RECOVERY POTENTIAL ASSESSMENT OF PURPLE WARTYBACK (*CYCLONAIAS TUBERCULATA*)

Photo Credit: DFO

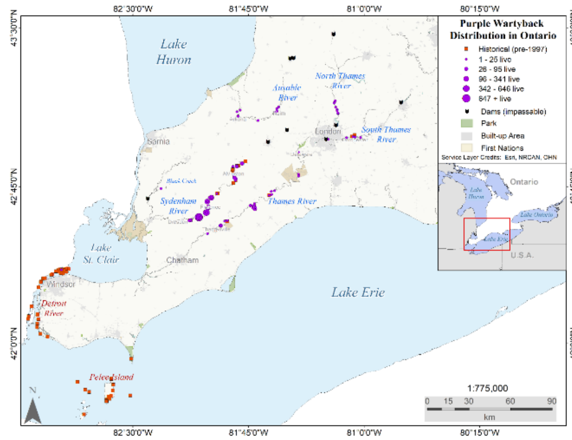

Figure 1. Distribution of Purple Wartyback in Canada. Red squares indicate historical records (prior to 1997) and purple circles indicate recent (1997–2022) collections of live individuals

Context:

*Purple Wartyback (*Cyclonaias tuberculata*) is a long-lived, medium-sized freshwater mussel currently found in three rivers in southwestern Ontario. It was assessed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in May 2021 owing to a restricted range, loss of two historical populations, and a continued decline in habitat quality related to pollution, climate change, aquatic invasive species and dredging activities.*

A Recovery Potential Assessment (RPA) process developed by Fisheries and Oceans Canada (DFO) was undertaken for Purple Wartyback in 2022 in support of the SARA listing decision. This RPA summarizes information up to 2022 on the distribution, abundance, population trends, habitat requirements of, and threats to (and potential mitigations for) Purple Wartyback in Canada, includes an allowable harm assessment and identifies suitable recovery targets. This information may be used to develop a recovery strategy and action plan, and provide scientific advice needed to meet various requirements of SARA, including decisions related to the issuance of permits and authorizations.

This Science Advisory Report is from the October 25-27, 2022 Recovery Potential Assessment of Purple Wartyback regional peer-review meeting held virtually over MS Teams. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule]() as they become available.

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SUMMARY

- Purple Wartyback is a long-lived (maximum age > 90 years) freshwater mussel (Unionidae). Age-at-maturity is estimated to be 6-10 years and generation time at 26 years in Canada.
- The current distribution of Purple Wartyback in Canada is limited to three rivers in southwestern Ontario, including the Ausable River (Lake Huron drainage), and the Sydenham and Thames rivers (Lake St. Clair drainage). Populations in the Sydenham and Thames rivers are showing positive population growth while the Ausable River is likely stable. It is extirpated from the Detroit River and Lake Erie around Pelee Island.
- In Canada, Purple Wartyback occupies medium to large rivers. Occurrence is associated with a range of habitat conditions including variable substrate types, depth, and water velocity.
- Purple Wartyback glochidia must encyst on the gills of an appropriate host fish to survive and metamorphose. The potential host fishes for Purple Wartyback in Canada include Black and Yellow bullheads (*Ameiurus melas, A. natalis*), Channel Catfish (*Ictalurus punctatus*) and possibly Flathead Catfish (*Pylodictis olivaris*). This is based on laboratory infestations in the United States (as infestation experiments have not occurred with Canadian Purple Wartyback), and distributional overlap of known ranges in Canadian waters.
- To achieve ~99% probability of persistence over 250 years requires ~2,800 (CI: 1,900-4,000) adult Purple Wartyback. A minimum of 623.3 m^2 (CI: 251.9-1,396.9) and 2,900 m^2 (CI: 301.5-17,166.3) of suitable habitat in the Sydenham and Thames rivers, respectively, is required to support a minimum viable population (MVP); there is sufficient habitat available in both rivers. The spatial configuration of populations and habitat is important and has not been considered.
- Population projections were completed for the quadrat-sampled area of the Sydenham, Thames, and Ausable rivers. Estimated abundance in the sampled habitats in the Sydenham River exceeded the estimated MVP upper confidence interval. Positive population growth rates were estimated in the Sydenham and Thames rivers, and the size distribution of Purple Wartyback suggests successful recruitment is occurring in both systems. The Ausable River populations have not exhibited positive population growth and remain at low density. Results are considered conservative because quadrat surveys have not been completed across all occupied habitat, and a substantial amount of habitat has not been surveyed.
- Purple Wartyback populations are generally most sensitive to perturbations in adult survival; however, they become more sensitive to perturbations to juvenile survival when experiencing significant population growth. Uncertainty in age-at-maturity and the proportion of reproduction that occurs later in life (relative fertility) affect how sensitive populations are to perturbations in adult and juvenile survival.
- Dreissenid mussels are the cause of extirpation of Purple Wartyback from the Detroit River and Lake Erie around Pelee Island. The greatest threats to extant populations are pollution from agricultural and urban sources, and road runoff; extreme weather events associated with climate change; aquatic invasive species (dreissenid mussels and Round Goby *Neogobius melanostomus*); and bridge or culvert construction/maintenance works.
- Key knowledge gaps remain regarding vital rates, glochidia-host relationships, and threat mechanisms, magnitude of impact, and interactions. Knowledge gaps resulting in uncertainties related to how Purple Wartyback will respond to threats and recovery actions should be addressed with additional research.

INTRODUCTION

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of Purple Wartyback (*Cyclonaias tuberculata*) in May 2021 as Threatened (COSEWIC 2021). The reason for this designation was that the species has a small and restricted range, known from only three rivers in Ontario (Ausable, Sydenham, and Thames rivers), and is considered extirpated from two historically occupied areas (Detroit River and western Lake Erie). Additionally, the habitat quality throughout its range is declining as a result of agricultural and urban sources of pollution, impacts from climate change (droughts), aquatic invasive species (AIS), and dredging activities. Purple Wartyback is not currently listed under the *Species at Risk Act* (SARA). Fisheries and Oceans Canada (DFO) developed the recovery potential assessment (RPA) process to provide information and science-based advice needed to inform listing decisions and to fulfill requirements of SARA, including the development of recovery strategies and action plans, and authorizations to carry out activities that would otherwise violate SARA. The process is based on DFO (2007) and updated guidelines (DFO unpublished) that assess 22 recovery potential elements. Supporting information is found in Colm and Morris (2023) and van der Lee and Koops (2023) and supplemental information in van der Lee et al. (in prep.[1]).

