DRAFT Recovery Strategy for the Purple Wartyback (*Cyclonaias tuberculata*) in Ontario

2024

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Declaration

The recovery strategy for the Purple Wartyback (*Cyclonaias tuberculata*) was developed in accordance with the requirements of the *Endangered Species Act, 2007* (ESA). This recovery strategy has been prepared as advice to the Government of Ontario, other responsible jurisdictions and the many different constituencies that may be involved in recovering the species.

The recovery strategy does not necessarily represent the views of all individuals who provided advice or contributed to its preparation, or the official positions of the organizations with which the individuals are associated.

The recommended goals, objectives and recovery approaches identified in the strategy are based on the best available knowledge and are subject to revision as new information becomes available. Implementation of this strategy is subject to appropriations, priorities and budgetary constraints of the participating jurisdictions and organizations.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy.

Responsible jurisdictions

Ministry of the Environment, Conservation and Parks
Fisheries and Oceans Canada

Executive summary

Purple Wartyback (*Cyclonaias tuberculata*) is a medium-sized, heavy-shelled freshwater mussel that is listed as threatened on the Species at Risk in Ontario (SARO) List. The species has been assessed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), but currently has no status under the federal *Species at Risk Act* (SARA) and is under consideration. Purple Wartyback's historical range is limited to southwestern Ontario in the Ausable River, Sydenham River, Thames River, Detroit River and Lake Erie. The species' current distribution is similar to its historic range, but it is now thought to be extirpated from the Detroit River and Lake Erie.

The shell of Purple Wartyback is circular to quadrate in shape and may grow to a maximum length of 200 mm. The shell is laterally compressed to moderately inflated and brown in colour with prominent raised bumps covering much of the surface. The inside of the shell is typically purple with large, serrated pseudocardinal teeth, and lateral teeth that are thick, short and slightly curved.

The most widespread and continuing threats to Purple Wartyback include pollution, climate change and severe weather events. Additional threats include invasive and other problematic species.

The recommended long-term recovery goal for Purple Wartyback is to restore self-sustaining populations within the Ausable, Sydenham and Thames rivers, and to increase the species' distribution within its native range in Ontario.

To achieve the recovery goal, the following recovery and protection objectives are recommended:

1. Protect and conserve populations by identifying and mitigating threats, implementing remedial actions where necessary, and increasing availability of suitable habitat.
2. Initiate research to fill knowledge gaps related to the species biology, habitat needs and availability, host species, population abundance and distribution, and threats in Ontario.
3. Monitor Purple Wartyback populations to track population trends, the condition of habitat for Purple Wartyback and its host(s) (once confirmed), and the success of threat mitigation and recovery activities.
4. Promote conservation through increased awareness about the significance, distribution, threats, and recovery of this species.

The area recommended for inclusion in a habitat regulation for Purple Wartyback is based on river reaches as delineated by the Aquatic Ecosystem Classification (AEC). Reaches should be considered occupied by Purple Wartyback if the species has been documented as live individual and/or fresh shell from 1996 onward, as this coincides

with the commencement of systematic surveys of freshwater mussel communities in southern Ontario. This includes but is not limited to areas within the Ausable, Thames and Sydenham River watersheds. Reaches should be considered occupied until sufficient survey effort has been applied to confidently determine the species' absence. It is recommended that the habitat regulation extend to areas with natural and semi-natural vegetation, including forest, woodland, thicket, wetland, old field, pasture or meadow habitats within 30 meters of occupied AEC segments. Manicured lawns and areas of agricultural cropland should not be included.

Within Lake Erie, Lake St. Clair and the Detroit River, it is recommended that a habitat regulation apply to new observations of Purple Wartyback, as they are thought to be extirpated from these locations. If there are new observations of Purple Wartyback within Lake Erie, Lake St. Clair and the Detroit River (areas where the AEC cannot be applied), habitat preferences of Purple Wartyback should be used to delineate the extent of habitat protections. Protections should apply to contiguous suitable habitat and only to areas with multiple individuals of varying age classes to indicate recruitment and recolonization. This recommendation is based on Fisheries and Oceans Canada's assessment of methods for identifying critical habitat in coastal areas (DFO 2011b).

Suitable habitat can be delineated by the following characteristics:

- Depths less than six meters.
- Substrates consisting primarily of cobble, gravel, mixed gravel and sand.
- Moderate to swift currents to a maximum of 2.63 m/s during periods of low flow.
- Absence of Zebra or Quagga Mussels.
- Availability of primary host fish species (Black Bullhead, Yellow Bullhead, and Channel Catfish).

Additional sampling effort utilizing appropriate methods would help to further refine the application of habitat protections in Lake Erie, Lake St. Clair and the Detroit River.

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1.0 Background information

1.1 Species assessment and classification

The following list provides assessment and classification information for the Purple Wartyback (*Cyclonaias tuberculata*). Note: The glossary provides definitions for abbreviations and technical terms in this document.

- SARO List Classification: Threatened
- SARO List History: Threatened (2023)
- COSEWIC Assessment History: Threatened (2021)
- SARA Schedule: No schedule, under consideration
- Conservation Status Rankings: G-rank: G5; N-rank: N2; S-rank: S2.

1.2 Species description and biology

Species description

Purple Wartyback (*Cyclonaias tuberculata*) is a freshwater mollusc from the Quadrulini tribe (Family Unionidae). Individuals are dioecious (i.e., individuals contain male or female reproductive organs), and rarely display hermaphrodism (Haggerty et al. 1995). Purple Wartyback does not display sexually dimorphic characteristics (i.e., sexes of the same species exhibiting different physical traits) (Watters et al. 2009). The shell of Purple Wartyback is thick and measures up to a maximum length of 200 mm in adulthood (COSEWIC 2021). The shape of the shell is generally circular to quadrate, with rounded anterior and ventral margins and a squared posterior end with a dorsal wing (COSEWIC 2021). The shell is generally laterally compressed to moderately inflated. The outermost layer of the shell (periostracum) in juveniles may exhibit yellow to yellow-green coloration with fine green rays, which typically fade in adulthood (COSEWIC 2021). In adults the periostracum is generally yellow-green to reddish-brown or dark brown. Prominent raised bumps (pustules) are present in the posterior two-thirds of the shell, transitioning to ridges along the dorsal wing (Figure 1) (COSEWIC 2021). Pustules follow growth lines and extend onto the beak. The beak extends only slightly above the hinge line and is characterized by numerous fine ridges that form a chevron pattern (COSEWIC 2021). Internally, the inner iridescent layer (nacre) of the shell is purple to deep purple (Figure 1), but may exhibit a central white coloration with purple around the outer edge (COSEWIC 2021). The pseudocardinal teeth are large and serrated, while lateral teeth are thick, short and slightly curved. The interdentum (between pseudocardinal and lateral teeth) is wide and flat (COSEWIC 2021).

Figure 1. Purple Wartyback (*Photo: G. MacVeigh, 2024*). Reddish-brown periostracum (left) with pustules along growth annual growth rings. Interior (right) exhibits purple nacre.

Glochidia (immature juveniles) are sub-elliptical in shape and are approximately 264µm in length and 325µm in height. Glochidia lack hooks – an adaptation that improves capabilities for attachment to the skin or fins of host fishes – suggesting that they are gill parasites (Barnhart et al 2008). Glochidia that lack hooks rely upon infestation of host gills, which offer softer tissues for attachment.

