Final

Species at Risk Act
Recovery Strategy Report Series

Report on the Progress of Recovery Strategy Implementation for the Round Hickorynut (*Obovaria subrotunda*) and Kidneyshell (*Ptychobranchus fasciolaris*) in Canada for the Period 2013 to 2018

2022

Canada

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For copies of the progress report, or for additional information on species at risk, including Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status reports, recovery strategies, residence descriptions, action plans, and other related recovery documents, please visit the Species at Risk Public Registry.

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« Rapport sur les progrès de la mise en œuvre de la stratégie de rétablissement de l'obovarie ronde (*Obovaria subrotunda*) et du ptychobranche réniforme (*Ptychobranchus fasciolaris*) au Canada pour la période allant de 2013 à 2018. »

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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 the protection of species at risk throughout Canada. Under section 46 of the *Species at Risk Act* (S.C. 2002, c.29) (SARA) the competent ministers are responsible for reporting on the implementation of the recovery strategy for a species at risk, and on the progress towards meeting its objectives within five years of the date when the recovery strategy was placed on the Species at Risk Public Registry and in every subsequent five-year period, until its objectives have been achieved or the species' recovery is no longer feasible.

Reporting on the progress of recovery strategy implementation requires reporting on the collective efforts of the competent minister(s), provincial and territorial governments and all other parties involved in conducting activities that contribute towards the species' recovery. Recovery strategies identify broad strategies and approaches that will provide the best chance of recovering species at risk. Some of the identified strategies and approaches are sequential to the progress or completion of others; not all may be undertaken or show significant progress during the time frame of a report on the progress of recovery strategy implementation (progress report).

The Minister of Fisheries and Oceans is the competent minister under SARA for the Round Hickorynut and Kidneyshell and has prepared this progress report.

As stated in the preamble to SARA, success in the recovery of species at risk depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in the recovery strategy and will not be achieved by Fisheries and Oceans Canada (DFO) or any other jurisdiction alone. The cost of conserving species at risk is shared amongst different constituencies. All Canadians are invited to join in supporting and implementing the recovery strategy for the Round Hickorynut and Kidneyshell for the benefit of the species and Canadian society as a whole.

Acknowledgements

This progress report was prepared by Josh Stacey (DFO) with input from Amy Boyko (DFO). To the extent possible, this progress report has been prepared with input from DFO Science, the province of Ontario, Ontario Ministry of Natural Resources and Forestry.

Executive summary

The Round Hickorynut (*Obovaria subrotunda*) and the Kidneyshell (*Ptychobranchus fasciolaris*) were both listed as endangered under the *Species at Risk Act* (SARA) in 2005. A recovery strategy for these species was first published in 2006. An updated “Recovery Strategy for the Round Hickorynut (*Obovaria subrotunda*) and Kidneyshell (*Ptychobranchus fasciolaris*) in Canada” (DFO 2013) was finalized and published on the Species at Risk Public Registry in 2013.

The main threats identified for these two species include invasive species (that is, dreissenid mussels, Round Goby), siltation and sedimentation, physical habitat loss, and reduced water quality.

The population and distribution objectives for Round Hickorynut and Kidneyshell 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)

During the time period reported by this progress report, the following activities have been accomplished in support of the recovery objectives as stated in the recovery strategy:

- research has been conducted that investigates the life history of Kidneyshell including potential host fishes and the timing of reproductive activities
- research into the feasibility of culturing and rearing Kidneyshell for future repatriations is currently underway
- genetic variation among Canadian populations of Kidneyshell has been assessed and characterized
- surveys have been completed in areas where both Round Hickorynut and Kidneyshell occur, including extant and historical locations
- progress has been made in terms of outreach and awareness of these species and stewardship practices that should be adopted to reduce threats to their habitat through funding provided to external agencies through the Habitat Stewardship Program

Taken together, these ongoing and/or completed activities indicate that progress is being made toward the goal of recovering Round Hickorynut and Kidneyshell populations in Canada; however, there are still a number of areas where further information is required. In particular, more research centred on Round Hickorynut is needed. The majority of life-history research conducted in the five years covered by this report has been centred on Kidneyshell and should also be implemented for Round Hickorynut. Further monitoring is also needed for Round Hickorynut within the Sydenham River, as well as Kidneyshell in the Thames River and St. Clair River delta to determine whether those populations are declining.

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1 Introduction

This progress report outlines the progress made towards meeting the objectives listed in the "Recovery Strategy for the Round Hickorynut (*Obovaria subrotunda*) and Kidneyshell (*Ptychobranchus fasciolaris*) in Canada" from 2013 to 2018 and should be considered part of a series of documents for these species that are linked and should be taken into consideration together, including the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status appraisal summary on the Kidneyshell (2013), the COSEWIC status appraisal summary on the Round Hickorynut (2013) and the recovery strategy (Fisheries and Oceans Canada [DFO] 2013)[1].

Section 2 of the progress report reproduces and summarizes key information on the threats to the species, population and distribution objectives for achieving their recovery, approaches to meeting the objectives, and performance indicators to measure the progress of recovery. For more details, readers should refer back to the recovery strategy. Section 3 reports the progress of activities identified in the recovery strategy to support achieving the population and distribution objectives. Section 4 provides a concluding statement about the progress made and the outcome of the recovery effort.

2 Background

2.1 COSEWIC assessment summary

The listing of the Round Hickorynut and Kidneyshell as endangered under the *Species at Risk Act* (S.C. 2002, c.29) (SARA) in 2005 led to the development and publication of the recovery strategy for these two species in 2013 (DFO 2013). The recovery strategy was mainly based on the information provided in the COSEWIC assessment and status reports for each of these species (COSEWIC 2013a; COSEWIC 2013b). This information has also been included in section 1.1 of the recovery strategy.

[1] The 2013 recovery strategy replaced the original 2006 recovery strategy for these species.

Round Hickorynut

Assessment summary: May 2013

Common name
Round Hickorynut

Scientific name
Obovaria subrotunda

Status
Endangered

Reason for designation
The Canadian population of this species has declined by 75 to 95% over the last 10 years, with an estimated 99% decline over the last 30 years. Populations in the Grand and Thames rivers are extirpated and populations in the Sydenham River and Lake St. Clair have declined to very low levels. Losses and declines are due to the combined effects of pollution from agriculture and residential runoff, and the impacts of invasive species like the Zebra Mussel.

Occurrence
Ontario

COSEWIC status history
Designated endangered in May 2003. Its status was re-examined and confirmed in May 2013.

Kidneyshell

Assessment summary: May 2013

Common name
Kidneyshell

Scientific name
Ptychobranchus fasciolaris

Status
Endangered

Reason for designation
By 2001, this species had been lost from about 70% of its historical range in Canada due to the impacts of the Zebra Mussel and habitat loss from land use practices. It is now restricted to the East Sydenham and Ausable rivers, Lake St. Clair delta, and Medway Creek of the Thames River. The population in Lake St. Clair is close to extirpation. Both Ausable and East Sydenham river populations appear to be reproducing, but populations in Medway Creek and Lake St. Clair are not reproducing. Populations are threatened by pollution from agriculture, urban and road runoff sources, and invasive species (dreissenids and Round Goby)

Occurrence
Ontario

COSEWIC status history
Designated endangered in May 2003. Its status was re-examined and confirmed in May 2013.

2.2 Distribution

Since the publication of the recovery strategy in 2013, Round Hickorynut has only been detected within the east Sydenham River and the St. Clair River delta (figure 1). The number of

sites where live Round Hickorynut were detected has declined when compared to its 1996 to 2010 distribution shown in the recovery strategy.

Live Kidneyshell have continued to be detected in the east Sydenham River and the Ausable River; however, no live specimens were detected in the Thames River or the St. Clair River delta. At the time of the recovery strategy publication, one live specimen had been discovered in Medway Creek, a tributary of the Thames River. No live specimens have been detected in the Thames River since 2010; however, one fresh shell has been found in the Thames River indicating the species likely still occurs there.

Weathered shells of both species were detected in Rondeau Bay in 2014 for the first time (figures 1 and 2); however, it is unlikely that any live specimens remain at that location. Similarly, neither species has been detected within eastern Lake Erie tributaries during the timeframe reported in this document (figures 1 and 3).

