PROPOSED

Species at Risk Act
Recovery Strategy Series

Recovery Strategy for the Round Hickorynut (*Obovaria subrotunda*) and Kidneyshell (*Ptychobranchus fasciolaris*) in Canada

Round Hickorynut and Kidneyshell

2013

Fisheries and Oceans Canada
Pêches et Océans Canada

Canada

Recommended citation:

Fisheries and Oceans Canada. 2013. Recovery Strategy for the Round Hickorynut (*Obovaria subrotunda*) and the Kidneyshell (*Ptychobranchus fasciolaris*) in Canada [proposed]. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada. Ottawa. vi + 70 pp.

For copies of the recovery strategy, or for additional information on species at risk, including COSEWIC Status Reports, residence descriptions, action plans, and other related recovery documents, please visit the SAR Public Registry.

Cover illustrations: Courtesy Environment Canada

Également disponible en français sous le titre
« Programme de rétablissement de l'obovarie ronde (*Obovaria subrotunda*) et du ptychobranche réniforme (*Ptychobranchus fasciolaris*) au Canada »

ISBN 0-662-43571-0
Cat. no. En3-4/2-2006E-PDF

Preface

The federal, provincial, and territorial government signatories under the Accord for the Protection of Species at Risk (1996) agreed to establish complementary legislation and programs that provide for effective protection of species at risk throughout Canada. Under the *Species at Risk Act* (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of recovery strategies for listed Extirpated, Endangered, and Threatened species and are required to report on progress within five years.

The Minister of Fisheries and Oceans is the competent minister for the recovery of the Round Hickorynut and Kidneyshell and has prepared this strategy, as per section 37 of SARA. It has been prepared in cooperation with:

- Jurisdictions – Environment Canada, Ontario Ministry of Natural Resources.
- Aboriginal groups – Southern First Nations Secretariat, London Chiefs Council, Walpole Island First Nation, Six Nations of the Grand, Chippewas of Stoney and Kettle Point, Chippewas of Sarnia, Caldwell First Nation, Moravian of Thames First Nation, Chippewas of the Thames, Oneida, Munsee-Delaware First Nation, Mississauga of New Credit First Nation.
- Environmental non-government groups – Ausable-Bayfield Conservation Authority, Grand River Conservation Authority, Maitland Valley Conservation Authority, St. Clair Region Conservation Authority, Upper Thames River Conservation Authority, Lower Thames Valley Conservation Authority, University of Guelph, University of Toronto/Royal Ontario Museum, McMaster University, Iowa State University.

Success in the recovery of these species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy and will not be achieved by Fisheries and Oceans Canada, or any other jurisdiction alone. All Canadians are invited to join in supporting and implementing this strategy for the benefit of the Round Hickorynut and Kidneyshell and Canadian society as a whole.

This recovery strategy will be followed by one or more action plans that will provide information on recovery measures to be taken by Fisheries and Oceans Canada and other jurisdictions and/or organizations involved in the conservation of the species. Implementation of this strategy is subject to appropriations, priorities, and budgetary constraints of the participating jurisdictions and organizations.

Acknowledgments

Fisheries and Oceans Canada would like to thank the following authors: T.J. Morris, K. McNichols-O'Rourke, and S.K. Staton. The following organizations, who are members of the Ontario Freshwater Mussel Recovery Team, offered their support in the development and/or updating of the recovery strategy for the Round Hickorynut and Kidneyshell: Environment Canada, Ontario Ministry of Natural Resources, University of Guelph, University of Toronto/Royal Ontario Museum, McMaster University, Ausable-Bayfield Conservation Authority, Grand River Conservation Authority, Maitland Valley Conservation Authority, St. Clair Region Conservation Authority, Upper Thames River Conservation Authority, Lower Thames Valley Conservation Authority, and the Walpole Island Heritage Centre.

Executive summary

Freshwater mussels (Unionidae) are amongst the world's most imperilled taxa with declines reported at global, continental, and national scales. Southern Ontario is home to the largest and most diverse mussel communities in Canada as three quarters of the nation's mussel species can be found in the lower Great Lakes drainage. Two of these species, the Round Hickorynut and the Kidneyshell, which are listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada, share common current and historic distributions and are facing similar threats to their continued existence. These two species are considered here in a multi-species recovery strategy to facilitate the protection and recovery of both species in Canada.

The Round Hickorynut is a small mussel reaching a maximum size of 60 - 65 mm in Canada. The mussel is readily recognized by its round shape and prominent centrally located, inward curving beaks that are elevated well above the hinge line. The Round Hickorynut prefers sand and gravel substrates with steady, moderate flows at depths of up to 2 m. The Round Hickorynut is considered globally secure (G4) and has a national status rank of N4 (secure) within the United States (although the American Fisheries Society has listed it as a species of special concern), and a Canadian national status of N1 (critically imperilled). Currently occupied habitat for the Round Hickorynut consists of a 12 km^2 region of the Canadian waters of the St. Clair River delta and a 60 km reach of the East Sydenham River from just upstream of Alvinston, downstream to Dawn Mills.

The Kidneyshell is a medium to large freshwater mussel that is readily distinguished by its elongate, elliptical shell and yellowish-brown periostracum with wide, interrupted green rays that look like squarish spots. The Kidneyshell prefers shallow areas with clear, swift-flowing water and substrates of firmly-packed coarse gravel and sand. The Kidneyshell is considered globally apparently secure (G4) and has a national status rank of N4N5 (apparently secure to secure) within the United States, and a Canadian national status of N1 (critically imperilled). Recent surveys have shown that the distribution of the Kidneyshell has been severely reduced and it is now limited to the Sydenham and Ausable rivers with a few specimens in the St. Clair River delta and the Thames River (including Medway Creek).

Threats to the Round Hickorynut and Kidneyshell are many and varied although they can be separated into two major groups: those affecting lake populations (i.e., Great Lakes and connecting channels) and those affecting in-land riverine populations. The main reason for the declines in lake populations, and the major current threat to the St. Clair River delta populations of the Round Hickorynut and the Kidneyshell, is the presence of exotic dreissenid mussels. Riverine populations of both mussel species are subject to different threats than the lake populations, with the primary threats being declining water quality and a general disappearance of suitable habitat. In addition, the obligate parasitic nature of the reproductive cycle of these mussels necessitates a consideration of threats to the host fish species as well as the direct threats to the mussel. Further investigation on the impacts and effects of these threats on the Round

Hickorynut and Kidneyshell populations are required to inform successful recovery efforts.

The original recovery strategy (finalized in 2006) was developed by the Ontario Freshwater Mussel Recovery Team; it was updated in 2012 by Fisheries and Oceans Canada to include the identification of critical habitat with further input from the recovery team.

The long-term goals of this recovery strategy are:

i. To prevent the extirpation of the Round Hickorynut and Kidneyshell in Canada;
ii. To return healthy self-sustaining populations of Round Hickorynut to the East Sydenham River and St. Clair River delta;
iii. To maintain healthy self-sustaining Kidneyshell populations in the Ausable and East Sydenham rivers while returning the St. Clair River delta and Thames River (including Medway Creek) populations to self-sustaining levels; and,
iv. To re-establish populations in historically occupied habitats, excluding areas where dreissenid mussels have now made habitats unsuitable.

These populations can only be considered recovered when they have returned to historically estimated ranges and/or population densities and are showing signs of reproduction and recruitment. The Detroit River, Lake Erie, Lake St. Clair proper, and the Niagara River are specifically excluded from the recovery goal as these areas of the Great Lakes have been devastated by dreissenid mussels and no longer provide suitable habitat for freshwater mussels.

The following specific short-term recovery objectives have been identified to assist with meeting the long-term goals:

i. Determine extent, abundance and population demographics of existing populations;
ii. Determine host fish and their distributions and abundances;
iii. Define key habitat requirements to identify critical habitat;
iv. Establish a long-term monitoring program for Round Hickorynut and Kidneyshell populations, their hosts and the habitat of both;
v. Identify threats, evaluate their relative importance and implement remedial actions to minimize their impacts;
vi. Examine the feasibility of relocations, reintroductions and the establishment of managed refuge sites; and,
vii. Increase awareness about the distribution, threats and recovery of these species.

The recovery team has identified a variety of approaches that are necessary to meet the recovery objectives. These approaches have been broadly organized into four categories: Research and Monitoring, Management, Stewardship, and Awareness.

Using available data, critical habitat has been identified at this time for the Round Hickorynut and Kidneyshell in the East Sydenham River as well as in the Ausable and Thames (including Medway Creek) rivers for the Kidneyshell. Additional areas of potential critical habitat for these species in the St. Clair River delta will be considered in collaboration with Walpole Island First Nation. A schedule of studies has been developed that outlines the necessary steps to obtain the information to further refine these critical habitat descriptions. Until critical habitat has been fully identified, the recovery team recommends that currently occupied habitats are habitats in need of conservation.

The approaches outlined in this strategy to achieve the recovery of the Round Hickorynut and Kidneyshell are best accomplished through cooperation with the existing ecosystem recovery teams. In watersheds with existing ecosystem teams, implementation of recovery actions should be coordinated to confirm that recovery activities are beneficial to all species at risk and to eliminate the possible duplication of efforts. Where ecosystem recovery teams are absent, Recovery Implementation Groups (RIGs) may be struck to facilitate the carrying out of recovery actions. Evaluation of the success of recovery actions will be achieved primarily through the routine monitoring programs established to track changes in population demographics and habitat quality and extent; however, RIGs will also incorporate specific milestones into on or more action plans for the recovery strategy. The entire recovery strategy will be reported on every five years to evaluate the progress towards achieving the goals and objectives, and to incorporate new information.

Table of Contents

Introduction

Freshwater mussels are among the world's most imperilled taxa with declines reported on a global scale (Bogan 1993, Lydeard *et al.* 2004). The rich unionid fauna of North America has been hit particularly hard with over 70% of the approximately 300 species showing evidence of declines with many now considered rare, endangered, threatened or imperilled (Allan and Flecker 1993, Williams *et al.* 1993). Canada is home to 55 unionid species, 41 of which can be found in the province of Ontario with 18 species having Canadian distributions restricted to this province. The rivers of southwestern Ontario, primarily those draining into Lake St. Clair and Lake Erie, are home to the richest unionid assemblages in Canada. The Sydenham River has historically been considered to be the richest unionid river in all of Canada (Clarke 1992) with a total species count of 34 (Metcalfe-Smith *et al.* 2003); however, recent evidence suggests that the Grand (Metcalfe-Smith *et al.* 2000) and Thames rivers (J. Metcalfe-Smith, National Water Research Institute, Burlington, Ontario, pers. comm.), also with historic species counts of 34, were equally diverse. In addition, recent surveys have shown that there are at least 26 mussel species currently occurring in the Ausable River (Baitz *et al.* 2008).

Despite the historic richness of these rivers, recent events have led to significant declines in the unionid communities of southwestern Ontario. Intensive agricultural activity, expanding urbanization and the introduction of invasive dreissenid mussels (Zebra [*Dreissena polymorpha*] and Quagga [*Dreissena bugensis*] mussels) have all been implicated in large scale declines observed in freshwater mussel populations over the last two to three decades (Nalepa 1994, Metcalfe-Smith *et al.* 2000, Metcalfe-Smith *et al.* 2003). During this time four, five and nine species have been lost from the Sydenham, Thames and Grand rivers, respectively. It is difficult to determine if there have been declines in species diversity in the Ausable River as very few mussel surveys were conducted prior to 1990 (Nelson *et al.* 2003). These declines, coupled with the near complete collapse of the Great Lakes populations (Nalepa *et al.*1996), have led to the designation of 13 Ontario mussel species as Endangered, Threatened or Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

The Ontario Freshwater Mussel Recovery Team (OFMRT) was formed in the spring of 2003 to address concerns about the status of Ontario's freshwater mussel populations and to begin to address the recovery planning obligations under Canada's new *Species at Risk Act* (SARA). The national *Recovery Strategy for the Round Hickorynut (Obovaria subrotunda) and the Kidneyshell (Ptychobranchus fasciolaris) in Canada* was developed by the OFMRT using the best available information in an effort to reduce threats, prevent their extirpation and, if possible, to restore these species to healthy, self-sustaining levels. In recognition of the degree of overlap between these species in both their historical and current distributions, as well as the commonality of threats, the OFMRT has adopted a multi-species approach to the recovery of these species.

I. Background

1. Species information – Round Hickorynut

COSEWIC assessment summary – May 2003

Common name: Round Hickorynut
Scientific name: *Obovaria subrotunda* (Rafinesque, 1820)
COSEWIC status: Endangered
COSEWIC reason for designation: This species has been lost from 90% of its former range in Canada. Populations in the Grand and Thames rivers are extirpated and populations in the Sydenham River are declining, all due to the combined effects of pollution and agricultural impacts. Most of the Great Lakes populations have been lost due to impacts of the Zebra Mussel, and the remaining population in the St. Clair delta near Walpole Island may be at risk. If the Eastern Sand Darter were the host of this species, then the decline of this threatened fish would affect the mussel's survival.
Occurrence: Ontario
COSEWIC status history: Designated Endangered in 2003.

The Round Hickorynut is one of only six species in the genus *Obovaria*. Only two of these species, *O. subrotunda* and *O. olivaria*, have distributions that extend into Canada, where both species are restricted to the lower Great Lakes/St. Lawrence River drainage.

Figure 1. Two Round Hickorynut specimens from the Lake St. Clair delta. Photo credit: D. McGoldrick, Environment Canada.

The Round Hickorynut is a small mussel reaching a maximum size of 60 - 65 mm in Canada. The mussel is readily recognized by its round shape and prominent centrally located, inward curving beaks that are elevated well above the hinge line. Beak sculpture is slight, consisting of four to five weak double bars, which are sinuous centrally, and angled posteriorly (Parmalee and Bogan 1998). The shell is generally dark in colour ranging from olive-brown to dark brown and is relatively smooth except for prominent growth rests. The posterior slope is often distinctly lighter than the rest of the shell (COSEWIC 2003a) (Figure 1). The hinge teeth of this species are heavy and strong. The left valve has two thick, roughened, triangular pseudocardinal teeth and two slightly curved short, strong, lateral teeth. The right valve has one large, massive serrated triangular pseudocardinal tooth, usually with a small, low compressed tubercular tooth on either side. There is one short, curved, thick, roughened lateral tooth and often an incomplete secondary lateral tooth in the right valve (Parmalee and Bogan 1998).

2. Distribution

Global range: The global distribution of the Round Hickorynut is restricted to eastern North America (Figure 2). In the U.S., the Round Hickorynut is considered nationally secure but is showing declines across its range. This species is historically known from the Ohio, Tennessee, Cumberland and Mississippi River systems as well as the St. Lawrence, Lake Erie, and Lake St. Clair drainages. It is currently found in Alabama, Arkansas, Indiana, Kentucky, Michigan, Mississippi, Ohio, Pennsylvania, Tennessee, and West Virginia, and is believed to have been extirpated from Georgia, Illinois, and New York (NatureServe 2012). In Canada the Round Hickorynut is found only in southwestern Ontario.

Canadian range: In Canada, the Round Hickorynut is historically known from the waters of western Lake Erie, Lake St. Clair and the Welland, Grand, Thames, Sydenham, and Detroit rivers (COSEWIC 2003a). Since 1996, live specimens have only been reported from the East Sydenham River and the St. Clair River delta (Figure 3).

Percent of global range in Canada: Approximately 1% of the global range of this species occurs in Canada.

Distribution trend: Since the invasion of the Great Lakes by dreissenid mussels the Canadian geographical distribution for this species has been reduced by 90%.

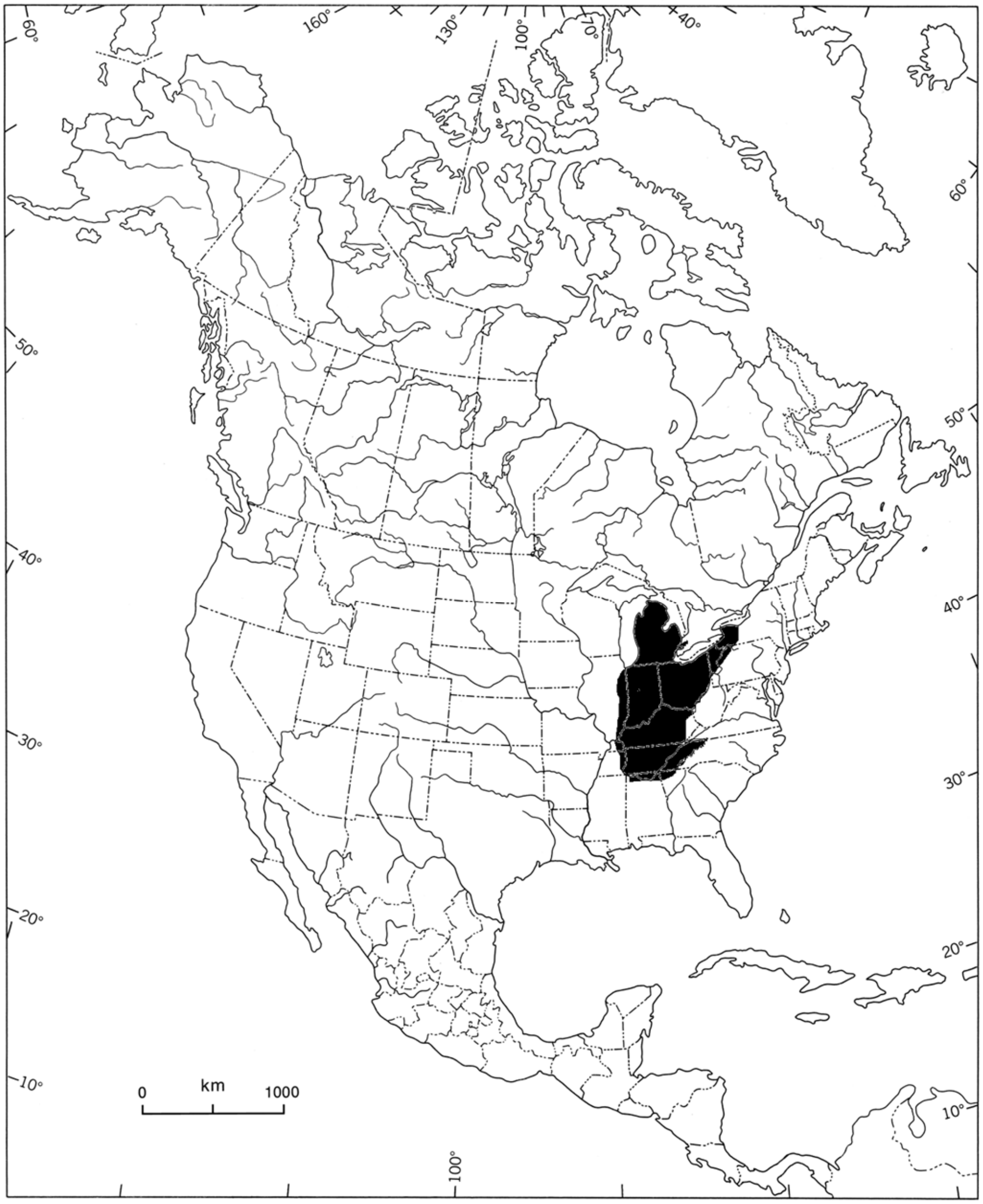

Figure 2. Global distribution of the Round Hickorynut (modified from Parmalee and Bogan 1998).