Species biology

Adult Purple Wartyback are a sedentary species that live burrowed into substrates along the bottom of rivers. In adulthood they are filter feeders, removing organic detritus, algae, and bacteria from the water column and sediment for nourishment (Beck and Neves 2003; Nichols et al. 2005; Tran 2017). Adults may make vertical movements within the upper layer of sediments (10-15 cm) seasonally or in response to changing water levels and temperatures, but are limited in their capacity for horizontal movements (Schwalb and Pusch 2007). The foot of a mussel (generally a hatchet shaped muscle extruding from the bottom of the shell) is utilized to anchor the animal in substrates and prevent dislodgement and displacement downstream to unsuitable habitats, but may also be used to make horizontal movements along the riverbed (Sullivan and Woolnough 2021).

Purple Wartyback, as with all members of the Unionidae family, require a vertebrate host to complete their reproductive cycle. Based on laboratory experiments completed in the United States (U.S.), it is likely that Purple Wartyback in Ontario uses Channel Catfish (*Ictalurus punctatus*), Yellow Bullhead (*Ameiurus natalis*) and Black Bullhead (*Ameiurus melas*) as vertebrate hosts to carry out development of glochidia (Hove et al.

1994; Hove 1997; Hove and Kurth 1997). Flathead Catfish (*Pylodictus olivaris*) was also identified as a host in the United States, but records of the species in Ontario are limited to the lower Thames River and Lake St. Clair, and are not widespread throughout the range of Purple Wartyback. Therefore, Flathead Catfish is not considered a primary host for Purple Wartyback in Ontario (COSEWIC 2021).

Purple Wartyback are short-term brooders and spawn in the spring and into summer; however, the precise timing of spawning is unknown in Ontario (Colm and Morris 2023). Available data pertaining to spawning is based on studies completed in West Virginia and Tennessee rivers (Jirka and Neves 1992, Haggerty et al. 1995, COSEWIC 2021). Male Purple Wartyback will release sperm into the water column as early as March, when water temperatures reach approximately 9°C, and may continue into July (Jirka and Neves 1992; Hagerty et al. 1995). Female individuals begin spawning in spring when temperatures reach approximately 10°C, which in Ontario is between early April into June (Jirka and Neves 1992). Females located downstream of the males will filter the sperm out of the water and into the posterior portion of their gills (suprabranchial chambers), where they fertilize mature ova for embryo development in the outer set of gills (marsupia). Female Purple Wartyback will brood young in marsupial gills from the egg to the larval stage, prior to release into the water column.

Brooding female Purple Wartyback uses a mantle display (inflated tissue around the excurrent siphon) or conglutinates (packages of glochidia) to attract host fish (Sietman et al. 2012). The mantle display is stomate-shaped and blue-grey in color, with faint, dark spots. Conglutinates form loose, gelatinous strands that are amorphous and transparent, between 5 to 20 cm in length (Sietman et al. 2012). The release of conglutinates by female Purple Wartyback elicits a predatory response in host fish, which causes the rupture and release of glochidia. There is some literature indicating that there may also be chemical cues associated with the use of both of these lures (Barnhart et al. 2008).

Glochidia encystment is a period of parasitism in which glochia are attached to the host fish. During glochidia encystment, immature juveniles feed on bodily fluids of the host fish over the span of 17 to 38 days, after which they release themselves from the host and settle into the substrate as free-living mussels (Hove et al. 1994; Hove 1997; Hove and Kurth 1997).

Following the period of encystment on a host fish, juvenile mussels burrow entirely below the substrate surface for the first three to five years of their life (Neves and Widlak 1987; Balfour and Smock 1995; Schwalb and Pusch 2007). Juveniles at this stage use filter feeding in combination with pedal feeding (using cilia on their foot to sweep food particles into their shell) to feed upon detritus, algae and bacteria from the interstitial pore space (spaces between particles of substrate). During the first two to three years they undergo accelerated growth (Gatenby et al. 1997; Watters et al. 2009). Age of maturity is approximately six to eight years, with an estimated 26-year generation time (Jirka and Neves 1992; Colm and Morris 2023, DFO 2023a). Purple Wartyback have been documented to live up to 90 years of age (Colm and Morris 2023).

1.3 Distribution, abundance and population trends

Purple Wartyback occurs within eastern North America, historically recorded within 20 American states, and one Canadian province within the Mississippi River and lower Great Lake's drainage basins (NatureServe 2024) (Figure 2). Its range extended from southwestern Ontario south to Alabama and Mississippi, and North Carolina west to Oklahoma. Declines in Purple Wartyback populations have been observed in the northern and outer limits of its range, but the species generally remains common within the southern portion of its range (NatureServe 2024). Due to declines, it is extirpated from Pennsylvania, and thought to be extirpated from South Dakota (NatureServe 2024).