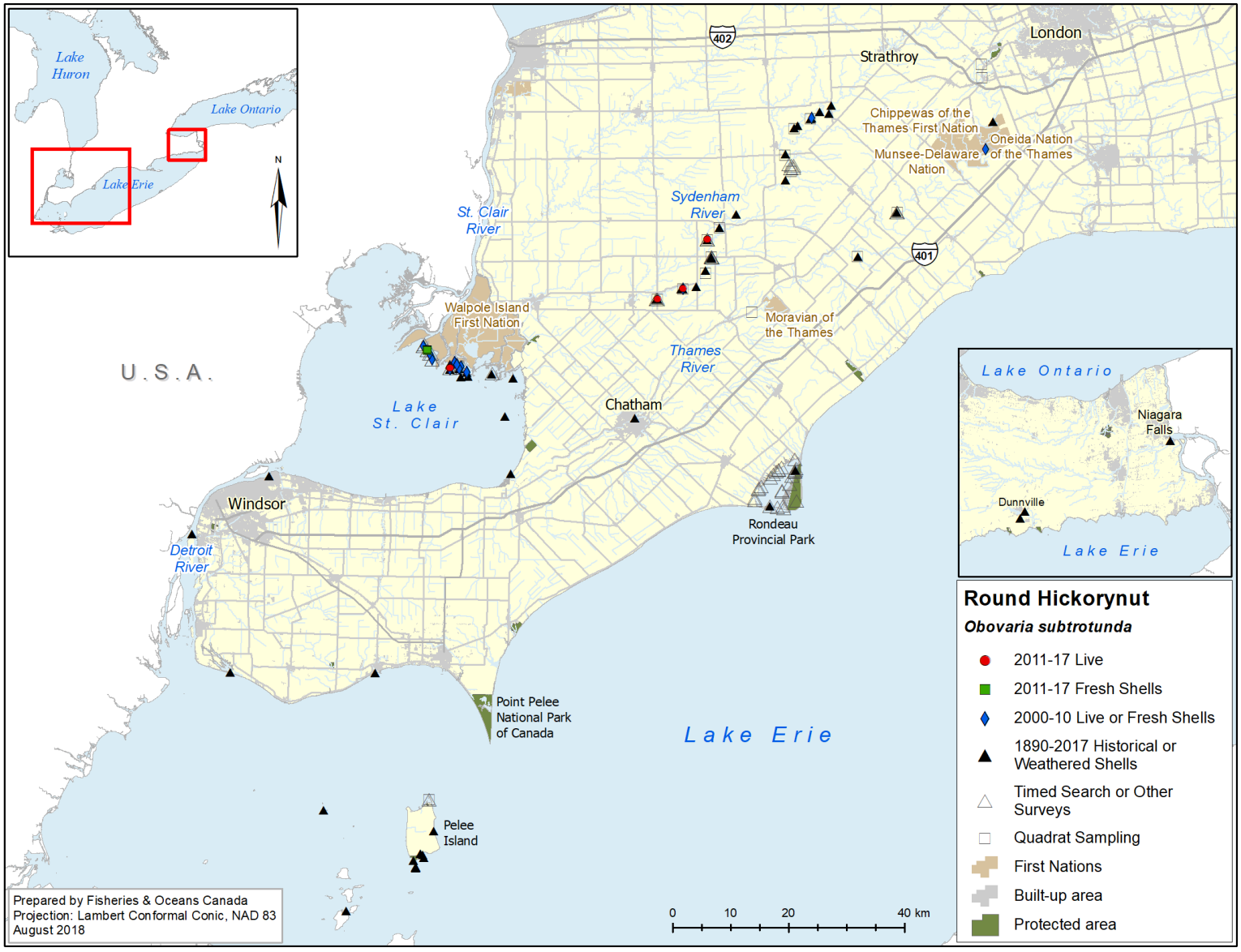

Figure 1. Historical distribution, recent detections and relevant sampling of Round Hickorynut in southwestern Ontario.

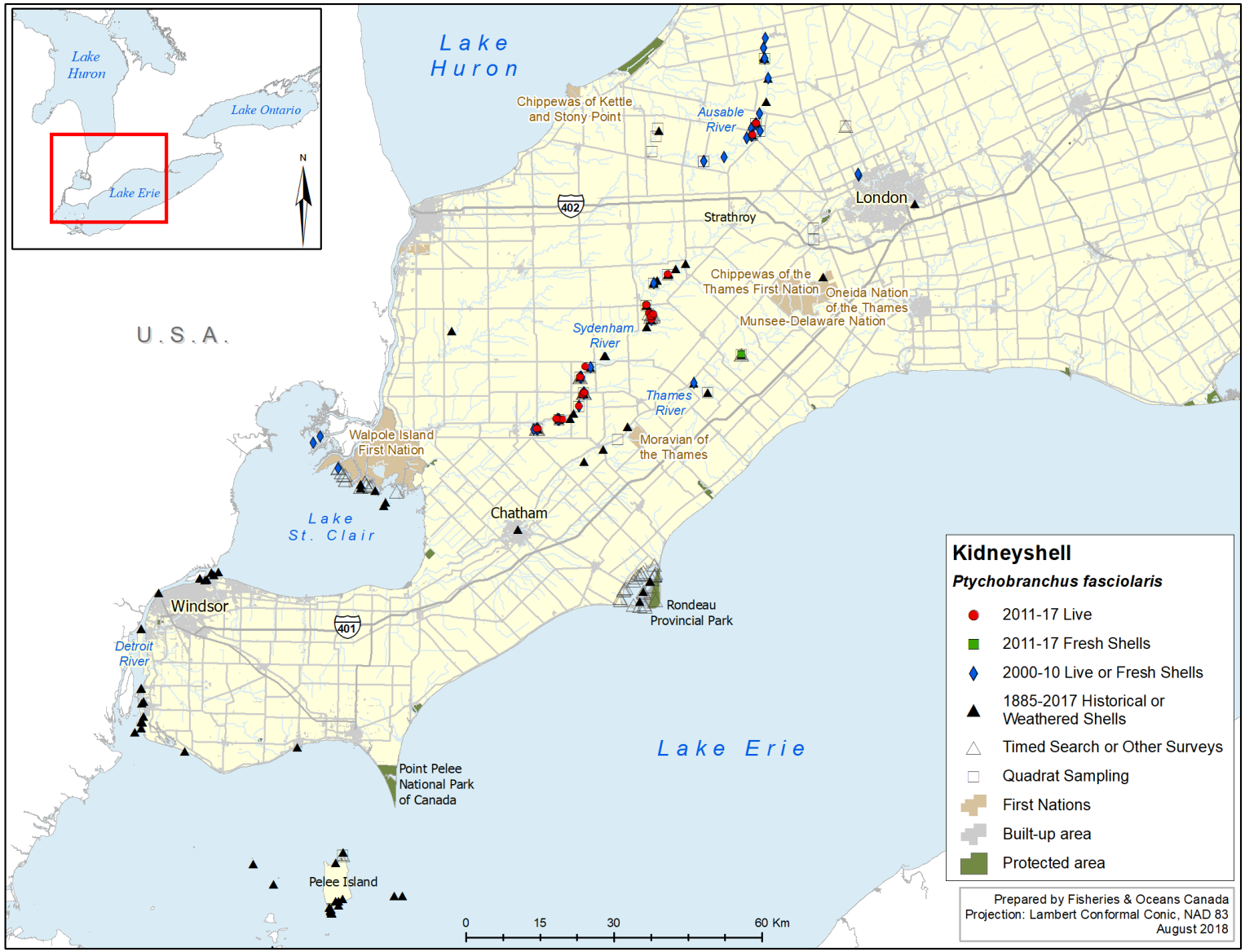

Figure 2. Historical distribution, recent detections and relevant sampling of Kidneyshell in southwest Ontario.

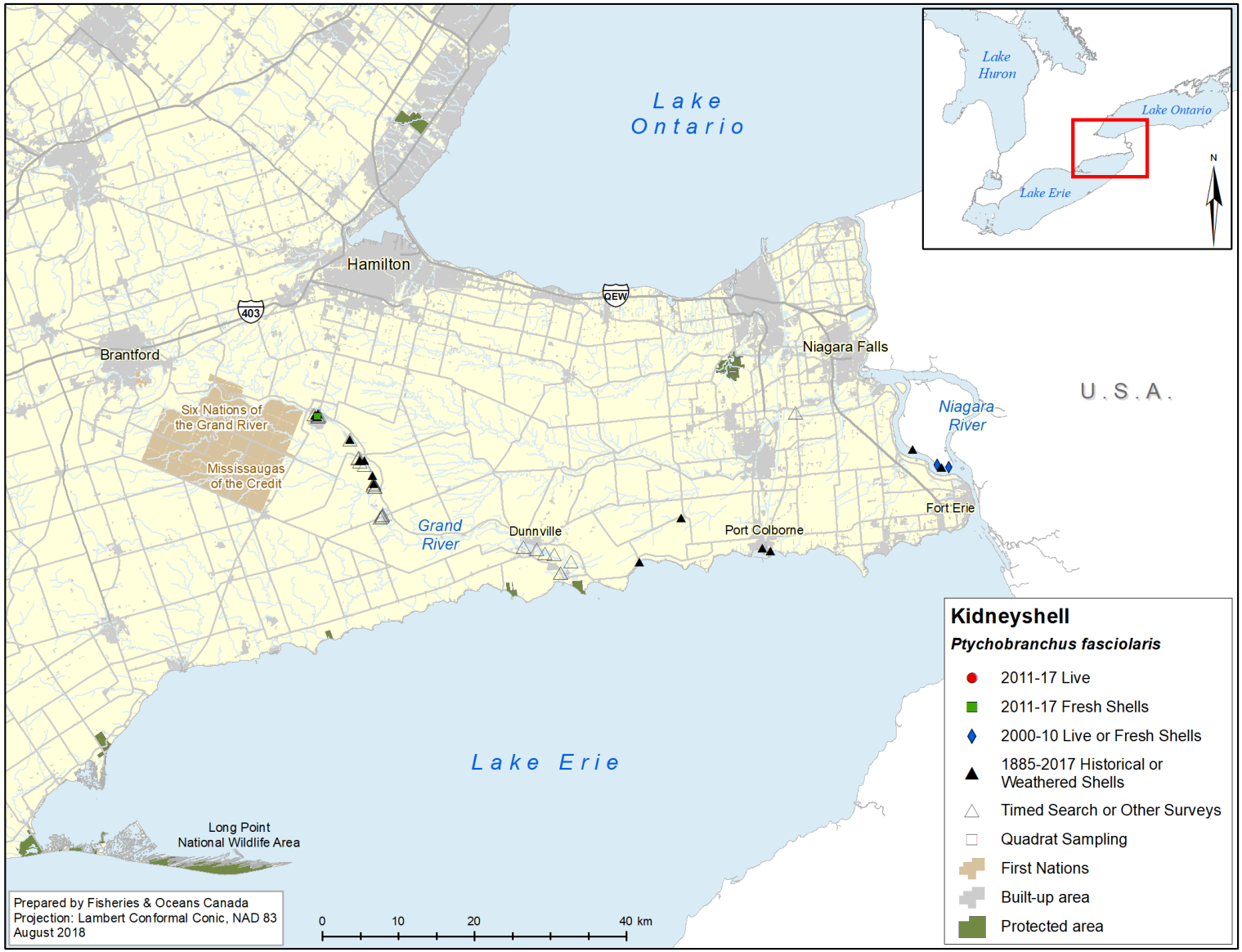

Figure 3. Historical detections, recent weathered shells and relevant sampling of Kidneyshell in eastern Lake Erie tributaries.