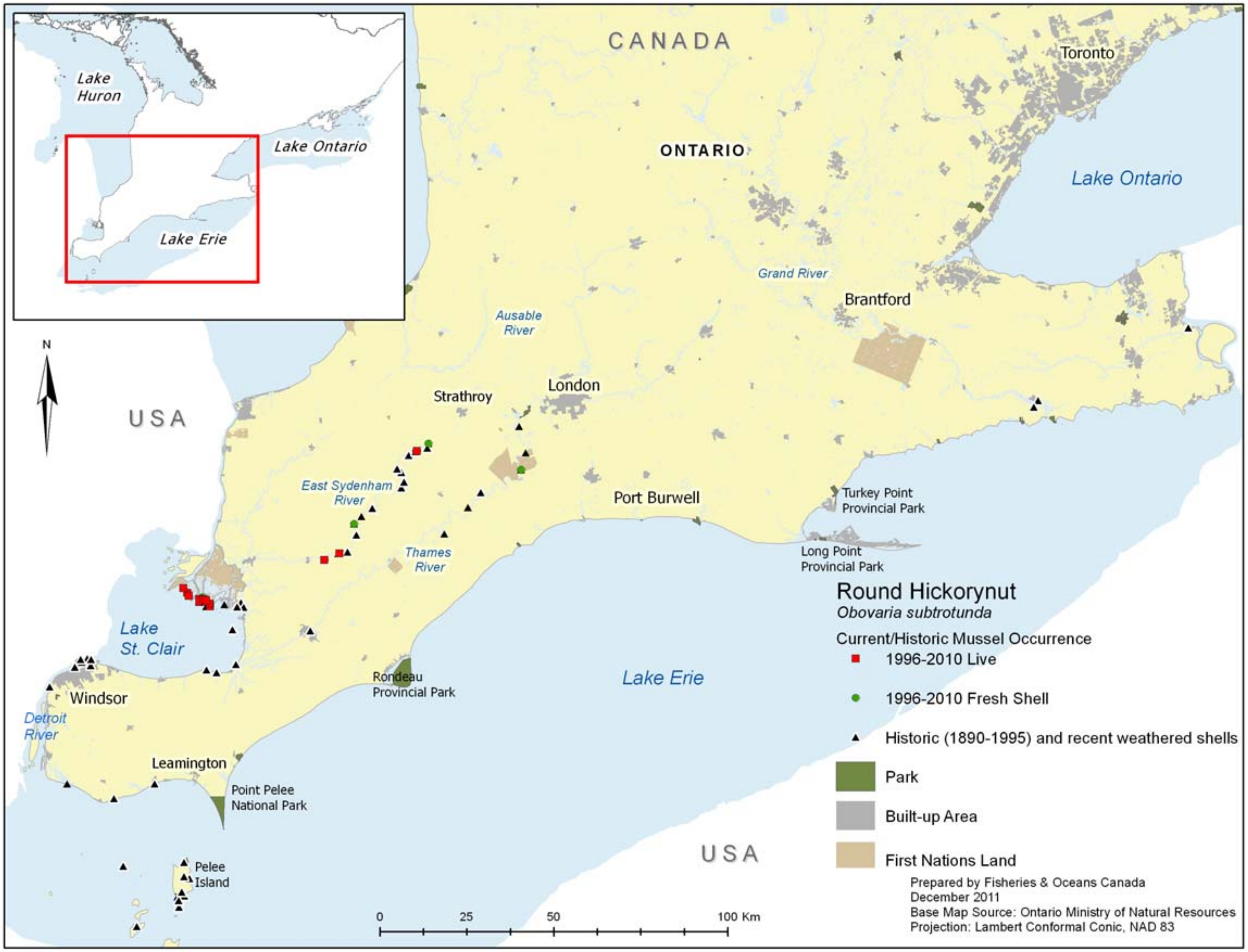

Figure 3. Distribution of the Round Hickorynut in Canada. Current distribution reflects surveys since 1996.

3. Population status and abundance

Global status and abundance: In the U.S., the Round Hickorynut is seldom a significant component of the mussel community, typically representing between 0.1 and 1.4% of the species present (COSEWIC 2003a). The Round Hickorynut is considered globally secure (G4), and nationally secure (N4) within the U.S. (NatureServe 2012), although the American Fisheries Society has listed it as a species of special concern. The species is beginning to show declines across its entire American distribution. It is considered possibly extirpated in Georgia (SH), presumed extirpated in Illinois (SX) and New York (SX), and critically imperilled or imperilled in Alabama (S2), Arkansas (S1), Indiana (S1), Michigan (S1), Mississippi (S2), and Pennsylvania (S1) (NatureServe 2012).

Canadian status and abundance: In Canada, the Round Hickorynut is considered critically imperilled nationally (N1) and provincially (S1) (NatureServe 2012). It was designated as Endangered by COSEWIC in 2003 and listed under SARA in 2005. The largest Canadian population of the Round Hickorynut occurs in the St. Clair River delta where it comprises 0.011% of the overall mussel community and occurs at a density of $0.0006/m^2$. In the Sydenham River, the Round Hickorynut represents approximately 0.0024% of the mussel community.

Percent of global abundance in Canada: Less than 1% of the global abundance of this species occurs in Canada.

Population trend: It is estimated that the population of Round Hickorynut in Canada has declined by 90% since the invasion of the Great Lakes by dreissenid mussels. This estimate is based on the number of historical records that occur in waters that now contain dreissenid mussels.

4. Needs of the Round Hickorynut

4.1 Habitat and biological needs

Spawning and fertilization: The reproductive biology of the Round Hickorynut follows the general reproductive biology of most unionid mussels. During spawning, male mussels release sperm into the water column and females filter it out of the water with their gills. Fertilization is then able to occur in specialized regions of the gills known as marsupia. No information could be found regarding the timing windows of fertilization in this species. Females bearing eggs were reportedly found in September (Ortmann 1919). However, gravid females have been observed in late May at 18°C in the St. Clair River delta (McNichols 2007). It is possible that this period extends between September and June and they may be using host fishes during this time (Clarke 1981, McNichols 2007, J. Ackerman, University of Guelph [UG], unpubl. data). Immature juveniles, known as glochidia, develop in the gill marsupia and are released by the female into the water column to undergo a period of parasitism on a suitable host fish species. Fecundity was estimated at 7500 to 13 900 glochidia per female mussel (McNichols 2007). However, this is most likely an under-estimate as the females were collected in late May for host identification experiments, and therefore had probably released some glochidia before the experiment took place (McNichols 2007). Successful gamete development (and perhaps gamete release) appears to be regulated by water temperature (Galbraith and Vaughn 2009); however, these temperatures have not been determined for the Round Hickorynut.

Glochidial stage: Further development to the juvenile stage cannot continue without a period of encystment on the host. The hookless glochidia become encysted on the gills of the host where they are nourished by the host until they metamorphose and break free, settling to the substrate to begin life as free-living juveniles. The glochidial (larval) stage is the most vulnerable and specialized life-stage because: (1) they are most sensitive to contaminant exposure (Gillis *et al.* 2008); and, (2) they must successfully attach to an appropriate host to complete their metamorphosis to the juvenile stage (Bauer 2001). The proportion of glochidia surviving to the juvenile stage is estimated to be as low as 0.000001% (Jansen *et al.* 2001). As this is a long-term brooder (bradytictic), glochidial release most likely occurs from September to June (Ortmann 1919, Clarke 1981). Host fishes for the Round Hickorynut in Canada have been identified as Blackside Darter (*Percina maculata*), Fantail Darter (*Etheostoma flabellare*), and Iowa Darter (*E. exile*; McNichols 2007). Five host species have been identified in the U.S. and these include: Varigate Darter (*E. variatum*), Frecklebelly Darter (*P. stictogaster*), Speckled Darter (*E. stigmaeum*), Greenside Darter (*E. blennioides*), and Emerald Darter (*E. baileyi*) (M. McGregor, Kentucky Department of Fish and Wildlife Resources [KDFWR], pers. comm., January 2004). Only the Greenside Darter is found in Canada where its range appears to be expanding. However, glochidia did not metamorphose on this species during host identification experiments (McNichols 2007). Glochidia were attached to the host species for 4 – 40 days (temperature = 19.5°C) before metamorphosis and drop off occurred (McNichols 2007). Water temperatures play a large role in determining when metamorphosis and excystment occurs; warmer temperatures generally lead to shorter glochidial attachment periods (Watters and O'Dee 1999); however, there are upper limits that cause glochidial excystment without successful metamorphosis (Dudgeon and Morton 1984).

Juvenile: The optimal habitat preferences of juvenile mussels are believed to be different from those of adults, but there have been few studies on this topic (Gordon and Layzer 1989). The juvenile life-stage is certainly more vulnerable than the adult stage, because juveniles have very little control over the habitat into which they are released by their host and may die quickly in unsuitable habitats (Wächtler *et al.* 2001). Because the habitat requirements of Round Hickorynut juveniles are unknown, optimal habitat requirements will be described in the adult section below and for this purpose it will be assumed that the adult and juvenile habitat requirements are similar until specific studies have addressed this topic.

Adult: The Round Hickorynut is typically found in medium-sized to large rivers (van der Schalie 1938, Strayer 1983, Parmalee and Bogan 1998), but was also known from Lake

Erie and Lake St. Clair (Clarke 1981, Strayer and Jirka 1997). The preferred habitat of the adult Round Hickorynut is generally described as sand and gravel substrates with steady, moderate flows at depths of up to 2 m (Ortmann 1919, Gordon and Layzer 1989, Parmalee and Bogan 1998). In the St. Clair River delta, Round Hickorynut currently occupy shallow (<1 m) nearshore areas with firm, sandy substrates (Zanatta *et al.* 2002). The Round Hickorynut, like all species of freshwater mussels, is a filter feeder as an adult. Its primary food sources are bacteria, algae, particles of organic detritus, and some protozoans (Nedeau *et al.* 2000, Strayer *et al.* 2004). Adults may also engage in some pedal feeding (Nichols *et al.* 2005).

4.2 Limiting factors

The Round Hickorynut may be limited by its complex lifecycle and by its dispersal mechanism. The dependency on a host for development (as described above) may limit the reproduction of the Round Hickorynut because any change that affects the host species can also affect the mussel. The availability and health of the host species may also pose a limitation to the Round Hickorynut. Additional research is needed to identify primary (high infestation and metamorphosis rates for glochidia and juvenile Round Hickorynut) and marginal (low rates) hosts, as well as functional hosts (e.g., distributional overlap between species, availability, and density).

Like most native freshwater mussels, Round Hickorynut adults are essentially sessile with movement limited to only a few metres on the river/lake bottom. Although adult movement can be directed upstream or downstream, studies have found a net downstream movement through time (Balfour and Smock 1995, Villella *et al.* 2004). The primary means for large scale dispersal, upstream movement, and the invasion of new habitat or evasion of deteriorating habitat, is limited to the encysted glochidial stage on the host fish; however, host mobility can vary greatly depending on the species (for example darters are thought to move very little, thus limiting dispersal for mussels that may parasitize them).

Food availability may also be a limiting factor for the St. Clair River delta population due to the high densities of Zebra Mussel, which are extremely efficient filter feeders (COSEWIC 2003a).

5. Species information – Kidneyshell

COSEWIC assessment summary – May 2003

Common name: Kidneyshell
Scientific name: *Ptychobranchus fasciolaris* (Rafinesque, 1820)
COSEWIC status: Endangered
COSEWIC reason for designation: This species has been lost from about 70% of its historical range in Canada due to impacts of the zebra mussel and land use practices. It is now restricted to the East Sydenham and Ausable rivers. Although both populations appear to be reproducing, there is evidence that abundance has declined in the East Sydenham River. Agricultural impacts, including siltation, have eliminated populations in the Grand and Thames rivers, and threaten the continued existence of this species in Canada.
Occurrence: Ontario
COSEWIC status history: Designated Endangered in 2003.

The Kidneyshell (Figure 4) is one of five members of the genus *Ptychobranchus* that occur in North America; however, it is the only member of the genus with a distribution that extends into Canada.

Figure 4. Two Kidneyshell specimens from the Sydenham River. Note the characteristic squarish spots. Photo credit: T. Morris, Fisheries and Oceans Canada.

The Kidneyshell is a medium to large freshwater mussel that is readily distinguished by its elongate, elliptical shell and yellowish-brown periostracum with wide, interrupted green rays that look like squarish spots. The type locality is the Muskingham River, Ohio. The following description of the species, reported in COSEWIC (2003b), was adapted from Clarke (1981), Strayer and Jirka (1997), and Parmalee and Bogan (1998). The shell is solid, heavy and compressed, and may have a humped shape in old individuals. The anterior end is rounded and the posterior end is bluntly pointed. Beak sculpture is poorly developed, consisting of several fine, indistinct wavy ridges. The surface of the shell (periostracum) ranges in colour from yellowish to yellowish-green, yellowish-brown, or medium brown, with generally distributed broad, interrupted green rays; the shells of old specimens may be a dark chestnut brown and rayless. The periostracum is unsculptured except for coarse growth rests and a roughened posterior slope. The nacre is generally white or bluish white, but may be pinkish in young specimens. The hinge teeth are heavy. The left valve has two low, thick, serrated triangular pseudocardinal teeth, and two lateral teeth that are short, nearly straight, and usually widely separated. The right valve has one somewhat compressed and pyramidal elevated tooth and one wide, elongated and serrated lateral tooth. The lateral teeth are almost pendulous distally, which is a good distinguishing feature. The interdentum is wide and the beak cavity is shallow. Females have a conspicuous groove on the inside of the shell that runs diagonally from the beak cavity towards the posterioventral end; this groove corresponds to the marsupium (COSEWIC 2003b).

6. Distribution

Global range: In the U.S., the Kidneyshell is currently found in Alabama, Illinois, Indiana, Kentucky, Michigan, Mississippi, New York, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia (NatureServe 2012), It is believed to be extirpated in Georgia and North Carolina (NatureServe 2012) (Figure 5). In Canada, the Kidneyshell is found only in southwestern Ontario.

Canadian range: The Kidneyshell has always had a Canadian distribution limited to southwestern Ontario, where it was once found in lakes St. Clair and Erie, as well as the Ausable, Detroit, Grand, Niagara, Sydenham, Thames, and Welland rivers. Since 1997, live specimens have only been reported from the Ausable, Sydenham, and Thames (Medway Creek) rivers, and the St. Clair River delta (Figure 6).

Percent of global range in Canada: Less than 5% of the global range of this species occurs in Canada.

Distribution trend: Since the invasion of the Great Lakes by dreissenid mussels the Canadian geographical distribution for this species has been reduced by 70%.

7. Population status and abundance

Global status and abundance: In the U.S., the Kidneyshell is seldom a significant component of the mussel community but may be locally abundant. It usually represents on average 2.5% (0.2-8.0%) of the mussel community in rivers but at individual sites where it is found the Kidneyshell may account for more than 10% of the community. It is considered globally secure (G4) and has a national rank of N4N5 in the U.S. (NatureServe 2012). The Kidneyshell is considered possibly extirpated in Georgia (SH), presumed extirpated in North Carolina (SX), and critically imperilled or imperilled in Alabama (S1), Illinois (S1), Indiana (S2), Mississippi (S1), and New York (S2) (NatureServe 2012).

Canadian status and abundance: In Canada, the Kidneyshell is considered critically imperilled nationally (N1) and provincially (S1) (NatureServe 2012). It was designated as Endangered by COSEWIC in 2003 and listed under SARA in 2005. The largest Canadian population of the Kidneyshell occurs in the Ausable

River where it comprised approximately 4% (estimated average density of $0.47/m^2$ at the four sites where live individuals were found) of the overall mussel community at seven different sites surveyed in 2006 (Baitz *et al.* 2008). In the Sydenham River, it occurs in an average estimated density of $0.12/m^2$ at sites where it was found alive. In Medway Creek, a tributary of the Thames River, only two large Kidneyshell were found during an excavation of a total area of 720 m^2, which equates to a density of $0.003/m^2$ (G. Mackie, UG, pers. comm., January 2012). In the St. Clair River delta, Kidneyshell comprised only 0.3% of the overall mussel community (COSEWIC 2003b).

Percent of global abundance in Canada: Less than 5% of the global abundance of this species occurs in Canada.

Population trend: It is estimated that the population of Kidneyshell in Canada has declined by 70% since the invasion of the Great Lakes by dreissenid mussels. This estimate is based on the number of historical records that occur in waters that now contain dreissenid mussels.

Figure 5. Global distribution of the Kidneyshell (modified from Parmalee and Bogan 1998).

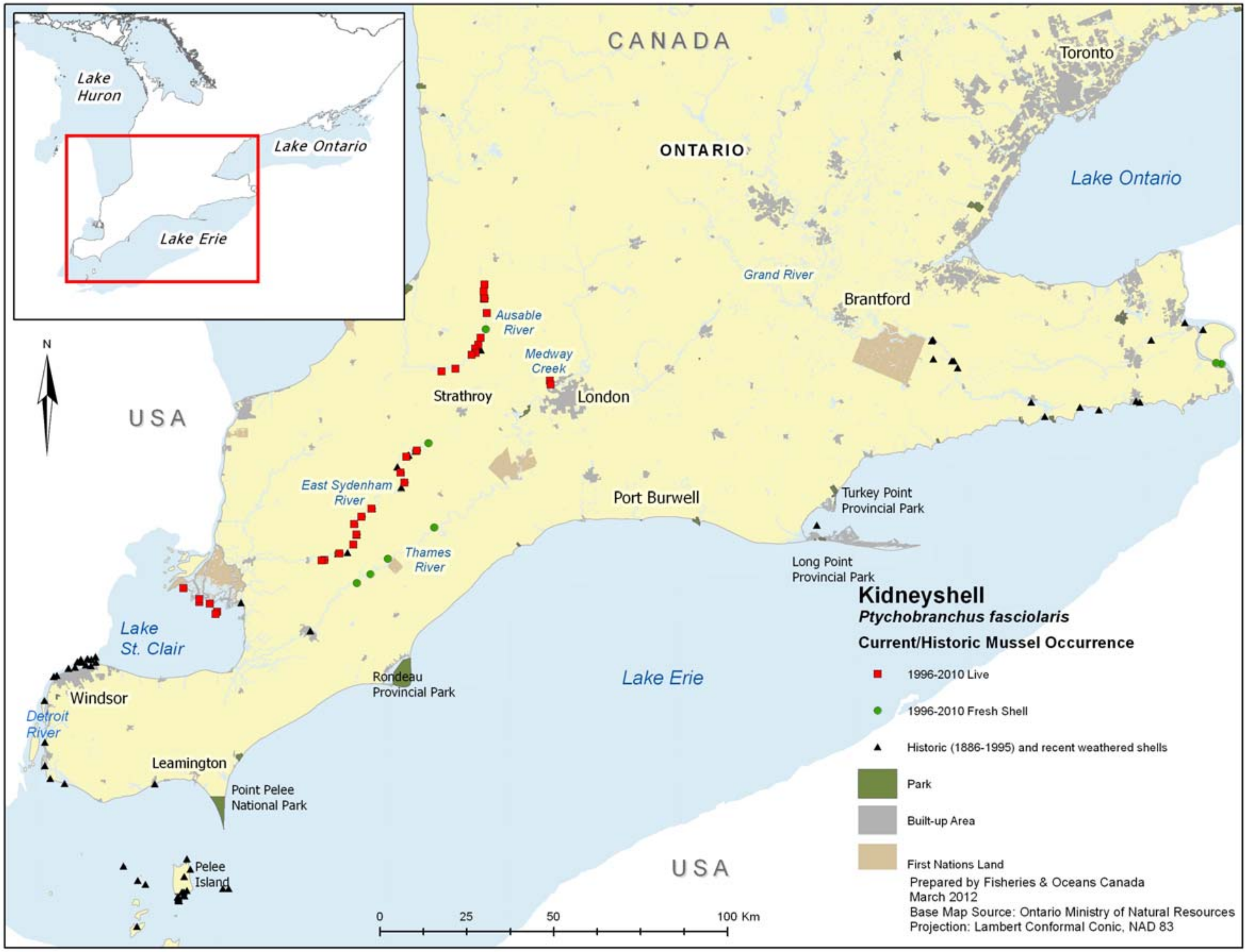

Figure 6. Distribution of the Kidneyshell in Canada. Current distribution reflects surveys since 1997.