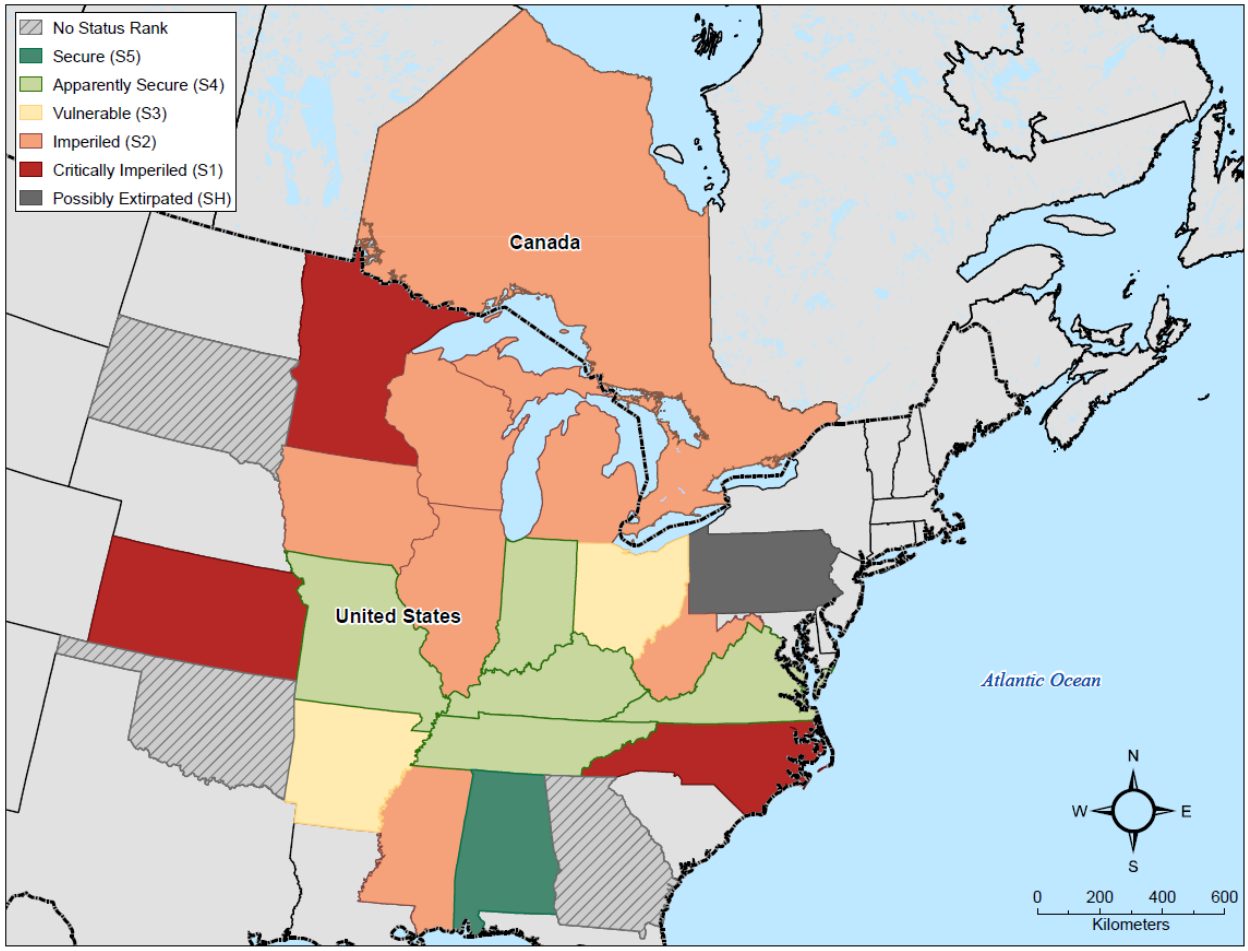

Figure 2. Global distribution and status of Purple Wartyback.

Within Canada, Purple Wartyback historically occurred within southwestern Ontario in the Lake Erie, Lake St. Clair and Lake Huron drainage basins. Specifically, Purple Wartyback was recorded from the Ausable River, Sydenham River, Thames River, Detroit River and Lake Erie. Its current distribution is similar to its historic range, but it is now thought to be extirpated from the Detroit River and Lake Erie, and restricted only to

the Lake Huron and Lake St. Clair drainages (Figure 3) (COSEWIC 2021). A single live individual was documented from the Detroit River during sampling in 1998 (Figure 3). However, substantial sampling has been completed within the Detroit River with no records since of live individuals.

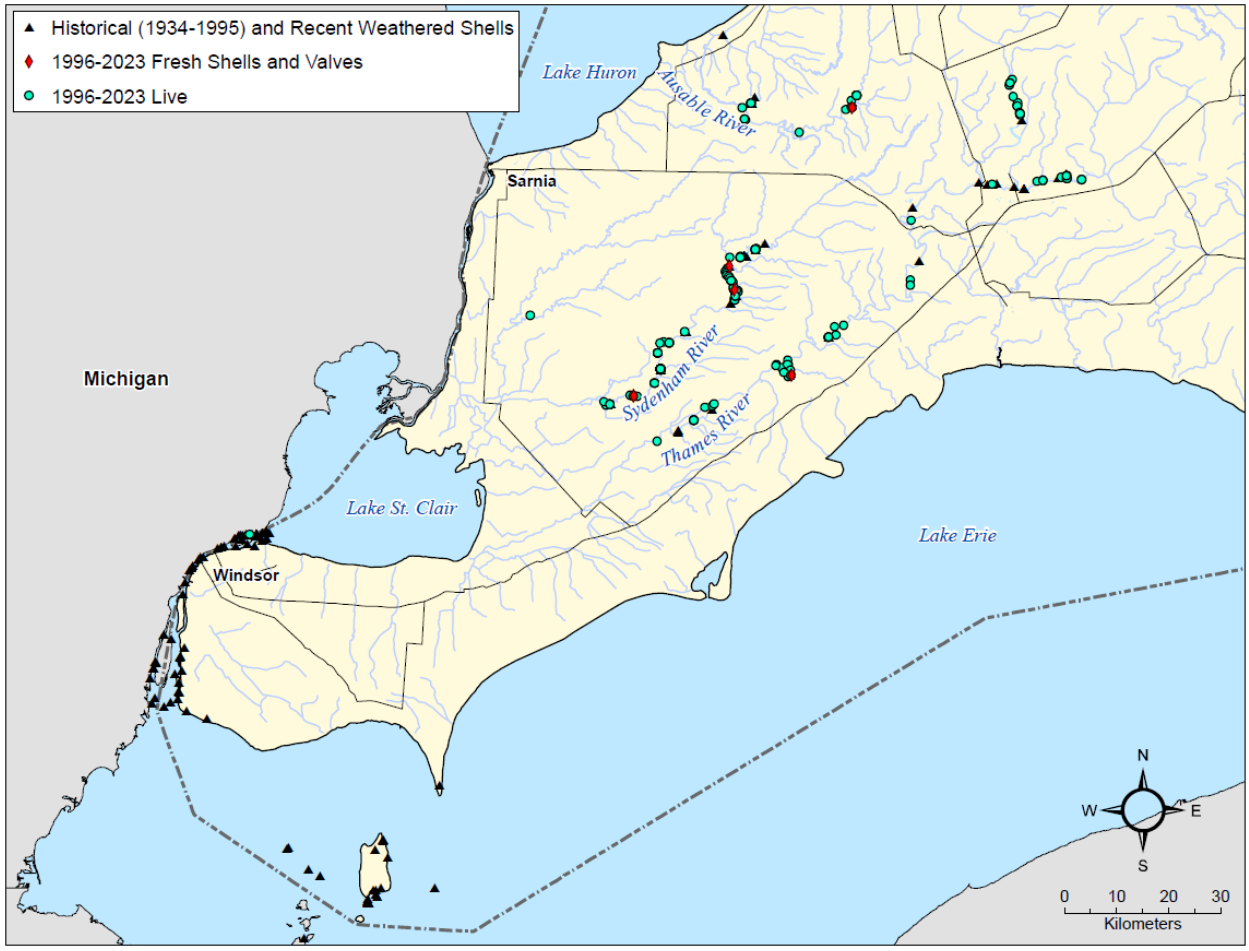

Figure 3. Historical and current distribution of Purple Wartyback in Ontario.

The total estimated population size of Purple Wartyback is approximately 7,824,000 (± 2,707,000) individuals within Ontario, distributed between three geographically separated subpopulations: the Sydenham River, Thames River and Ausable River (COSEWIC 2021). The Sydenham River subpopulation is the largest, with approximately 5,400,000 (± 1,600,000) individuals (COSEWIC 2021). This subpopulation is distributed throughout the watercourse from Napier to just upstream of Dresden, and includes a tributary (Black Creek) to the North Sydenham River. The Thames River subpopulation comprises approximately 2,400,000 (± 1,100,000) individuals distributed along the Lower Thames River from Delaware to the mouth of the river, a small stretch of the North Thames River upstream of the Fanshawe Dam, and the South Branch of the Thames River downstream to below the confluence of the Middle Branch (COSEWIC 2021). The Ausable River subpopulation comprises

297 approximately 24,000 (± 7,000) individuals distributed between two separate segments
298 of the river, located around Nairn and north of Arkona (COSEWIC 2021).