Biology

The Purple Wartyback is a thick-shelled, medium-sized freshwater mussel that is laterally compressed to moderately inflated with a circular to sub-quadrate shape. The periostracum is typically yellow to yellow-green in juveniles and can range from yellow-green to reddish-brown in adults. The nacre is purple and iridescent. The anterior of the shell is generally smooth, while the posterior is covered in nodules following the growth lines that extend onto the beak, occasionally forming ridges along the dorsal wing. The beaks are low, the beak cavity deep, and the beak sculpture has numerous wavy (or zig-zag) ridges (Metcalfe-Smith et al. 2005). The species is often reported to reach 130 mm in length, but can reach a maximum of 200 mm in Canada. It is dioecious but not sexually dimorphic. Purple Wartyback glochidia are relatively large, with a smooth, rounded edge and no hooks.

Spawning likely occurs in early spring through summer once temperatures reach approximately 9 °C. Like all freshwater mussels, males release sperm through their excurrent siphon, and it is filtered through the gills of females located downstream. Once filtered by the female, the sperm enters the posterior portion of the gill (suprabranchial chambers) where mature ova are stored and then fertilized, and embryos mature in the outer set of gills (marsupia). Purple Wartyback is a short-term brooder (tachytictic), meaning that eggs are fertilized and glochidia released within the same spawning season. Females likely brood glochidia through to late July, which are released (or displayed) for approximately one month in late summer through early fall when water temperatures range 19–27 °C. The number of eggs produced by females is not known, but can be estimated from shell length to be approximately 170,000 (Haag 2012, van der Lee and Koops 2023).

The glochidia require a period of encystment on a host fish where they feed on body fluids and undergo a metamorphosis to complete their development. Purple Wartyback glochidia in Ontario are presumed to use larger members of the North American catfishes family

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[1] van der Lee, A.S., Goguen, M.N., McNichols-O'Rourke, K.A., Morris, T.J., and Koops, M.A. In prep. Evaluating the status and biology of an imperilled freshwater mussel, Purple Wartyback (Cyclonaias tuberculata), in Southern Ontario. In preparation.

(Ictaluridae), including Black and Yellow bullheads (*Ameiurus melas, A. natalis*), Channel Catfish (*Ictalurus punctatus*) and possibly Flathead Catfish (*Pylodictis olivaris*) based on laboratory infestation studies from the U.S. (Hove et al. 1994,1997). Females may use two host attraction techniques, a mantle display and amorphous conglutinates; however, females appear to use one or the other in a given spawning season (Sietman et al. 2012). The mantle display consists of loose glochidia present on the stomate-shaped, mantle magazine (inflated tissue around the excurrent siphon). Conglutinates formed loose, gelatinous strands of mucous with embedded glochidia. These are typically pale in colour and may resemble dead animal tissue, likely attractive to their omnivorous, benthic-feeding hosts. Recent evidence from the Sydenham River suggests Purple Wartyback glochidia are most abundant at dawn and dusk, the latter suggests timing of release is generally well matched to periods of activity for (presumed) nocturnal catfish hosts (Smodis 2022). The period of encystment for Purple Wartyback glochidia have been reported to last 17–38 days, but timing may depend on water temperature and species of host (Hove et al. 1994, 1997). Dispersal of the host fish also allows for upstream movement of mussels and genetic exchange between subpopulations. After the period of encystment, the juvenile mussels drop off the host fish and burrow into the sediment where they remain for several years (likely > 6 years for Purple Wartyback) for growth. Once mature, adult mussels move up to the sediment surface and remain relatively sedentary.

Purple Wartyback is a long-lived species. Recent aging data suggests it may live to over 90 years. The generation time of Canadian populations was estimated to be 26 years, and maturity may be reached at 6–8 (estimated 7.2) years of age, or < 53.1 mm in length (van der Lee et al. in prep.[1], Jirka and Neves 1992). From quadrat surveys from 1997 through 2021, the mean shell length of Purple Wartyback detected in the Ausable River was 60.3 mm, 80.4 mm in the Sydenham River, and 59.8 mm in the Thames River (van der Lee et al. in prep.[1]). Length-frequency data suggest spawning has recently occurred in all three rivers. The largest Canadian specimen was 198.9 mm in length observed in the Sydenham River, and the oldest individual was aged 92 years (van der Lee et al. in prep.[1]). Glochidia collected from gravid females in the Ausable, Sydenham, and Thames rivers had a mean shell length of 0.264 mm (±0.005 mm), mean shell height of 0.325 mm (±0.009 mm), and mean hinge length of 0.124 mm (±0.005 mm) (Tremblay et al. 2015).

Adult unionid mussels are suspension feeders, generally consuming organic debris, algae and bacteria from the water column and sediment. Juveniles, remaining buried in the sediment for the first few years of life, feed on organic material available through interstitial pore water. Larval mussels (glochidia) feed on host fish tissue while encysted. No specific diet data exist for Purple Wartyback.

ASSESSMENT

Abundance

Reliable abundance estimates are lacking for all populations of Purple Wartyback in Canada. To coarsely understand relative population size, COSEWIC (2021) calculated catch per unit effort (CPUE; from timed-search surveys) and average density (estimated from quadrat surveys)[2] for

[2] COSEWIC 2021 also coarsely estimated population abundance by extrapolating the mean site-level densities across the known distribution in each river. The population estimates likely overestimate the true population size, as sampling was designed for evaluating trends through time and not for estimating population size, so are not included here.

each river; additionally, the occupied reach length in each river is approximated based on length of continuous Ontario Hydro Network stream segments with occurrence records (Mandrak et al. 2014) (Table 1). Site-specific abundance estimates were generated using quadrat survey data from DFO's Unionid Monitoring and Biodiversity Observation (UMBO) monitoring network for the Sydenham and Thames rivers (van der Lee et al. in prep.[1]), and for the Ausable River following methods in van der Lee et al. (in prep.[1]). A hierarchical Bayesian model was used to project site-specific density estimate across the entirety of surveyed habitat. Projections were made for 2022 in the Ausable River, 2015 in the Sydenham River, and 2017 for the Thames River; these years represent the most recent year of sampling in each river. This yielded abundance estimates of 294 (95% credible intervals (CI): 207–409) Purple Wartyback in the Ausable River, 10,504 (95% CI: 9,563–11,505) in the Sydenham River, and 872 (95% CI: 696–1,091) in the Thames River, covering approximately 2,490 m^2, 3,600 m^2, 3,000 m^2, respectively, in each river. Population growth rates were also estimated from this model using quadrat data from 2006–2022 in the Ausable River, 1999–2015 from the Sydenham River and 2004–2017 from the Thames River. Populations in the latter two rivers have increased in size since the survey commenced, while no significant trend was detected in the Ausable River (Table 1).