8. Needs of the Kidneyshell

8.1 Habitat and biological needs

Spawning and fertilization: The reproductive biology of the Kidneyshell follows the general reproductive biology of most unionid mussels. Refer to Section 4.1 (Habitat and biological needs) for the general reproductive biology of freshwater mussels. No information could be found regarding the timing windows of fertilization in the Kidneyshell. As this is a long-term brooder (bradytictic), its breeding period is suspected to be from early August until the following June (Clarke 1981). Eggs appear in August and glochidia generally develop by September (Ortmann 1919). Gravid females have been observed from mid-August to October in water temperatures of 17 - 26°C (McNichols 2007, J. Ackerman, UG, unpubl. data). Fecundity has been estimated at 18 750-184 375 (mean = 88 641) glochidia per female mussel (McNichols 2007).

Encysted glochidial stage: Further development to the juvenile stage cannot continue without a period of encystment on the host. Refer to Section 4.1 (Habitat and biological needs) for further information on freshwater mussel glochidia. Members of the genus *Ptychobranchus* have evolved a specialized method of delivering glochidia designed to increase the likelihood of encountering a suitable host. The glochidia are released in mucous-encased packages termed conglutinates, which have been shown to resemble fish fry complete with eye spots, or benthic invertebrates such as chironomids. These two forms represent prey items of the host species, which stimulate feeding instincts of the host. This results in conglutinates being ingested by the host, where they rupture, releasing glochidia in close proximity to the gills of the host. It is important to note that the use of conglutinates by the Kidneyshell protects the glochidia from external contaminants. For example, Gillis *et al.* (2008) determined that Kidneyshell conglutinates could withstand a higher concentration (by a four-fold increase) of copper exposure than free Kidneyshell glochidia. Glochidia that have encysted on their host have also been found to be at least ten times more resistant to acute copper exposure than free glochidia (Jacobson *et al*. 1997). Five glochidial host fishes have been identified for the Kidneyshell in Canada: Blackside Darter, Fantail Darter, Johnny Darter (*E. nigrum*), Iowa Darter, and Brook Stickleback (*Culaea inconstans*; McNichols 2007). Glochidia were attached to the host species for 22 - 29 days (temperature = 19.5°C) before metamorphosis and drop off occurred (McNichols 2007). Further research is required on how water temperatures affect the current populations of Kidneyshell.

Juvenile: Refer to Section 4.1 (Habitat and biological needs) for further information on juvenile freshwater mussels. The optimal habitat preferences of juvenile mussels are believed to be different from those of adults, but there have been no studies focusing on Kidneyshell juveniles since the review by Gordon and Layzer (1989). Because populations of Kidneyshell in both the Sydenham and Ausable rivers show evidence of recruitment, it appears that the quality of the habitat in at least some reaches is suitable, therefore until the habitat requirements of Kidneyshell juveniles are defined, optimal habitat requirements will be described in the adult section below.

Adult: The Kidneyshell is most commonly found in small- (6-16 m wide) to medium-sized (15-20 m) rivers (COSEWIC 2003b). This species has very distinct ecological preferences, favouring riffle areas with substrates of firmly-packed coarse gravel and sand and moderate to swift flows (Ortmann 1919, Gordon and Layzer 1989), and has an aversion to ponded or backwater conditions (van der Schalie 1938). In the Great Lakes, it was found on gravel shoals in Lake Erie and Lake St. Clair. Monitoring programs have been developed for the Sydenham River (Metcalfe-Smith *et al.* 2007) and the Ausable River (Baitz *et al.* 2008) in 2007 and 2008, respectively. During these studies, physical characteristics for the different sites examined were measured and it was found that Kidneyshell were reported at sites with: (1) water depth between 11-16 and 16-30 cm (summer depth); and, (2) velocity of 0.23-0.70 and 0.1-0.3 m/s in the Sydenham and Ausable rivers, respectively. In addition, substrate type in the Sydenham River where Kidneyshell were found was made up of ~ 16% boulder, 21% rubble, 27% gravel, 21% sand, 9.5% silt, 2.2% clay, and muck (Metcalfe-Smith *et al.* 2007). In the Ausable River, the substrate showed a high percentage of gravel (67-100%) and low percentages (0-33%) of boulder, rubble, sand, silt, muck, and clay (Baitz *et al.* 2008). The Kidneyshell is usually found deeply burrowed in stable substrates at water depths of <1 m. Further studies are required to determine specific optimal habitat requirements, as these percentages are based on nine sites in the Sydenham River and seven sites in the Ausable River. However, these data are the best available information to date. In Lake Erie, the Kidneyshell was found in shallow water on sandy or slightly gravelly shoals exposed to wave action (Ortmann 1919, Gordon and Layzer 1989).

In the Sydenham River, the Kidneyshell was also found in close proximity to the Plain Pocketbook (*Lampsilis cardium*). This suggests that these two species may have similar habitat and/or environmental preferences, and because the Plain Pocketbook is generally more abundant than the Kidneyshell, it may indicate the presence of the Kidneyshell (Metcalfe-Smith *et al.* 2007). The Kidneyshell has also been frequently found adjacent to beds of Water Willow (*Justicia americana*), an emergent aquatic plant (Ortmann 1919, Gordon and Layzer 1989); however, there have been no studies to date addressing this relationship in Canada. Water Willow is currently listed as Threatened under SARA.

Kidneyshell, like all species of freshwater mussels, are filter feeders as adults. Their primary food sources are bacteria, algae, particles of organic detritus, and some protozoans (Nedeau *et al.* 2000, Strayer *et al.* 2004). Adults may also engage in some pedal feeding (Nichols *et al.* 2005).

8.2 Limiting factors

Refer to Section 4.2 (Limiting factors) for the limiting factors for Kidneyshell.

9. Ecological role

Freshwater mussels play an integral role in the functioning of aquatic ecosystems (Vaughn *et al.* 2004). Vaughn and Hakenkamp (2001) have summarized much of the literature relating to the role of unionids and identified numerous water column and sediment processes mediated by the presence of mussel beds (e.g., size-selective filter-feeding, nutrient cycling, biodeposition of feces and pseudofeces). In addition, epizoic invertebrates and epiphytic algae colonize shells, and benthic invertebrate densities have been positively correlated with mussel density (Vaughn and Hakenkamp 2001). Vaughn *et al.* (2008) demonstrated the importance of mussel communities to aquatic ecosystem food webs. Welker and Walz (1998) have shown that freshwater mussels are capable of limiting plankton in European rivers while Neves and Odom (1989) reported that mussels also play a role in the transfer of energy to the terrestrial environment through predation by muskrats and raccoons.

10. Threats

The Round Hickorynut and the Kidneyshell, like most mussel species, are sensitive to a wide variety of stressors including invasive species, poor water quality resulting from point (industrial and urban discharge) and non-point (herbicide, pesticide and surface run-off) sources, loss of host fish species, impoundments, siltation/sedimentation, predation, urbanization, physical habitat loss/modification, and recreational activities. The following discussion of threats focuses on those threats that are specific to the two remaining populations of the Round Hickorynut (St. Clair River delta, Sydenham River) and four remaining populations of the Kidneyshell (St. Clair River delta, Sydenham River, Ausable, and Thames rivers), although it is likely that all stressors listed previously have contributed to the decline of these species in Canada.

10.1 Threat classification

Threats believed to be affecting extant populations of the Round Hickorynut and Kidneyshell are listed in Table 1. Ten potential threats were ranked by the recovery team based on their expected relative impacts, spatial extent and expected severity for each population.

Table 1. Assessment of threats to extant populations of the Round Hickorynut and Kidneyshell. St. Clair River delta and Sydenham River threats apply to Round Hickorynut and Kidneyshell populations. Ausable River and Thames River (including Medway Creek) threats apply only to Kidneyshell populations in those rivers.

Threat	**Relative impact** predominant/contributing				**Spatial/Temporal** widespread/local chronic/ephemeral				**Certainty** probable/speculative/unknown			
	St. Clair River delta	Sydenham River	Ausable River	Thames River	St. Clair River delta	Sydenham River	Ausable River	Thames River	St. Clair River delta	Sydenham River	Ausable River	Thames River
Invasive spp. (i.e., dreissenid mussels, Round Goby*)	predominant	contributing	-	-	widespread chronic	local chronic	-	-	probable	probable	-	-
Siltation	-	predominant	predominant	predominant	-	widespread chronic	widespread chronic	widespread chronic	-	probable	probable	probable
Water quality – nutrients & contaminants	contributing	contributing	contributing	contributing	widespread chronic	widespread chronic	widespread chronic	widespread chronic	speculative	probable	probable	probable
Water quantity	-	contributing	contributing	contributing	-	widespread ephemeral	widespread ephemeral	widespread ephemeral	-	speculative	speculative	speculative
Decline of host fish	contributing	contributing	-	unknown	widespread chronic	widespread chronic	-	unknown	speculative	speculative	-	unknown
Urbanization	-	contributing	contributing	contributing	-	local chronic	local chronic	Local chronic	-	speculative	speculative	speculative
Physical habitat loss/ Modification	contributing	contributing	contributing	contributing	local chronic	local chronic	local chronic	local chronic	probable	probable	probable	probable
Impoundments	-	contributing	-	-	-	local chronic	-	-	-	unknown	-	-
Predation	-	contributing	contributing	contributing	-	local ephemeral	local ephemeral	local ephemeral	-	unknown	unknown	unknown
Recreational activities	contributing	contributing	contributing	contributing	local ephemeral	local ephemeral	local ephemeral	local ephemeral	probable	probable	probable	probable

**Neogobius melanostomus*

10.2 Description of threats

Invasive species: The introduction and spread of the exotic Zebra and Quagga mussels throughout the Great Lakes basin has resulted in steep declines of native mussel species (Gillis and Mackie 1994, Schloesser *et al.* 1996). These invasive mussels are known to attach to the shells of native unionids and can cause death by interfering with feeding, respiration, excretion, and locomotion (Haag *et al.* 1993, Baker and Hornbach 1997). COSEWIC (2003b) reported that 64% of the Canadian sites where Round Hickorynut was historically found are now infested with Zebra Mussel, rendering much of the habitat unsuitable for unionids. The St. Clair River delta population occurs in waters inhabited by Zebra Mussel, and Round Hickorynut was found in areas with relatively high Zebra Mussel infestation rates (D. McGoldrick, National Water Research Institute, Environment Canada, pers. comm., October 2003). It is not known why the mussels of the St. Clair River delta have survived when other areas in Lake St. Clair have been devastated by the Zebra Mussel invasion (Nalepa *et al.* 1996) nor is it known if this population will persist (Zanatta *et al.* 2002). The St. Clair River delta Round Hickorynut and Kidneyshell populations are very small, with only nine Round Hickorynut and one Kidneyshell detected during sampling of nearly 15 000 m^2 in 2003 (Metcalfe-Smith *et al.* 2004); in 2011, these sites were revisited and neither species was found, although a single live Round Hickorynut was encountered during sampling in an adjacent area (T. Morris, Fisheries and Oceans Canada [DFO], pers. comm., January 2012). While earlier data had indicated poor reproductive success with the possibility of frequent year-class failure (COSEWIC 2003b), it now appears that these populations may be functionally extirpated due to very low numbers and apparent lack of reproduction.

Any threats that affect the host species' abundance, movements, or behaviour during the glochidial encystment must be considered as threats to these mussels as well. For example, the invasive Round Goby has been implicated in the following declines of native benthic fish species in the lower Great Lakes: 1) Logperch (*P. caprodes*) and Mottled Sculpin (*Cottus bairdii*) populations in the St. Clair River (French and Jude 2001); 2) Johnny Darter, Logperch, and Trout-perch (*Percopsis omiscomaycus*) in Lake St. Clair (Thomas and Haas 2004); and, 3) Channel Darter (*P. copelandi*), Fantail Darter, Greenside Darter, Johnny Darter, and Logperch in the Bass Islands, western Lake Erie (Baker 2005). Index trawling data from 1987 to 2004 (Reid and Mandrak 2008) indicate that similar declines have occurred in the Inner Bay of Long Point Bay and the western basin of Lake Erie. Potential causes include Round Goby predation on eggs and juveniles, competition for food and habitat, and interference competition for nests (French and Jude 2001, Janssen and Jude 2001). A new study (Poos *et al.* 2010) has estimated that 89% of benthic fishes and 17% of mussels that occur in rivers where the secondary invasion of the Round Goby has occurred have been or will be negatively impacted. In particular, Poos *et al.* (2010) reported Round Goby in the lower portions of several rivers including the Sydenham, Ausable and Thames between 2003 and 2008, suggesting that upstream invasion was in progress. This study also predicted a high degree of potential impact to benthic fish hosts of the Kidneyshell and Round Hickorynut as well as other endangered mussels. The continued spread of the Round Goby thus poses a real threat to host fish populations and could devastate remaining mussel populations by disrupting their reproductive cycle.

Siltation and water quality (including nutrients and contaminants): The Sydenham River flows through an area of prime agricultural land in southwestern Ontario and over 85% of the land in the watershed is in agricultural use, with 60% of land in tile drainage (Staton *et al.* 2003). Large areas of the river have little to no riparian vegetation as only 12% of the original forest cover remains. Strayer and Fetterman (1999) identified high sediment and nutrient loads and toxic chemicals from non-point sources, especially agricultural activities, as the primary threat to riverine mussels. Agricultural lands, particularly those with little riparian vegetation and no underlying tile drainage, allow large inputs of sediments to the watercourse. In the case of tile-drained land, the sediment input is often of a very fine grain, which can clog the gill structures of mussels, resulting in decreased feeding and respiration rates and reductions in growth efficiency. The Sydenham River has historically shown high nutrient levels with total phosphorus levels consistently exceeding provincial water quality levels over the last 30 years, while chloride levels have shown recent inclines due to an increased use of road salt (Staton *et al.* 2003). A recent study (Gillis 2011) has shown that glochidia of the Wavyrayed Lampmussel (*Lampsilis fasciola*) were acutely sensitive to sodium chloride. Assuming that the salt sensitivities of the Round Hickorynut and Kidneyshell are comparable to that of the Wavyrayed Lampmussel, and because their range is limited to southern Ontario, Canada's most road-dense and thus heavily salted region, chloride from road salt is a substantial threat to the early life-stages. Although water does buffer the toxic effects of chloride to the glochidia, chloride levels in mussel habitat have been reported at levels (>1300 mg/L) that are toxic to these species (Gillis 2011).

Agriculture is also the dominant land-use within the Ausable River basin, with over 80% of the land in agricultural use and 71% of the land area in tile drainage (Nelson *et al.* 2003). Suspended sediment levels are high throughout the river, with levels in the lower main channel consistently exceeding those required to maintain good fisheries (Nelson *et al.* 2003). Nutrient levels (nitrogen, phosphorus, un-ionized ammonia) regularly exceed provincial Water Quality Objectives for the protection of wildlife and Canadian Council of Ministers of Environment guidelines. Recent evidence has shown that juvenile mussels are among the most sensitive aquatic organisms to ammonia toxicity (Mummert *et al.* 2003, Newton 2003, Newton *et al.* 2003, Newton and Bartsch 2007).

Water quality in the Thames River basin has historically suffered greatly from agricultural activities. Because agriculture accounts for 75-85% of land use in the Thames River basin, it is likely that agricultural impacts are primarily responsible for the decline of Kidneyshell in this river. Tile drainage, wastewater drains, manure storage and spreading, and insufficient soil conservation have all contributed to poor water quality within the Thames basin (Metcalfe-Smith *et al.* 2000). Phosphorus and nitrogen loadings have increased steadily and some of the highest livestock loadings for the entire Great Lakes basin have been reported for the Thames River watershed (WQB 1989, Upper Thames River Conservation Authority [UTRCA] 2004). Mean ammonia concentrations in all sub-basins of the Thames River exceed the federal freshwater aquatic life guidelines (Metcalfe-Smith *et al.* 2000).

Dissolved oxygen (DO) levels in the East Sydenham River typically average about 10 mg/L; however, levels at all four Provincial Water Quality Monitoring Stations in this basin have dropped as low as 5 mg/L during the last 35 years (Jacques Whitford Environment Ltd. 2001). Over the same time period, DO levels in the Ausable River have on occasion fallen to comparable levels (2-3 mg/L) (Nelson *et al.* 2003). Johnson *et al.* (2001) have found mussel survival rates are closely related to DO levels, while Tetzloff (2001) reported massive mussel die-offs in Big Darby Creek, Ohio, following a low oxygen event resulting from a chemical spill. Kidneyshell was one of the most sensitive species to these conditions, with greater than 95% mortality, much of it coming rapidly after the onset of low oxygen conditions. Three years after the low DO event many of the affected species have still not recovered to pre-event levels (J. Tetzloff, Darby Creek Association Inc., pers. comm. March 2004). In southern Ontario, fertilizer and liquid manure spills have also occurred in the rivers where remaining Kidneyshell and Round Hickorynut occur.

Water quantity: Hydrologic regimes can affect mussels in a number of ways. High flow conditions can cause dislodgement and passive transport of mussels from areas of suitable habitat into areas of lesser or marginal habitat. Neither the Round Hickorynut nor the Kidneyshell show the typical shell adaptations associated with resistance to scour and shear stress associated with hydrologically flashy rivers (pustules, ridges, fluting) (Watters 1994). In contrast to the dislodgement associated with high flows, low flows can result in depressed DO levels, desiccation, and elevated temperatures. In a study of drought conditions in relation to mussel survival, Johnson *et al.* (2001) identified the need for instream flow protection as a critical issue for mussel conservation and protection in the southwestern U.S. Low flow events in the Ausable River often result in the stranding of mussels. Spooner *et al.* (2011) used a model to determine how a decrease in water quantity would affect species-discharge relationships, using mussels and their host fish species. This study showed that there are severe reductions in mussel and fish richness due to changes in climate change and water use. This will, in turn, have negative effects on food webs and nutrient recycling (Spooner *et al.* 2011).

Urbanization: The over application or misuse of herbicides and pesticides (now prohibited in Ontario for residential cosmetic use) and the release of urban and industrial pollution into rivers where Round Hickorynut and Kidneyshell are found, effectively changing water chemistry, will affect habitat and host fish availability. Nutrient loadings can result from municipal wastewater discharges, domestic septic systems and run-off associated with lawn maintenance. Many forms of pollution resulting from human use may be present in Round Hickorynut and Kidneyshell habitat (e.g., run-off of lawn fertilizers and pesticides, road salts and heavy metals from industrial sources) (e.g., Pip 1995). Exposure to municipal wastewater effluent can negatively affect unionid health (e.g., Gagné *et al.* 2004, 2011, Gagnon *et al.* 2006). Pharmaceuticals can enter streams, rivers and lakes, largely via effluent from sewage treatment plants. There is an increasing concern of possible endocrine and reproductive effects from these chemicals on aquatic biota; related work with unionids is in its infancy (see Cope *et al.* 2008), but there is reason for concern as significant effects on freshwater fish communities have been demonstrated (Kidd *et al.* 2007), including reports of feminization of fishes in the Grand River, a significant mussel habitat in Ontario (Tetreault *et al.* 2011). Gagné *et al.* (2011) determined that Eastern Elliptio (*Elliptio complanata*) in Quebec showed a dramatic increase in the proportion of females, and that males showed a female-specific protein downstream of a municipal effluent outfall, indicating that pollution is disrupting gonad physiology and reproduction of this species.