299 The minimum viable population (defined as the minimum adult population size for
300 desired probability of persistence over approximately 10 generations) is estimated to be
301 approximately 1,400 adult females (DFO 2023b). If a 1:1 sex ratio is assumed, the
302 minimum viable population including all adult Purple Wartyback is approximately 2,800
303 individuals (DFO 2023b). Estimates of population size, including both adults and
304 juveniles, were made based upon a 3,600 m^2 section of the Sydenham River and a
305 3,000 m^2 section of the Thames River (van der Lee and Koops 2023). The estimated
306 number of Purple Wartyback within the sampled region of the Sydenham River was
307 10,504 individuals. Based on the length-frequency distribution, 87% of sampled mussels
308 were adults (n = 9,139) (van der Lee et al. in prep., van der Lee and Koops 2023).
309 Therefore, it can be assumed that Purple Wartyback in the Sydenham River currently
310 exceeds the minimum viable population size. The estimated number of Purple
311 Wartyback (n = 872) within the sampled region of the Thames River is less than the
312 minimum viable population size. However, given the estimated rate of population
313 growth, the Thames River population may reach the minimum viable population size in
314 20 years (van der Lee and Koops 2023, DFO 2023b). No estimates were calculated for
315 the Ausable River population.

316 In addition to minimum viable population, population densities required to support stable
317 populations within the Sydenham and Thames rivers can be estimated (van der Lee and
318 Koops 2023). Current estimated densities of live Purple Wartyback are 2.52
319 individuals/m^2, 0.26 individuals/m^2 and 0.09 individuals/m^2 within the Sydenham,
320 Thames and Ausable rivers, respectively (COSEWIC 2021, DFO 2023b). Densities
321 required to support stable populations (i.e., $\lambda = 1$) are estimated to be 2.21 adult
322 females per m^2 and 0.48 adult females per m^2 within the Sydenham and Thames rivers,
323 respectively (van der Lee and Koops 2023). Calculations for the Ausable River were not
324 completed, though the estimated population growth rate for this subpopulation indicates
325 that it is likely stable (van der Lee and Koops 2023). Given that the current density
326 estimates within the Sydenham and Thames rivers include both male and female Purple
327 Wartyback, as well as all age classes, it is assumed that the densities of adult females
328 are less than the estimated densities required to support stable populations in the
329 respective rivers.

330 Historical collections do not provide details of sampling methods or effort, and a lack of
331 relative abundance or density estimates makes it impossible to determine population
332 trends (COSEWIC 2021). Despite the lack of sufficient data to compare current and
333 historical population distribution and densities, this species is inferred to have
334 experienced, and continues to experience, declines as a result of habitat degradation
335 throughout its Ontario range. Rescue and recolonization from U.S. populations is
336 unlikely despite the potential for large-scale dispersal of vertebrate fish hosts, as U.S.
337 subpopulations of Purple Wartyback within the Lake Huron and Erie drainages are also
338 imperiled (Zanatta et al. 2015; COSEWIC 2021).

Recent quadrat surveys completed by Fisheries and Oceans Canada (DFO) at select monitoring sites within the Ausable, Sydenham and Thames rivers have provided insight into populations trends within each watershed. Based on these surveys, the Sydenham and Thames River subpopulations appear to be increasing (COSEWIC 2021; Colm and Morris 2023, DFO 2023a). The Ausable River subpopulation was identified as potentially decreasing in recent years within the federal assessment and status report (COSEWIC 2021), but additional sampling data from 2019 to 2022 resulted in more recent population assessments which suggest this population is stable (Colm and Morris 2023). However, interpretation of the data is cautioned: meaningful changes in densities of freshwater mussel species at risk are difficult to determine, as low population densities and high variability in sampling effort among sites and years can skew results (Reid and Morris 2017). Similarly, there is a lack of information regarding the spatial stability of mussel beds (areas of substrate densely populated by mussels) within Ontario rivers, and therefore the changes in habitat, and as a result, distribution and abundances, are difficult to quantify (COSEWIC 2021).

Detecting freshwater mussels can be challenging as they typically occur in low densities, are spatially clustered, and are imperfectly detected due to various factors, including shell size and sculpture, burrowing tendencies, flow conditions within riverine habitats, substrate composition, and experience of field staff (Reid 2016). As such, sites with previous detections of Purple Wartyback should continue to be considered occupied until a minimum of two repeat timed-search surveys or a single systematic quadrat-based survey have failed to detect the species (Reid 2016, Reid and Morris 2017). These survey methods are expected to detect upwards of 80% of mussel species present at a site (Reid 2016, Reid and Morris 2017), which is likely sufficient to determine Purple Wartyback presence or absence.

1.4 Habitat needs

Adult Purple Wartyback inhabit small to large rivers with moderate to swift currents and cobble, gravel, mixed gravel and sand substrates. It is occasionally found in lake habitats (COSEWIC 2021; Colm and Morris 2023). Purple Wartyback appears to prefer cobble, gravel and sand, based on substrate compositions observed during surveys of the Sydenham and Thames rivers (Morris, unpub. data, LeBaron et al. 2023). Purple Wartyback can be found at depths of 0.32 m to 6.0 m (Parmalee and Bogan 1998; COSEWIC 2021). Mean stream velocities at sites where Purple Wartyback were observed (post-1997) were 0.376 m/s for adults, ranging from 0.00 to 2.63 m/s (Colm and Morris 2023). Similarly, the mean water velocity recorded during Unionid Monitoring and Biodiversity Observation (UMBO) surveys from recent sampling events in Ontario was observed to be 0.373 m/s, ranging from 0.00 to 2.05 m/s (Colm and Morris 2023). However, water velocity measurements were taken during low-flow conditions, and therefore do not reflect the full range of water velocities that may be encountered when burrowed into substrates (T. Morris, pers. comm. 2024). The species has also been documented in dammed habitats and lakes, suggesting it is tolerant of low water velocities (Haggerty et al. 1995; Ostby 2005; COSEWIC 2021).

Juvenile Purple Wartyback, generally defined as individuals under the age of six to eight years, have limited ability for habitat selection when releasing from their host fishes, and subsequently limited ability for relocating to better habitats (COSEWIC 2021). Juvenile movement is variable and dependent upon water flow, hydrodynamics, water temperature and behaviour (Schwalb et al. 2011). Therefore, survival rates and recruitment of juvenile Purple Wartyback depends upon habitat suitability when the juvenile mussels drop off their host (Schwalb and Ackerman 2011; Schwalb et al. 2011). Juveniles are generally found within similar habitats as adults, but are burrowed into the substrates, generally up to 8 cm below the surface (Colm and Morris 2023).

As obligate parasites at the glochidial stage, individuals are subject to habitat preferences of their host fishes during gill encystment. Bullheads (*Ameiurus* spp.) inhabit slow-flowing, warmwater watercourses, wetlands, and shallow bays of lakes throughout southern Ontario (Scott and Crossman 1998). Bullheads often inhabit areas with instream cover, such as heavily vegetated habitats, and are associated with soft substrates (Scott and Crossman 1998). Channel Catfish inhabits warmwater lakes and medium to large rivers throughout southern Ontario, and is primarily associated with sand, gravel and cobble substrates (Scott and Crossman 1998). This species is not associated as closely with benthic habitats as Bullheads, and typically inhabits cooler, clearer habitats with coarser substrates. Channel Catfish has also been documented to migrate large distances, up to and greater than 90 km (Scott and Crossman 1998; Enders et al. 2019).

1.5 Limiting factors

Purple Wartyback, as with other Unionidae, are obligate parasites and require encystment on a vertebrate host to complete their life cycle. Therefore, the availability of suitable hosts represents a potential limiting factor to recruitment. Presumed host fish species for Purple Wartyback are widely distributed throughout the range of Purple Wartyback in Ontario, therefore this does not appear to be a limiting factor.