2.3 Threats

This section summarizes the most recent information on threats to survival and recovery of Round Hickorynut and Kidneyshell as well as threats to their critical habitat.

2.3.1 Threats to Round Hickorynut and Kidneyshell

Population-level threats for Round Hickorynut and Kidneyshell, ranked by priority were identified in the recovery strategy (DFO 2013). For more information on these threats and examples of activities that are likely to result in the destruction of critical habitat, please refer to section 1.5 and section 7.6 of the recovery strategy, respectively.

2.4 Recovery

This section summarizes the information found in the recovery strategy (DFO 2013) on the population and distribution objectives necessary for the recovery of Round Hickorynut and Kidneyshell. This section also describes the performance indicators that provide a way to define and measure progress toward achieving the population and distribution objectives.

Section 2 of the recovery strategy identified the following goals and objectives necessary for the recovery of the species:

Recovery goals

The long-term goals of this recovery strategy are to:

i. prevent the extirpation of Round Hickorynut and Kidneyshell in Canada
ii. return healthy self-sustaining populations of Round Hickorynut to the East Sydenham River and St. Clair River delta
iii. 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
iv. re-establish populations in historically occupied habitats, excluding areas where dreissenids have made habitats unsuitable

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)

Recovery objectives

The short-term recovery objectives toward achieving the population and distribution objectives are:

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
vii. increase awareness about the distribution, threats and recovery of these species

2.4.1 Performance indicators

The recovery strategy did not include performance indicators or measures to define and evaluate progress towards achieving the recovery goals and objectives. Progress will be informed by the advancement of the recovery strategy goals and objectives as described in section 3 below.

3 Progress towards recovery

The recovery strategy for Round Hickorynut and Kidneyshell divides the recovery approaches into four broad strategies: 1) research and monitoring; 2) management; 3) stewardship; and 4) awareness. Progress in carrying out these broad strategies is reported in section 3.1. Section 3.2 reports on the activities identified in the schedule of studies to identify critical habitat. Section 3.3 reports on the progress towards meeting the recovery objectives and other commitments (for example, action plans and critical habitat orders) identified in the recovery strategy and information obtained through its implementation.

3.1 Activities supporting recovery

Table 1. Research and monitoring approaches conducted/ongoing between 2013 and 2018.

Approach	Descriptions and results	Recovery objectives	Participants
1-1 Research reproduction: Identify spawning periods of Round Hickorynut and Kidneyshell. Determine length of encystment period on host in nature.	The life history of Kidneyshell has been examined within the Ausable and Sydenham rivers (McNichols-O'Rourke and Morris In Prep.). This study included investigations of the timing of sperm and egg production, release of sperm, glochidia (parasitic larval form) production, and host encystment. The results of this study indicate that spawning for Kidneyshell within the Ausable River takes place in June and July, after which females become gravid with glochidia in August. The fish community was sampled within locations where both Round Hickorynut and Kidneyshell occur, to examine whether glochidia are present on the gills of fish species, including the putative host species identified in McNichols (2007). For more details on the results of this sampling, refer to approach 1-2. The glochidia of Round Hickorynut and Kidneyshell were found on the gills of several species between late May and mid-August and late June to late October, respectively. The duration of host encystment has not yet been determined. No research has been conducted during the reporting period regarding the life history of Round Hickorynut.	i, iii	Fisheries and Oceans Canada (DFO)
1-2 Research host fishes: Confirm the host fish species for Round Hickorynut and Kidneyshell.	Building off of the findings of laboratory experiments conducted by McNichols (2007), follow-up work has been conducted for Round Hickorynut and Kidneyshell to confirm the presence of glochidia on the gills of the identified host species within a wild setting. Three potential Kidneyshell host fish species were examined for the presence of glochidia, including Blackside Darter (*Percina maculata*), Greenside Darter (*Etheostoma blennioides*), and Johnny Darter (*Etheostoma nigrum*). Kidneyshell glochidia were detected on the gills of all three species in both the Ausable and Sydenham rivers. Furthermore, glochidia were also found on the gills of Logperch (*Percina caprodes*) in the Ausable River, as well as Bluntnose Minnow (*Pimephales notatus*), Channel Catfish (*Ictalurus punctatus*), and Creek Chub (*Semotilus atromaculatus*) in the Sydenham River. However, the discovery of glochidia on these additional species does not imply that they are functional hosts since there is no laboratory evidence to suggest that such cases of encystment lead to survival	ii, v	DFO

Approach	Descriptions and results	Recovery objectives	Participants
	and the successful metamorphosis into juveniles. McNichols (2007) identified the Fantail Darter (*Etheostoma flabellare*), Iowa Darter (*Etheostoma exile*), and Blackside Darter (*Percina maculata*) as host species for the Round Hickorynut; however, follow-up research examining the use of these species in the wild has only led to their detection on the gills of Blackside Darter. Round Hickorynut glochidia were also found on the gills of several other species including Greenside Darter (*Etheostoma blennioides*), Johnny Darter (*Etheostoma nigrum*), Logperch, and Round Goby (*Neogobius melanostomus*). Of these species, Round Goby has been documented to be a sink[2] for the glochidia of other at risk mussel species (Tremblay et al. 2016), and McNichols (2007) observed that glochidia did not survive on the gills of Greenside Darter, Johnny Darter, or Logperch. The putative hosts for both species may be further confirmed through the observation of glochidial release from specimens that were infested in the wild, and the evaluation of their survivorship in a laboratory setting or in situ, if feasible, to verify the findings of McNichols (2007).		
1-3 Surveys for host fishes: Determine the distribution, abundance, and health of the host species at sites where Round Hickorynut and Kidneyshell currently occur.	Fish community assessments are undertaken at the freshwater mussel monitoring sites, which provide insight on the availability of host fishes within stream reaches. In addition, DFO fish sampling has been conducted in a number of other areas within the Sydenham, Thames and Ausable rivers, using a variety of gear types such as boat electrofishing, seine netting, fyke nets, etc.	ii, v	DFO
1-4 Research critical habitat: Determine the habitat requirements for all life-stages, particularly for juveniles.	No research has been conducted at this stage that would further our understanding of the specific habitat needs at all life stages, specifically juveniles, for Round Hickorynut and Kidneyshell beyond what has already been described in the recovery strategy (DFO 2013). However, research has been conducted that examined the clearance rate[3] of adult Kidneyshell in flow and no flow scenarios, with regard to particle size, algal taxa, and in terms of dietary overlap with other mussel species (Tran 2017). The results of this study indicate that Kidneyshell feeds at a higher rate and more selectively within lotic (rapidly moving water) environments and showed an avoidance of smaller particles. The results of this study suggest that flow rate is an important habitat	iii	DFO, University of Guelph

[2] In this case, a host fish on which encysted glochidia may experience little to no survival.
[3] The rate at which particles, consumed as food items, are filtered out of the water by mussels.

Approach	Descriptions and results	Recovery objectives	Participants
	feature that allows Kidneyshell to feed more efficiently and avoid dietary overlap with other co-occurring mussel species by being more selective of specific algal species. However, experimental studies conducted on other freshwater mussel species (Mistry and Ackerman 2018) have demonstrated that their ability to discriminate and select preferred algae species is diminished in situations where there are high rates of algal flux[4]. Therefore, future work should aim to identify what range of flows are ideal for Kidneyshell to feed. In addition, a study is underway that aims to physically model juvenile mussels using microbeads for release within a DFO reference site where critical habitat has been identified (Farrow and Ackerman 2018). This research will provide a better understanding of the transport and settlement of juvenile mussels under varying flow conditions after they have released from their fish hosts. This will help to characterize the type of habitat features where juvenile mussels settle as a result of passive transport and consequently, where future sampling for juvenile mussels should be focused within a stream reach. Further research is also underway with the objective to further identify critical habitat for juvenile unionids by investigating the role of bed shear stress[5] in the settlement of juvenile mussels (Lum and Ackerman 2018). These authors hypothesize that shear stress determines the settlement and resuspension of juvenile mussels as well as the saltation[6] of sediment within lotic environments. Data, including measurements of bed shear stress, water depth, and quantitative mussel sampling within quadrats, has been collected from sites in the Ausable, Sydenham and Thames rivers.		
1-5 Research and survey critical habitat: Prepare a distribution map of areas of suitable habitat (currently occupied and unoccupied).	No progress has been made in this regard further to what was mapped in the recovery strategy.	iii, vi	

[4] Refers to a value that represents the combined interactive effects of water velocity and algal concentration.
[5] Bed shear stress is a measure of fluid force per unit of area on the stream bed.
[6] In this instance saltation refers to the transport of particles from the streambed to a downstream location.