Urbanization may also have substantial impacts on in-stream habitat and flow characteristics important to freshwater mussels and their hosts. As the percentage of impervious cover (e.g., paved surfaces) in a watershed increases, flow regimes become flashier and sediment supply is altered (e.g., more fines). These changes result in reduced bank and riverbed stability, and a decline in the availability of well-defined riffle and pool habitats important in defining benthic invertebrate and fish communities (S. Reid, Ontario Ministry of Natural Resources [OMNR], pers. comm., May 2012).

Decline of host fish(es): The Round Hickorynut and Kidneyshell are obligate parasites unable to complete their early life-stages without a suitable host. Host species for the Round Hickorynut have been identified as Blackside Darter, Fantail Darter, and Iowa Darter (McNichols 2007). In addition, Clarke (1977) noticed an association between the Round Hickorynut and the Eastern Sand Darter (*Ammocrypta pellucida*), suggesting a possible host relationship, although this species has not been formally tested (M. McGregor, KDFWR, pers. comm., January 2004). The Eastern Sand Darter is listed as a Threatened species in Canada but can be found in the East Sydenham River in areas where the Round Hickorynut persists. Siltation resulting from agricultural activities has been cited as one of the main reasons for the decline of the Eastern Sand Darter (Holm and Mandrak 1996).

Five glochidial host fishes have been identified for the Kidneyshell in Canada: Blackside Darter, Fantail Darter, Johnny Darter, Iowa Darter, and Brook Stickleback (McNichols 2007). Recent surveys have shown that Johnny and Blackside darters are abundant throughout the Ausable (Nelson *et al.* 2003) and Sydenham rivers (N. Mandrak, DFO, pers. comm., March 2004) while Fantail Darter are neither abundant nor widespread in either system. If Johnny or Blackside darters are acting as a host for wild populations in the Ausable or Sydenham rivers, then host limitation should not be a primary cause of the observed declines. Blackside, Fantail, and Johnny darters are present, although in variable numbers, in the stretch of river where Kidneyshell have been recently found in the Thames River (Medway Creek); however, Iowa Darter and Brook Stickleback have not been found (J. Schwindt, UTRCA, pers. comm.). Therefore, only a heavy reliance on the Iowa and Fantail darters or Brook Stickleback as hosts would appear to place these species in danger of being host-limited at this location.

Any activity that disrupts the connectivity between mussel populations and their host species must be taken into consideration. Activities that may disrupt the mussel-host relationship include, but are not limited to, damming, dewatering, and sport or commercial harvest (e.g., baitfish harvesting). Note that activities occurring outside the currently occupied habitat zone may affect the host population(s) within the zone (e.g., downstream damming activities may prevent the movement of fishes into the zone during the period of mussel reproduction). Any activity that impacts a host population within an area of currently occupied habitat should be evaluated to ensure that the reproductive cycle is not disrupted.

Physical habitat loss/modification: Destruction of habitat through grading, excavation and other forms of channelization, including measures that result in flow reduction and practices that result in changes in water temperatures, can have negative affects on these mussel species. River channel modifications such as dredging can result in the direct destruction of mussel habitat and lead to siltation and sand accumulation of local and downstream mussel beds. Other forms of direct habitat loss can result from the placement of material or structures in water (e.g., infilling and groynes). The construction of dams and barriers can also result in direct habitat loss and fragmentation.

Impoundments: There are both short-term and long-term impacts on freshwater mussel habitat associated with impoundments. The construction of impoundments can lead to the fragmentation of habitat (which can limit the reproductive capabilities of mussels by eliminating or decreasing the number of hosts available), habitat conversion (upstream riffle habitats will be flooded), and the clearing of riparian zones (resulting in the loss of cover, increased rates of siltation, and thermal shifts). In addition, changes to the flow regime and sediment supply will alter the geomorphic character of downstream habitats and increase the embeddedness of bed material in riffle areas (S. Reid, OMNR, pers. comm., May 2012). All of these factors can be deleterious to Round Hickorynut and Kidneyshell populations.

Predation: A variety of fish species, muskrat, mink and raccoon are known to predate on freshwater mussels (Bouvier and Morris 2011). However, the direct impact of predation on species such as Kidneyshell and Round Hickorynut in southwestern Ontario is currently unknown. Although predation would be expected to be relatively low, local impacts may increase during low flow events.

Recreational activities: Driving all-terrain vehicles (ATVs) and other motorized vehicles through streams may negatively impact mussel beds. ATVs are noted as a potential threat to mussel beds in the Thames, Ausable and Sydenham rivers where ATVs travel up and down waterways, crushing mussel beds (Bouvier and Morris 2011) and disrupting substrates and water clarity.

11. Knowledge gaps

- *What is/are the Canadian host(s) for the Round Hickorynut and Kidneyshell?* Although the hosts for the Round Hickorynut have been identified as Blackside, Fantail and Iowa darters, these need to be confirmed and primary and functional hosts identified. Five glochidial host fishes have been identified for the Kidneyshell: Blackside Darter, Fantail Darter, Johnny Darter, Iowa Darter, and Brook Stickleback (McNichols 2007). In addition, there may be other species that act as hosts that have yet to be examined in Canada. For example, the Eastern Sand Darter, a threatened species in Canada, has been suggested as a possible host for Round Hickorynut (COSEWIC 2003); however, this has not been tested in the laboratory.

- *What are the habitat requirements of the Round Hickorynut and Kidneyshell?* Habitat use must be quantified for all life-stages with particular attention to the glochidial, encysted and juvenile stages when mortality is high.

- *Are the Round Hickorynut and Kidneyshell host-limited?* Host fish distributions for both mussel species need to be mapped in high detail. Host fish(es) may be functionally unavailable to mussels if their distributions do not overlap at times when female mussels are releasing mature glochidia.

- *Are there life-stage specific threats?* The relative importance of each identified threat to each distinct life-stage (glochidium, juvenile, adult) must be identified.

- *Can the St. Clair River delta refuge sites be maintained?* It must be determined, in collaboration with Walpole Island First Nation, if these sites represent permanent refugia or whether the mussels at these sites will eventually succumb to the harmful effects of dreissenid mussels. If these sites cannot be naturally maintained then the feasibility of actively managing these sites to reduce the effects of dreissenid mussels must be investigated.

- *Can these species be relocated from other jurisdictions or artificially propagated for reintroduction?* Conservation genetics need to be assessed as they relate to relocations/reintroductions and the technical feasibility of artificial propagation should be examined.

12. Biological and technical feasibility of recovery

Recovery of the Round Hickorynut and Kidneyshell is believed to be both biologically and technically feasible as reproducing populations still exist as potential sources to support recovery, suitable habitat can be made available through recovery actions, threats can be mitigated, and proposed recovery techniques are anticipated to be effective. Although recovery at the species level is believed to be feasible the effort required to achieve recovery will not be uniform across all populations.

- Mussels are slow growing and sedentary animals, dependant upon their host fishes for the survival and dispersal of their young. The slow rate of population growth of freshwater mussels makes the natural recovery of decimated populations extremely difficult.
- The habitat in the Sydenham and Ausable rivers could be improved significantly with proper stewardship of both agricultural and urban lands in the watershed.
- Reductions in soil erosion and turbidity in all the watersheds can be achieved but would be challenging due to the number and intensity of the impacts.
- Complete removal of the impacts of dreissenid mussels to the St. Clair River delta populations is not possible at this time; however, it may be possible to establish managed refuge sites to reduce the impacts of dreissenid mussels on Round Hickorynut and Kidneyshell.

A high level of effort will be required to recover the Sydenham River and St. Clair River delta populations of the Round Hickorynut. There is little evidence of natural reproduction within these populations and recovery may require captive breeding and/or relocations from U.S. populations.

A low to moderate level of effort will be required to recover the Sydenham and Ausable river populations of the Kidneyshell. These populations are believed to be threatened by general habitat loss resulting from characteristic land-use practices within the basin. A general suite of ecosystem recovery actions such as those proposed by Dextrase *et al.* (2003) will assist with the recovery of this population. For the recently discovered Thames River (Medway Creek) population of the Kidneyshell, a high level of effort will be required. Two years after a relocation from an area to be crossed by a sewer pipeline, one specimen increased from 113.5 mm to 114.5 mm and the other showed no growth (121.8 mm), suggesting that both specimens are at their asymptotic growth phase; the absence of smaller individuals suggests lack of recruitment (G. Mackie, UG, pers. comm., January 2012). With no evidence of reproduction, this relict population may require captive breeding and/or relocations from healthier extant Canadian populations.

Recovery of the St. Clair River delta populations of both species will require a high degree of effort. Active management of selected refuge sites including the regular cleaning of dreissenid mussel infested individuals will be required to maintain and recover this population. Long-term population augmentation and/or translocations may also be required to return the Round Hickorynut and Kidneyshell to healthy self-sustaining levels in Canada.

II. Recovery

1. Recovery goal

The long-term goals of this recovery strategy are:

i. To prevent the extirpation of the Round Hickorynut and Kidneyshell in Canada;
ii. To return healthy self-sustaining populations of Round Hickorynut to the East Sydenham River and St. Clair River delta;
iii. To maintain healthy self-sustaining Kidneyshell populations in the Ausable and East Sydenham rivers while returning the St. Clair River delta and Thames River (including Medway Creek) populations to self-sustaining levels; and,
iv. To re-establish populations in historically occupied habitats, excluding areas where dreissenids have now made habitats unsuitable.

These populations can only be considered recovered when they have returned to historically estimated ranges (see Figure 3 and 6) and/or population densities, and are showing signs of reproduction and recruitment. Because much of the Great Lakes and its connecting channels have been devastated by the introduction of dreissenid mussels, these areas no longer provide suitable habitat for freshwater mussels (DFO 2011a). For this reason, the Detroit River, Lake Erie, Lake St. Clair proper, and the Niagara River are currently excluded from the recovery goal for the Round Hickorynut and Kidneyshell. If in the future it is determined that the restoration of suitable habitats in these locations is possible, the recovery goal will be revisited.

2. Population and distribution objectives

The population and distribution objectives for these species are to return/maintain self-sustaining populations in the following locations:

(1) St. Clair River delta and East Sydenham River (Round Hickorynut and Kidneyshell)
(2) Ausable River and Thames River (including Medway Creek) (Kidneyshell).

The populations at these locations could be considered recovered when they have returned to historically estimated ranges and/or population densities, and demonstrate active signs of reproduction and recruitment throughout their distribution. More quantifiable objectives (that may include consideration of extirpated populations where suitable habitats may be present) will be developed once necessary surveys and studies have been completed (refer to Section 7.5 Schedule of studies to identify critical habitat).

3. Recovery objectives (5 year)

i. Determine extent, abundance and population demographics of existing populations;
ii. Determine host fishes and their distributions and abundances;
iii. Define key habitat requirements to identify critical habitat;
iv. Establish a long-term monitoring program for Round Hickorynut and Kidneyshell populations, their hosts and the habitat of both;
v. Identify threats, evaluate their relative importance and implement remedial actions to minimize their impacts;
vi. Examine the feasibility of relocations, reintroductions and the establishment of managed refuge sites; and,
vii. Increase awareness about the distribution, threats and recovery of these species.

4. Approaches to meeting recovery objectives

The approaches to recovery have been organized into four distinct groups – Research and Monitoring (Table 2), Management (Table 3), Stewardship (Table 4), and Awareness (Table 5). Successful recovery across the ranges of the Round Hickorynut and Kidneyshell will require consideration of approaches from all categories. A narrative has been included after each table where appropriate.

Recovery of these two species cannot be achieved through the actions of any one party. Implementation of the recovery approaches outlined below will require a concerted effort of many groups including, but not limited to, federal, provincial and municipal governments, conservation authorities, academic institutions, First Nations communities, non-governmental organizations, and local citizens.

Table 2. Recovery planning table - research and monitoring approaches for Round Hickorynut (RH) and Kidneyshell (KS) populations.

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
URGENT	1-1	i, iii	Research – reproduction.	Identify spawning periods of RH and KS. Determine length of encystment period on host in nature.	Determine reproductive timing windows for entire lifecycle, which will ensure that these stages can be protected.	Component of fish host declines
URGENT	1-2	ii, v	Research – host fishes.	Confirm the host fish species for the RH and KS.	Will help determine if host abundance is limiting the RH and KS. Will assist with defining the larval encystment stage and in identifying critical habitat.	Host fishes declines
URGENT	1-3	ii, v	Surveys – host fishes.	Determine the distribution abundance, and health of the host species at sites where RH and KS currently occur.	Will help determine if hosts are limiting the RH and KS.	Host fishes declines
URGENT	1-4	iii	Research – critical habitat.	Determine the habitat requirements for all life-stages, particularly for juveniles.	Will assist with further refining critical habitat for the RH and KS.	

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
URGENT	1-5	iii, vi	Research and surveys – critical habitat.	Prepare a distribution map of areas of suitable habitat (currently occupied and unoccupied).	Will assist with refining critical habitat and identifying potential areas of reintroduction. Will assist with explanations of why mussel species are not in habitats/sites that seem suitable.	All threats
URGENT	1-6	vi	Research – managed refuge sites.	Investigate the feasibility of establishing actively managed refuge sites in the St. Clair River delta.	Will determine if RH in the St. Clair River delta can be insulated from the effects of dreissenid mussels.	Invasive species
NECESSARY	1-7	i, iv	Monitoring – mussel and fish host populations.	Continue to monitor the current stations and establish a network of permanent monitoring stations throughout the distributions of the RH and KS..	Will permit tracking of populations, analysis of trend patterns, and permit the evaluation of recovery actions.	Host fishes declines
NECESSARY	1-8	iv, v	Monitoring – habitat.	Establish permanent monitoring sites for tracking changes in habitat.	Provides trend data for key habitat and will help evaluate the relative threat of habitat loss.	All threats

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
URGENT	1-9	v	Research – threats.	Identify and evaluate threats to all life-stages (including toxic contaminants).	Will assist with determining reasons for declines and developing remedial actions.	All threats
NECESSARY	1-10	vi	Research – conservation genetics.	Compare the within and among population genetic variability of Canadian populations and determine if populations show genetic structure by comparing variability between populations in Canadian and U.S. waterways.	Will assist with determining if population translocation or augmentation is appropriate. Identify designatable units and population structure and viability.	

1-1 - 1-3: Very little is known regarding the reproductive stages of these species especially in Canada. It is important that specific spawning periods (sperm release, fertilization, length of encystment on host) are known to inform the protection and recovery of these species. Without this knowledge, it will be difficult to determine when these species (mussels and fishes) are susceptible to many of the threats listed above.

The necessity for a period of encystment represents a potential bottleneck in the lifecycle of the mussel. Research and recovery actions focusing on the pre- or post-encystment period may prove unproductive if the presence of a host fish is the limiting step. To determine if these species are host limited it is necessary to first identify the host species, and then to confirm that the distributions of the mussel and its host overlap in time and space, in a manner that will permit successful encystment. The identification of high host specificity in some mussel species requires that hosts be identified for local populations whenever possible. McNichols (2007) has identified three host species for Round Hickorynut in Canada, and five host species for

Kidneyshell. Efforts should be directed towards confirming that these species identified are, in fact, functional host species in nature.

Once the Canadian hosts have been confirmed for both of these species, it is necessary to verify that host species distributions overlap with the Round Hickorynut and Kidneyshell distributions. Because adult mussels are essentially sessile this can be accomplished by confirming that members of the hosts species occur in reaches with mature female mussels at times when the female mussels possess mature glochidia.

1-4 & 1-5: Determination and refinement of critical habitat is an essential component in the recovery of these species. Although adult mussels are relatively passively distributed, distinct habitat types can be associated with adult distributions suggesting that survival is linked to local habitat conditions. Habitat conditions may be equally important during the juvenile stage (optimal substrate, temperature, water chemistry), and attention must also be paid to the habitat preferences of the hosts. The identification and refinement of critical habitat will be a multi-stage incremental process.

1-6: The healthiest remaining population of Round Hickorynut, along with a small population of Kidneyshell, can be found in the St. Clair River delta, despite the presence of dreissenid mussels. Metcalfe-Smith *et al.* (2004) reported Zebra Mussel infestation rates ranging from 0 to 36 Zebra Mussel/unionid in this area during 2003. While this rate of infestation is below the lethal limits reported elsewhere (Ricciardi *et al.* 1995), it may be resulting in long-term chronic effects that are causing prolonged declines. Comparisons of collections made in 2001 with those in 2003 showed that abundance of all unionids had declined by about 14%, while declines were much higher for some species (i.e., 80% decline of Round Hickorynut) (Metcalfe-Smith *et al.* 2004). Although the overall trend was toward declining unionid densities, some sites showed stable overall abundances. These sites were associated with low Zebra Mussel infestation rates and high unionid diversity and may represent potential refuge sites. Because these sites are still affected by Zebra Mussel, it is likely that unionids will need to be actively managed with regular Zebra Mussel removal and the active relocation of Round Hickorynut, Kidneyshell and other mussel species at risk, to these locations from the more heavily infested sites. The feasibility of actively managing refuge sites in the St. Clair River delta must be determined quickly as this will likely represent the only chance of saving the Round Hickorynut.

1-7 & 1-8: A network of detailed, permanent monitoring stations should be established throughout the present and historic ranges of the Round Hickorynut and Kidneyshell if they do not already occur. Monitoring sites should be established in a manner so as to permit:

- Quantitative tracking of changes in mussel abundance or demographics (size distribution, age structure etc.) or that of their hosts.
- Detailed analyses of habitat use and the ability to track changes in use or availability.
- The ability to detect the presence of invasive species (i.e., dreissenid mussels). Reservoirs represent the likely seed locations for dreissenid mussels in the

Sydenham and Ausable rivers. Monitoring sites should be established within or close to these reservoirs to permit the early detection of dreissenid mussels in the event that they invade these systems. Monitoring of invasive species in the St. Clair River delta will likely be conducted in close association with the managed refuge sites.

Table 3. Recovery planning table - management approaches for Round Hickorynut (RH) and Kidneyshell (KS) populations.

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
URGENT	2-1	i-vi	Capacity building.	Continue to promote and enhance expertise in freshwater mussel identification/biology and provide for the transfer of knowledge.	Will ensure correct identification and understanding of mussel species at risk.	All threats
URGENT	2-2	v, vi	Cooperation – ecosystem recovery strategies.	Work with existing ecosystem recovery teams to implement recovery actions.	Encourage a seamless implementation of all recovery actions.	All threats
NECESSARY	2-3	v	Municipal planning	Encourage municipal planning authorities to consider critical habitat in official plans.	Will provide further protection for the RH and KS and promote future development that does not degrade important habitat.	Urbanization, water quality, water quantity, impoundments
NECESSARY	2-4	v	Reduction of chloride loading.	Encourage municipalities to adapt Best Management Practices (BMPs) to reduce the use of road salt.	Will reduce the loading of road salt and decrease the potential impact of chloride levels on freshwater mussels.	Water quality

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
NECESSARY	2-5	v	Drainage	Work with drainage supervisors, engineers and contractors to limit the effects of drainage activities on mussel habitat.	Will reduce the harmful effects of drainage activities.	Water quality, siltation, water quantity
NECESSARY	2-6	v	Baitfish	Work with the baitfish industry to reduce the impacts of commercial baitfishing on host species. Update baitfish guide to include information on the mussel lifecycle and note potential host fishes and time frames when encystment is likely to occur.	Will provide protection for potential host species. Will increase public knowledge of mussels and the importance of baitfish for natural ecological processes.	Host fishes declines
NECESSARY	2-7	v	Wastewater treatment plants and stormwater management facilities.	Verify that wastewater treatment plants are functioning up to specifications and encourage upgrading where appropriate. Review stormwater management facilities for quantity and quality control in new developments, and retro-fit existing development where possible.	Will improve water quality by reducing nutrient and suspended solid inputs from urban centres.	Water quality, water quantity, impoundments

2-1: The current capacity within southwestern Ontario to perform the necessary survey and monitoring work is insufficient. Knowledge of freshwater mussel identification, distribution, life history and genetics is limited to a small number of individuals from a limited number of government and academic institutions. Furthermore, the retirement and relocation out of province of several key researchers has occurred over the past five years. A concerted effort must be made to increase this capacity by:

- Training personnel in the identification of all mussel species with emphasis on the rare species (e.g., DFO freshwater mussel identification course).
- Promote the use of the freshwater mussel field guide (Metcalfe-Smith *et al.* 2005).
- Encourage graduate and post-graduate research aimed at fulfilling the needs identified under Research and Monitoring.
- Encouraging the public to learn more about freshwater mussels and their importance.