As Purple Wartyback is a relatively sedentary species, large-scale dispersal is reliant upon host fish movements during glochidial encystment. Similarly, due to the limited ability to make horizontal movements, Purple Wartyback are challenged in their ability to disperse to new habitats should their habitat become sub-optimal.

Purple Wartyback, as with other freshwater mussels, is a slow-growing species. It takes several years to reach sexual maturity and demonstrates slow rates of population growth (Colm and Morris 2023).

Estimates suggest that there is sufficient habitat available in the Sydenham and Thames rivers to support sustainable populations, therefore habitat is not likely limiting.

1.6 Threats to survival and recovery

Pollution, climate change and severe weather events are considered to be the most significant threats to Ontario populations of Purple Wartyback (COSEWIC 2021; Colm and Morris 2023). Threats were identified based upon the Threats Calculator completed on November 27, 2018 in support of the COSEWIC Assessment and Status Report (COSEWIC 2021). Threats posing less severe impacts include invasive and other problematic species and genes (COSEWIC 2021; Colm and Morris 2023).

Pollution – Agricultural & forestry effluents (medium-low impact)

Land within the areas surrounding the Ausable, Sydenham and Thames rivers is primarily used for agricultural purposes. As a result, nutrient run-off – specifically nitrogen and phosphorus – from agricultural practices has surpassed suggested guidelines (COSEWIC 2021). These nutrients may stem from fertilizers, herbicides, manure, detergents and waste associated with livestock and crop production (Staton et al. 2003; Nelson et al. 2003; Cudmore et al. 2004; UTRCA 2022). Increased concentrations of nitrogen and phosphorus can stimulate growth and decomposition of algae and aquatic vegetation, resulting in decreased levels of available oxygen within watercourses (Carpenter et al. 1998). The decrease in oxygen reduces respiration for Purple Wartyback and other mussel species, and may impact fish communities on which these species rely to complete their life cycle (Tetzloff 2001; Jackson et al. 2001).

Additionally, one of the primary threats for most species at risk mussels in southern Ontario, including Purple Wartyback, is increased suspended solids resulting in higher turbidity (cloudiness) (DFO 2011a; Bouvier et al. 2014). Increased turbidity may reduce the ability of host fishes to visually locate the reproductive lure/attractant (i.e., mantle or conglutinate) used by Purple Wartyback, and therefore decreases the potential for successful recruitment (Sietman et al. 2012). Practices such as installation of tile drainage features, removal of riparian vegetation, and allowing livestock access to streams may result in stream bank erosion and instability (Colm and Morris 2023). Siltation and substrate deposition resulting from increased erosion can smother mussels and interfere with feeding, respiration, growth and reproduction by clogging the gill structures necessary to carry out these processes (Williams et al. 1993; Wood and Armitage 1997; Strayer and Fetterman 1999; Tuttle-Raycraft et al. 2017). The deposition of these fine sediments may also reduce water velocities and dissolved oxygen concentrations within the interstitial spaces in the stream bed, which are required to support mussels when burrowed as juveniles or adults (Österling et al. 2010).

Pollution – Domestic & urban waste water (medium-low impact)

Land use within the Ausable, Sydenham and Thames River watersheds is predominantly agricultural in nature, but increasing urban development may pose threats to Purple Wartyback stemming from urban pollutants. As a filter feeder, Purple Wartyback is particularly susceptible to sediment contamination and water pollution (Colm and Morris 2023). Run-off from roadways and urban areas provides inputs of

contaminants such as oil and grease, heavy metals and chlorides to watercourses (Gillis 2011; Archambault et al. 2018). The presence of pesticides, including the persistence of banned pesticides and actively utilized pesticides in agriculture (e.g., Polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloroethane (DDT), Malathion, Rotenone, Glyphosate), and heavy metals may inhibit respiration and accumulate in muscle tissue, affecting growth, filtration ability, enzyme activity, and behaviour (USFWS 1994; Naimo 1995; Conners and Black 2003). Juvenile mussels and glochidia are particularly sensitive to heavy metals, acidity, salinity, and chloride (Huebner and Pynnonen 1992; Gillis et al. 2008; Gillis 2011). The application of road salt for ice removal within Canada is most commonly in the form of sodium chloride, with calcium chloride, magnesium chloride and potassium chloride used less often (Prosser et al. 2017). It was determined that chloride is the primary toxic compound associated with salt-impacted road-runoff (Prosser et al. 2017). The Upper Thames River Conservation Authority (UTRCA) has indicated that chloride levels within the Thames River have been on an upward trend (E. Carroll, pers. comm. 2024).

Human population growth has been increasing in urban centers within Purple Wartyback's range, particularly in the municipality of London, Ontario (Thames River watershed). Although increasing urbanization will result in decreases of agricultural pollution, it results in additional wastewater and sewage treatment volumes. Wastewater and sewage treatment plants located within or upstream of Purple Wartyback's range may introduce pollutants and contaminants that negatively affect populations. Wastewater effluent may contain high nitrite and ammonia levels and traces of pharmaceuticals and personal care products that, in high enough concentrations, may be toxic or result in endocrine disruption (Gagné et al. 2004; Gagné et al. 2011; Tetreault et al. 2011; Gillis et al. 2017). Studies on endocrine and reproductive disruption as a result of pharmaceutical inputs have identified an increase in females and males with elevated female-specific proteins in other mussel species (Gagné et al. 2011). Juvenile mussels have also been identified as highly susceptible to toxicity from un-ionized ammonia that may be present in wastewater and sewage effluent (Newton 2003; Newton et al. 2003).

Climate Change and Severe Weather – Droughts (medium – low impact)

Climate change may have direct and indirect impacts on mussels and their habitats, though the degree to which it may affect populations of Purple Wartyback in the Ausable, Sydenham and Thames rivers is unknown. Direct impacts may result from increased frequency and severity of drought, causing a decrease in available habitat and degradation of suitable habitats (van der Lee and Koops 2023). Decreases in available habitat would result in indirect impacts associated with increased interspecific and intraspecific competition as a result of crowding. (COSEWIC 2021; Colm and Morris 2023). With the reduction of available habitat and subsequent crowding, further impacts include an increased risk of disease, reduced dissolved oxygen through consumption, and increased risk of predation (van der Lee and Koops 2023). With decreased water levels associated with droughts, and potential for more frequent and severe heat waves, riverine habitats may have reduced thermal buffering capacity over repeat occurrences, potentially leading to thermal stress on Purple Wartyback (Seuront et al. 2019).

Flooding may result in indirect impacts associated with the disruption of occupied riverine habitats. The scouring of stream beds poses a risk of flushing mussels downstream into less suitable habitat (COSEWIC 2021; Colm and Morris 2023). Erosion of substrates and deposition elsewhere within the riverine system may result in increased nutrient and turbidity loading, altered flow regimes, and changes in water temperatures, distribution of host fish species, habitat availability and interactions with competitors and predators (COSEWIC 2021; Colm and Morris 2023).