Table 1. Current catch per unit effort (CPUE; individuals/Person-Hour) from timed-search surveys, and mean density from quadrat surveys for Purple Wartyback in Canada; adapted from COSEWIC (2021). An estimate of occupied habitat is provided based on continuous, occupied Ontario Hydro Network segments. Median density and population growth rate estimates (including 95% confidence intervals (CI)) from van der Lee et al. (in prep.[1]) for the Sydenham and Thames rivers, and calculated for the Ausable River following methods in van der Lee et al. (in prep.[1]).

Locality	CPUE (ind/PH ± SE)	Mean Density (live/m^2 ± SE)	Approximate occupied river length (km)	Median Density (live/m^2) (95% CI)	Population Growth Rate (95% CI)
Ausable River	0.61 (± 0.17)	0.09 (± 0.03)	62.2 km	0.031 (CI: 0.002-0.25)	1.016 (CI: 0.985-1.049)
Sydenham River	6.63 (± 2.38)	2.52 (± 0.76)	85.9 km	1.82 (CI: 0.94-3.87)	1.047 (CI: 1.037-1.058)
Thames River	1.53 (± 0.27)	0.26 (± 0.12)	136.0 km (lower) 23.6 km (South) 9.6 km (North)	0.12 (CI: 0.03-0.42)	1.157 (CI: 1.10-1.221)

Distribution and Current Status

Globally, Purple Wartyback is known from the Mississippi River and lower Great Lakes drainages. It is found in the province of Ontario in Canada, and in 20 states in the U.S.A. In Canada, the current and historical distribution of Purple Wartyback is limited to five waterbodies in southwestern Ontario (Figure 1). Extant locations include the Ausable River in the Lake Huron drainage, and the Sydenham and Thames rivers (including North Thames River, South Thames River, and lower Thames River) in the Lake St. Clair drainage. Purple Wartyback is thought to be extirpated from the Detroit River and Lake Erie around Pelee Island. Since its discovery in Canada, there have been approximately 7,000 live individuals observed from over 200 sampling records.

Ausable River

The occurrence of Purple Wartyback in the Ausable River is a relatively new discovery, likely the result of increased search effort. The species was first reported in 1998 when four live individuals and two fresh shells (one whole, one valve) were detected during a timed-search survey. The species was subsequently detected during timed-search and quadrat surveys in 2002 (n=2), 2004 (1 weathered shell), 2006 (n=38), 2007 (n=2), 2008 (n=14 + 1 weathered shell), 2011 (n=26), 2012 (n=25), 2013 (n=35), 2014 (n=3), 2015 (n=2), 2016 (n=10), 2018 (n=13), 2019 (n=27) and 2022 (n=15). The distribution of live animals in the Ausable River was previously thought to be two distinct stretches of river, one at Nairn and one at Arkona; however, a detection in 2019 in between these reaches suggest Purple Wartyback may occupy a longer stretch, approximately 62.2 km.

Sydenham River

Purple Wartyback was first documented in the East Sydenham River in 1963 (n=5), representing the first live individuals of the species reported in Canada. Live individuals have been consistently detected since that time, with records from 1965 (n=3 + 25 fresh shells), 1967 (n=10), 1971 (n=17), 1973 (n=14 + 8 fresh shells), 1985 (n=1), 1991 (n=21), 1997 (n=241 + 53 fresh shells and 1 fresh valve), 1998 (n=40 + 3 fresh shells), 1999 (n=44), 2001 (n=95), 2002 (n=704), 2003 (n=392), 2008 (n=110), 2010 (n=25), 2012 (n=2,886), 2013 (n=981), 2014 (n=153), 2015 (n=424), 2017 (n=217), 2018 (n=29), 2019 (n=11), 2020 (n=268), 2021 (n=265), and 2022 (n=680) representing timed-search and quadrat surveys. The distribution of Purple Wartyback in the East Sydenham River is an approximately 85.9 km (nearly continuous) stretch from Napier to downstream of Dresden.

In 2013, a single live Purple Wartyback was incidentally observed in Black Creek, a tributary of the North Sydenham River (COSEWIC 2021). It is unknown whether this represents a population.

Thames River

Evidence of Purple Wartyback was first found in the lower Thames River in 1935 (four fresh shells), and 1965 (one fresh shell), but the first live individual was not detected until 1985. Additional observations of the species were reported from timed-search and quadrat surveys in 1986 (n=1), 1994 (one fresh valve), 1997 (n=30 + 11 fresh shells and valves, 23 weathered shells and valves), 2004 (n=9), 2005 (n=65 + 1 fresh shell), 2010 (n=7), 2012 (n=39), 2013 (n=37 + 1 weathered shell), 2015 (n=24 +1 weathered shell), 2016 (n=125), 2017 (n=1), 2018 (n=3), 2021 (n=28 + 1 weathered shell), and 2022 (n=10 + 1 weathered shell and 1 weathered valve). In the lower Thames River, Purple Wartyback is widespread from Delaware to downstream of Thamesville (Kent Bridge), totaling approximately 136 km. Given continuous suitable habitat and limited surveys further downstream, the distribution may continue to the mouth of the river for an additional 46.9 km; brail surveys conducted by MNRF in 2022 from Kent Bridge to the confluence at Jeannette's Creek did not detect the species.

In the upper Thames River watershed, a fresh shell was first observed in the South Thames River in Dorchester in 1936. Only four surveys were undertaken in the upper Thames River watershed until 1997, when the first live individuals (n=2) were found near the historical Dorchester shell record during a timed-search survey. Live individuals were observed in the South Thames River during quadrat surveys in 2004 (n=3), 2017 (n=8), and 2018 (n=5). The distribution of Purple Wartyback in the South Thames River is from Dorchester to within the city of London (upstream of Hunt Dam and the Forks), comprising approximately 21.4 km. In the North Thames River, live individuals were observed in 2004 (n=9), 2008 (n=20), 2015 (n=6), 2018 (n=7), 2021 (n=14), and 2022 (n=72) during timed-searches and quadrat surveys.

Observations in the North Thames River occur over a 7 km stretch from Plover Mills to immediately upstream of Fanshawe Lake.

Detroit River

Purple Wartyback was historically distributed throughout the Detroit River. The earliest known record of Purple Wartyback in Canada came from the Detroit River in 1934, and the first live individuals were observed in this system in 1982 (n=5 + 4 fresh valves). A total of 32 live individuals were captured in the 80's and 90's, with an additional 38 fresh valves and 22 weathered valves collected over this time. It had not been detected in the Detroit River since 1998 when one live individual was last observed. It is believed that the invasion of dreissenid mussels (*Dreissena polymorpha* and *D. rostriformis*) led to its extirpation. In 2019, 72 weathered shells were reported from the Detroit River but no live individuals were collected and the species is considered extirpated from this system (Keretz et al. 2021, COSEWIC 2021).

