| Sydenham River | 2015 | 40 | 0 | 0 | 4 | 3 | 24.0 PH |
| Sydenham River | 2016 | 35 | 5 | 0 | 5 | 3 | 71.0 PH |
| Sydenham River | 2017 | 46 | 0 | 0 | 7 | 6 | 64.5 PH |
| Sydenham River | 2018 | 56 | 0 | 0 | 17 | 6 | 79.5 PH |
| Sydenham River | 2019 | 8 | 0 | 1 | 32 | 8 | 152.2 PH |
| Sydenham River | 2020 | 35 | 6 | 0 | 14 | 12 | 49.5 PH; 50 $m^2$ |
| Sydenham River | 2021 | 44 | 0 | 0 | 5 | 0 | - |
| Sydenham River | 2022 | 58 | 0 | 0 | 40 | 5 | 18.0 PH; 16,200 m brail |
| Thames River | 1997 | 0 | 2 | 4 | 12 | 0 | 45.0 PH |
| Thames River | 1998 | 0 | 0 | 1 | 6 | 0 | 4.5 PH |
| Thames River | 2001 | 0 | 0 | 0 | 1 | 0 | - |
| Thames River | 2004 | 0 | 0 | 0 | 6 | 0 | 12.0 PH |
| Thames River | 2005 | 0 | 1 | 2 | 9 | 0 | 40.5 PH |
| Thames River | 2006 | 0 | 0 | 0 | 1 | 0 | - |
| Thames River | 2008 | 0 | 0 | 0 | 9 | 0 | 4.0 PH |
| Thames River | 2009 | 0 | 0 | 0 | 2 | 0 | - |
| Thames River | 2010 | 0 | 0 | 0 | 2 | 0 | 1.0 PH |
| Thames River | 2011 | 0 | 1 | 1 | 8 | 0 | 80.0 PH; 70 $m^2$ |

| Waterbody | Year | Number of Live Kidneyshell | Number of Fresh Shells or Valves | Number of Weathered Shells or Valves | Number of Sites Sampled | Number of Sites with Live Kidneyshell | Effort (when reported) |
|---|---|---|---|---|---|---|---|
| Thames River | 2012 | 0 | 0 | 0 | 7 | 0 | 1007 $m^2$ |
| Thames River | 2013 | 0 | 0 | 0 | 6 | 0 | 643 $m^2$ |
| Thames River | 2014 | 0 | 0 | 0 | 2 | 0 | 32.0 PH |
| Thames River | 2015 | 0 | 0 | 0 | 8 | 0 | 50.0 PH |
| Thames River | 2016 | 0 | 0 | 0 | 6 | 0 | 38.0 PH |
| Thames River | 2017 | 0 | 0 | 1 | 1 | 0 | - |
| Thames River | 2018 | 0 | 0 | 0 | 4 | 0 | 9.0 PH |
| Thames River | 2019 | 0 | 0 | 0 | 4 | 0 | 13.5 PH |
| Thames River | 2020 | 0 | 0 | 0 | 2 | 0 | 1.5 PH |
| Thames River | 2021 | 0 | 0 | 1 | 14 | 0 | 41.5 PH |
| Thames River | 2022 | 0 | 0 | 1 | 45 | 0 | 54.0 PH; 19,500 m brail |
| Welland River (Niagara River) | 2008 | 0 | 0 | 0 | 6 | 0 | - |
| Welland River | 2014 | 0 | 0 | 0 | 1 | 0 | 12.5 PH |
| Welland River | 2015 | 0 | 0 | 0 | 9 | 0 | 37.5 PH |
| Welland River | 2016 | 0 | 0 | 0 | 1 | 0 | 9.0 PH |
| Welland River | 2017 | 0 | 0 | 0 | 2 | 0 | 14.5 PH |
| Welland River | 2019 | 0 | 0 | 0 | 2 | 0 | - |
| Welland River | 2020 | 0 | 0 | 0 | 2 | 0 | - |