Invasive and other problematic species and genes (low impact)

The introduction of dreissenid mussels (i.e., Zebra Mussels [*Dreissena polymorpha*] and Quagga Mussels [*D. rostriformis*]) in the late 1980s resulted in significant impacts to native mussel populations within the Great Lakes Basin (COSEWIC 2021). It is likely that the introduction of these non-native species resulted in the extirpation of Purple Wartyback within the Detroit River and Lake Erie (Colm and Morris 2023). Dreissenids are typically found in low abundances in riverine habitats such as the Ausable, Sydenham and Thames rivers; however, they have been documented within reservoirs and lower reaches of these watercourses (Morris and Edwards 2007). Dreissenids have been documented attaching to the shells of native mussels, smothering siphons, restricting valve movements, hindering burrowing and feeding, and impacting growth, reproduction and survival (Nalepa et al. 1996; Schloesser et al. 2006). Recent data suggests populations of dreissenid mussels are declining in Ontario, and may result in fewer detrimental impacts to native mussels (Karatayev et al. 2015).

Round Goby (*Neogobius melanostomus*) has also been documented throughout much of Purple Wartyback's range (Poos et al. 2010). Round Goby may directly impact Purple Wartyback through predation upon juveniles, and indirectly affect populations through competition with, or predation upon, host fishes (Poos et al. 2010; Tremblay et al. 2016). Round Goby may also act as a sink for glochidia through low or unsuccessful metamorphosis, reducing successful recruitment of Purple Wartyback (Tremblay et al. 2016).

1.7 Knowledge gaps

There are several knowledge gaps associated with the life history of Purple Wartyback, such as timing of the spawning season in Ontario and life-history parameters for population modeling (Colm and Morris 2023). Aspects related to species biology, such as fertility, juvenile survival, age-at-maturity and relative contribution to reproduction, maximum population growth rate, and density dependence are poorly understood and could benefit from additional research to support the development of more accurate population models (van der Lee and Koops 2023, DFO 2023b).

Knowledge gaps related to species abundance and distribution exist as well, which could be improved through additional survey effort. The distribution data for Purple Wartyback is limited to distinct portions of the occupied habitat (i.e., Ausable, Sydenham, and Thames rivers). Areas between the mapped occurrences of Purple

Wartyback may contain suitable habitat, but further survey effort is required to confirm this. Optimal conditions for completing life processes also remain poorly understood, such as ideal habitat conditions (including microhabitats) (e.g., water velocities, substrate types, dissolved oxygen concentrations, and temperature) and food availability (Colm and Morris 2023). Similarly, the toxicity limits and pollution tolerances of Purple Wartyback are based upon multi-species studies and require additional research to better understand the response of the species to anthropogenic stressors (i.e., pollution tolerances) (Colm and Morris 2023).

Host fishes for Purple Wartyback in Ontario are presumed based on U.S. studies but have yet to be confirmed, and infestation or metamorphosis rates of glochidia on host fishes lack sufficient research. The abundance of freshwater mussels within a river system is correlated with the abundance of their host species (van der Lee and Koops 2023). Therefore, understanding population dynamics of host fishes and the interspecific relationships with Purple Wartyback may provide insight into the influence of host fishes on Purple Wartyback population trends and ability to disperse and colonize new habitats. By confirming the host species for Purple Wartyback, we can subsequently examine how impacts to host species would influence the persistence or recovery of Purple Wartyback.

1.8 Recovery actions completed or underway

The Upper Thames River Conservation Authority (UTRCA), Ausable Bayfiled Conservation Authority (ABCA), Lower Thames Valley Conservation Authority (LTVCA), St. Clair Region Conservation Authority (SCRCA), and DFO are conducting ongoing monitoring within the Ausable, Sydenham and Thames rivers to collect baseline data on mussel and host distribution and population size. Additionally, in 2022 the Ministry of Natural Resources and Forestry (MNRF) completed mussel brail sampling in non-wadeable habitats within the Purple Wartyback range, including the Ausable, Sydenham, and Thames rivers. This data has provided, and will continue to provide, further insight into Purple Wartyback distribution, subpopulation sizes and trends, and habitat requirements for the species.

Ecosystem-based recovery initiatives, such as the Ausable River Action Plan (DFO 2020), Sydenham River Action Plan (DFO 2018) and the Thames River Ecosystem Recovery Strategy (TRRT 2005) have been implemented in their respective watersheds. The respective action plans have identified monitoring sites within the Sydenham and Thames rivers, provide guidelines for the maintenance of flow regimes and establishing riparian buffer zones and promote working with landowners to reduce impacts and increase public awareness of potentially harmful invasive species. Recovery strategies have been prepared and implemented for several other mussel species at risk, some of which overlap in range with Purple Wartyback. Implementation of these recovery strategies will also benefit Purple Wartyback.

The UTRCA, ABCA, SCRCA, and LTVCA have identified that stewardship projects, such as tree planting and wetland or riparian habitat creation are ongoing (E. Carroll,

pers. comm. 2024; K. Jean, pers. comm. 2024, C. Paterson, pers. comm. 2024, V. McKay pers. comm. 2024). Additionally, the LTVCA encourages livestock managers allowing livestock access to the Thames River tributaries to install exclusion fencing and utilize alternate watering sources (V. McKay pers. comm. 2024). These activities will benefit aquatic species at risk by reducing sediment and nutrient inputs. The UTRCA, ABCA, SCRCA, and LTVCA are also involved in education and outreach programs for watershed residents, including best management practices for agriculture. These programs will help inform residents of methods for protecting watercourses and the species that inhabit them.

Ongoing surveys for native mussels, including Purple Wartyback, are being conducted by DFO. Additional data may be collected by university researchers, other government agencies, and private sector firms such as environmental consulting agencies. This research may provide more details regarding the abundance and distribution of Purple Wartyback within each watershed, and may provide insight into other life processes where knowledge is lacking.

2.0 Recovery

2.1 Recommended recovery goal

The recommended long-term recovery goal for Purple Wartyback is to return self-sustaining populations to the Ausable, Sydenham and Thames rivers and to increase the species' distribution within its native range in Ontario.

2.2 Recommended protection and recovery objectives

1. Protect and conserve populations by identifying and mitigating threats, implementing remedial actions where necessary, and increasing availability of suitable habitat.
2. Initiate research to fill knowledge gaps related to the species biology, habitat needs and availability, host species, population abundance and distribution, and threats in Ontario.
3. Monitor Purple Wartyback populations to track population trends, the condition of habitat for Purple Wartyback and its host(s) (once confirmed), and the success of threat mitigation and recovery activities.
4. Promote conservation through increased awareness about the significance, distribution, threats, and recovery of this species.

2.3 Recommended approaches to recovery

Table 1. Recommended approaches to recovery of the Purple Wartyback in Ontario.