2-2: Many of the threats to the Round Hickorynut and Kidneyshell can be classified as widespread and chronic (Table 1) and represent general ecosystem threats affecting numerous other aquatic species. Efforts to remediate these threats will benefit many species in addition to these two mussel species and should be attempted in close connection with the aquatic ecosystem recovery teams for the Ausable, Thames and Sydenham rivers (see Section 6, Activities already completed or underway) to eliminate duplication of efforts, and ensure that undertaken activities are not detrimental to other species.

2-6: The host species for the Round Hickorynut (Blackside, Fantail, and Iowa darters) and Kidneyshell (Blackside, Johnny, Iowa, and Fantail darters, and Brook Stickleback) are not listed under SARA. While these host species are not typically targeted as baitfishes, they are potentially collected as bycatch during legal bait harvesting activities. Effort should be made to minimize potential bycatch of these species and to verify that gear selection and operation do not contribute to habitat degradation, which may adversely affect host populations. In watersheds supporting Round Hickorynut and Kidneyshell, live bait storage ponds should be isolated from the watercourse to prevent accidental escapement of Round Goby. Mechanisms to confirm that bait bucket releases do not further spread the Round Goby and detrimentally impact host populations should be employed.

Table 4. Recovery planning table - stewardship approaches for Round Hickorynut (RH) and Kidneyshell (KS) populations.

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
URGENT	3-1	v	Riparian buffers	Establish riparian buffer zones in areas of high erosion potential by encouraging naturalization or planting of native species.	Will improve water quality by reducing bank erosion, sedimentation and overland run-off.	Water quality, siltation, water quantity
URGENT	3-2	v	Tile drainage	Work with landowners to mitigate the effects of tile drainage.	Will reduce nutrient and sediment inputs.	Water quality, siltation, water quantity
URGENT	3-3	v	Herd management	Encourage the active exclusion of animals from the watercourse.	Will reduce bank erosion, sediment and nutrient inputs.	Water quality, siltation
URGENT	3-4	v	Livestock waste management	Assist with establishing adequate manure collection and storage systems to avoid accidental spills, and winter-spreading of manure.	Will improve water quality by reducing nutrients.	Water quality
URGENT	3-5	v	Farm planning	Encourage the development and implementation of Environmental Farm Plans and Nutrient Management Plans.	Will assist with minimizing inputs of nutrients and sediments.	Water quality
URGENT	3-6	v	Sewage treatment	Work with landowners to improve faulty septic systems.	Will improve water quality by reducing nutrient inputs.	Water quality

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
BENEFICIAL	3-7	v	Soil testing	Encourage soil testing to determine fertilizer application rates.	Will reduce nutrient inputs to the river.	Water quality

The stewardship activities outlined here can be described as “best management practices” and represent a non-exhaustive selection of activities that can be encouraged within these predominantly agricultural watersheds to help reduce the impacts of terrestrial practices on aquatic ecosystems. Encouragement can be achieved through increasing awareness of these activities as well as through the provision of financial assistance to local landowners.

Table 5. Recovery planning table - awareness approaches for Round Hickorynut (RH) and Kidneyshell (KS) populations.

Priority	Number	Recovery objective addressed	Broad approach/ strategy	Specific steps	Anticipated effect	Threat addressed
URGENT	4-1	vii	Awareness – stewardship actions	Increase public knowledge of stewardship options and financial assistance available to participate in activities.	Increased public participation in recovery actions and a reduction in threats to the RH and KS.	Water quality, siltation, water quantity
URGENT	4-2	vii	Invasive species	Increase public awareness of the potential impacts of transporting/releasing invasive species.	Will reduce the risk of dreissenid mussels or Round Goby becoming established.	Invasive species
BENEFICIAL	4-3	vii	Outreach	Encourage public support and participation by developing awareness materials and programs.	Will increase public awareness of the importance of species at risk.	All threats

Public participation in the recovery process for these species is essential, as the primary threats to populations in the Sydenham, Ausable and Thames rivers result from diffuse non-point source inputs relating to the general agricultural activities within these watersheds. Recovery cannot occur without the full participation of local citizens and landowners. The need for an effective public awareness program is crucial to the recovery of these two species.

5. Evaluation

The routine monitoring programs will provide the primary means of evaluating the success of the listed recovery approaches. The monitoring programs will provide trend through time data allowing the tracking of Round Hickorynut and Kidneyshell populations and habitat, and will form the basis of an adaptive management program. Recovery Implementation Groups will develop specific targets in one or more action plans for the recovery strategy to provide a further basis for evaluating success. The entire recovery strategy will be reported on every five years at which time all goals, objectives, and approaches will be re-evaluated.

6. Actions already completed or underway

Sydenham River aquatic ecosystem recovery strategy: The Sydenham River Recovery Team became the first group in Canada to adopt an ecosystem approach to recovering aquatic species when they completed the Sydenham River aquatic ecosystem recovery strategy (SRAERS) in 2003 (Dextrase *et al.* 2003). The recovery strategy focuses on the 14 aquatic species at risk (five mussels, eight fishes, one turtle) within the basin that are designated as Endangered, Threatened or of Special Concern by COSEWIC. Both the Round Hickorynut and the Kidneyshell were designated after the SRAERS was completed and so these species are not directly considered within the strategy; despite this, many of the actions proposed by Dextrase *et al.* (2003) use an ecosystem approach that will not only benefit the five included mussel species but the Round Hickorynut and Kidneyshell as well.

Thames River recovery ecosystem strategy: The Thames River Recovery Team (TRRT) has set out to develop an ecosystem-based recovery strategy for the Thames River watershed. The stated goal is to develop "a recovery plan that improves the status of all aquatic species at risk in the Thames River through an ecosystem approach that sustains and enhances all native aquatic communities" (TRRT 2003). This recovery strategy addresses 25 COSEWIC-designated species including seven mussels, 12 fishes, and six reptiles. Both the Round Hickorynut and the Kidneyshell are included in this strategy as both species historically occurred within this watershed. Although only the Kidneyshell is still known to occur in a Thames River tributary, recovery actions proposed by the TRRT will increase the likelihood that recovery habitat for these species in the Thames River will prove suitable for possible future repatriations.

Ausable River ecosystem recovery strategy: The Ausable River Recovery Team (ARRT) is developing an ecosystem-based recovery strategy for the 14 COSEWIC-designated aquatic species in the Ausable River basin. This plan covers four Endangered mussel species including the Kidneyshell. The overall goal of the strategy is to "sustain a healthy native aquatic community in the Ausable River through an ecosystem approach that focuses on species at risk "(ARRT 2006). The ARRT (2006) has also established a species-specific recovery goal for all mussels of "maintain(ing) existing populations of species at risk and restor(ing) self-sustaining populations of each species to areas of the river where they formerly occurred".

Grand River fish species at risk recovery strategy: The Grand River Recovery Team has developed a draft recovery strategy for fish species at risk in the Grand River. The goal of this strategy is "to conserve and enhance the native fish community using sound science, community involvement and habitat improvement measures" (Portt *et al.* 2003). Although the strategy does not directly address any mussels species, their "habitat preferences and requirements will be taken into account when assessing management actions targeting fish species at risk. In most cases, it is anticipated that recovery actions benefiting fishes at risk will also benefit these other rare species” (Portt *et al.* 2003).

Walpole Island ecosystem recovery strategy: The Walpole Island Ecosystem Recovery Strategy Team was established in 2001 to develop an ecosystem-based recovery strategy for the area containing the St. Clair River delta with the goal of outlining steps to maintain or rehabilitate the ecosystem and species at risk (Walpole Island Heritage Centre 2002). The strategy identifies all known COSEWIC-designated species within Walpole Island First Nation, both aquatic and terrestrial.

Host fish identification: A research group led by Dr. J. Ackerman and Dr. G.L. Mackie has been established at the University of Guelph to investigate aspects of the reproductive cycle of freshwater mussels (host fish determination, glochidial development, juvenile growth and survival). The group conducts its research at the Hagen Aqualab on the grounds of the University in Guelph, Ontario, Canada. This facility has been used to investigate potential hosts for four species of endangered mussels including the Kidneyshell (McNichols and Mackie 2004). Five glochidial host fishes have been identified for the Kidneyshell at this facility: Blackside Darter, Fantail Darter, Johnny Darter, Iowa Darter, and Brook Stickleback (McNichols 2007). In addition, host species for the Round Hickorynut have been identified as Blackside Darter, Fantail Darter, and Iowa Darter (McNichols 2007).

Stewardship activities: Stewardship activities occurring throughout the ranges of these two mussels are able to occur, in large part, because of funding obtained through the federal Habitat Stewardship Program. Stewardship programs are implemented by local conservation authorities within the Ausable, Sydenham, Grand, and Thames River watersheds for projects involving: tree planting; stream stabilization; wetland creation; buffer strips; grassed waterways; sediment traps; repair or replacement of faulty septic systems; manure storage facilities; clean water diversions; runoff collection systems; fencing livestock from watercourses; plugging and repairing wells; nutrient management plans; and, the Ontario Drinking Water Stewardship Program. Implementation of these projects improves and protects rural water quality, and the habitat for aquatic species at risk.

Mussel monitoring network: Fifteen permanent monitoring stations for mussels have been established on the Sydenham River and a further six on the Thames River. Seven monitoring stations have been established on the Ausable River. These sites will be part of an ongoing monitoring system as part of the Sydenham, Ausable and Thames ecosystem recovery strategies and will provide quantitative trend through time data to evaluate recovery actions as well as the overall status of mussel communities.

Nutrient Management Act: Implementation of this provincial legislation, which came into force September 30, 2003, will regulate the storage and use of nutrients including manure, farmyard run-off and farm washwater. This should reduce nutrient inputs to the watercourses, which will benefit the aquatic habitats of the mussels.

Ontario's Clean Water Act: This Act came into affect in 2006 and protects Ontario's source water via local committees that list existing and potential threats and implement actions that will reduce or eliminate these threats (OMOE 2011). This allows communities to take a "hands on" approach to conserve and protect their own watersheds and is based on sound science. The implementation of this legislation will benefit all aquatic species; however, it is particularly important for freshwater mussels as they are sensitive to copper, ammonia, and nitrogen (see Section 10 Threats).

7. Critical habitat

7.1 General identification of the Round Hickorynut and Kidneyshell's critical habitat

The identification of critical habitat for Threatened and Endangered species (on Schedule 1) is a requirement of SARA. Once identified, SARA includes provisions to prevent the destruction of critical habitat. Critical habitat is defined under section 2(1) of SARA as:

> "…*the habitat necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species*". [s. 2(1)]

SARA defines habitat for aquatic species at risk as:

> *"… spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced."* [s. 2(1)]

For the Round Hickorynut and Kidneyshell, critical habitat has been identified to the extent possible, using the best information currently available. The critical habitat identified in this recovery strategy describes the geospatial areas that contain the habitat necessary for the survival or recovery of the species. The current areas identified may be insufficient to achieve the population and distribution objectives for the species. As such, a schedule of studies has been included to further refine the description of critical habitat (in terms of its biophysical functions/features/attributes as well as its spatial extent) to support its protection.

7.2 Information and methods used to identify critical habitat

Using the best available information, critical habitat has been identified using a 'bounding box' approach for extant riverine populations of the Round Hickorynut and Kidneyshell in the Sydenham River as well as for the Kidneyshell populations in the Ausable River and Medway Creek (a tributary of the Thames River); additional areas of potential critical habitat within the St. Clair River delta region will be considered in collaboration with Walpole Island First Nation.

This approach requires the use of essential functions, features and attributes for each life-stage of these two species to identify patches of critical habitat within the ‘bounding box’, which is defined by occupancy data for the species. Life-stage habitat information was summarized in chart form using available data and studies referred to in Sections 4.1 and 8.1 (Habitat and biological needs) for both species. The ‘bounding box’ approach was the most appropriate, given the limited information available for the species and the lack of detailed habitat mapping for these areas. This approach and the methods used to identify reaches of critical habitat are consistent with the approaches recommended by DFO (2011b) for freshwater mussels.

Within the rivers currently occupied by the Kidneyshell and Round Hickorynut, an ecological classification system was used in the identification of critical habitat. The OMNR’s Aquatic Landscape Inventory System (ALIS version 1) (Stanfield and Kuyvenhoven 2005) was used as the base unit for defining reaches within riverine systems. This technique has been used for populations of the Round Hickorynut and Kidneyshell in the Sydenham River as well as for the Kidneyshell populations in the Ausable River and Medway Creek. The ALIS system employs a valley classification approach to define river segments with similar habitat and continuity, on the basis of hydrography, surficial geology, slope, position, upstream drainage area, climate, landcover, and the presence of instream barriers, all of which are believed to have a controlling effect on the biotic and physical processes within the catchment. Therefore, if the species has been found in one part of the ecological classification, it would be reasonable to expect that it would be present in other spatially contiguous areas of the same valley segment. Within all identified river segments (i.e., valley segments) the width of the habitat zone is defined as the area from the mid-channel point to bankfull width on both the left and right banks. Critical habitat for the Round Hickorynut and Kidneyshell within the Sydenham, Ausable and Thames rivers was therefore identified as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present; segments or reaches were excluded only when supported by robust data indicating species absence and/or unsuitable habitat conditions. Current occupancy for these species was defined by recent records of live individuals (and/or fresh shells) from 1996 onward; this is the point in time when systematic surveys of freshwater mussel communities in southern Ontario began. Unoccupied ALIS segments with suitable habitats were also included when limited sampling had occurred (i.e., the species was assumed to be present).

While individual ALIS segments generally represent relatively homogenous habitat conditions, an exception was noted relative to the Kidneyshell in the Sydenham River. In this case, the very long ALIS segment was broken at the point where stream gradient flattens out by using river gradient profiles to exclude the lower stretches of the river below Dresden; below this point, the Kidneyshell’s preferred riverine habitat of riffles and runs would not be present due to insufficient stream gradient.

7.3 Identification of critical habitat: biophysical function, features and their attributes

Tables 6 and 7 summarize the limited, available knowledge of the functions, features and attributes for each life-stage of the Round Hickorynut and Kidneyshell (refer to Sections 4.1 and 8.1 Habitat and biological needs for full references). Areas within which critical habitat is found must be capable of supporting one or more of these habitat functions. Note that not all attributes in Tables 6 and 7 must be present for a feature to be identified as critical habitat. If the features as described in Tables 6 or 7 are present and capable of supporting the associated function(s), the feature is considered critical habitat for the species, even though some of the associated attributes might be outside of the range indicated in the table. All attributes may be used to help inform management decisions for the recovery and/or protection of habitat.

Table 6. General summary of the functions, features and attributes of critical habitat for each life-stage of the Round Hickorynut (riverine populations).

Life-stage	Function	Feature(s)	Attribute(s)

Spawning and fertilization (time period unknown)
 	
Glochidia present in females (long term brooder: Sept-June)
	Reproduction	Reaches of rivers and streams with steady to moderate flows and sand and gravel substrates present (includes ‘bankfull’ channel)	• Attributes assumed to be same as for adults (see below)
			• Flow present (distribution of sperm)
			• Summertime water temperatures reach ~18°C (range unknown) for successful development
			• Low contaminants levels – including the following:
			  ◦ Long-term chloride levels < 120 mg/L (CCME 2011)
			  ◦ Mean concentrations of < 0.3 mg/L total ammonia as N at pH 8; for protection of all life-stages of freshwater mussels (Augspurger *et al.* 2003)
			• Copper levels < 3 µg/L (CCME 2005) should protect sensitive glochidia (Gillis *et al.* 2008).

Encysted glochidial stage (June-July) on host fish(es) until drop off	Feeding Cover Nursery	Same as above with host fish(es) present	• Attributes assumed to be same as below (as these conditions support both fish hosts and adults) • Presence of host fish(es) (e.g., Blackside, Fantail or Iowa darters) • DO levels sufficient to support host (> 4 mg/L; PWQO [1994] for protection of warmwater species)
Adult/Juvenile	Feeding Cover Nursery	Reaches of rivers and streams with steady to moderate flows and sand and gravel substrates present (includes ‘bankfull’ channel)	• Steady to moderate flows (in sufficient volume to prevent stranding and increased predation) • Presence of sand (0.1–3.0 mm) and gravel (3-80 mm) substrates • Adequate supply of food (plankton: bacterial, algae, organic detritus, protozoans) • Depths up to 2 m • Dreissenids absent or in low abundance • Warm water temperatures (gamete production and development)

Table 7. General summary of the functions, features and attributes of critical habitat for each life-stage of the Kidneyshell (riverine populations).

Life-stage	Function	Feature(s)	Attribute(s)

Spawning and fertilization
Glochidia present in females
(long term brooder: August – May; Ortmann 1919, Watters *et al.* 2009)
	Reproduction	Reaches of rivers and streams with riffle and/or run habitats and gravel and sand substrates present
		(includes 'bankfull' channel)
			• Attributes assumed to be same as for adults (see below)
			• Flow present (distribution of sperm)
			• Spring temperature threshold for spawning (?)
			• Summertime water temperatures reach 17-26°C for successful development of glochidia
			• Low contaminants levels – including the following:
			  • Long-term chloride levels < 120 mg/L (CCME 2011)
			  • Mean concentrations of < 0.3 mg/L total ammonia as N at pH 8; for protection of all life-stages of freshwater mussels (Augspurger *et al.* 2003)
			• Copper levels < 3 µg/L (CCME 2005) should protect sensitive glochidia (Gillis *et al.* 2008).

Encysted glochidial stage (April - August) on host fish(es) until drop off (Ortmann 1919, Watters *et al.* 2009)	Feeding Cover Nursery	Same as above with host fish(es) present	• Attributes assumed to be same as below (as these conditions support both fish hosts and adults) • Presence of host fish(es) (e.g., Blackside, Fantail, Johnny or Iowa darters, and Brook Stickleback) • DO levels sufficient to support host (> 4 mg/L; PWQO [1994] for protection of warmwater species)
Adult/Juvenile	Feeding Cover Nursery	Reaches of rivers and streams with riffle and/or run habitats and gravel and sand substrates present (includes 'bankfull' channel)	• Moderate to swift flows (~0.1-0.7 m/s average summer baseflow) in sufficient volume to prevent stranding and increased predation • Presence of firmly packed coarse gravel (3-80 mm) and sand (0.1–3.0 mm) substrates • Adequate supply of food (plankton: bacterial, algae, organic detritus, protozoans) • Clear waters (low to moderate turbidity/total suspended solids) • Warm water temperatures (gamete production and development) • Dreissenids absent or in low abundance

Studies to further refine knowledge on the essential functions, features and attributes for various life-stages of the Round Hickorynut and Kidneyshell are described in Section 7.5 (Schedule of studies to identify critical habitat).