Lake Erie

Purple Wartyback was historically known from Pelee Island and surrounding islands (East Sister Island, Little Chicken Reef, Hen Island) and Point Pelee National Park. It was first reported there in 1960 (20 fresh shells, 19 weathered shells, one valve). Live individuals were reported in 1969 (n=2), 1970 (n=3), and 1982 (n=1), and an additional 236 fresh shells were observed from 1961 through 1990. A live individual was last observed in Lake Erie in 1982, and the most recent evidence of the species from this location is five weathered valves collected in 2005. Purple Wartyback is considered extirpated from this location (COSEWIC 2021).

Population Assessment

To assess the population status, populations were ranked in terms of abundance (Relative Abundance Index; Extirpated, Low, Medium, High, or Unknown) and trajectory (Population Trajectory; Increasing, Decreasing, Stable, or Unknown). The Relative Abundance Index considers the median density estimates along with the coarse estimates of occupied river length, and the Population Trajectory is based on the estimates of population growth rate (Table 1). Populations were assessed relative to the Sydenham River, the largest and best-studied population in Canada. A certainty value was assigned based on the type of information used to assess the population (1=quantitative analysis, 2=catch per unit effort, 3=expert opinion). The Relative Abundance Index and Population Trajectory were combined to yield a Population Status (Table 2). Refer to Colm and Morris (2023) for detailed methods.

Table 2. Population Status of all Purple Wartyback 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	Certainty
Ausable River	Poor	1
Sydenham River	Good	1
Thames River	Fair	1

Habitat Requirements

Purple Wartyback inhabits medium to large rivers and occasionally deeper lake habitats. It is typically found in areas with moderate to swift currents, but is tolerant of slow flow**.** It is found at the substrate-water interface at a wide range of depths up to 6.0 m, and generally over coarser substrates of gravel, sand, and cobble, and occasionally silt or boulders. Adult mussels are often found in river locations that have stable substrates under peak flows, but will remain wetted during low flows, and may also be related to hydrodynamics where juvenile mussels settle out. Information on juvenile habitat is limited; juveniles are thought to occupy similar habitats as adults, but buried in the sediment. Glochidia require a fish host, presumed to be ictalurid catfishes (Black and Yellow bullheads, Channel Catfish, Flathead Catfish), which occupy a range of habitats throughout the Great Lakes basin and are found throughout the distribution of Purple Wartyback (except Flathead Catfish known only from the lower Thames River).

Residence, in the context of SARA, is considered to be a dwelling-place occupied by the organism during all or part of their life cycle. Purple Wartyback does not construct a residence during its life cycle.

There are several physical barriers located in the Ausable, Sydenham, and Thames rivers that could prevent Purple Wartyback and its host fishes from dispersing or accessing new habitats. Most notably, the Fanshawe Dam is completely impassable for fishes and effectively isolates the North Thames River subpopulation of Purple Wartyback from the rest of the Thames River. Hunt Dam on the lower South Thames River may also be impassable. Other major dams exist in the three watersheds but not within the known distribution of Purple Wartyback. There are several hundred smaller dams and barrier structures located throughout the watersheds within the distribution of Purple Wartyback, but the extent to which these smaller structures prevent movement of aquatic animals is unknown. Additionally, dreissenid mussels continue to prevent Purple Wartyback from recolonizing the Great Lakes and connecting channels, thus represent a constraint between occupied areas.

Functions, Features, and Attributes

A description of the functions, features, and attributes associated with the habitat of Purple Wartyback in Canada can be found in Table 3. The habitat required for each life stage has been assigned a life-history function that corresponds to a biological requirement of Purple Wartyback. In addition to the life-history function, a habitat feature has been assigned to each life stage. A feature is considered to be the structural component of the habitat necessary for the species. Habitat attributes have also been provided; these are measurable components describing how the habitat features support the life-history function for each life stage.

Table 3. Summary of the essential functions, features, and attributes for each life stage of Purple Wartyback in Canada. Habitat attributes from the published literature and those recorded during recent sampling events (Lower Great Lakes Unionid Database (LGLUD) unpublished, Quider, E. 2021) can be used to support delineations of critical habitat.

Life Stage	Function	Feature	Attribute		Critical Habitat
			Scientific Literature	Recent Knowledge	
Spawning and fertilization (spring through early summer)	Reproduction	Reaches of small to large rivers	Substrate of cobble, gravel, small boulders; water depth 0.4–1.2 m; water temperature ≥ 9 °C (Jirka and Neves 1992)	-	Reaches of medium to large rivers with moderate to swift current and sand, gravel and cobble substrates
Encysted glochidial stage (late summer through fall)	Feeding Cover Nursery	Same as above with host fishes present (presumed host fishes: Black and Yellow bullheads, Channel Catfish, possibly Flathead Catfish)	Black and Yellow bullheads: low gradient streams, shallow, warmwater bays of lakes and wetlands; Channel and Flathead catfishes: medium to large rivers or deeper areas of lakes with ample vegetation and in stream cover (e.g., coarse woody debris) (Scott and Crossman 1998, Holm et al. 2009)	water chemistry: mean conductivity = 558.6 µs/cm (range: 5.49–863 µs/cm); mean dissolved oxygen = 9.07 mg/L (5.68–20 mg/L); mean pH = 8.32 (7.19–9.12); physical parameters: mean depth = 2.07 m (0.26–9.60 m); mean water velocity = 0.02 m/s (0–0.26 m/s); mean stream width = 93 m (11–233 m); mean coarse woody debris cover = 13% (0–60%); mean substrate composition: 39% (0–95%) clay, 36% (0–80%) silt, 13% (0–80%) organic, 9% (0–100%) sand. (Fish Biodiversity Database, from Ausable, Sydenham, and Thames rivers where host fishes occur)	Same as above Presence of sufficient host fishes
Juvenile (age 0 to approximately age 7 or 55 mm)	Feeding Cover Nursery	Reaches of small to large rivers with a combination of soft and hard substrates suitable for burrowing	-	mean water velocity of 0.373 m/sec (range: 0.00–2.05 m/s); mean depth of 0.250 m (0.04–0.78 m); mean substrate composition of 33% (0–85%) gravel, 25% (0–75%) sand, 25% (0–70%) cobble, 10% (0–80%) boulder, and 5% (0–40%) silt. (LGLUD unpublished data)	Same as above

Life Stage	Function	Feature	Attribute		Critical Habitat
			Scientific Literature	Recent Knowledge	
Adult (> age 7 or 55 mm)	Feeding Cover	Reaches of small to large rivers	Variable substrate of sand, gravel, cobble, small boulders, occasionally silt; flow nearly absent to swift; (Jirka and Neves 1992, Haggerty et al. 1995); depths from 0.6–6.0 m (Parmalee and Bogan 1998, COSEWIC 2021)	mean water velocity 0.376 m/s (range: 0.00–2.63 m/s); mean water depth 0.249 m (0.04–0.78 m); mean substrate composition: 32% (0–90%) gravel, 26% (0–80%) sand, 24% (0–70%) cobble, 10% (0–80%) boulder, and 6% (0–60%) silt. (LGLUD unpublished data)	Same as above

Threats

A number of threats may limit the survival and recovery of Purple Wartyback in Canada. Pollution from agricultural and urban sources, impacts of climate change (e.g., droughts), biotic interactions from AIS, and dredging were considered the greatest threats to this species (COSEWIC 2021). Knowledge of threat impacts on Purple Wartyback populations is limited, as there is a paucity of threat-specific cause and effect information in the literature. Although Purple Wartyback is dependent on host fishes for completing its life cycle, the threat assessment does not consider threats to hosts.