Objective 1: Protect and conserve populations by identifying and mitigating threats, implementing remedial actions where necessary, and increasing availability of suitable habitat.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Short-term	Protection, Management	**1.1** Develop and implement Best Management Practices for Purple Wartyback. • Undertake appropriate management actions (e.g., invasive species control, water quality treatment, salt management, etc.) to maintain and improve existing habitat. • Develop recommended targets/thresholds for stormwater management facility outfalls to known habitat. • Develop monitoring program guidelines to document changes in habitat over time and the effectiveness of threat mitigation and habitat restoration activities.	Threats: • All threats

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Necessary	Ongoing	Protection, Management, Stewardship	**1.2** Identify opportunities and undertake activities to enhance and/or expand existing habitat. • Identify site-specific threats and opportunities for mitigation or habitat enhancement. • Continue to undertake habitat stewardship programs and employ habitat enhancement where feasible. • Complete monitoring within sections of river undergoing threat mitigation and/or habitat enhancement to determine whether positive impacts to Purple Wartyback are realized as a result.	Threats: • All threats

Objective 2: Initiate research to fill knowledge gaps related to the species biology, habitat needs and availability, host species, population abundance and distribution, and threats in Ontario.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Ongoing	Inventory, Monitoring and Assessment, Research	**2.1** Undertake inventories and monitoring surveys of the Ausable, Sydenham, and Thames rivers and previously extirpated habitats within Purple	Knowledge gaps: • Population distribution and abundance

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
			Wartyback's historic range. • Establish/conduct routine monitoring surveys within the current distribution of Purple Wartyback to determine the extent, abundance and demographics of known populations in Ontario and to monitor population trends. • Conduct surveys within sections of riverine habitat upstream or downstream of known occurrences where survey data is lacking or insufficient. • Conduct targeted surveys within the historical distribution of Purple Wartyback for previously undetected populations in high probability areas with suitable habitat. Determine the extent and abundance of any new populations detected. • Conduct surveys within Black Creek to determine whether a viable population exists within this tributary of the Sydenham River.	

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Short-term	Research	**2.2** Conduct research on threats to Purple Wartyback and its tolerances to understand adaptability and resilience to potential threats. • Determine toxicity limits in response to pollutants at various life stages, utilizing more common and closely-related species as a surrogate for toxicity testing. • Determine the extent and abundances of invasive species within the range of Purple Wartyback. • Determine the direct and indirect impacts of invasive dreissenid mussels and Round Goby on Purple Wartyback. • Conduct studies on physiological tolerances (e.g., temperature, dissolved oxygen, rapid changes in flows) to environmental stressors on Purple Wartyback and its host fishes to infer potential effects of climate change.	Knowledge gaps: • Pollution tolerance Threats • Invasive species • Climate change

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Ongoing	Research	**2.3** At extant sites, determine specific habitat characteristics supporting the persistence of Purple Wartyback. • Determine habitat requirements for different life stages (juvenile and adult). • Determine microhabitat requirements (water velocities, substrate types, dissolved oxygen concentrations, temperatures, etc.) to carry out specific life processes (e.g., spawning).	Knowledge gaps: • General biology • Microhabitat requirements
Necessary	Short-term	Research	**2.4** Conduct research on the general biology, life history, and population dynamics of Purple Wartyback to inform recovery potential and population predictors. • Collect data on reproduction (i.e., fertility, age-at-maturity and relative contribution to reproduction), density dependence, and general life-cycle biology. • Conduct research to determine conditions	Knowledge gaps: • General biology • Reproduction and life history •

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
			required to initiate spawning and the general timing within Ontario watersheds. • Conduct research on recruitment rates and juvenile survival rates.	
Necessary	Short-term	Research, Management, Inventory	**2.5** Identify/confirm host fish species for Purple Wartyback. • Conduct studies to confirm the host fish species within Ontario. • Assess infestation and metamorphosis rates of glochidia on host fishes.	Knowledge gaps: • Host fishes • Life history
Beneficial	Ongoing	Inventory, Monitoring and Assessment	**2.6** Determine the distribution and abundance of the identified host fish species in Ontario. • Utilize existing data and on-going monitoring/surveys to confirm and characterize populations of the identified host fish species. • Determine barriers within each subpopulation (watershed basis) that may limit dispersal of Purple Wartyback.	Knowledge gaps: • Host fishes as dispersal method

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Objective 3: Monitor Purple Wartyback populations to track population trends, the condition of habitat for Purple Wartyback and its host (once confirmed), and the success of threat mitigation and recovery activities.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Long-term	Inventory, Monitoring and Assessment, Research	**3.1** Establish/conduct a long-term monitoring program to detect changes in the distribution and abundance of extant populations of Purple Wartyback populations and invasive species. • Continue to apply quadrat sampling and timed-search surveys within wadeable habitats to monitor Purple Wartyback subpopulations. • Establish a long-term monitoring program for Purple Wartyback in non-wadeable habitats (e.g., brail and/or SCUBA). • Undertake inventory of habitat characteristics (i.e., water quality, substrates, flows, etc.) in conjunction with long-term monitoring of Purple Wartyback to characterize changes to habitat availability and quality. • Monitor Purple Wartyback in areas where threat mitigation and/or habitat enhancement has taken place, as per Objective 1, to determine effectiveness of recovery actions. • Determine the distribution of dreissenid mussels and Round Goby to identify potential threats to subpopulations of Purple Wartyback.	Threats: • Invasive species Knowledge gaps: • Population distribution and abundances • Microhabitats

Objective 4: Promote conservation of Purple Wartyback by increasing awareness of the species' significance, distribution and threats, and actions that can be taken to promote the species' protection and recovery.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Necessary	Short-term	Education and Outreach, Communication or Stewardship	**4.1** Develop and distribute outreach materials and encourage landowners to participate in stewardship activities. • Erect educational signage at public accesses in areas of existing sites. • Develop and distribute outreach materials about the importance and benefits of maintaining habitat for Purple Wartyback and threats they currently face. • Offer incentive programs and landowner support for habitat management, including enhancement of vegetation in areas of manicured lawn or agricultural lands, in alignment with Best Management Practices.	Threats: • All threats Knowledge gaps: • Distribution

2.4 Performance Measures

The performance measures presented below provide a way to define and measure progress toward achieving the recovery goal identified in Section 2.1:

1. Densities of adult female Purple Wartyback are estimated at 2.21 per square meter within the Sydenham River watershed and 0.48 per square meter within the Thames River watershed to support stable populations by 2044.
2. Estimates of sustainable densities of adult female Purple Wartyback in the Ausable River are determined by 2044.
3. Distribution of Purple Wartyback within its' native range has increased.

2.5 Area for consideration in developing a habitat regulation

Under the ESA, a recovery strategy must include a recommendation to the Minister of the Environment, Conservation and Parks on the area that should be considered if a habitat regulation is developed. A habitat regulation is a legal instrument that prescribes an area that will be protected as the habitat of the species. The recommendation provided below by the author will be one of many sources considered by the Minister, including information that may become newly available following the completion of the recovery strategy should a habitat regulation be developed for this species.

The habitat regulation is recommended to be based upon the Aquatic Ecosystem Classification (AEC) method; a spatial data tool that classifies river and stream segments based on physical attributes and watershed characteristics (Jones and Schmidt 2022). These characteristics impact the biotic and physical processes within the catchment, and it would therefore be reasonable to expect that if Purple Wartyback is present within one part of a river or stream, it could be present in spatially contiguous areas of the same river or stream. Occupancy of AEC segments should be based on observations of live individuals and fresh shells from 1996 onwards, as this coincides with the commencement of systematic surveys of freshwater mussel communities in southern Ontario. Reaches should continue to be considered occupied until sufficient survey effort has been applied to confidently determine the species' absence.

Considering the above, it is recommended that a habitat regulation for Purple Wartyback include the occupied reach of a watercourse as defined by the AEC, up to the high-water mark. This includes but is not limited to areas within the Ausable, Thames, and Sydenham River watersheds.