Approach	Descriptions and results	Recovery objectives	Participants
1-6 Research managed refuge sites: Investigate the feasibility of establishing actively managed refuge sites in the St. Clair River delta.	No actively managed restoration sites have been established at this stage within the St. Clair River delta. The delta as a whole was considered by organizations including DFO and Wapole Island First Nation (WIFN) to be a refuge for freshwater mussels since 2003; however, subsequent sampling conducted in 2011 and 2016 has indicated a continual decline in threatened and endangered species including Kidneyshell and Round Hickorynut, which calls into question the adequacy of the delta as a refuge for these species (Morris et al. 2018).	vi	DFO, WIFN
1-7 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 Round Hickorynut and Kidneyshell.	Monitoring stations have been established within the Ausable, Sydenham and Thames rivers where sampling is conducted over time to track changes in the abundance of freshwater mussel species such as Round Hickorynut and Kidneyshell, measure environmental variables, and undertake fish community assessments that provide information regarding the availability of host fishes. **Occupied locations** **Thames River**: There are five index monitoring stations that have been established and sampled since 2011, which are located within the lower Thames River where Round Hickorynut historically and Kidneyshell more recently occurred. No live Round Hickorynut or Kidneyshell were captured during sampling events at these index sites over the last five years. Timed-search surveys were conducted by the University of Guelph at three sites located just upstream of Tate's Bridge, which led to the detection of a fresh shell of Kidneyshell in the lower Thames River in 2011. In addition, both quadrat and timed-search surveys were conducted by a consultant at two sites, respectively, within Medway Creek in 2013, which are upstream of a reach that is identified as critical habitat within the recovery strategy; however, no Kidneyshell were detected. **Sydenham River (east branch)**: There are 10 index monitoring sites within the Sydenham River, which are within the distributions of Round Hickorynut and Kidneyshell. Between 2012 and 2015, these sites were sampled by DFO using quadrat surveys. Similarly, five additional sites in the Sydenham Nature Reserve were sampled using quadrat surveys in 2017. Timed-search surveys were also conducted by DFO and external agencies at three of the monitoring stations as well as seven additional locations. A total of two live Round Hickorynut were detected at two sites, one through quadrat surveys and the	i, iv	DFO, ABCA, OMNRF, OP, U of Guelph, Stantec, Water Systems Analysis (WSA), ECCC, WIFN

Approach	Descriptions and results	Recovery objectives	Participants
	other through timed-search surveys. Kidneyshell was present at all 10 of these sites with a total of 598 live individuals being captured by DFO as a result of quantitative quadrat surveys. Additionally, 134 and 171 live specimens were detected through timed-search surveys by DFO and external agencies, respectively. **Ausable River**: There are a total of seven monitoring stations in the Ausable River, all of which have been sampled since 2011 through quadrat surveys conducted by Ausable Bayfield Conservation Authority (ABCA). A total of 102 Kidneyshell were detected at four of these stations. Furthermore, ABCA undertook quadrat surveys at an additional location within the Ausable River as well as one site on Nairn Creek, a tributary of the Ausable River where Kidneyshell had previously been detected; however, no specimens were captured at these locations. DFO timed-search sampling led to the detection of 338 live Kidneyshell at one of ABCA's seven monitoring sites on the Ausable River, while quadrat sampling conducted by the ABCA captured four Kidneyshell at two sites. ABCA also undertook timed-search sampling in Nairn Creek; however, there were no detections. **Lake St. Clair:** Both Round Hickorynut and Kidneyshell are known to occur within the St. Clair River delta. DFO conducted sampling in 2011, 2015, and 2016 using specialized plot and transect survey approaches to monitor the abundance of freshwater mussels. In 2017, timed-search surveys were used to examine additional sites in the area. In 2011, 11 sites were sampled among locations such as Bassett Island, Pocket Bay, Squirrel Island and St. Anne's Bay. Two live specimens of Round Hickorynut were captured between Bass Bay and Bassett Island, while no Kidneyshell were detected. In 2015, one site was sampled by WIFN within Chematogan Bay using a visual/tactile survey approach. No Round Hickorynut or Kidneyshell were detected. In 2016, eight sites were sampled by DFO between Bassett Island and Squirrel Island. Two fresh shells of Round Hickorynut were found but no live specimens were detected. No Kidneyshell were detected. In 2017, two sites were sampled by DFO within Bassett Island and Squirrel Island, respectively. The shell of a Round Hickorynut, which was tagged and relocated in 2003 or 2004, was detected. No live Round Hickorynut		

Approach	Descriptions and results	Recovery objectives	Participants
	or Kidneyshell were detected. Based on trends observed from sampling conducted over the last 12 years, the abundance of Round Hickorynut and Kidneyshell within the St. Clair River delta appears to be declining. **Historical locations** **Lake Henry (Pelee Island):** Both Round Hickorynut and Kidneyshell occurred historically in the waters surrounding Pelee Island; however, no formal surveys had been conducted at this location since the invasion of dreissenid mussels (Zebra Mussel [*Dreissena polymorpha*] and Quagga Mussel [*D. bugensis*]). In 2015, the Ontario Ministry of Natural Resources and Forestry (OMNRF) and Ontario Parks (OP) conducted snorkelling surveys in Lake Henry, a partially enclosed coastal area on the northern tip of Pelee Island. They discovered five freshwater mussel species; however, neither Round Hickorynut nor Kidneyshell were detected. In 2016, DFO conducted surveys within Lake Henry using a hybrid approach of timed quadrat surveys within 21 50 m x 50 m blocks. No Round Hickorynut or Kidneyshell were captured during those surveys (Morris et al. 2018). **Rondeau Bay:** Neither Round Hickorynut or Kidneyshell were known to occur within Rondeau Bay when the recovery strategy was developed. Although no live specimens of either species have been detected, which would indicate that populations exist at that location, weathered shells of both species were discovered by the OMNRF in 2014 (Reid et al. 2016). **Grand River:** Both Round Hickorynut and Kidneyshell are considered extirpated from this location as no evidence of either species has been detected since 1972 and 1988, respectively. No quadrat surveys have been conducted below the Caledonia Dam where both species occurred; however, since 2011, 21 sites have been sampled that are below the Caledonia Dam using timed searches by DFO, the University of Guelph, Environment and Climate Change Canada (ECCC), and consulting agencies. Round Hickorynut and Kidneyshell were not detected during these sampling events. **Welland River:** Both Round Hickorynut and Kidneyshell historically occupied the Welland River, although both species are likely extirpated as they have not		

Approach	Descriptions and results	Recovery objectives	Participants
	been detected in decades. No quadrat sampling has been conducted in the Welland River; however, one timed-search survey was conducted by DFO in 2015, which was in close proximity to the location of historical Kidneyshell records but well upstream of historical Round Hickorynut records. Neither species were detected during this sampling event (Wright et al. 2017).		
1-8 Monitoring habitat: Establish permanent monitoring sites for tracking changes in habitat.	Monitoring sites have been established within the Sydenham River, Thames River, and St. Clair River delta that are applicable to the distributions of Round Hickorynut and Kidneyshell. Furthermore, monitoring stations have been established within the Ausable River where Kidneyshell occurs. Quantitative mussel sampling conducted at these locations is also paired with assessments of habitat conditions. Quadrat sampling, which is conducted within riverine habitats, includes observations of habitat parameters including: water velocity; depth; degree of siltation; aquatic macrophyte presence/absence; algal growth; degree of shading; and streambed/substrate composition. Provincial water-quality monitoring stations exist within the distributions of both Round Hickorynut and Kidneyshell, where the Ontario Ministry of Environment, Conservation and Parks (OMECP) measures concentrations of dissolved nutrients, chlorophyll, phosphorus, metals, and sodium chloride from road salt runoff. Specifically, monitoring stations can be found in: the Sydenham River in three and four locations that are applicable for Kidneyshell and Round Hickorynut, respectively; at three locations in the Ausable River, which are within the distribution of Kidneyshell; as well as four locations within the lower Thames River where Kidneyshell may still occur.	iv, v	DFO, ABCA, OMECP
1-9 Research threats: Identify and evaluate threats to all life stages (including toxic contaminants).	**Invasive species** A literature review exploring the impacts of invasive Common Reed (*Phragmites australis australis*) on freshwater mussels has been conducted by DFO in partnership with the Invasive Phragmites Control Centre (IPCC) (Yuckin and Gilbert 2018). This study focused on both the direct effects to species at risk, as well as indirect effects including habitat alteration or loss and the reduced availability of suitable host fishes. A preliminary threat level ranking was included as a component of this document that listed Phragmites as a low threat to Round Hickorynut in coastal areas of Lake St. Clair given that it rarely grows in water depths >1m. In contrast, Phragmites is listed as a moderate threat to Kidneyshell along edges and in narrow sections of coastal	v	DFO, IPCC, University of Guelph, Central Michigan University (CMU)