*Table A1.2. Summary of all quadrat surveys completed in waterbodies where Kidneyshell was historically known (live or shells) from 1997–2023.*

| Waterbody | Year | Number of Live Kidneyshell | Number of Quadrats Sampled ($m^2$) | Number of Quadrats with Live Kidneyshell | Number of Blocks Sampled | Number of Blocks with Live Kidneyshell |
|---|---|---|---|---|---|---|
| Ausable River | 2006 | 138 | 506 | 78 | 144 | 44 |
| Ausable River | 2007 | 0 | 66 | 0 | 22 | 0 |
| Ausable River | 2008 | 4 | 199 | 4 | 74 | 4 |
| Ausable River | 2009 | 0 | 146150 | 0 | 56 | 0 |
| Ausable River | 2011 | 102 | 457 | 4 | 6 | 4 |
| Ausable River | 2013 | 0 | 75 | 0 | 3 | 0 |
| Ausable River | 2018 | 36 | 226 | 2 | 3 | 2 |
| Ausable River | 2019 | 229 | 226 | 2 | 3 | 2 |
| Ausable River | 2022 | 0 | 75 | 0 | 3 | 0 |
| Little Ausable River | 2006 | 0 | 77 | 0 | 1 | 0 |
| Little Ausable River | 2011 | 0 | 75 | 0 | 1 | 0 |
| Little Ausable River | 2018 | 1 | 75 | 1 | 1 | 1 |
| Nairn Creek | 2014 | 0 | 1 | 0 | 1 | 0 |
| Grand River | 2007 | 0 | 234 | 0 | 78 | 0 |
| Grand River | 2010 | 0 | 225 | 0 | 75 | 0 |
| Grand River | 2017 | 0 | 300 | 0 | 100 | 0 |
| Grand River | 2018 | 0 | 225 | 0 | 75 | 0 |
| Sydenham River | 1999 | 20 | 147 | 19 | 49 | 15 |
| Sydenham River | 2001 | 17 | 156 | 14 | 52 | 13 |
| Sydenham River | 2002 | 23 | 306 | 21 | 102 | 18 |
| Sydenham River | 2003 | 11 | 312 | 11 | 104 | 11 |
| Sydenham River | 2012 | 243 | 591 | 190 | 97 | 57 |
| Sydenham River | 2013 | 139 | 300 | 82 | 100 | 48 |
| Sydenham River | 2015 | 216 | 150 | 110 | 50 | 49 |
| Sydenham River | 2017 | 13 | 50 | 4 | 5 | 2 |
| Sydenham River | 2020 | 6 | 50 | 6 | 5 | 4 |
| Sydenham River | 2021 | 19 | 50 | 12 | 5 | 4 |
| Sydenham River | 2022 | 218 | 300 | 142 | 100 | 78 |
| Bear Creek (N Sydenham River) | 2001 | 0 | 80 | 0 | 20 | 0 |
| Bear Creek (N Sydenham River) | 2002 | 0 | 72 | 0 | 24 | 0 |
| Bear Creek (N Sydenham River) | 2003 | 0 | 75 | 0 | 25 | 0 |
| Bear Creek (N Sydenham River) | 2012 | 0 | 73 | 0 | 24 | 0 |
| Bear Creek (N Sydenham River) | 2013 | 0 | 75 | 0 | 25 | 0 |

| Waterbody | Year | Number of Live Kidneyshell | Number of Quadrats Sampled ($m^2$) | Number of Quadrats with Live Kidneyshell | Number of Blocks Sampled | Number of Blocks with Live Kidneyshell |
|---|---|---|---|---|---|---|
| Bear Creek (N Sydenham River) | 2015 | 0 | 75 | 0 | 25 | 0 |
| Bear Creek (N Sydenham River) | 2022 | 0 | 75 | 0 | 25 | 0 |
| Thames River | 2004 | 0 | 66 | 0 | 22 | 0 |
| Thames River | 2005 | 0 | 69 | 0 | 23 | 0 |
| Thames River | 2010 | 0 | 270 | 0 | 90 | 0 |
| Thames River | 2015 | 0 | 150 | 0 | 50 | 0 |
| Thames River | 2016 | 0 | 150 | 0 | 50 | 0 |
| Thames River | 2017 | 0 | 150 | 0 | 50 | 0 |