7.4 Identification of critical habitat: geospatial

Using the best available information, critical habitat has been identified for Round Hickorynut and Kidneyshell populations in the following watercourses:

1. East Sydenham River (Round Hickorynut and Kidneyshell)
2. Ausable River (Kidneyshell)
3. Medway Creek (Kidneyshell)
4. Lower Thames River (Kidneyshell)

Areas of critical habitat identified at these locations may overlap with critical habitat identified for other co-occurring species at risk (e.g., Northern Riffleshell [*Epioblasma torulosa rangiana*], Snuffbox [*Epioblasma triquetra*], Rayed Bean [*Villosa fabalis*], Salamander Mussel [*Simpsonaias ambigua*], Round Pigtoe [*Pleurobema sintoxia*], Eastern Sand Darter and Northern Madtom [*Noturus stigmosus*]); however, the specific habitat requirements within these areas may vary by species.

The areas delineated on the following maps (Figures 7-11) represent the extent of critical habitat that can be identified at this time. Note that the areas delineated include the entire 'bankfull' channel; this supports long-term channel forming discharges important in maintaining in-stream habitat conditions required by freshwater mussels. *Using the 'bounding box' approach, critical habitat is not comprised of all areas within the identified boundaries, but only those areas where biophysical features/attributes are present and are capable of supporting one or more habitat functions* (refer to Tables 6 and 7). Brief explanations for the areas within which critical habitat is identified are provided below.

Table 8 below provides the geographic coordinates that situate the boundaries within which critical habitat is found for the Round Hickorynut and Kidneyshell; these points are indicated on Figures 7-11).

Table 8. Coordinates locating the boundaries within which critical habitat is found for the Round Hickorynut (RHN) and Kidneyshell (KS) at five locations*.

	Coordinates† locating areas of critical habitat				
Location (species)	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**
East Sydenham River (RHN)	42° 54' 14.98"N 81° 42' 12.31"W	42° 51' 35.43"N 81° 44' 0.29"W	42° 51' 35.54"N 81° 52' 1.57"W	42° 39' 12.60"N 81°59' 56.18"W	42° 32' 33.71"N 82° 25' 1.58"W
East Sydenham River (KS)	42° 54' 14.98"N 81° 42' 12.31"W	42° 51' 35.43"N 81° 44' 0.29"W	42° 51' 35.54"N 81° 52' 1.57"W	42° 39' 12.60"N 81°59' 56.18"W	42° 35' 40.42"N 82° 10' 46.31"W
Ausable River (KS); includes Nairn Creek	43° 17' 45.52"N 81° 31' 17.26"W	43° 6' 39.54"N 81° 32' 38.60"W	43° 3' 48.24"N 81° 42' 18.06W		
Medway Creek (KS)	43° 1' 42.56"N 81° 18' 25.99"W	43° 0' 45.90"N 81° 17' 56.72"W			
Lower Thames River (KS)	42° 43' 41.52"N 81° 35' 2.89"W	42° 31' 27.05"N 82° 1' 33.52"W			

* Riverine habitats are delineated to the midpoint of channel of the uppermost stream segment(s) and lowermost stream segment
† All coordinates obtained using map datum NAD 83

East Sydenham River: The area within which critical habitat is found for the Round Hickorynut and Kidneyshell in the East Sydenham River is currently identified as the reach of river represented by a single ALIS segment with the species present (Figure 7 and 8). Also connected with this segment are the lower reaches (< 3 km) of the following tributaries: Fansher, Brown, and Spring creeks. This critical habitat description includes the entire ‘bankfull’ channel. These areas represent a total river reach of approximately 150 km for the Round Hickorynut and 120 km for the Kidneyshell. In the case of the Kidneyshell, the downstream extent of critical habitat ends at the County Road 21 (George Street) bridge in the town of Dresden; by this point the gradient of the river has flattened out causing low current velocities that no longer support the required habitat. The downstream extent of critical habitat for Round Hickorynut ends at the confluence of the East Sydenham River and the Chenail Ecarte. The upstream extent of critical habitat for both species in the East Sydenham River is the bridge at Murphy Drive (approximately 15 km northeast of Alvinston).

Ausable River: The area within which critical habitat for the Kidneyshell is found in the Ausable River is currently identified as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present in (Figure 9). This critical habitat description includes the entire ‘bankfull’ channel and represents a stretch of river approximately 70 km long. This reach extends from Crediton Road downstream on the main stem of the Ausable River, to a point about 1 km downstream of Centre Road (# 81), and includes the lower reaches of the Nairn Creek tributary (< 2 km length) where the species has also been found.

Thames River (Medway Creek): The area within which critical habitat for the Kidneyshell is found in Medway Creek is currently identified as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present (Figure 10). This critical habitat description includes the entire ‘bankfull’ channel. This reach, located on the western edge of the City of London, represents a stretch of river approximately 3 km long, bisected by Fanshawe Park Road West. Note that live Kidneyshell from the occurrence site downstream of Fanshawe Park Road West were relocated to the upstream site (due to a development project); however, both occurrence points are within a single ALIS segment.

Lower Thames River: The area within which critical habitat for the Kidneyshell is found in the lower Thames River is currently identified as the reach that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present (Figure 11). This critical habitat description includes the entire ‘bankfull’ channel and includes a stretch of river approximately 55 km long, from the vicinity of Tate Corners downstream to a point approximately 5 km southwest of Thamesville (Figure 11).

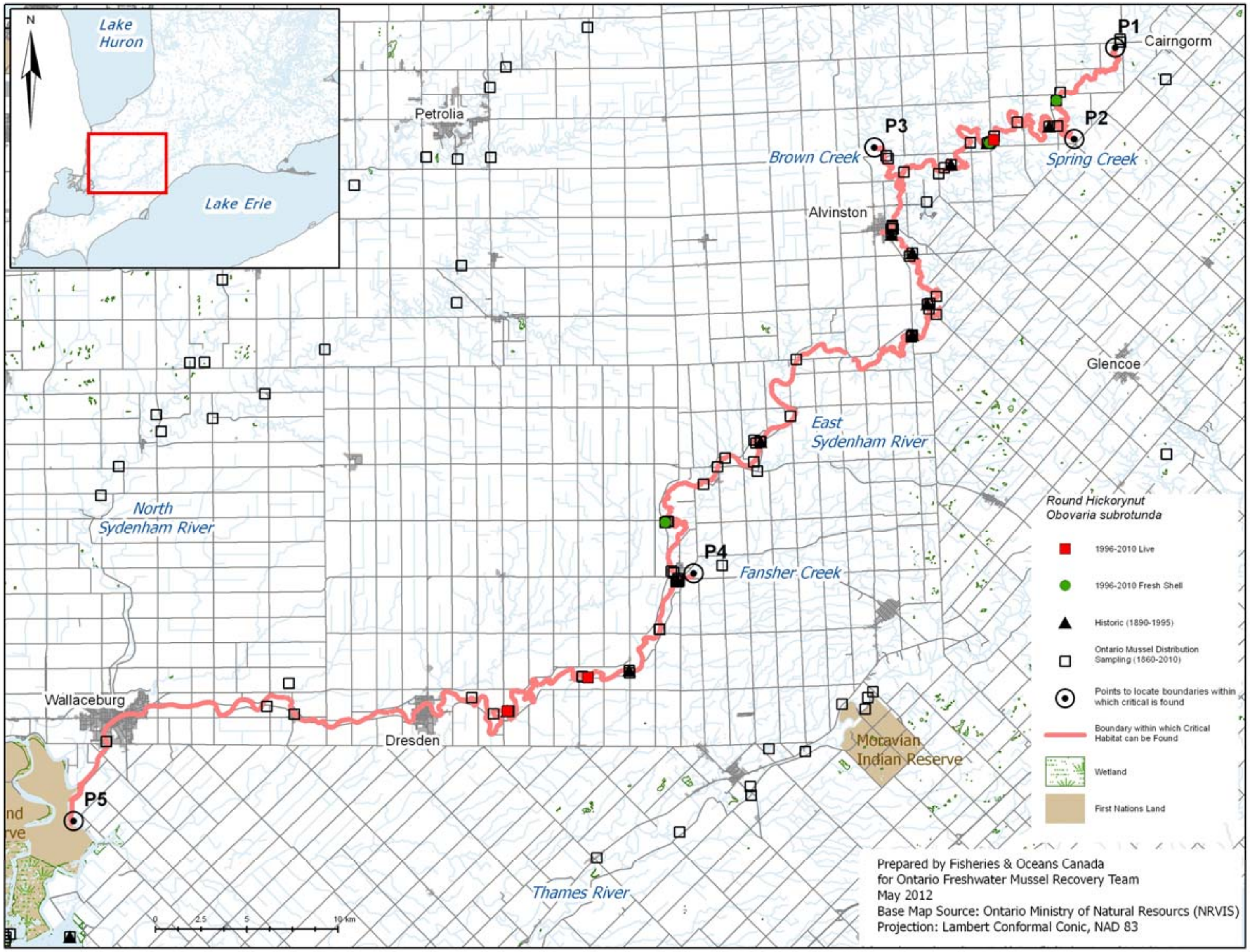

Figure 7. Area within which critical habitat is identified for the Round Hickorynut in the East Sydenham River.

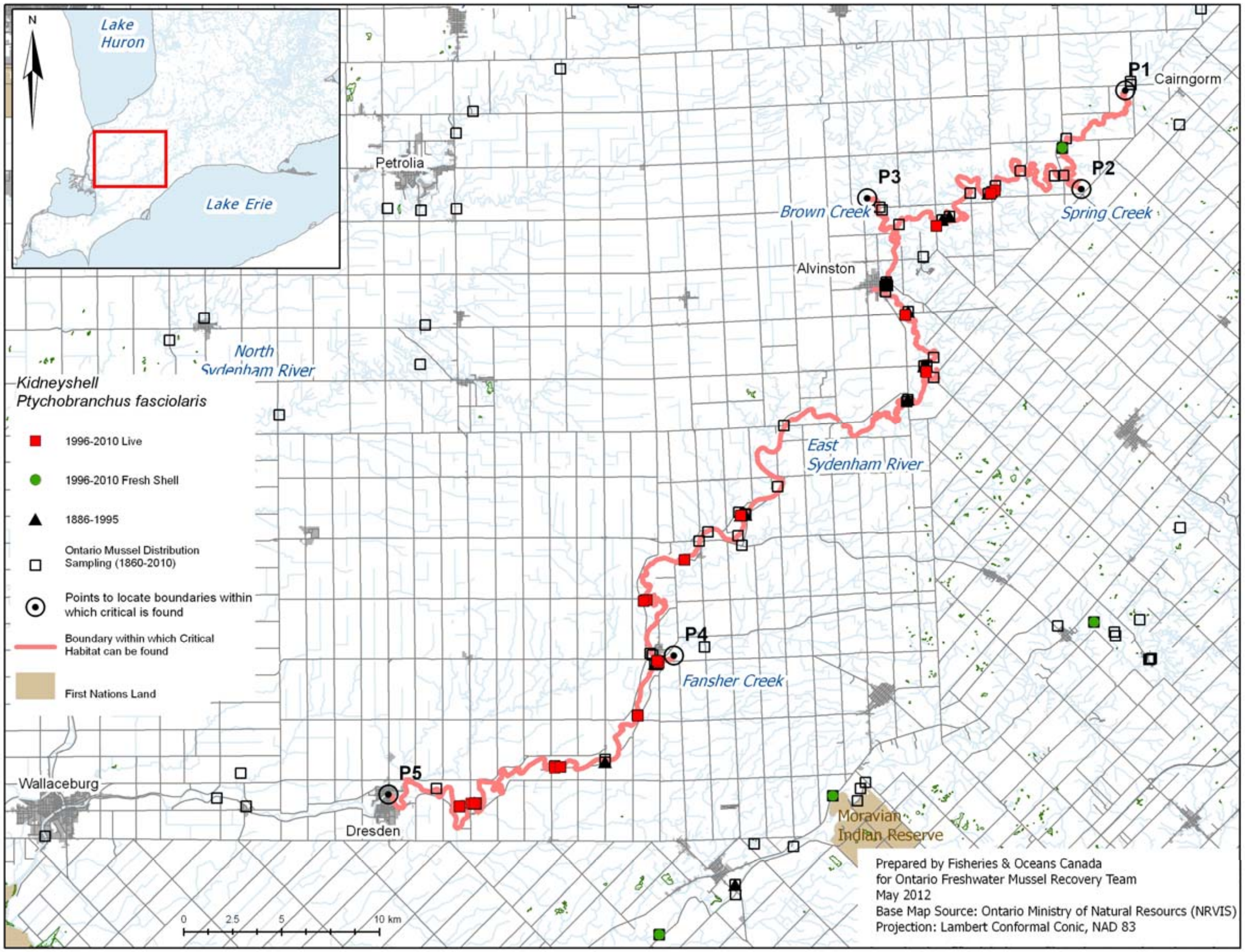

Figure 8. Area within which critical habitat is identified for the Kidneyshell in the Sydenham River.

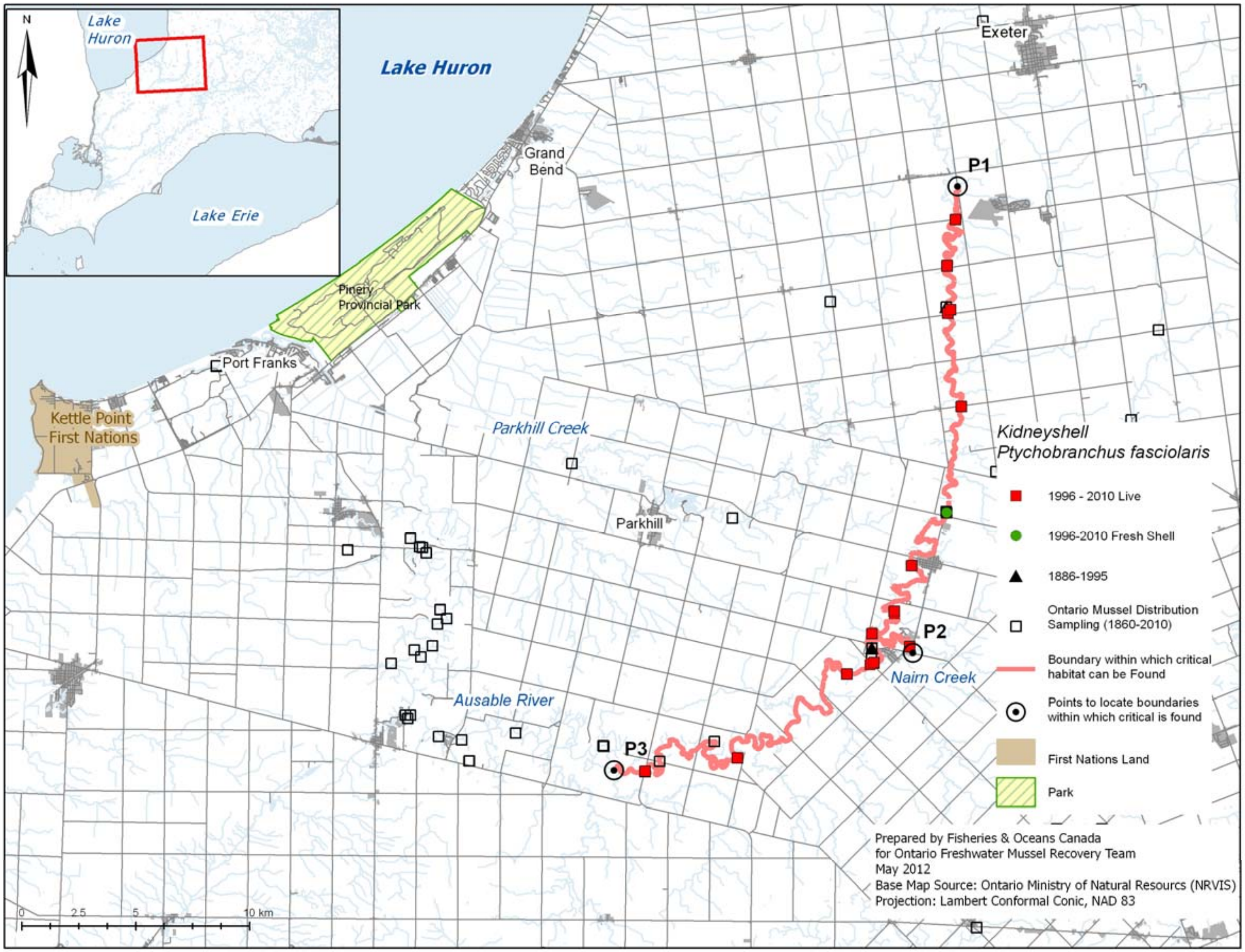

Figure 9. Area within which critical habitat is identified for the Kidneyshell in the Ausable River.

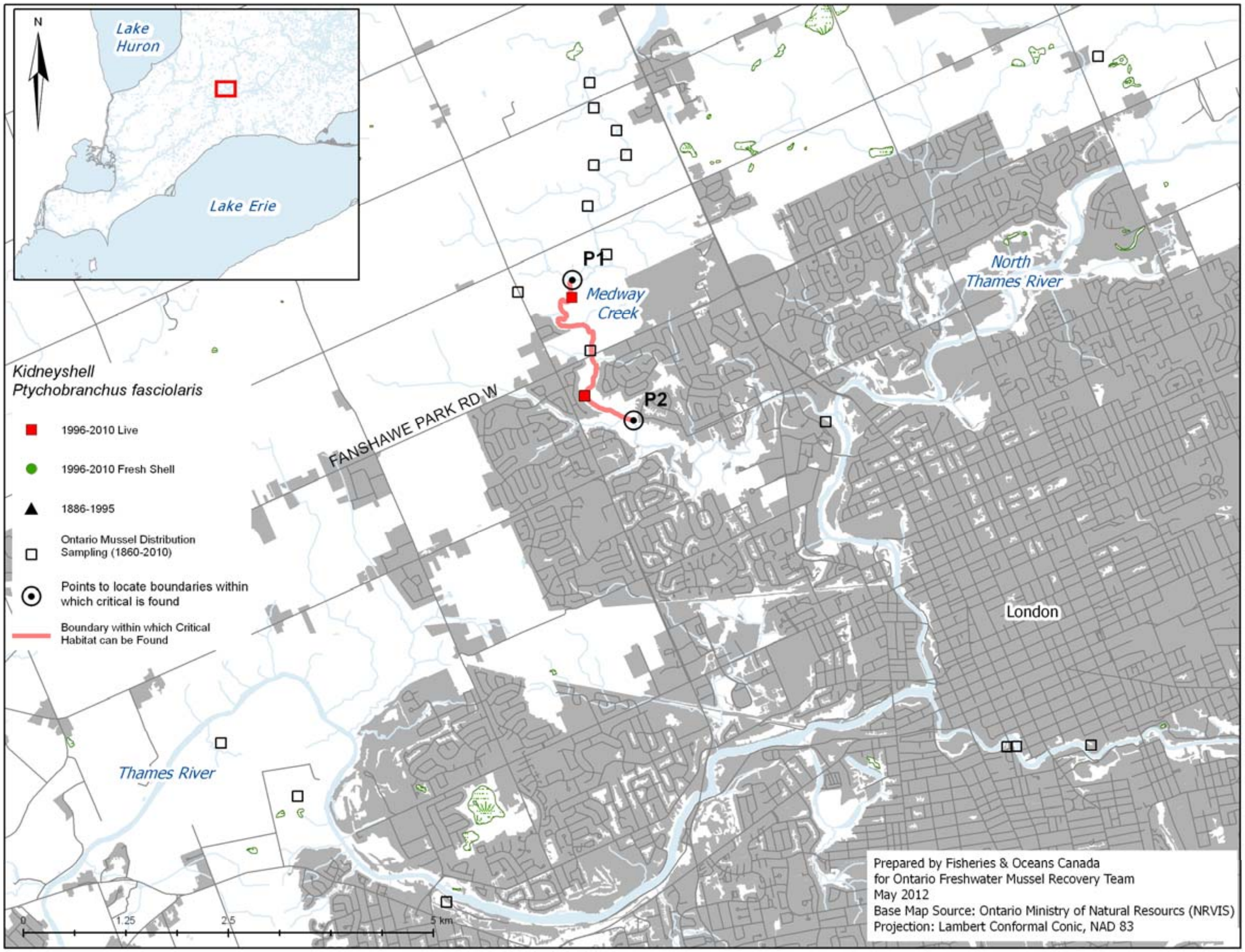

Figure 10. Area within which critical habitat is identified for the Kidneyshell in the Thames River (Medway Creek).