Pollution

As sedentary filter-feeders, freshwater mussels are generally vulnerable to the effects of pollution both in the water column and in the sediment. Glochidia and juvenile mussels are most sensitive to contaminant effects, while adults are better able to withstand acute exposures with behavioural avoidance (valve closure/burrowing). Early life stages are the most sensitive to pollution; however, pollutants that impact adult Purple Wartyback are more likely to result in population-level declines (van der Lee and Koops 2023). Agricultural land use is intensive in all three watersheds occupied by Purple Wartyback. Siltation and sedimentation of watercourses is a major outcome of agricultural land use practices (including upstream drain maintenance activities) that may result in heavy suspended sediment loads, which can clog incurrent siphons and gills interrupting feeding, respiration, growth, and reproduction; or sediments can settle out and deposit on coarser substrates or live animals. Nutrient loading from agricultural runoff can negatively affect mussels and host fishes by increasing primary productivity, particularly algal growth, which can lead to reduced dissolved oxygen, affecting respiration. Fertilizers and other nitrogenous compounds can result in increased ammonia levels and potassium, and early-stage freshwater mussels are among the most sensitive taxa to these contaminants. Pesticides applied to farm fields or occasionally in or near water for invasive species control (e.g., glyphosate for *Phragmites australis australis* control or lampricides for Sea Lamprey (*Petromyzon marinus*) control) may also be toxic to freshwater mussels depending on exposure concentration, or have genotoxic effects.

Although the majority of land use surrounding the Ausable, Sydenham and Thames watersheds is agricultural, urban development may also negatively affect Purple Wartyback. Road salts applied for winter de-icing are a major concern, as chloride is among the most toxic substances to unionids particularly at the glochidial stage (Gillis 2011, Pandolfo et al. 2012, Todd and Kaltenacker 2012). Other contaminants associated with roadways (e.g., polycyclic aromatic hydrocarbons (PAHs) and heavy metals) are likely to negatively affect feeding, behaviour, reproduction, and growth, but can also have toxic and mutagenic effects on freshwater mussels. There are numerous wastewater or sewage treatment plants found in the Ausable, Sydenham and Thames watersheds that could negatively affect Purple Wartyback. Municipal wastewater effluent often contains high nitrite and ammonia levels, as well as pharmaceuticals and personal care products, which may have toxic or endocrine disrupting effects, depending on concentration (Gagné et al. 2004, Gagné et al. 2011, Tetreault et al. 2011, Gillis et al. 2017). 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 2014). Microplastics from urban and industrial sources are also appearing in surface waters and sediments around the Great Lakes basin (Driedger et al. 2015, Dean et al. 2018) and have been documented in Flutedshell (*Lasmigona costata*) in the Grand River (Wardlaw and Prosser 2020), but further research on impacts to biological function is required.

Climate Change and Severe Weather

Unionids are generally considered vulnerable to impacts of climate change as they are reliant on host fishes to complete their life cycle and have a limited ability to disperse to new habitats if conditions become unfavourable (Brinker et al. 2018). Climate change may 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 hosts, competitors and/or predators, but the magnitude and direction of these changes is difficult to predict (Lemmen and Warren 2004, COSEWIC 2021). The most significant impact of climate change for Purple Wartyback is expected to be a reduction of habitat quantity and quality due to increasing frequency and severity of droughts. van der Lee and Koops (2023) note that extinction probability increased with large-scale die offs that could be associated with drought conditions. 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. Heat waves are also expected to increase in frequency and intensity, and increased thermal stress may reduce thermal buffering capacity over repeat exposures (Seuront et al. 2019). The lethal thermal tolerance of Purple Wartyback is not known, but ranges reported for other freshwater mussels encompass 33.2–40.8 °C (Pandolfo et al. 2010, Martin 2016). The upper thermal limits of Purple Wartyback's presumed catfish hosts have been reported to range between 33.5–37.5 °C (Scott and Crossman 1998). Extreme flood events may also negatively affect Purple Wartyback and its habitat by flushing mussels to less ideal habitats and scouring stream beds.

Invasive and Other Problematic Species and Genes

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, and is the likely cause of the extirpation of Purple Wartyback from the Detroit River and Lake Erie around Pelee Island. Dreissenid mussels are typically found in low abundances in riverine habitats as they have poor attachment abilities under flowing conditions, as such, the Ausable, Sydenham, and Thames river populations of Purple Wartyback are likely at relatively low risk of impacts. However, Zebra Mussels have been detected in the lower reaches of the Sydenham River (below the distribution of Purple Wartyback), in Fanshawe Lake on the North Thames River, and from the Forks to Thamesville on the lower Thames River, including attached to live unionids (Morris and Edwards 2007).

Round Goby is a small-bodied benthic fish native to the Ponto-Caspian Sea that now occupies much of the Purple Wartyback distribution in the Ausable, Sydenham, and Thames rivers (Poos et al. 2010). Round Goby may predate on juvenile mussels, may compete with or prey on host fishes, or may be a sink for glochidia by offering poor metamorphosis success (Poos et al. 2010, Tremblay et al. 2016). The impacts of Round Goby on Purple Wartyback are unclear.

Additional Threat Considerations

Bridge and culvert construction or maintenance projects have the potential for direct and indirect local effects, which may include: mortalities, increased turbidity, altered substrate and flow regimes, streambank erosion, altered nutrient and food resources, and loss of connectivity for fish hosts. Although local effects could be severe, population-level impacts are unlikely, and thus, the overall impact of this threat is thought to be negligible. Should these activities increase in frequency, occur without relocations, or project planning does not account for high density patches of mussels, this threat should be reconsidered.