*Table A1.3. Historical (pre-1997) records of Kidneyshell. Specimens from the American side of the waterbody are presented in brackets, where applicable, from survey efforts that spanned the border. Sampling effort or method were seldom recorded. State of specimen or condition of shells was not always available (indicated with unk for unknown).*

| Waterbody Name | Year | Live Kidneyshell | Fresh Shells or Valves | Weathered Shells or Valves |
|---|---|---|---|---|
| Ausable River | 1994 | 6 | 0 | 0 |
| Welland River (Chippawa Creek) | pre-1926 | 0 | 0 | ~15 |
| Detroit River | 1982 | 1(15) | 1(8) | 0 |
| Detroit River | 1983 | 0(17) | 0 | 30 |
| Detroit River | 1984 | 1(5) | 0 | 8(19) |
| Detroit River | 1992 | 0(63) | 39(31) | 0 |
| Detroit River | 1994 | 0(1) | 0(54) | 0 |
| Grand River | 1934 | 0 | 1 | 0 |
| Grand River | 1935 | unk | ≥ 1 | unk |
| Grand River | 1963 | 0 | 2 | 0 |
| Grand River | 1966 | 0 | 0 | > 0 |
| Grand River | 1972 | 0 | 21 | 0 |
| Grand River | 1988 | 0 | 1 | 0 |
| Lake Erie (Port Colborne) | 1885 | 0 | 2 | 0 |
| Lake Erie (Western Basin north shore) | 1890 | 0 | 1 | 0 |
| Lake Erie (Port Colborne) | 1934 | 0 | 1 | 0 |
| Lake Erie | 1937 | unk | unk | unk |
| Lake Erie (Pelee Island) | 1953 | 0 | 1 | 0 |
| Lake Erie (Pelee Island) | 1957 | 0 | 1 | 0 |
| Lake Erie (Pelee Island) | 1960 | 0 | 13 | 0 |

| Waterbody Name | Year | Live Kidneyshell | Fresh Shells or Valves | Weathered Shells or Valves |
|---|---|---|---|---|
| Lake Erie (Pelee Island) | 1961 | 0 | 1 | 0 |
| Lake Erie (Pelee, PC, LPB) | 1963 | unk | ≥ 4 | unk |
| Lake Erie (Pelee Island) | 1966 | 0 | 3 | 0 |
| Lake Erie (Pelee Island) | 1967 | 0 | 4 | 0 |
| Lake Erie (Pelee Island) | 1968 | unk | unk | unk |
| Lake Erie (Pelee Island) | 1969 | 0 | 9 | 0 |
| Lake Erie (Pelee Island) | 1977 | 0 | 3 | 0 |
| Lake Erie (Pelee Island) | 1978 | 0 | 5 | 0 |
| Lake Erie (Western Basin north shore) | 1982 | unk | unk | unk |
| Lake Erie (Pelee Island) | 1985 | unk | unk | unk |
| Lake Erie (Pelee Island) | 1990 | 0 | 11 | 0 |
| Lake Erie (Pelee Island) | 1992 | unk | unk | unk |
| Lake Erie (Western Basin north shore) | 1993 | unk | unk | unk |
| Lake St. Clair | 1934 | 0 | 2 | 0 |
| Niagara River | 1934 | 0 | 1 | 0 |
| Sydenham River | 1963 | 1 | 0 | 0 |
| Sydenham River | 1965 | 2 | 23 | 0 |
| Sydenham River | 1967 | 13 | 35 | 0 |
| Sydenham River | 1971 | 3 | 0 | 0 |
| Sydenham River | 1973 | 5 | 5 | 0 |
| Sydenham River | 1985 | unk | unk | unk |
| Sydenham River | 1991 | 14 | 0 | 0 |
| Sydenham River | 1992 | unk | unk | unk |
| Thames River | 1894 | 0 | 2 | 0 |
| Thames River | 1933 | unk | unk | unk |
| Thames River | 1995 | 0 | 1 | 0 |