Approach	Descriptions and results	Recovery objectives	Participants
	areas such as Lake St. Clair. A laboratory study was conducted to investigate the potential of the invasive species Round Goby (*Neogobius melanostomus*) to act as a sink[7] for the glochidia of four other at risk mussel species including Northern Riffleshell (*Epioblasma rangiana*), Snuffbox (*Epioblasma triquetra*), Wavyrayed Lampmussel (*Lampsilis fasciola*) and Rainbow (*Villosa iris)* (Tremblay et al. 2016). Encystment on Round Goby led to successful metamorphosis into juveniles for Snuffbox and Rainbow, and even in these cases the success rates were very low. Although Kidneyshell and Round Hickorynut glochidia were not included in this research, the authors conclude from their findings that Round Goby are a sink for the glochidia of unionids and consequently may affect recruitment. The risk to freshwater unionids stemming from a potential invasion of Black Carp (*Mylopharyngodon piceus*) is currently being assessed (T. Morris, DFO pers. comm 2018). Black Carp, a large molluscivore originating from eastern Asia, is likely to prey upon freshwater mussel species within the Great Lakes watersheds should it become established. This study examines the potential risk to native freshwater mussel species, including those that are federally and provincially listed, by examining the relationship between the gape limitation of Black Carp and the size distribution and growth patterns exhibited by mussels (Morris et al. 2016). **Habitat alteration** A meta-analysis study was conducted that explored academic literature to investigate relationships between habitat condition and mortality in freshwater mussels. The studies included in this meta-analysis contain a variety of habitat variables such as substrate composition, nutrient levels within the water, water depth, water temperature, pH, dissolved oxygen, sedimentation, flow, presence of host fishes, and others. The results of this research provide insight towards species-specific threat evaluation and help to prioritize avenues of threat mitigation research (Morris et al. 2018). No research has been conducted on the specific feeding behavior of Round		

[7] In this case, a host fish on which encysted glochidia may experience little to no survival.

Approach	Descriptions and results	Recovery objectives	Participants
	Hickorynut or Kidneyshell at various life-stages and the potential threat mechanisms that may indirectly impact such behavior; however, experimental research has been conducted with a number of other mussel species, which will likely provide information that is representative of the impact of sediment loading and habitat alteration on mussel feeding behavior and diet more generally. For example, Mistry and Ackerman (2017) have examined the clearance rates[8] of the recently metamorphosed juveniles of other mussel species (which can be used as surrogates for other species at risk) under ecologically relevant conditions of algal flux[9]. These surrogate species include: Fatmucket (*Lampsilis siliquoidea*); Wavyrayed Lampmussel (*Lampsilis fasciola*); Rainbow (*Villosa iris*); and Eastern Pondmussel (*Ligumia nasuta*). The results of this study showed that the clearance rates of the juvenile mussels increased with algal flux as well as in relation to the mussel size (shell length). These findings demonstrate that changes in pore water velocity and/or algae concentration (algal flux), which can result from sediment loading and habitat alteration, can impact the growth and survival of juvenile mussels. In addition, research conducted by Mistry and Ackerman (2018) examining the clearance rates of adult mussels of the aforementioned species under varying levels of algal flux has demonstrated that their ability to discriminate and select preferred algae species is diminished when exposed to higher rates of flux. These findings suggest that increased flows resulting from hydro facilities, climate change, and land-use practices could limit the ability of mussels to select algae species of higher nutritional value, consequently impacting their growth and survival. Further experimental research is currently underway to examine the feeding habits of juvenile Fatmucket by examining their clearance rates when exposed to interstitial and river water under varying degrees of algal flux (Morris et al. 2018). Increased total suspended sediment (TSS) has also been implicated as a threat that can impact freshwater mussel populations with regard to feeding and reproductive success. For example, Gasho et al. (2013) conducted		

[8] The rate at which mussels feed on suspended particles.
[9] Refers to a value that represents the combined interactive effects of water velocity and algal concentration.

Approach	Descriptions and results	Recovery objectives	Participants
	experiments in ponds to explore the effects of total suspended solids on the growth, nutritional status, reproduction, and clearance rate of another freshwater mussel species, Pondmussel (*Ligumia subrostrata*). They found that TSS negatively impacted the number of females that became gravid and caused a decline in clearance rates. They hypothesize that the decrease of gravid females in relation to increasing TSS may be the consequence of reduced clearance rate, which might diminish their likelihood of encountering suspended sperm while filter feeding or cause them to inadvertently pass the sperm they have filtered within their pseudofeces. Similarly, Tuttle-Raycraft et al. (2017) conducted experiments to investigate the impacts of TSS on the clearance rate of the juvenile and adult mussels of four species (the same used in Mistry and Ackerman 2017; 2018). The clearance rate of both juvenile (two to four weeks old) and adult mussels decreased with TSS concentration. The impacts to feeding were five times greater for juveniles, which indicates that high levels of suspended sediment may have detrimental effects on recruitment for mussel populations. In addition, Hansen et al. (2016) used a modelling approach to investigate the role that TSS may have, when combined with other parameters, in driving the decline of freshwater mussels. These authors developed a process based interaction model that includes variables such as streamflow, suspended sediment, phytoplankton, and mussel abundance to explore the likelihood that suspended sediment, and the associated impacts on mussel feeding, are the main factors affecting population density through simulations. The results of this study showed that long-term sedimentation, which is often driven by land use within a watershed, had a significant impact on mussel density. Although this study was conducted within the Minnesota and St. Croix River watersheds, and did not explore the specific impacts to Round Hickorynut or Kidneyshell, the results of this study represent progress in understanding the complex and interactive process through which land use driven changes in water quality parameters (that is, suspended sediment) can impact freshwater mussel populations. More recently, Tuttle-Raycraft and Ackerman (2018) conducted an experimental study to examine the impacts of four different treatments of suspended sediments (mixed sediments, clay, coarse silt and fine silt) on the		

Approach	Descriptions and results	Recovery objectives	Participants
	clearance rates of Fatmucket, Wavyrayed Lampmussel, Eastern Pondmussel and Rainbow. They hypothesized that the smallest, clay-sized particles would not affect the clearance rates of the mussels. In contrast, their results showed that clay, course silt and mixed sediment all caused reductions in the clearance rates of each mussel species, while fine silt was comparable to control treatments where no sediment was added. They indicate that the clay particles contained greater amounts of algae, protein and lipid contents demonstrating that the quality of particles has a greater impact on the clearance rate of mussels compared to particle size. Further experimental research is underway that is examining the combined effect of water temperature, turbidity and flow on the clearance rate of adult unionids including both common and at risk species (Luck and Ackerman 2018). Preliminary experiments have been focused on the non-listed species, Fatmucket. **Contaminants** The potential impacts of pesticides on multiple life-stages of two other freshwater mussel species (Fatmucket and Rainbow) were investigated (Salerno et al. 2018). The pesticides used as treatments with all life-stages in this study, which have all been detected in surface waters in Ontario, included four fungicides, three neonicotinoids, two carbamates, one organophosphate and one butenolide. The juvenile and adult life-stages were also exposed to one additional fungicide and two additional neonicotinoids. The results of this study suggest that the pesticides examined pose a minimal risk to freshwater mussels (in acute and subchronic exposures), and occur in much lower concentrations within Ontario streams when compared to concentrations used in experimental treatments. The impacts of contaminants from urban environments on freshwater mussels has been examined in the Grand River (Gillis et al. 2014). Adult Flutedshell (*Lasmigona costata*) were collected from sites on the Grand River where there is exposure to wastewater effluent and road run-off. They found that mussels living downstream of urban areas had elevated levels of lead, chromium, zinc and silver and showed evidence of oxidative stress. The bioaccumulation of pharmaceutical and personal care products (PPCPs)		

Approach	Descriptions and results	Recovery objectives	Participants
	emanating from wastewater effluent in another unionid species, the Flutedshell, has been investigated within the Grand River where Kidneyshell and Round Hickorynut historically occurred (de Solla et al. 2016). The results of this study demonstrated that freshwater mussels bioaccumulate a number of substances including stimulants, contrasting agents, anti-inflammatory drugs, anti-bacterial agents, antibiotics, antidepressants, antihistamines, progestins, and illicit drugs (cocaine and amphetamines). The toxicity of these substances to freshwater mussels is currently unknown but it is thought that effluent from wastewater treatment plants on the Grand River may be impacting the fertilization success, egg survival, and increased incidence of intersex that has been documented in fish populations within the same study area (Bahamonde et al. 2015; Fuzzen et al. 2015). Although Kidneyshell and Round Hickorynut are considered extirpated from the Grand River, the results of these studies may be representative of PPCPs and other urban contaminants present in the Thames River, and to a lesser extent the Sydenham River.		
1-10 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 United States (U.S.) waterways.	The genetic variability of Canadian populations of Kidneyshell both within and between the Sydenham and Ausable rivers has been investigated (Galbraith et al. 2015). Genetic divergence was evident between Kidneyshell populations at the river level; however, this level of divergence was considered to be relatively low when compared to the other mussel species investigated in this study, which is surprising considering the limited potential for dispersal attributable to the host fish species for Kidneyshell. Furthermore, no genetic structuring was observed within river populations in either of the two rivers. No investigations into the population structure of Round Hickorynut have been undertaken at this time.	vi	Trent University, U.S. Geological Survey (USGS), CMU, OMNRF
Research the feasibility of repatriations (not prescribed in recovery strategy).	The OMNRF's Fish Culture Section (White Lake OMNRF Fish Culture Station) is currently developing expertise in the culture of four at risk mussel species including Wavyrayed Lampmussel, Snuffbox, Northern Riffleshell and Kidneyshell so as to be ready to support the culture and stocking of these species should doing so be required as part of future recovery efforts (C. Wilson, OMNRF, pers. comm. 2018). Research conducted through this program over the last two years has assessed the infestation rates and cumulative survival of juvenile Kidneyshell using both the primary host (Blackside Darter) and the secondary host (Johnny Darter) (Loftus and Wilson	vi	OMNRF, DFO, CMU, Carleton University