Recreational vehicle (e.g., ATV) use within streams can cause impacts to the surrounding riparian areas through soil compaction, damaged vegetation, and transport of invasive species; and to water quality (through increased pollution and turbidity), stream bed composition, and cause mortality of aquatic animals. Given the localized area of impact, and the robust, thick shells of the species, these activities are unlikely to have population-level effects. This threat is thought to have a negligible impact on Purple Wartyback at this time, but should be reconsidered if activities increase in frequency or intensity.

Lastly, the areas inhabited by Purple Wartyback are likely experiencing multiple threats concurrently, which may interact in complex and context-dependent ways. Research on multiple threat effects is growing, and has highlighted that cumulative impacts are likely when conditions such as increased temperature, sedimentation, extremely high or low flows, and multiple contaminants (such as ammonia, chloride, copper, and potassium) are combined (Salerno et al. 2020, Beermann et al. 2021, Luck and Ackerman 2021). All of these conditions are likely with climate change and increasing development in southern Ontario.

Threat Assessment

A threat assessment was completed for Purple Wartyback following guidelines provided in DFO (2014). Given the long generation time for Purple Wartyback (26 years) this threat assessment was evaluated over a 10-year time frame. Each threat was ranked in terms of the threat Likelihood of Occurrence, threat Level of Impact, and Causal Certainty. The Likelihood of Occurrence and Level of Impact for each population were subsequently combined in a Threat Risk Matrix resulting in the population-level threat assessment. Terms used to describe threat categories are described in Table 4. Threats were then rolled-up to create a species-level threat assessment, presented in Table 5. Refer to Colm and Morris (2023) for detailed methods.

Table 4. Definition and terms used to describe likelihood of occurrence (LO), level of impact (LI), causal certainty (CC), population level threat occurrence (PTO), threat frequency (PTF) and threat extent (PTE) reproduced from DFO (2014).

Term	Definition
Likelihood of Occurrence (LO)	
Known or very likely (K)	This threat has been recorded to occur 91-100%
Likely (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)	

Term	Definition
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 5. Species-level Threat Assessment of all Purple Wartyback populations in Canada, resulting from a roll-up of the Population-level Threat Assessment. The species-level Threat Assessment retains the highest level of risk for any population. The number in brackets refers to the highest Causal Certainty associated with the Threat Impact (1 = Very High; 2 = High; 3 = Medium; 4 = Low; 5 = Very Low). All categories of Threat Occurrence (H = Historical; C = Current; A = Anticipatory) and Threat Frequency (S = Single; R = Recurrent; C = Continuous) are retained, and the species-level Threat Extent (E = Extensive; B = Broad; NA = Narrow; R = Restricted) is the mode of the population-level Threat Extent.

IUCN Threat Category	Sub-category	Details	Species-level Threat (certainty)	Species-level Occurrence	Species-level Frequency	Species-level Extent
Pollution	Agricultural and Forestry Effluents	Sedimentation (field runoff, upstream drain maintenance)	Low (5)	H/C/A	C	B
		Nutrient Loading (+ ammonia)	Low (5)	H/C/A	C	B
		Pesticides (+ granular Bayluscide)	Low (5)	H/C/A	C	B
	Domestic and Urban Wastewater (incl. urban runoff)	Nutrient Loading (+ ammonia)	Low (5)	H/C/A	C	B
		Pharmaceuticals and estrogenic compounds	Low (5)	H/C/A	C	B
		Chloride	Low (5)	H/C/A	R	B
		Heavy Metals	Low (5)	H/C/A	C	B
Climate Change and Severe Weather	-	Frequent and severe droughts and heat waves	Low (5)	C/A	R	B
Invasive and other Problematic Species and Genes	-	Dreissenid mussels, Round Goby	Low (5)	H/C/A	C	N

Recovery Modelling

Long-term monitoring data collected from the Sydenham and Thames rivers through DFO's Unionid Monitoring and Biodiversity Observation (UMBO) network was used to model population-specific estimates of population trajectory and density, growth and survival rate (van der Lee et al. in prep.[1]). Similar methods were used to estimate population trajectory and density for Ausable River populations. Recovery potential modelling was completed in three main steps. Firstly, information on vital rates was compiled to build projection matrices that incorporate parameter uncertainty, environmental stochasticity and density-dependence acting on the first year of life (specifically, following detachment from host fish). The impact of anthropogenic harm to populations was then quantified with the use of elasticity and simulation analyses. Lastly, estimates of recovery targets for abundance and habitat were made with estimation of the minimum viable population (MVP) and the minimum area for population viability (MAPV). As many uncertainties around Purple Wartyback life-history remain, ranges of plausible parameter values were included in the models to account for this; estimates of harm and recovery targets can be refined as more research is conducted on the species to fill in knowledge gaps. Refer to van der Lee and Koops (2023) for complete methods, and supporting analyses are found in van der Lee et al. (in prep.[1]).

Allowable Harm

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

In most instances, Purple Wartyback population growth was most sensitive to changes in adult survival rate, but juvenile survival rate had the next greatest influence on population growth rate, and exceeded that of adult survival when populations were experiencing significant population growth ($\lambda > \sim 1.2$). Fertility (encompassing both egg production and first year survival) perturbations generally had a relatively small impact on population growth. The fertility of old adults had a small impact, and was less than that of fertility of young adults. Vital rate elasticities were influenced by uncertain life-history characteristics particularly population growth, age-at-maturity, and relative fertility (the relative contribution of reproduction between older adults and. younger adults). The elasticity for adult survival generally increased with relative fertility; the adult stage became more important if a greater proportion of reproduction occurred later in life (i.e., after age 35), while juvenile survival became more important when maturity occurred at younger ages.

The maximum amount of harm that would maintain stable or growing populations (i.e., population growth rate at or above 1.0) was estimated for the Sydenham and Thames river systems based on their current states. As the population growth rates differed between these two populations, estimates of allowable harm also differed. In the Sydenham River, harm to adult survival would have the greatest impact (harm leading to a 6.4% reduction in adult survival would still allow for a stable population), whereas in the Thames River where population growth rate was much higher, reductions in juvenile survival were of greatest consequence to population growth (harm leading to a 20.0% decrease in juvenile survival would still allow for a stable population). In both systems, harm applied to both juvenile and adult survival would have the greatest impact (Table 6). Neither system was particularly sensitive to harm to fertility (i.e., interruptions to reproduction or harm to glochidia/post-settlement age-0 mussels). Due to the uncertainty in some life-history parameters and the population growth estimates, it is prudent to take the lower confidence intervals (Table 6) as the representation of maximum allowable harm.