## APPENDIX 2

*Table A2.1. Additional justification and literature support for threat impacts and causal certainty scoring. The reference list provided is not an exhaustive list of literature on the topic, but is meant to be representative of important considerations for Kidneyshell in Ontario.*

| IUCN Threat Category | Sub-category | Details | Level of Impact | References |
|---|---|---|---|---|
| Pollution | Agricultural and Forestry Effluents | Sedimentation (field runoff, upstream drain maintenance) | Glochidia are highly sensitive to pollutants like chloride, ammonia, potassium, etc., but Kidneyshell populations are most sensitive to harm to adults (Fung et al. 2025). A substantial body of literature exists on pollution impacts to freshwater mussels across life stages and over acute and chronic periods of exposure, but there is no evidence that these pollutants are currently causing a decline in either the Ausable or Sydenham rivers. Some pollutants may have extreme impacts locally (e.g., immediately downstream of point sources), at certain times of the year (e.g., chloride pulses associated with spring melt), or to more sensitive life stages (e.g., glochidia). It is likely these contaminants are not occurring at high enough concentrations (at least chronically) to cause population-level impacts. These considerations make different interpretations of the level of impact of various pollutants possible. | Aldridge et al. 1987, Madon et al. 1998, Brim-Box and Mossa 1999, Osterling et al. 2010, Tokumen et al. 2016, Tuttle-Raycraft and Ackerman 2017 and 2019, Goldsmith et al. 2021, Luck and Ackerman 2022 |
| | | Nutrient Loading (+ ammonia and potassium) | | Augsperger et al. 2003, Wang et al. 2007, Salerno et al. 2020, Gillis et al. 2021 |
| | | Pesticides (+ granular Bayluscide) | | Keller and Ruessler 1997, Bringolf et al. 2007, Prosser et al. 2016, Salerno et al. 2018; Newton et al. 2017, Andrews et al. 2021, Smyth and Drake 2021 |
| | Domestic and Urban Wastewater (incl. urban runoff) | Nutrient Loading (+ ammonia) | | Augsperger et al. 2003, Wang et al. 2007, Gillis et al. 2017b, Salerno et al. 2020, Gillis et al. 2021, |
| | | Pharmaceuticals and estrogenic compounds | | Gagné et al. 2004, Gagné et al. 2011, de Solla et al. 2016, Gilroy et al. 2014, 2017; Gillis et al. 2014, 2017; Hayward et al. 2022 |
| | | Chloride | | Gillis 2011; Todd and Kaltenecker 2012; Pandolfo et al. 2012b; Prosser et al. 2017; Gillis et al. 2021, Gillis et al. 2022 |
| | | Heavy Metals / PHAs | | Keller and Zam 1991, Marvin et al. 1994, Naimo 1995, Archambault et al. 2018, Salerno et al. 2020 |
| Invasive and other Problematic Species and Genes | | Round Goby, Dreissenid mussels | Dreissenid mussels are the likely cause of the extirpation of most native unionids (including Kidneyshell) in the Great Lakes and connecting channels, but are less successful in lotic systems and the densities at which they are expected to persist likely pose a low threat to Kidneyshell in extant locations. | Poos et al. 2010, French and Jude 2001, Tremblay et al. 2016, Gillis and Mackie 1994, Schloesser and Nalepa 1994, Nalepa et al. 1996, Ricciardi et al. 1996, Schloesser et al. 2006 |

| IUCN Threat Category | Sub-category | Details | Level of Impact | References |
|---|---|---|---|---|
| | | | Direct impacts of Round Goby on Kidneyshell are thought to be limited. Indirect impacts through negative interactions with hosts are likely but outcomes are highly uncertain and context dependent. | |
| Climate Change and Severe Weather | - | Frequent and severe droughts and extreme temperatures | Impacts of climate change are measurable in Ontario. Mean annual temperatures are increasing, precipitation is increasing in the winter and decreasing in the summer, periods of ice cover are reduced. But these do not appear to be leading to declines in Kidneyshell at this time. | Golladay et al. 2004, Haag and Warren 2008, Galbraith et al. 2010, Spooner et al. 2011, Atkinson et al. 2014, McDermid et al. 2015, Brinker et al. 2018, Lopez et al. 2022, Fogelman et al. 2023 |