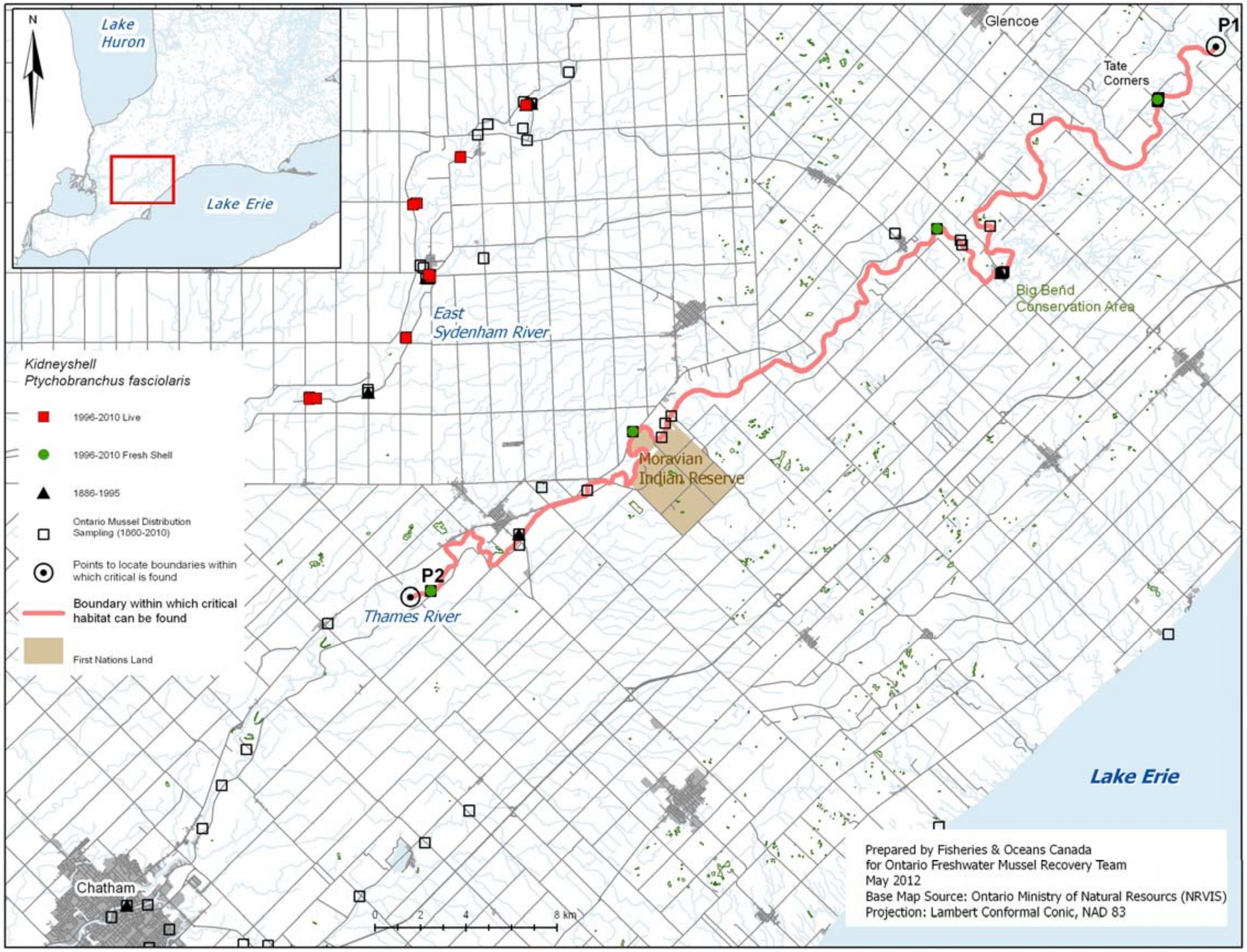

Figure 11. Area within which critical habitat is identified for the Kidneyshell in the lower Thames River.

The identification of critical habitat within the Sydenham, Ausable and Thames rivers will ensure that currently occupied riverine habitat is protected, until such time as critical habitat is further refined according to the schedule of studies laid out in Section 7.5. (Schedule of studies to identify critical habitat). The schedule of studies outlines activities necessary to refine the current critical habitat descriptions at confirmed extant locations as well as address locations with limited information (e.g., St. Clair River delta). Critical habitat descriptions will be refined as additional information becomes available to support the population and distribution objectives. Until critical habitat has been fully identified for the Round Hickorynut and Kidneyshell, the recovery team recommends that all currently occupied habitats be recognized as habitat in need of conservation for these species.

7.5 Schedule of studies to identify critical habitat

This recovery strategy includes an identification of critical habitat to the extent possible, based on the best available information. Further studies are required to refine critical habitat identified for the Round Hickorynut and Kidneyshell to support the population and distribution objectives for these species. The activities listed in Table 9 are not exhaustive and it is likely that the process of investigating these actions will lead to the discovery of further knowledge gaps that need to be addressed.

Table 9. Schedule of activities to identify critical habitat.

Description of activity	Rationale	Approximate time frame[1]
Assess time frames (sperm and ova production/release, timing of fertilization, timing and duration of gravid periods, timing and duration of glochidial release, attachment and transformation) and habitat required for spawning	Very little is known regarding spawning in these Canadian populations. The presence of glochidia has been briefly noted; however, there is a need to determine when sperm are released and what the optimal conditions are for successful fertilization	2012-2014
Conduct mussel population surveys	Will define current Round Hickorynut and Kidneyshell distribution and aid in defining population trajectories.	2012-2015
Assess and map habitat conditions in occupied areas (e.g., flow, substrate, water clarity and quality)	Will aid in identifying adult Round Hickorynut and Kidneyshell habitat requirements.	2013-2015
Determine any life-stage differences in habitat use	There is almost no published information on the optimal habitat requirements for juvenile Round Hickorynut and Kidneyshell. Determining habitat requirements for each life-stage will ensure that all types of critical habitat for this species will be identified.	2012-2017

Description of activity	Rationale	Approximate time frame[1]
Determine/confirm host fish species (laboratory and functional) and their distributions and home ranges	Will allow a determination or confirmation of the extent to which the Round Hickorynut and Kidneyshell ranges are constrained by host fish(es) distribution	2012-2014
Assess habitat use by host species	Determining habitat requirements for each life-stage will ensure that this feature of critical habitat is available for hosting mussel glochidia. Will determine potential range of host fish(es)	2014-2016
Determine areas of overlap between mussel and host habitat	Will determine potential range of the Round Hickorynut and Kidneyshell based on host fish(es) distribution	2015-2017
Based on collected information, review population and distribution goals. Determine amount and configuration of critical habitat required to achieve goal if adequate information exists.	Will aid in reviewing population and distribution goals	ongoing

[1] Timeframes are subject to change as new priorities arise or as a result of changing demands on resources or personnel

7.6 Examples of activities likely to result in the destruction of critical habitat

Under SARA, critical habitat must be legally protected from destruction within 180 days of being identified in a recovery strategy or action plan. For the Round Hickorynut and Kidneyshell critical habitat, it is anticipated that this will be accomplished through a SARA Protection Order made under subsections 58(4) and (5), which will invoke the prohibition in subsection 58(1) against the destruction of the identified critical habitat.

The Round Hickorynut and the Kidneyshell, like most mussel species, are sensitive to a wide variety of stressors. Therefore, the activities described in Table 10 are neither exhaustive nor exclusive and have been guided by the general threats described in Section 10 (Threats) of the recovery strategy for these species. The absence of a specific human activity does not preclude, or fetter the department's ability to regulate it pursuant to SARA. Furthermore, the inclusion of an activity does not result in its automatic prohibition since it is destruction of critical habitat that is prohibited. Since habitat use is often temporal in nature, every activity is assessed on a case-by-case basis and site-specific mitigation is applied where it is reliable and available. In every case, where information is available, thresholds and limits are associated with attributes to better inform management and regulatory decision making. However, in many cases the knowledge of a species and its critical habitat may be lacking and in particular, information associated with a species' or habitat thresholds of tolerance to disturbance from human activities, is lacking and must be acquired.

Table 10. Examples of human activities likely to result in the destruction of critical habitat for Round Hickorynut (RH) and Kidneyshell (KS). The pathway of effect for each activity is provided as well as the potential links to the biophysical functions, features and attributes of critical habitat (If attributes are not specified RH or KS, then they apply to both species).

Activity	Affect-Pathway	Function affected	Feature affected	Attribute affected
Siltation and turbidity: Work in or around water with improper sediment and erosion control (e.g., installation of bridges, pipelines, culverts; overland runoff from ploughed fields, run-off from urban and residential development; use of industrial equipment; cleaning or maintenance of bridges, drains or other structures); Unfettered livestock access to waterbodies Removal or cultivation of riparian vegetation	Improper sediment and erosion control or mitigation can cause increased turbidity and sediment deposition, changing preferred substrates, impairment of feeding and reproductive functions. When livestock have unfettered access to waterbodies damage to shorelines, banks and watercourse bottoms can cause increased erosion and sedimentation, affecting turbidity and water temperatures. Agricultural lands, particularly those with little riparian vegetation and without tile drainage, allow large inputs of sediments to the watercourse.	Reproduction Feeding Nursery Cover	Reaches of rivers and streams with steady to moderate flows and sand and gravel substrates present (RH) Reaches of rivers and streams with riffle and/or run habitats and gravel and sand substrates present (KS) (includes ‘bankfull’ channel) Presence of host fish(es)	• Warm water temperatures • Water clarity • Sand and gravel substrates (RH) • Firmly packed coarse gravel and sand substrates (KS) • Presence of host fish species • Food supply

Activity	Affect-Pathway	Function affected	Feature affected	Attribute affected
Water quality: Over-application of fertilizer and improper nutrient management (e.g., organic debris management, wastewater management, animal waste, septic systems and municipal sewage) Introduction of high levels of chloride through activities such as excessive salting of roads in winter	Improper nutrient management can cause nutrient loading of nearby waterbodies. Elevated nutrient levels (phosphorus and nitrogen) can cause increased turbidity causing harmful algal blooms, changing water temperatures, and reduced DO levels. Chloride levels have shown recent inclines due to an increased use of road salt. Sensitive glochidia require habitat with low chloride levels. Mussel survival rates are closely related to DO levels, with Kidneyshell being one of the most sensitive species. Low DO may also cause mortality of warm water fish hosts thereby disrupting mussel reproductive cycles.	Reproduction Feeding Nursery Cover	Reaches of rivers and streams with steady to moderate flows and sand and gravel substrates present (RH) Reaches of rivers and streams with riffle and/or run habitats and gravel and sand substrates present (KS) Presence of host fish(es) (includes 'bankfull' channel)	• Warm water temperatures • Water clarity • Presence of host fish species • Food supply • Low contaminants levels – chloride and ammonia • DO levels • Adequate flow
Water quantity: Water-level management (e.g., through dam	High flow conditions (and 'flashier' flows) can cause dislodgement and passive transport of mussels from	Same as above	Same as above	• Adequate flow

Activity	Affect-Pathway	Function affected	Feature affected	Attribute affected
operation) or water extraction activities (e.g., for irrigation), that causes dewatering of habitat or excessive flow rates; large increases in impervious surfaces from urban and residential development.	areas of suitable habitat into areas of lesser or marginal habitat. Low flows can result in depressed DO levels, desiccation, elevated temperatures, and strandings. Host fish(es) may also be impacted, thereby disrupting reproduction. Altered flow patterns can affect habitat availability (e.g., by 'dewatering' habitats) in creeks and rivers, sediment deposition (e.g., changing preferred substrates), and water temperatures.			• Warm water temperatures • Food supply • DO levels • Presence of host fish species • Sand and gravel substrates (RH) • Firmly packed coarse gravel and sand substrates (KS)
Decline of host fish(es): Direct removal of host fish(es) (through harvest) or indirect means (e.g., damming activities may prevent fish movement) Excessive baitfish collection; baitfish releases	Any activities that affect the host species' abundance, movements, or behaviour during the period of encystment or release may disrupt the reproductive cycle of these mussels. Can affect number and health of available host fishes. Spread of aquatic invasive species (boats, bait buckets)	Reproduction	Same as above	• Presence of host fish species • Dreissenids absent or in low abundance
Urbanization: Over application or misuse of herbicides	Introduction of toxic compounds (e.g., high chloride levels from	Reproduction Nursery	Same as above	• Presence of host fish species

Activity	Affect-Pathway	Function affected	Feature affected	Attribute affected
and pesticides Release of urban and industrial pollution into habitat (including the impact of stormwater runoff from existing and new developments)	stormwater runoff) into habitat used by these species can change water chemistry affecting habitat and host fish(es) availability or use; especially during sensitive life-stages (glochidia, juvenile).	Cover		• Low contaminants levels – chloride, ammonia and copper
Physical habitat loss/modification: Dredging Grading Excavation Placement of material or structures in water (e.g., groynes, piers, infilling, partial infills, jetties) Construction of dams and/or barriers	Changes in bathymetry, shoreline and channel morphology caused by dredging and nearshore grading and excavation can move mussels, alter preferred substrates, change water depths, change flow patterns potentially affecting turbidity, nutrient levels, and water temperatures. Placing material or structures in water reduces habitat availability (e.g., the footprint of the infill or structure is lost). Placing of fill can cover organisms and preferred substrates for mussels and their host fish(es). Dams/barriers can result in direct loss of habitat or fragmentation, which can limit the reproductive capabilities of mussels by	Reproduction Nursery Cover Feeding	Same as above	• Warm water temperatures • Water clarity • Sand and gravel substrates (RH) • Firmly packed coarse gravel and sand substrates (KS) • Presence of host fish species • Food supply • Water depth

Activity	Affect-Pathway	Function affected	Feature affected	Attribute affected
	eliminating or decreasing the number of hosts available.			
Recreational activities: Use of motor vehicles in the river	Disrupt substrate, dislodge mussels.	Reproduction Nursery Cover Feeding	Same as above	• Presence of host fish species • Sand and gravel substrates (RH) • Firmly packed coarse gravel and sand substrates (KS) • Water clarity

In future, threshold values for some stressors may be informed through further research. For some of the above activities, BMPs may be enough to mitigate threats to the species and its habitat; however, in some cases, it's not known if BMPs are adequate to protect critical habitat and further research is required.

8. Habitat protection

The federal SARA was proclaimed in June of 2003. Under SARA there are general prohibitions against killing, harming, taking, possessing, capturing, and collecting the Round Hickorynut or Kidneyshell. Once identified, SARA includes provisions to prevent the destruction of critical habitat.

Provincially, protection is also afforded under the *Planning Act*. Planning authorities are required to be "consistent with" the provincial Policy Statement under Section 3 of Ontario's *Planning Act*, which prohibits development and site alteration in the habitat of endangered or threatened species. In addition, the Round Hickorynut and Kidneyshell are listed as Endangered under Ontario's *Endangered Species Act*, 2007. Under the Act, individuals of both species are currently protected and their habitat will be protected under the general habitat protection provisions of the Act as of June 30, 2013, unless a species-specific habitat regulation is developed by the provincial government at an earlier date. Stream-side development in Ontario is managed through flood plain regulations enforced by local conservation authorities. The majority of land in the Sydenham and Ausable rivers where these mussels are found is privately owned, while the land in the St. Clair River delta is controlled by the Walpole Island First Nation.

9. Potential impacts of the recovery strategy on other species/ecological processes

The Round Hickorynut and Kidneyshell are sensitive species, particularly to issues of water quantity and quality. For this reason, it is expected that efforts made to improve conditions for these mussels will benefit most other aquatic species. A few opportunistic species that can readily adapt to degraded conditions (e.g., Giant Floater [*Pyganodon grandis*] or Fathead Minnow [*Pimephales promelas*]) may see a decline in numbers/range as a result of rehabilitative efforts. These changes should not be viewed in a negative light but rather as a restoration of the aquatic community to pre-disturbance conditions.

10. Statement on action plans

One or more action plans relating to this recovery strategy will be produced within five years of the final strategy being posted on the public registry. Wherever possible, action plans should be linked to existing watershed recovery teams. Recovery resources in southwestern Ontario (both fiscal and personnel) are limited. Partnership with these other recovery teams will ensure that efforts are not duplicated and will help to prevent the implementation of recovery efforts for differing species that may conflict. As such, DFO, in partnership with the Sydenham River Recovery Team, intends to develop a multi-species, ecosystem-based action plan for the Sydenham River to be completed in 2012.

References

Allan, J.D. and A.S. Flecker. 1993. Biodiversity conservation in running waters. BioScience 43: 32-43.

ARRT (Ausable River Recovery Team). 2006. Recovery strategy for species at risk in the Ausable River: an ecosystem approach, 2005-2010. [Draft]. Fisheries and Oceans Canada. 140 pp.

Augspurger, T., A.E. Keller, M.C. Black, W.D. Cope, and F.J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environmental Toxicology and Chemistry 22: 2569–2575.

Baitz, A., M. Veliz, H. Brock, and S. Staton. 2008. Monitoring program to track the recovery of endangered freshwater mussels in the Ausable River, Ontario [DRAFT]. Prepared for the Ausable River Recovery Team, the Interdepartmental Recovery Fund, and Fisheries and Oceans Canada. 26 pp.

Baker, K. 2005. Nine year study of the invasion of western Lake Erie by the round goby (*Neogobius melanostomus*): changes in goby and darter abundance. Ohio Journal of Science 105: A-31.

Baker, S.M. and D.J. Hornbach. 1997. Acute physiological effects of zebra mussel (*Dreissena polymorpha*) infestation on two unionid mussels, *Actinonaias ligamentina* and *Amblema plicata*. Canadian Journal of Fisheries and Aquatic Sciences 54: 512-519.

Balfour, D.L. and L.A. Smock. 1995. Distribution, age structure, and movements of the freshwater mussel *Elliptio complanata* (Mollusca: Unionidae) in a headwater stream. Journal of Freshwater Ecology 10: 255-268.

Bauer, G. 2001. Factors affecting naiad occurrence and abundance. *In* Ecology and evolution of the freshwater mussels Unionida. *Edited by* G. Bauer and K. Wächtler. Springer-Verlag, Berlin, Heidelberg. pp. 155-162.

Bogan, A.E. 1993. Freshwater bivalve extinctions (Mollusca: Unionidae): a search for causes. American Zoologist 33: 599-609.

Bouvier, L.D. and T.J. Morris. 2011. Information in support of a recovery potential assessment of Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadrula*), and Rainbow (*Villosa iris*) in Canada. DFO Canadian Science Advisory Secretariat Research Document 2010/120. vi + 51 pp.

CCME (Canadian Council of Ministers of the Environment). 2005. Canadian water quality guidelines. Canadian Council of Ministers of the Environment, Environment Canada, Ottawa, ON.