Much like elasticity analyses, simulations used to identify impacts of periodic harm revealed that harm applied to the adult stage or all stages had a significant impact on abundance. Small amounts of mortality had large impacts on population size. Annual mortality rates of only 1–2% applied to the adult stage resulted in a 25% reduction in population size. With harm applied every other year, every 5 years, or every 10 years, this became ~3%, ~7% and ~15% mortalities, respectively. The effects of harm were smaller but still significant if it only juvenile mussels were impacted. As with the elasticity analysis, Purple Wartyback populations were not as impacted by harm to fertility, particularly if harm occurred infrequently.

Populations in the Ausable River are low density and stable. As such there is little to no scope for harm as any disturbance will increase the chances of extirpation.

Table 6. Maximum allowable harm estimates for Sydenham River and Thames River populations of Purple Wartyback. The values represent the maximum percent decrease in vital rates that will allow the population to maintain a population growth rate ≥ 1. Allowable harm estimates are made based on estimated population growth rates for each river (van der Lee et al. in prep.[1]); Sydenham River: 1.03-1.07, Thames River: 1.07-1.27.

Vital Rate	Median	LCI	UCI
Sydenham River			
Juvenile Survival	9.9	6.1	16.1
Adult Survival	6.2	3.7	10.0
Juvenile & Adult Survival	3.8	2.5	5.5
Fertility	65.4	49.3	84.6
Thames River			
Juvenile Survival	19.4	11.0	31.3
Adult Survival	24.5	9.2	48.2
Juvenile & Adult Survival	10.9	5.4	17.6
Fertility	> 100	80.7	> 100

Recovery Targets

Abundance (Minimum Viable Population)

The concept of demographic sustainability was used to identify potential minimum recovery targets for Purple Wartyback. Demographic sustainability is related to the concept of a minimum viable population (MVP), and was defined as the minimum adult population size that results in a desired probability of persistence over 250 years (~ 10 Purple Wartyback generations). MVP was estimated using simulation analysis, which incorporated parameter uncertainty, environmental stochasticity and density-dependence. The median MVP estimate was ~1,400 (CI: 950-2,000) adult females, based on a 1% probability of extinction. If a 1:1 sex ratio is assumed, then MVP including all adult PWB was ~2,800 (CI: 1,900-4,000).

Habitat (Minimum Area for Population Viability)

Minimum area for population viability (MAPV) represents the quantity of habitat required to support a population of MVP size. MAPV is estimated by dividing the MVP estimate by density. Density estimates were available for PWB populations in the Sydenham and Thames rivers from a hierarchical Bayesian model fit to quadrat survey data (van der Lee et al. in prep.[1]); however, these estimates, taken with the positive population growth for both rivers, suggest neither population is at carrying capacity, and thus would produce an over-estimate of the quantity of habitat required to support a population of MVP size. The matrix population model was used to provide an estimate of the density that would give a stable population size based on the current density and population growth rate. Expected density of adult females in the Sydenham River that yielded a stable population growth rate (λ=1.0) was 2.21 mussels·m^{-2} (CI: 1.14-5.04) and for the Thames River was 0.48 mussels·m^{-2} (CI: 0.08-4.47). This corresponds to MAPV estimates of 623.3 m^2 (CI: 251.9-1,396.9) and 2,900 m^2 (CI: 301.5-17,166.3) for the Sydenham and Thames rivers respectively. The quantity of habitat available to Purple Wartyback in both systems exceeds these estimates; however, the MAPV estimate only identifies the amount of habitat required to house an MVP sized population and does not account for other considerations such as rearing habitat or spatial configuration of populations.

Time to Recovery

Time to recovery was estimated for the Thames River population as the time taken for the current population to reach MVP size for a given catastrophe rate. Carrying capacity of the available Thames River habitat was solved for using the population projection matrix, given estimates of the current population size and trajectory (van der Lee et al. in prep.[1]). Median time to recovery was 20 years (CI: 10-240). The Sydenham River population exceeds the estimated MVP (after juveniles accounted for), therefore was not included.

Mitigations and Alternatives

Threats to Purple Wartyback survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects resulting from works, undertakings or activities (w/u/a) associated with projects in Purple Wartyback habitat. From November 2013 through January 2022, a variety of w/u/a have occurred in Purple Wartyback habitat including: bridge and culvert construction and maintenance, stream bank stabilizations, dredging, docks/boathouse construction, directional drill piping, channel modifications and stormwater management. A review has been completed summarizing the types of projects that have been undertaken in habitat known to be currently occupied by Purple Wartyback (see Colm and Morris 2023 for details). A total of 25 projects were identified, 23 of which were in the Thames River watershed. No projects were authorized under the *Fisheries Act* as most were deemed low risk to fishes and fish habitat (mussels included) and were addressed through letters of advice with standard mitigation and avoidance measures. Without appropriate mitigations, projects or activities occurring adjacent or close to these areas could have impacted Purple Wartyback (e.g., through increased turbidity, sedimentation, direct mortality or other physiological impacts). The most frequent project type was bridge and culvert construction or maintenance. Based on the assumption that historical and anticipated development pressures are likely to be similar, it is expected that similar types of projects will likely occur in or near Purple Wartyback habitat in the future.

Numerous threats affecting Purple Wartyback populations in Canada are related to habitat loss or degradation (Table 7). The DFO Fish and Fish Habitat Protection Program (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. Additionally, 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 Purple Wartyback. 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. Advice developed for relocating mussels during in-stream works and for mitigating non-habitat related threats is summarized below.

*Table 7. Summary of works, undertakings and activities that have occurred during the period of November 2013 to January 2022 in areas known to be occupied by Purple Wartyback. Threats known to be associated with these types of works, undertakings, and activities are indicated with a checkmark. The number of works, undertakings, and activities associated with each Purple Wartyback population, as determined from the project assessment analysis, has been provided. Applicable Pathways of Effects are indicated for each threat associated with a work, undertaking, or activity: 1 – Vegetation Clearing; 2 – Grading; 3 – Excavation; 4 – Use of explosives; 5 – Use of industrial equipment; 6 – Cleaning or maintenance of bridges or other structures; 7 – Riparian planting; 8 – Streamside livestock grazing; 9 – Marine seismic surveys; 10 – Placement of material or structures in water; 11 – Dredging; 12 – Water extraction; 13 – Organic debris management; 14 – Wastewater management; 15 – Addition or removal of aquatic vegetation; 16 – Change in timing, duration and frequency of flow; 17 – Fish-passage issues; 18 – Structure removal. *contaminants and toxic substances come from agricultural pesticides, and domestic and urban wastewater and runoff*

Work/Undertaking/Activity	**Threats** (associated with work/undertaking/activity)			**Watercourse/Waterbody** (number of works/undertakings/activities between November 2013 and January 2022)		
Applicable pathways of effects for threat mitigation and project alternatives	Pollution: Sedimentation	Pollution: Nutrient loading	Pollution: Contaminants and Toxic Substances*	Ausable River	Sydenham River	Thames River
	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 18	1, 4, 7, 8, 11, 12, 13, 14, 15, 16	1, 4, 5, 6, 7, 11, 12, 13, 14, 15, 16, 18			
Water Crossings (bridges, culverts, piping)	✓	-	✓	0	2	9
Shoreline/Streambank Works (dykes, bank stabilization, infilling, beach creation, riparian vegetation management)	✓	✓	✓	0	0	5
Dam/Barrier Structures in Water (maintenance, modifications, hydro retrofits)	✓	-	✓	0	0	4
Instream Works (drain maintenance, aquatic vegetation removal, dredging, channel modifications/realignments)	✓	✓	✓	0	0	1
Water Management (stormwater management, water withdrawal)	✓	✓	✓	0	0	0
Structures in Water (boat launches, docks/boathouses, effluent outfalls, water intakes)	✓	✓	✓	0	0	4

Mussel Relocation Protocol

Guidance for conducting surveys to detect the presence of Species at Risk (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.