Approach	Descriptions and results	Recovery objectives	Participants
	2018). Furthermore a protocol is being finalized for mussel propagation and rearing techniques. The findings of this research will be beneficial if federal or provincial jurisdictions decide to undertake repatriation programs. Similarly, captive rearing may be useful to provide specimens for research needs considering wild caught individuals of listed species such as Round Hickorynut and Kidneyshell are endangered or threatened. In addition, investigations have been initiated at that will compare the genetic diversity of wild and captive bred unionids, including Kidneyshell (Zanatta and Van Tassel 2018). Juvenile Kidneyshell (50 one-year old individuals) will be acquired from the White Lake OMNRF Fish Culture Station, including individuals from both the primary and secondary hosts. These juveniles will be genotyped using the same approach used in Galbraith et al. (2015), who explored genetic variation among Canadian populations of Kidneyshell (see measure 1-10). The genetic diversity of the captive reared individuals will then be compared to that of the wild populations characterized in Galbraith et al. (2015) to determine if captive rearing has led to a reduction of genetic diversity. This is important research because it serves to assess the potential for deleterious impacts to the genetic fitness of remnant Kidneyshell populations that could arise from population augmentation. Furthermore, it will inform the development of repatriation approaches by providing estimations of the number of females needed to match the genetic diversity of wild populations. A systematic review of published information is underway that will investigate the efficacy of captive breeding programs for imperilled freshwater fishes and mussels in terms of their achievement of conservation of recovery objectives in the wild (Cooke and Donaldson 2018).		
Investigate the efficacy of monitoring protocols (not prescribed in recovery strategy).	Research has been conducted that explores the efficacy of quadrat sampling in its ability to detect species at risk, estimate their abundance, and detect changes in their density (Reid and Morris 2017). The results of this study demonstrate that the quadrat sampling approach is more effective than visual tactile surveys that do not involve excavation; however, it is still limited in its ability to reliably capture the majority of species at risk given their lower detection probabilities. Similarly, the results of this study indicate that the protocol generally leads to imprecise estimates of density for species at risk, consequently leading to an inability to detect subtle changes in species abundance. In fact, for species such as Round Hickorynut and Kidneyshell,	iv	

Approach	Descriptions and results	Recovery objectives	Participants
	only extreme changes in density (that is, ≥ 70% and 50%, respectively) are likely to be detected, which limits the ability of biologists to measure impacts stemming from in-water works and accidental spills, and address factors driving declines until recovery is no longer feasible. Furthermore, this study indicates that extensive sampling effort is needed to reliably detect rare species such as Round Hickorynut, let alone calculate population estimates.		
Research the applicability of eDNA sampling for detecting freshwater mussels (not prescribed in recovery strategy).	A research study has been conducted (Currier et al. 2018) that evaluates the effectiveness of eDNA sampling for four at-risk mussel species, including Kidneyshell, by: investigating the efficacy of this sampling approach for confirming the presence or absence of a species; comparing detection results between eDNA and traditional sampling approaches; and exploring the potential effects that mussel density and sampling depth may have on detection rates. The results of this study indicate that freshwater mussels such as Kidneyshell can be detected and distinguished at the species level using eDNA methods. In addition, Currier et al. (2018) conclude that eDNA sampling is comparable to traditional quadrat sampling in its effectiveness to detect a given species; however, unlike traditional methods, this approach is not limited to shallow, wadable streams. They also note that eDNA concentrations were correlated with mussel density; however, traditional sampling should still be conducted to estimate the density of a given species within a stream reach. Further research is ongoing that will explore the efficacy of eDNA as a means of detecting mussel species within wetlands and in areas where a given species is below the detection limit for traditional sampling approaches, as well as the potential ability to sample complete mussel communities simultaneously (Morris et al. 2018). Considering that Reid and Morris (2017) found that Round Hickorynut has a low probability of detection when using the quadrat sampling approach, and an extensive amount of sampling is required to reliably detect the species, eDNA sampling may be a beneficial tool that can be conducted with quadrat and timed-search surveys to increase the likelihood of detection while balancing the amount of effort and resources expended on this one species.	iv	DFO, Trent University, OMNRF

Table 2. Management approaches conducted/ongoing between 2013 and 2018.

Approach	Descriptions and results	Recovery objectives	Participants
2-1 Capacity building: Continue to promote and enhance expertise in freshwater mussel identification/biology and provide for the transfer of knowledge.	Fisheries and Oceans Canada (DFO), in partnership with St. Clair Region Conservation Authority (SCRCA), has continued to conduct a hands-on mussel identification course that is offered to government, agency, non-government organizations, Indigenous peoples, and the general public. In addition, DFO has worked with the Toronto Zoo to develop an online application called Clam Counter for android (available on the Google Play Store) and iOS (available in the App Store) devices.	i - iv	DFO, SCRCA, Toronto Zoo
2-2 Cooperation with ecosystem recovery strategies: Work with existing ecosystem Recovery Teams to implement recovery actions.	Ongoing collaboration with applicable recovery teams (for example, Sydenham and Ausable rivers) on stewardship and research activities has maximized knowledge and resource transfer and minimized redundancy. Two recently posted documents pertaining to these species include: the “Action Plan for the Sydenham River in Canada: An Ecosystem Approach” (DFO 2018a), which identifies stewardship and recovery objectives that apply directly to both Round Hickorynut and Kidneyshell; and the “Action Plan for the Ausable River in Canada: An Ecosystem Approach”, which prescribes measures that apply to Kidneyshell (DFO 2018b). A multi-stakeholder partnership led by the International Union for Conservation of Nature (IUCN), which included DFO, has led to the development of a document that identifies Freshwater Key Biodiversity Areas in Canada (Tognelli et al. 2017). Within this report, Round Hickorynut was identified as a trigger species (that is, a species that meets the Key Biodiversity Areas thresholds and criteria) in the Sydenham River and Eastern Lake St. Clair, where ≥ 0.5% of its global population occurs. This has led to the delineation of Key Biodiversity Areas (KBA) within sections of these two waterbodies. Furthermore, a KBA has been delineated within the Ausable River based on the presence of two trigger species, Snuffbox (*Epioblasma triquetra*) and Northern Riffleshell (*Epioblasma torulosa*), which encompasses the range of Kidneyshell within that watershed. The designation of these areas may garner international recognition, which in turn could lead to further protection and the implementation of habitat restoration activities that benefit Round Hickorynut and Kidneyshell.	v, vi	DFO, Ausable Bayfield Conservation Authority (ABCA), SCRCA, IUCN
2-3 Municipal planning: Encourage municipal planning authorities to consider critical habitat in official plans.	DFO species at risk guidance has been provided to Ontario municipalities that have aquatic (fish/mussel) species at risk within their areas to be used for municipal Official Plan updates. Initial contact has been made with	v	DFO

Approach	Descriptions and results	Recovery objectives	Participants
	municipalities that were actively updating their official plans. Species at risk guidance was updated in 2015 and additional contact/outreach to Ontario municipalities with species at risk in their areas is ongoing.		
2-4 Reduction of chloride loading: Encourage municipalities to adapt best management practices (BMPs) to reduce the use of road salt.	No progress has been made on this measure.	v	
2-5 Drainage: Work with drainage supervisors, engineers and contractors to limit the effects of drainage activities on mussel habitat.	Fish and Fish Habitat Protection Program biologists at DFO provide species at risk-specific guidance regarding proposed drainage activities on an ongoing basis. Furthermore, DFO Species at Risk Biologists have delivered presentations to drainage supervisors and engineers that identify issues and threats to species at risk, including Round Hickorynut and Kidneyshell, which may arise as a result of drainage activities such as cleanouts. Furthermore, mitigation measures and BMPs are communicated through these presentations. Lastly, a DFO document, “Guidance for Maintaining and Repairing Municipal Drains in Ontario” (Kavanagh et al. 2017) has been published that provides a more detailed description of BMPs that should be employed to reduce harmful impacts to fishes and freshwater mussel species, including those that are at risk.	v	DFO
2-6 Baitfish: Work with the baitfish industry to reduce the impacts of commercial baitfishing on host species. Update Baitfish Primer to include information on the mussel life cycle and note potential host fishes and time frames when encystment is likely to occur.	No progress has been made regarding this measure.	v	
2-7 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.	No progress has been made regarding this measure.	v	

Table 3. Stewardship approaches conducted/ongoing between 2013 and 2018.