CCME (Canadian Council of Ministers of the Environment). 2011. Canadian water quality guidelines (Chloride). Canadian Council of Ministers of the Environment, Environment Canada, Ottawa, ON.

Clarke, A.H. 1977. The endangered mollusks of Canada. *In:* T. Mosquin and C. Suchal (eds.) Canada's threatened species and habitats. Canadian Nature Federation Special Publication Number 6. pp. 148-150.

Clarke, A.H. 1981. The freshwater molluscs of Canada. National Museums of Canada, Ottawa, Canada. 446 pp.

Clarke, A.H. 1992. Ontario's Sydenham River, an important refugium for freshwater mussels against competition from the zebra mussel *Dreissena polymorpha*. Malacology Data Net 3: 43-55.

Cope, W.G., R.B. Bringolf, D.B. Buchwalter, T.J. Newton, C.G. Ingersoll, N. Wang, T. Augspurger, F.J. Dwyer, M.C. Barnhart, R.J. Neves, and E. Hammer. 2008. Differential exposure, duration, and sensitivity of unionoidean bivalve life stages to environmental contaminants. Journal of the North American Benthological Society 27: 451-462.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003a. COSEWIC assessment and update status on the Round Hickorynut *Obovaria subrotunda* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 31 pp.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003b. COSEWIC assessment and update status on the Kidneyshell *Ptychobranchus fasciolaris* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 32 pp.

Dextrase, A.J., S.K. Staton, and J.L. Metcalfe-Smith. 2003. National recovery strategy for species at risk in the Sydenham River: an ecosystem approach. National Recovery Plan No. 25. Recovery of Nationally Endangered Wildlife (RENEW). Ottawa, Ontario. 73 pp.

DFO (Fisheries and Oceans Canada). 2011a. Recovery potential assessment of Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadrula*), and Rainbow (*Villosa iris*) in Canada. DFO Canadian Science Advisory Secretariat Science Advisory Report 2010/073.

DFO (Fisheries and Oceans Canada). 2011b. Assessment of methods for the identification of critical habitat for freshwater mussels. DFO Canadian Science Advisory Secretariat Science Advisory Report 2011/047.

Dudgeon, D. and B. Morton. 1984. Site selection and attachment duration of *Anodonta woodiana* (Bivalvia: Unionacea) glochidia on fish hosts. Journal of Zoology (London) 204: 355-362.

French, J.R.P. and D.J. Jude. 2001. Diets and diet overlap of nonindigenous gobies and small benthic native fishes co-inhabiting the St. Clair River, Michigan. Journal of Great Lakes Research 27: 300-311.

Gagné, F., C. Blaise, and J. Hellou. 2004. Endocrine disruption and health effects of caged mussels, *Elliptio complanata*, placed downstream from a primary-treated municipal effluent plume for 1 year. Comparative Biochemistry and Physiology Part C: Toxicology and Pharmacology 138(1): 33-44.

Gagné, F., B. Bouchard, C. André, E. Farcy, and M. Fournier. 2011. Evidence of feminization in wild *Elliptio complanata* mussels in the receiving water downstream of a municipal effluent outfall. Comparative Biochemistry and Physiology, Part C: Toxicology and Pharmacology 153: 99-106.

Gagnon, C., F. Gagné, P. Turcotte, I. Saulnier, C. Blaise, M. Salazar, and S. Salazar. 2006. Metal exposure to caged mussels in a primary-treated municipal wastewater plume. Chemosphere 62: 998-1010.

Galbraith, H.S. and C.C. Vaughn. 2009. Temperature and food interact to influence gamete development in freshwater mussels. Hydrobiologia 636: 35-47.

Gillis P.L. 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: implications for salinization of surface waters. Environmental Pollution 159(6): 1702-1708.

Gillis, P.L and G.L. Mackie. 1994. Impact of the zebra mussel, *Dreissena polymorpha*, on populations of Unionidae in Lake St. Clair. Canadian Journal of Zoology 72: 1260-1271.

Gillis, P.L., R.J. Mitchell, A.N. Schwalb, K.A. McNichols, G.L. Mackie, C.M. Wood, and J.D. Ackerman. 2008. Sensitivity of glochidia (larvae) of freshwater mussel to copper: assessing the effect of water hardness and dissolved organic carbon on the sensitivity of endangered species. Aquatic Toxicology 88: 137-145.

Gordon, M.E. and J.B. Layzer. 1989. Mussels (Bivalvia: Unionoidea) of the Cumberland River: review of life histories and ecological relationships. Biological Report 89(15). U.S. Department of the Interior, Fish and Wildlife Service, Washington D.C. vii + 99 pp.

Haag, W.R., D.J. Berg, D.W. Garton, and J.L. Farris. 1993. Reduced survival and fitness in native bivalves in response to fouling by the introduced zebra mussel (*Dreissena polymorpha*) in western Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences 50: 13-19.

Holm, E. and N.E. Mandrak. 1996. The status of the Eastern Sand Darter, *Ammocrypta pellucida* in Canada. Canadian-Field Naturalist 110(3): 462-469.

Jacobson, P.J., R.J. Neves, D.S. Cherry, and J.L Farris. 1997. Sensitivity of glochidial stages of freshwater mussels (Bivalvia: Unionidae) to copper. Environmental Toxicology and Chemistry 16(11): 2384–2392,

Jacques Whitford Environment Ltd. 2001. Sydenham River recovery project: synthesis and analysis of background data. Report to the Sydenham River Recovery Team. December 2001. 50 pp. + Appendix.

Jansen, W., G. Bauer, and E. Zahner-Meike. 2001. Glochidial mortality in freshwater mussels. Pages 185-211 *in* G. Bauer and K. Wächtler (editors). Ecology and Evolution of the Freshwater Mussels Unionoida. Springer-Verlag Berlin Heidelberg New York.

Janssen, J. and D.J. Jude. 2001. Recruitment failure of mottled sculpin *Cottus bairdi* in Calumet Harbour, southern Lake Michigan, induced by the newly introduced round goby *Neogobius melanostomus*. Journal of Great Lakes Research 27:319-328.

Johnson, P.M., A.E. Liner, S.W. Golladay, and W.K. Michener. 2001. Effects of drought on freshwater mussels and instream habitat in Coastal Plains tributaries of the Flint River, southwest Georgia (July-October, 2000) Final Report to the Nature Conservancy Apalachicola River and Bay Project, August 25, 2001. 30 pp. (en anglais seulement) (Accessed July, 2012).

Kidd, K.A., P.J. Blanchfield, K.H. Mills, V.P. Palace, R.E. Evans, J.M. Lazorchak, and R.W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. Proceedings of the National Academy of Science 104: 8897-8901.

Lydeard, C., R.H. Cowie, W.F. Ponder, A.E. Bogan, P. Bouchet, S.A. Clark, K.S. Cummings, T.J. Frest, O. Gargominy, D.G. Herbert, R. Hershler, K.E. Perez, B. Roth, M. Seddon, E.E. Strong, and F.G. Thompson. 2004. The global decline of nonmarine mollusks. BioScience 54: 321-330.

McNichols, K.A. 2007. Implementing recovery strategies for mussel species at risk in Ontario. M.Sc. Thesis, University of Guelph, pp. 171.

McNichols, K.A. and G.L. Mackie. 2004. Fish host determination of endangered freshwater mussels in the Sydenham River, Ontario, Canada. ESRF 2003/2004 Final Report. 26 pp.

Metcalfe-Smith, J.L., J. Di Maio, S.K. Staton, and S.R. De Solla. 2003. Status of the freshwater mussel communities of the Sydenham River, Ontario, Canada. American Midland Naturalist 150: 37-50.

Metcalfe-Smith, J.L., A. MacKenzie, I. Carmichael, and D. McGoldrick. 2005. Photo field guide to the freshwater mussels of Ontario. St. Thomas Field Naturalist Club Incorporated, St. Thomas, Ontario. 60 pp.

Metcalfe-Smith, J.L., G.L. Mackie, J. Di Maio, and S. Staton. 2000. Changes over time in the diversity and distribution of freshwater mussels (Unionidae) in the Grand River, southwestern Ontario. Journal of Great Lakes Research 26(4): 445-459.

Metcalfe-Smith, J.L., D.J. McGoldrick, M. Williams, D.W. Schloesser, J. Biberhofer, G.L. Mackie, M.T. Arts, D.T. Zanatta, K. Johnson, P. Marangelo, and T.D. Spencer. 2004. Status of a refuge for native freshwater mussels (Unionidae) from the impacts of the exotic zebra mussel (*Dreissena polymorpha*) in the delta area of Lake St. Clair. Environment Canada, National Water Research Institute, Burlington, Ontario. Technical Note No. AEI-TN-04-001.

Metcalfe-Smith, J.L, D.J. McGoldrick, D.T. Zanatta, and L.C. Grapentine. 2007. Development of a monitoring program for tracking the recovery of endangered freshwater mussels in the Sydenham River, Ontario. Prepared for the Sydenham River Recovery Team, the Interdepartmental Recovery Fund and Fisheries and Oceans Canada. 61 pp.

Mummert, A.K., R.J. Neves, T.J. Newcomb, and D.S. Cherry. 2003. Sensitivity of juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total and un-ionized ammonia. Environmental Toxicology and Chemistry 22: 2545-2553.

Nalepa, T.F. 1994. Decline of native unionid bivalves in Lake St. Clair after infestation by the zebra mussel, *Dreissena polymorpha*. Canadian Journal of Zoology 61: 832-838.

Nalepa, T.F., D.J. Hartson, G.W. Gostenik, D.L. Fanslow, and G.A Lang. 1996. Changes in the freshwater mussel community of Lake St. Clair: from Unionidae to *Dreissena polymorpha* in eight years. Journal of Great Lakes Research 22: 354-369.

NatureServe. 2012. NatureServe explorer an online encyclopedia of life (web application). Version 7.1. NatureServe, Arlington, Virginia. (en anglais seulement) Accessed: July, 2012.

Nedeau, E.J., M.A. McCollough, and B.I. Swartz. 2000. The freshwater mussels of Maine. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 118 pp.

Nelson, M., M. Veliz, S. Staton, and E. Dolmage. 2003. Towards a recovery strategy for species at risk in the Ausable River: synthesis of background information. Final Report prepared for the Ausable River Recovery Team. September 2003. 92 pp.

Neves, R.J. and M.C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. Journal of Wildlife Management 53(4): 934-941.

Newton, T.J. 2003. The effects of ammonia on freshwater unionid mussels. Environmental Toxicology and Chemistry 22: 2543-2544.

Newton, T.J., J.W. Allran, J.A. O'Donnell, M.R. Bartsch, and W.B. Richardson. 2003. Effects of ammonia on juvenile unionid mussels (*Lampsilis cardium*) in laboratory toxicity tests. Environmental Toxicology and Chemistry 22: 2554-2560.

Newton, T.J. and M.R. Bartsch. 2007. Lethal and sublethal effects of ammonia to juvenile *Lampsilis* mussels (Unionidae) in sediment and water-only exposures. Environmental Toxicology and Chemistry 26: 2057-2065.

Nichols, S.J., H. Silverman, T.H. Dietz, J.W. Lynn, and D.L. Garling. 2005. Pathways of food uptake in native (Unionidae) and introduced (Corbiculidae and Dreissenidae) freshwater bivalves. Journal of Great Lakes Research 31: 87-96.

OMOE (Ontario Ministry of the Environment). 2011. Great Lakes protection legislation [Accessed July, 2012]

Ortmann, A.E. 1919. A monograph of the naiads of Pennsylvania, Part III. Systematic Account of the Genera and Species. Memoirs of the Carnegie Museum 8(1), Carnegie Institute, Pittsburgh, Pennsylvania. 384 pp.

Parmalee, P.W. and A.E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville. 328 pp.

Pip, E. 1995. Cadmium, lead and copper in freshwater mussels from the Assiniboine River, Manitoba, Canada. Journal of Molluscan Studies 61: 295-302.

Poos, M.A., A.J. Dextrase, A.N. Schwalb, and J.D. Ackerman. 2010. Secondary invasion of the round goby into high diversity Great Lakes tributaries and species at risk hotspots: potential new concerns for endangered freshwater species. Biological Invasions 12: 1269–1284.

Portt, C., G. Coker, and K. Barrett. 2003. Recovery strategy for fish species at risk in the Grand River, Ontario. Draft report prepared for the Grand River Recovery Team, March 31, 2003.

PWQO (Provincial Water Quality Objectives). 1994. Ontario provincial water quality objectives (Ontario). (en anglais seulement) (Accessed July, 2012).

Reid, S.M. and N.E. Mandrak. 2008. Historical changes in the distribution of Threatened Channel Darter (*Percina copelandi*) in Lake Erie with general observations on the beach fish assemblage. Journal of Great Lakes Research 34: 324-33.

Ricciardi, A., F.G. Whoriskey, and J.B. Rasmussen. 1995. Predicting the intensity and impact of *Dreissena* infestation on native unionid bivalves from *Dreissena* field density. Canadian Journal of Fisheries and Aquatic Sciences 52: 1449-1461.

Schloesser, D.W., T.F. Nalepa, and G.L. Mackie. 1996. Zebra mussel infestation of unionid bivalves (Unionidae) in North America. American Zoologist 36: 300-310.

Spooner, D., M. Xenopoulos, C. Schneider, and D. Woolnough. 2011. Coextirpation of host-affiliate relationships in rivers: the role of climate change, water withdrawal, and host-specificity. Global Change Biology 17(4): 1720.

Stanfield, L. and R. Kuyvenhoven. 2005. Protocol for applications used in the Aquatic Landscape Inventory Software application for delineating, characterizing and classifying valley segments within the Great Lakes basin. Ontario Ministry of Natural Resources Report, July 27, 2005.

Staton, S.K., A. Dextrase, J.L. Metcalfe-Smith, J. Di Maio, M. Nelson, J. Parish, B. Kilgour, and E. Holm. 2003. Status and trends of Ontario's Sydenham River ecosystem in relation to aquatic species at risk. Ecological Monitoring and Assessment 88: 283-310.

Strayer, D.L. 1983. The effects of surface geology and stream size on freshwater mussel (Bivalvia: Unionidae) distribution in southwestern Michigan, USA. Freshwater Biology 13: 253-264.

Strayer, D.L., J.A. Downing, W.R. Haag, T.L. King, J.B. Layzer, T.J. Newton, and S.J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. BioScience 54(5): 429-439.

Strayer, D.L. and A.R. Fetterman. 1999. Changes in the distribution of freshwater mussels (Unionidae) in the Upper Susquehanna River Basin, 1955-1965 to 1996-1997. American Midland Naturalist 142: 328-339.

Strayer, D.L. and K.J. Jirka. 1997. The pearly mussels of New York State. Memoirs of the New York State Museum 26: 113 pp. + 27 plates.

Tetreault G.R., C.J. Bennett, K. Shires, B. Knight, M.R. Servos, and M.E. McMaster. 2011. Intersex and reproductive impairment of wild fish exposed to multiple municipal wastewater discharges. Aquatic Toxicology 104: 278–290.

Tetzloff, J. 2001. Survival rates of unionid species following a low oxygen event in Big Darby Creek, Ohio. Ellipsaria 3: 18-19.

Thomas, M.V. and R.C. Haas. 2004. Status of Lake St. Clair fish community and sport fish,1996-2004. Michigan Department of Natural Resources, Fisheries Division. Fisheries Research Report 2067. 26 pp.

TRRT (Thames River Recovery Team). 2003.Thames River recovery plan – terms of reference. Upper Thames Region Conservation Authority. (en anglais seulement) (Accessed July, 2012).

UTRCA (Upper Thames River Conservation Authority). 2004. UTRCA water report (en anglais seulement) (Accessed August 24, 2011).

van der Schalie, H. 1938. The naiad fauna of the Huron River, in southeastern Michigan. Miscellaneous Publication No. 40, Museum of Zoology, University of Michigan. University of Michigan Press, Ann Arbor, Michigan. 83 pp. + Plates I-XII.

Vaughn, C.C., K.B. Gido, and D.E. Spooner. 2004. Ecosystem processes performed by unionid mussels in stream mesocosms: species roles and effects of abundance. Hydrobiologia 527: 35-47.

Vaughn, C.C. and C.C. Hakenkamp. 2001. The functional role of burrowing bivalves in freshwater ecosystems. Freshwater Biology 46: 1431-1446.

Vaughn, CC., S.J. Nichols, and D.E. Spooner. 2008. Community and foodweb ecology of freshwater mussels. Journal of North American Benthological Society 27(2): 409–423

Villella, R.F., D.R. Smith, and D.P. Lemarie. 2004. Estimating survival and recruitment in a freshwater mussel population using mark-recapture techniques. American Midland Naturalist 151: 114-133.

Wächtler, K., M.C. Dreher-Mansur, and T. Richter. 2001. Larval types and early post larval biology in Naiads (Unionoida). *In* Ecology and Evolution of the Freshwater Mussels Unionida. *Edited by* G. Bauer and K. Wächtler. Springer-Verlag, Berlin, Heidelberg. pp. 93-125.

Walpole Island Heritage Centre. 2002. Walpole Island First Nation heritage centre newsletter. Special Edition. Summer/Fall 2002. Published by the Walpole Island

Heritage Centre, R.R. 3 (Walpole Island), Wallaceburg, Ontario, Canada, N8A 4K9. 16 pp.

Watters, G.T. 1994. Form and function of unionoidean shell sculpture and shape (Bivalvia). American Malacological Bulletin 11: 1-20.

Watters, G.T., M.A. Hoggarth, and D.H. Stansberry. 2009. The freshwater mussels of Ohio. The Ohio State University, Columbus, Ohio. 421 pp.

Watters, G.T. and S.H. O'Dee. 1999. Glochidia of the freshwater mussel *Lampsilis* overwintering on fish hosts. Journal of Molluscan Studies 65: 453-459.

Welker, M. and N. Walz. 1998. Can mussels control the plankton in rivers? A Plantological approach applying Lagrangian sampling strategy. Limnology and Oceanogarphy 43: 753-762.

Williams, J.D., M.L. Cummins Jr., K.S. Harris, and R.J. Neves. 1993. Conservation status of the freshwater mussels of the United States and Canada. Fisheries 18: 6-22.

WQB (Water Quality Branch). 1989. The application of an interdisciplinary approach to the selection of potential water quality sampling sites in the Thames River basin. Environment Canada, Water Quality Branch, Ontario Region. 122 pp.

Zanatta, D.T., G.L. Mackie, J.L. Metcalfe-Smith, and D.A. Woolnough. 2002. A refuge for native freshwater mussels (Bivalvia: Unionidae) from impacts of the exotic zebra mussel (*Dreissena polymorpha*) in Lake St. Clair. Journal of Great Lakes Research 28(3): 479-489.

Appendix 1: Effects on the environment and other species

A strategic environmental assessment (SEA) is conducted on all SARA recovery planning documents, in accordance with the *Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals*. The purpose of a SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally sound decision making.

Recovery planning is intended to benefit species at risk and biodiversity in general. However, it is recognized that strategies may also inadvertently lead to environmental effects beyond the intended benefits. The planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts upon non-target species or habitats. The results of the SEA are incorporated directly into the strategy itself, but are also summarized below in this statement.

This recovery strategy will clearly benefit the environment by promoting the recovery of the Round Hickorynut and the Kidneyshell. The potential for the strategy to inadvertently lead to adverse effects on other species was considered. The SEA concluded that this strategy will clearly benefit the environment and will not entail any significant adverse effects. Refer to the following sections of the document in particular: Description of the species' needs – biological needs, ecological role and limiting factors; Effects on other species; and Recommended approach for recovery, as applicable.