Mitigations

- Identify a suitable 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 Purple Wartyback directly (through competition/ predation) and indirectly (through habitat modifications or attachment/biofouling).

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 Purple Wartyback 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 Purple Wartyback.

- Do not enhance habitat for non-native species in areas inhabited by Purple Wartyback.
- 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

Life History

There are several gaps in our knowledge of Purple Wartyback life history. In particular, timing of the spawning season (including glochidia displays) is not known for Ontario, and would be helpful for understanding suitable timing windows for instream projects. Additionally, there were significant uncertainties in life-history parameters used in the population models, including: nearly all aspects of fertility, juvenile survival, age-at-maturity and relative contribution to reproduction with age, maximum population growth rate, and assumptions around density dependence. To account for this uncertainty, a range of potential values were used in the models represented by probability distributions, but more precise results could be extracted should more information become available. Each river was treated as a single population, but more complex population structure is possible (especially in the Thames River with impassable barriers at each branch) which may impact how abundance is estimated and the persistence probability of the population as a whole.

The frequency of catastrophes is an unknown variable and was very impactful on the population model results. The rate of catastrophe may vary among locations due to environmental variability, and therefore the most appropriate recovery target may also vary. Estimates based on more frequent catastrophes are more conservative especially if the frequency of large-scale stochastic disturbances increases with climate change.

Abundance

Long-term monitoring data for tracking trends through time has allowed for estimates of population growth rates for Purple Wartyback in Canada. These data were also used to estimate density (and infer population size), but additional data, including habitat and density information from a randomized study design would offer a better understanding of how habitat influences density, and allow more spatially accurate estimates of population abundance across the river systems.

Distribution

Despite extensive survey effort, there remains uncertainty in the full distribution of Purple Wartyback within known locations, and possibly beyond. The distribution in the Ausable River now consists of three small stretches, but it is unknown if they occupy the full reach between these areas. Similarly, on the Thames River, Purple Wartyback is known from Delaware to Kent Bridge, and is assumed to occupy the river down to the mouth; however, due to sampling constraints, this is not confirmed. One individual was recently detected in Black Creek, a tributary of the North Sydenham River, but it is unknown whether a viable population exists in this tributary.

Species Interactions

There are many uncertainties surrounding mussel-host interactions. Large-bodied ictalurid catfishes are the presumed host fishes of Purple Wartyback in Canada, but this is not confirmed. There is no information on optimal density of host fishes for successful encounters, or on infestation or metamorphosis rates of glochidia on hosts. The dispersal ability of glochidia while encysted on host fishes is also unknown, but may help understand the Black Creek detection. Interactions between Purple Wartyback and host fishes could not be explicitly incorporated into the population model, but impacts to host species populations could significantly influence persistence or recovery of Purple Wartyback. For example, a host population may be subject to random catastrophes in the same manner as was assumed for Purple Wartyback in MVP simulations. Even if a Purple Wartyback population avoids the impacts of the catastrophic event initially they could be greatly impacted if their hosts become limited, and recovery may be delayed or limited by host abundance.

Habitat

Species-habitat Associations by Life Stage

Purple Wartyback appears relatively tolerant of a range of environmental conditions, but optimal habitat for completing life-history processes remains unknown. The ideal (or upper limits on) habitat conditions (e.g., flow rate, substrate type, dissolved oxygen, temperature) and food availability in those micro-habitats remains unknown.

Habitat Supply

The Purple Wartyback distribution is considered distinct stretches in each of the three occupied rivers, but it is unlikely that the entirety of these stretches contain suitable habitat. As the ideal habitat properties for Purple Wartyback are not explicitly known, the spatial extent of these properties within the (historically and currently) occupied rivers also remains unknown. Additionally, the quantity of habitat needed to support healthy and sufficiently dense populations of host fishes is unknown, but using MAPV as a rough estimate, is presently not thought to be limiting.

Threats

Mechanism of Impact

All freshwater mussels are known to be pollution sensitive, but there have been few, if any, toxicology studies on Purple Wartyback specifically. Toxicity ranges for freshwater mussels are known from lab studies on other species; however, without specific studies on Purple Wartyback, it is not possible s to understand lethal limits or broader impacts on life history and vital rates (e.g., growth, metabolism, reproduction). To what degree more common, closely related species could serve as suitable surrogates warrants investigation. Climate change will have numerous impacts on aquatic ecosystems, many of which are likely to interact with other anthropogenic stressors. The mechanisms through which climate change will impact Purple Wartyback and its host fishes could be better understood through the study of the physiological tolerances to environmental stressors (e.g., temperature, dissolved oxygen, rapid changes in flow). Additionally, further research relating changes in climatic conditions (or other stressors) to changes in vital rates would help improve population recovery models.

Probability, Extent, and Magnitude of Impact

Although point measurements of some contaminants are available in the watersheds in which Purple Wartyback is found, environmentally realized concentrations at localities occupied by the species, and the persistence of contaminants in the water column and at the substrate surface are unknown. It is unclear to what extent dams and other barriers may impact the dispersal of host fishes, and how that affects Purple Wartyback dispersal. Furthermore, the dams are relatively new in the context of the Purple Wartyback lifespan for effects to be determined. The mechanisms of impact of AIS are often clear (e.g., competition, predation, habitat alteration, biofouling), but the extent and magnitude of these impacts on Purple Wartyback particularly in riverine habitats remain unclear. Purple Wartyback faces multiple threats and the interactions of these threats are likely to result in different impacts than any threat on its own, but the extent and magnitude of those interactions is poorly understood.

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SOURCES OF INFORMATION

This Science Advisory Report is from the October 25–27, 2022 regional peer-review meeting on the Recovery Potential Assessment of Purple Wartyback (*Cyclonaias tuberculata*). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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