Approach	Descriptions and results	Recovery objectives	Participants
3-1 Riparian buffers: Establish riparian buffer zones in areas of high erosion potential by encouraging naturalization or planting of native species.	Riparian restoration projects have been conducted by conservation authorities and non-government organizations with funding provided through the Habitat Stewardship Program (HSP). At total of 18.37 km of riparian habitat has been restored along the Ausable River since 2013. In addition to riparian stabilization, vegetation planting has been conducted in 22.8 ha of land along or adjacent to the Ausable River, which will limit erosion and sedimentation and contribute to the maintenance of a cooler thermal regime within the stream. These activities are beneficial to the recovery of Kidneyshell. Similarly, 20.23 ha of applicable vegetation planting has been undertaken in areas of the Thames River by the Carolinian Canada Coalition (CCC) through HSP funding that will benefit both Kidneyshell and Round Hickorynut.	v	Fisheries and Oceans Canada (DFO), Ausable Bayfield Conservation Authority (ABCA), CCC
3-2 Tile drainage: Work with landowners to mitigate the effects of tile drainage. **3-3 Herd management:** Encourage the active exclusion of animals from the watercourse. **3-4 Livestock waste management:** Assist with establishing adequate manure collection and storage systems to avoid accidental spills, and winter spreading of manure. **3-5 Farm planning:** Encourage the development and implementation of Environmental Farm Plans and Nutrient Management Plans.	It is currently unknown if work has been conducted in partnership with landowners to mitigate the impacts of tile drainage in areas of applicable waterbodies where Kidneyshell and/or Round Hickorynut may occur. Furthermore, management planning specific to farming uses have not been implemented; however, land management plans or manuals have been developed by CCC through HSP funding, which are aimed at adjusting landuse practices to mitigate threats to species at risk through the application of BMPs. A total of 20.23, 2013.04 and 75.76 ha of land on the Thames, Sydenham and Ausable rivers, respectively, are applying land management plans or manuals. Livestock exclusion from watercourses and waste management activities have not been implemented in areas where Kidneyshell and Round Hickorynut occur since 2013.	v	DFO, CCC
3-6 Sewage treatment: Work with landowners to improve faulty septic systems.	No progress has been made regarding this measure.	v	
3-7 Soil testing: Encourage soil testing to determine fertilizer application rates.	No progress has been made regarding this measure.	v	
Habitat protection/land easement (not prescribed in recovery strategy)	Ontario Nature (ON) has acquired 193 acres of property (Sydenham River Nature Reserve), which includes a 2 km stretch of the Sydenham River where Round Hickorynut and Kidneyshell occur (Sydenham Nature Reserve).	N/A	ON

Table 4. Awareness approaches conducted/ongoing between 2013 and 2018.

Approach	Descriptions and results	Recovery objectives	Participants
4-1 Stewardship actions: Increase public knowledge of stewardship options and financial assistance available to participate in activities.	Presentations regarding species at risk, threats, critical habitat as well as species recovery and protection measures were delivered by Fisheries and Oceans Canada (DFO) to: environmental students at Fleming College; the Ontario Aboriginal Lands Association (OALA) and the Ontario First Nations Economic Development Association (OFNEDA); partner agencies; Oneida First Nation; potential drainage superintendents as a component of their course training; and members of the Ontario Land Trust Alliance. In addition, DFO has developed an outreach strategy for species at risk in southwestern Ontario targeting the following audiences: local municipal staff (managers, planners, engineers, field staff, and consultants); development industries (representatives of local development industries and/or their consultants); landowners (representatives of the local landowners, farmers, and cottagers, as well as recreational groups such as ATV/trail users); and conservation/environmental/stewardship organizations (fish and game clubs, naturalist and environmental protection organizations, students, and stewardship councils). The Ausable Bayfield Conservation Authority (ABCA) has conducted stewardship related outreach activities through funding from Habitat Stewardship Program (HSP) including: mailing letters and/or postcards with information pertaining to species at risk to 750 landowners from 2013 to 2014; and conducting info sessions at Ailsa Craig and Exeter where landowners were informed about local species at risk and stewardship approaches to mitigate the threats that are impacting them. The St. Clair Region Conservation Authority (SCRCA) also contributed to awareness of stewardship options by: conducting tours that showcased former erosion control projects, which were funded through HSP, to encourage other landowners to incorporate similar best management practices (BMPs) on their own land; attending Ontario Soil and Crop Improvement Association meetings as well as other similar events to inform the community of stewardship related funding that is available; drafting a species at risk newsletter that included habitat improvement/stewardship approaches to be published in Strathroy and Sarnia newspapers, which are read by a broad audience throughout the Sydenham River watershed;	vii	DFO, ABCA, SCRCA

Approach	Descriptions and results	Recovery objectives	Participants
	providing information to landowners regarding grants for stewardship projects on their website; and, providing information to farmers regarding crop rotation and practices to reduce overland runoff.		
4-2 Invasive species: Increase public awareness of the potential impacts of transporting/releasing invasive species.	Aquatic invasive species information has been disseminated through the Watercraft Inspection Program and through educational outreach material distributed by DFO (public postings and direct engagement) that provides info regarding species at risk as well as invasive species that threaten them. Furthermore, licensed commercial baitfish harvesters in Ontario have completed Hazard Analysis and Critical Control Point training, which focuses on impacts and prevention of the spread of aquatic invasive species. In addition, research funded by DFO (Drake and Mandrak 2014a; 2014b) has quantified the risk of invasive fish species introductions throughout the province as a result of the bait industry. Guidelines and effective strategies for the control and removal of Common Reed are described for invasive species mitigation and wetland restoration projects (Ontario Ministry of Natural Resources and Forestry [OMNRF] 2011). The OMNRF, in partnership with Ontario Federation of Anglers and Hunters (OFAH), has developed the Early Detection Distribution Mapping System that allows the general public and citizen scientists to share their information regarding the distribution of Common Reed and provides guidance and direction on how to control this invasive species.	vii	DFO, OMNRF, OFAH
4-3 Outreach: Encourage public support and participation by developing awareness materials and programs.	Awareness of species at risk and the threats they are facing has been communicated to the general public and school children by DFO at the Canadian Centre for Inland Water open house events in 2017 and 2018. Furthermore, outreach material was provided by DFO at the Day on the Grand Brantford Arts Music Festival 2017, although both Kidneyshell and Round Hickorynut are likely extirpated from this watershed. ABCA has conducted similar outreach with funding from HSP to increase awareness of aquatic species at risk including: presentations to 50 school classes over the time period of 2013 to 2017; and holding 16 information/education sessions for adult community members.	vii	DFO, ABCA, SCRCA

Approach	Descriptions and results	Recovery objectives	Participants
	SCRCA has also raised awareness of species at risk with funding from HSP by: reaching 600 and ~1000 students who participated in their species at risk program in 2016 and 2017, respectively; reaching 13,900 and 11,700 students, through their SCRCA education programs, which include a component on species at risk in 2016 and 2017, respectively; presentations and displays at community events; their website (Sydenham River watershed), which provides information on species at risk; a mussel identification program for high school students; and drafting a species at risk newsletter that included information on species at risk to be published in Strathroy and Sarnia newspapers, which are read by a broad audience throughout the Sydenham River watershed.		

3.2 Activities supporting the identification of critical habitat

Table 5 provides information on the implementation of the studies outlined in the schedule of studies to identify critical habitat from the recovery strategy. Each study has been assigned one of four statuses:

1. completed: the study has been carried out and concluded
2. in progress: the study is underway and has not concluded
3. not started: the study has been planned but has yet to start
4. cancelled: the study will not be started or completed

Table 5. Status and details of the implementation of the schedule of studies outlined in the recovery strategy.

Study	Timeline	Status	Descriptions and results	Participants
Assess timeframes (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	2013 to 2015	In progress	Research is ongoing that investigates the timing of sperm and ova production, the release of sperm, glochidia production and gravid periods, glochidial release and attachment and transformation for Kidneyshell. No research of this nature has been started for Round Hickorynut.	Fisheries and Oceans Canada (DFO)
Conduct mussel population surveys	2013 to 2016	In progress	Monitoring surveys have been conducted within occupied/recently occupied locations including the Thames (Kidneyshell), Sydenham (both species) and Ausable rivers (Kidneyshell). Quantitative survey methods were employed at these locations that allow for inferences of species abundance, which in turn inform population trajectory estimates.	DFO, Ausable Bayfield Conservation Authority (ABCA)
Assess and map habitat conditions in occupied areas (for example, flow, substrate, water clarity and quality)	2014 to 2016	In progress	Habitat conditions are evaluated as a component of the quadrat surveys, which were conducted at monitoring stations where populations of Kidneyshell and Round Hickorynut occur; however, no mapping component regarding habitat conditions has been undertaken at this point.	DFO
Determine any life-stage	2013 to 2017	Not started	Research regarding the life-stage specific habitat use	DFO