Natural and semi-natural vegetation adjacent to watercourses plays an important role in maintaining aquatic features and water quality attributes necessary to support populations of Purple Wartyback (Caskenette et al. 2020). These habitats offer soil stability to mitigate against erosion and sedimentation, and filter pollutants to minimize run-off into the adjacent watercourse (Caskenette et al. 2020). Based on research from the University of California, 30-meter vegetated buffers effectively remove

approximately 85%of pesticides, sediment, nitrogen, and phosphorus from runoff (Zhang et al. 2010). Based on the threats to Purple Wartyback described in Section 1.6, protection of 30 meters adjacent to occupied habitat would provide effective mitigation against agricultural and forestry effluent and domestic and urban wastewater. Additionally, natural and semi-natural vegetation adjacent to the watercourse would provide shade relief to maintain the thermal classification and mitigate against the effects of climate change (Brian et al. 2004). Therefore, areas with natural and semi-natural vegetation, including forest, woodland, thicket, wetland, old field, pasture, or meadow habitats within 30 meters of the occupied AEC segment are recommended to be included in a habitat regulation. Lawns and areas of agricultural cropland should not be included.

Should Purple Wartyback be detected within Lake Erie, Lake St. Clair or the Detroit River where it is currently thought to be extirpated, it is recommended that a habitat regulation apply. The AEC does not apply to non-riverine habitats or to boundary rivers, including the Detroit River; therefore, the habitat regulation for these areas should rely upon habitat preferences for Purple Wartyback to delineate the extent of habitat protections. A habitat regulation should only apply to areas with multiple individuals of varying age classes to indicate recruitment and recolonization. This recommendation is based on Fisheries and Oceans Canada's assessment of methods for identifying critical habitat in coastal areas (DFO 2011b). Suitable habitats should be characterized by water depths less than six meters, substrates of cobble, gravel, mixed gravel and sand, maximum water velocities of 2.63 m/s during periods of low flow, absence of Zebra Mussels and Quagga Mussels, and availability to Purple Wartyback's primary host fishes (Black Bullhead, Yellow Bullhead and Channel Catfish). Additional research on Purple Wartyback distribution and microhabitats within these systems is required to further refine the habitat regulation recommendation within these waterbodies. Studies confirming the distribution and microhabitats of Purple Wartyback will provide insight into additional habitat characteristics required for survival within near-shore lake and large river habitats.

Glossary

Committee on the Status of Endangered Wildlife in Canada (COSEWIC): The committee established under section 14 of the Species at Risk Act that is responsible for assessing and classifying species at risk in Canada.

Committee on the Status of Species at Risk in Ontario (COSSARO): The committee established under section 3 of the *Endangered Species Act, 2007* that is responsible for assessing and classifying species at risk in Ontario.

Conservation status rank: A rank assigned to a species or ecological community that primarily conveys the degree of rarity of the species or community at the global (G), national (N) or subnational (S) level. These ranks, termed G-rank, N-rank and S-rank, are not legal designations. Ranks are determined by NatureServe and, in the case of Ontario's S-rank, by Ontario's Natural Heritage Information Centre. The conservation status of a species or ecosystem is designated by a number from 1 to 5, preceded by the letter G, N or S reflecting the appropriate geographic scale of the assessment. The numbers mean the following:

1 = critically imperiled
2 = imperiled
3 = vulnerable
4 = apparently secure
5 = secure
NR = not yet ranked

Anterior margin: located near the front of an animal, at the forward-facing side of the shell.

Beak: the raised part of the dorsal margin of the shell representing the earliest period of shell growth; also known as the umbo.

Boundary river: a river that separates different states/provinces and/or countries from each other. The Detroit River is an example of a boundary river, as it separates the United States from Canada.

Brail sampling: employs a wooden or metal bar with groups of multi-pronged hooks attached by either chain or rope and towed behind a boat to collect mussels from the substrates. When mussels encounter the hooks, the valves will close tightly on the prongs and are pulled from the riverbed.

Cilia: microscopic, hair-like structures that create and control the current that allows food and water to flow over the gills. Cilia also help capture and sort food particles.

Dorsal wing: an extension of the shell, typically thin, located along the back (opposite of the ventral side) of the shell.

Endangered Species Act, 2007 (ESA): The provincial legislation that provides protection to species at risk in Ontario.

Excurrent siphon: otherwise known as the exhalent siphon; an opening formed by the mantle margins through which filtered water, waste, sperm, and glochidia are expelled; located dorsal to the inhalant siphon. (*Related)* Inhalent siphon: an opening formed by the mantle margins through which water, food, and sperm are brought into the body; located ventral to the exhalent siphon.

Fresh shells: recently predated or deceased mussel, which may or may not contain decomposing flesh. Shells have not decayed and weathered through long-term exposure of elements and therefore represent recent occurrences.

Glochidia: the larval form of freshwater mussel that attaches as an external parasite to a vertebrate host, usually a fish, where it transforms into a free-living juvenile mussel.

Hinge: the portion of the dorsal margin of the shell where the two valves are held together by an elastic ligament.

Interdentum: a flattened area of shell between the pseudocardinal and lateral teeth.

Lateral teeth: elongated teeth that extend along the hinge line of the shell.

Mantle: a sheath of tissue inside the shell that encloses the body of the mussel, secretes the shell material and serves a sensory function.

Marsupia: a pouch in the female gill that contains the developing embryos.

Nacre: the inside layer of the shell; often iridescent and referred to as mother-of-pearl.

Periostracum: the thin, fibrous material covering the outside of the shell.

Posterior: further back in position, nearer to the rear or hind-end of the shell.

Pseudocardinal teeth: triangular-shaped hinge teeth located near the anterior end of the shell in front of the lateral teeth.

Species at Risk Act (SARA): The federal legislation that provides protection to species at risk in Canada. This Act establishes Schedule 1 as the legal list of wildlife species at risk. Schedules 2 and 3 contain lists of species that at the time the Act came into force needed to be reassessed. After species on Schedule 2 and 3 are reassessed and found to be at risk, they undergo the SARA listing process to be included in Schedule 1.

Species at Risk in Ontario (SARO) List: The regulation made under section 7 of the *Endangered Species Act, 2007* that provides the official status classification of

772 species at risk in Ontario. This list was first published in 2004 as a policy and
773 became a regulation in 2008 (Ontario Regulation 230/08).

774 Stream order: means the order of a stream as defined by Strahler (1957), where the
775 smallest unbranched channels are considered as 1st order, whereby adjoining of
776 two channels forms a 2nd order, and subsequent unions of similar stream orders
777 results in successively higher stream order.

778 Ventral margin: located near or on the lower surface of an animal, opposite to the back
779 (dorsal) side.

780 Watercourse segment: a distinct section of a river or stream characterized by relatively
781 small hydrography and surficial geology and which is not separated by in-stream
782 barriers that prevent fish passage.

783 List of abbreviations

784 COSEWIC: Committee on the Status of Endangered Wildlife in Canada
785 COSSARO: Committee on the Status of Species at Risk in Ontario
786 CWS: Canadian Wildlife Service
787 DFO: Department of Fisheries and Oceans Canada
788 ESA: Ontario's *Endangered Species Act, 2007*
789 ISBN: International Standard Book Number
790 MECP: Ministry of the Environment, Conservation and Parks
791 MNRF: Ministry of Natural Resources and Forestry
792 SARA: Canada's *Species at Risk Act*
793 SARO List: Species at Risk in Ontario List

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