Study	Timeline	Status	Descriptions and results	Participants
differences in habitat use			has not been undertaken at this stage for Round Hickorynut or Kidneyshell.	
Determine/confirm host fish species (laboratory and functional) and their distributions and home ranges	2013 to 2015	In progress	Research has been conducted to detect the presence of glochidia on the gills of wild caught species identified in previous laboratory experiments as potential hosts for Kidneyshell and Round Hickorynut. Kidneyshell glochidia were detected on the gills of all three species identified in previous experiments (Greenside Darter, Johnny Darter, and Blackside Darter), while Round Hickorynut glochidia were only found on the gills of one of the previously identified hosts (Blackside Darter).	DFO
Assess habitat use by host species	2015 to 2017	In progress	Fish community assessments have been conducted at mussel monitoring stations to assess the presence and habitat use of host species. In addition, sampling for fish species has been undertaken by DFO in a number of projects unrelated to mussel research, within sites that are relevant to Kidneyshell and Round Hickorynut.	DFO
Determine areas of overlap between mussel and host habitat	2016 to 2017	In progress	See row above	DFO
Based on collected information, review population and distribution goals. Determine amount and configuration of critical habitat required to achieve goal if adequate information exists.	Ongoing	Not started	Sampling conducted in the last five years has not led to the detection of Round Hickorynut or Kidneyshell at new or historically occupied locations; therefore, there is no new information available to justify the need to identify additional critical habitat.	DFO

3.3 Summary of progress towards recovery

3.3.1 Status of performance evaluation

Table 6 provides a summary of the progress made toward meeting the five-year recovery objectives outlined in section 3 of the recovery strategy for the Round Hickorynut and Kidneyshell in Canada. Each indicator has been assigned one of four statuses:

1. not met: the recovery objective has not been met, and little to no progress has been made
2. not met, underway: the recovery objective has not been met, but there has been moderate to significant progress made
3. met: the recovery objective has been met and no further action is required
4. met, ongoing: the recovery objective has been met, but efforts will continue until such time the population is considered to be recovered (that is, the indicator will be reported against in the next five-year progress report)

Table 6. Summary of the progress made toward meeting the recovery objectives outlined in section 3 of the recovery strategy.

Recovery objectives	Status	Details
Determine extent, abundance and population demographics of existing populations	Met, ongoing	Quantitative mussel sampling has been conducted at monitoring sites within the Thames River where Round Hickorynut historically and Kidneyshell recently occurred, the Sydenham River where both species occur, as well as Ausable River where Kidneyshell occurs. These surveys could potentially be used to assess the abundance of both species and infer population trends. However, Reid and Morris (2017) suggest that using the quadrat method at current mussel monitoring stations to assess population trends may yield inaccurate results considering that: 1) exhaustive sampling efforts may be required to reliably detect Round Hickorynut and Kidneyshell; 2) the current network of monitoring sites does not meet the assumption of randomly selected sites, which is required to derive statistically based population estimates, but rather they represent areas where dense aggregations of mussel species were already known to occur; 3) the sites represent areas where higher numbers of multiple species occur, which may not always represent the habitat of individual species; and 4) the number of monitoring stations are spatially unbalanced among watersheds, which can further bias population estimates. Based on the results of this study, the feasibility of generating reliable population estimates, and the sampling approaches applied to inform them, need to be revaluated. Timed-search surveys have also been conducted in both occupied and historically occupied waterbodies, which are applicable to both species.
Determine host fishes and their distributions and	Met, ongoing	Research has been undertaken to confirm the presence of glochidia on the gills of potential host species of Kidneyshell that were identified in McNichols (2007); however, further research is needed to provide conclusive results. Fish community

Recovery objectives	Status	Details
abundances		assessments have been conducted at mussel monitoring stations to assess the presence and habitat use of host species and data are available from other Fisheries and Oceans Canada (DFO) led surveys; however, the distribution and abundance of host fishes has not been fully characterized or determined.
Define key habitat requirements to identify critical habitat	Not met, underway	Sampling conducted at monitoring stations where these two species occur included the assessment of habitat variables, which may be used in the future to examine associations between the presence of Round Hickorynut and Kidneyshell and with habitat parameters using a modelling approach that may help to further identify critical habitat in the future. In addition, the Ontario Ministry of Environment, Conservation and Parks monitors concentrations of metals, nutrients, and turbidity in a number of locations where these species occur, which may be useful to determine when critical habitat is being destroyed. Research has also been conducted that examines the clearance rate of Kidneyshell in flow and no flow scenarios, with regard to particle size, algal taxa, and in terms of dietary overlap with other mussel species (Tran 2017).
Establish a long-term monitoring program for Round Hickorynut and Kidneyshell populations, their hosts and the habitat of both	Met, ongoing	DFO conducts sampling for the presence/absence of Round Hickorynut and Kidneyshell using timed-search surveys, which are suitable for areas of historical or potential occupancy as well as those where other sampling methods are not feasible. In areas where these species are known to occur, and where feasible, quantitative mussel surveys are employed using the quadrat method to measure the abundance of these two species. Monitoring stations have been established at suitable locations within the Thames, Sydenham and Ausable rivers, which incorporate fish community surveys as well as the observation of habitat composition and condition. However, as mentioned above, there are limitations to the effectiveness of these monitoring methods, and new approaches, which may pair methods such as quadrat sampling, timed-searches, and eDNA surveys, may be required to more reliably detect these two mussel species.
Identify threats, evaluate their relative importance and implement remedial actions to minimize their impacts	Met, ongoing	Since the publication of the recovery strategy, a laboratory study has been undertaken that investigated the potential of an invasive species, Round Goby, to act as a sink for the glochidia of four other at risk mussel species. Though the glochidia of Round Hickorynut and Kidneyshell were not included in the design of this study, the results demonstrate that there may be potential impacts to unionids in general, including these two species (Tremblay et al. 2016). In addition, one meta-analysis study is underway, while another has been completed: one exploring the impacts of the invasive Common Reed on freshwater mussels and their hosts (Yuckin and Gilbert 2018); the other, investigating

Recovery objectives	Status	Details
		relationships between habitat condition, which includes a wide variety of parameters, and mortality in freshwater mussels (Morris et al. 2018). Research has been conducted that investigates the impacts of elevated total suspended sediment (TSS) on the reproductive success and feeding ability of other freshwater mussel species, as well as the potential impacts that alterations to flow and algal concentration may have on the foraging ability and behavior of freshwater mussels (Gasho et al. 2013; Hansen et al. 2016; Mistry and Ackerman 2017; Mistry and Ackerman 2018; Tuttle-Raycraft et al. 2017; Luck and Ackerman 2018; Tuttle-Raycraft and Ackerman 2018) . Lastly, an investigation into the risk to freshwater unionids stemming from a potential invasion of Black Carp has been completed (T. Morris, DFO pers. comm 2018).
Examine the feasibility of relocations, reintroductions and the establishment of managed refuge sites	Met, ongoing	Habitat improvement projects such as riparian restoration, vegetation planting, etc., which were funded through Habitat Stewardship Program (HSP) and are applicable for both Round Hickorynut and Kidneyshell populations, have been quantified for watersheds within the Thames (Kidneyshell), Sydenham (both species) and Ausable rivers (Kidneyshell).
Increase awareness about the distribution, threats and recovery of these species	Met, ongoing	Outreach centred specifically on the distribution, threats, and recovery of Round Hickorynut and Kidneyshell has not been conducted; however, presentations have been given to a number of audiences by DFO as well as federally funded external agencies that discuss the ecology, recovery of, and threats to freshwater mussel species at risk.

3.3.2 Completion of action plans

The "Action Plan for the Ausable River in Canada: An Ecosystem Approach" (2018) includes recovery activities for Kidneyshell. Furthermore, the "Action Plan for the Sydenham River in Canada: An Ecosystem Approach" (2018) includes activities for implementation that apply to both Round Hickorynut and Kidneyshell.

3.3.3 Critical habitat identification and protection

Using the best available information, critical habitat has been identified for Round Hickorynut in the East Sydenham River. Critical habitat has been identified for Kidneyshell in the Ausable River, East Sydenham River, lower Thames River, and Medway Creek (a tributary of the Thames River). The critical habitat for these two species is identified in the recovery strategy (2013). Critical habitat orders for both species came into effect in 2019.

3.3.4 Recovery feasibility

There may be a need to review the recovery feasibility for these two species considering new information has been gathered that would suggest that their respective populations within Canadian waters no longer meet the feasibility criteria laid out in the recovery strategy. For example, there may not be enough reproducing individuals of Round Hickorynut in the Sydenham River or Kidneyshell in the St. Clair River Delta and Thames River to support recovery objectives. The recovery for these two species in these respective locations may only be feasible if more active approaches are employed such as supplemental stocking, for which there is currently no supporting policy or facilitative infrastructure in place. It is worth noting that the Ontario Ministry of Natural Resources and Forestry (OMNRF) is currently rearing Kidneyshell to build capacity and expertise should population augmentation become a necessity in the future.

4 Concluding statement

Since the publication of the updated recovery strategy with the inclusion of critical habitat in 2013, there has been a fair amount of progress with regard to recovery implementation. For example, both quadrat and timed-search monitoring surveys have been conducted within occupied locations in the Thames (Kidneyshell), Sydenham (both species) and Ausable rivers (Kidneyshell), and modified survey methods have been undertaken within the St. Clair delta, which apply to both species. In addition, sampling has also been conducted in areas that were historically occupied by both species including Pelee Island and the Grand and Welland rivers. Further monitoring is needed within the Sydenham and Thames rivers to determine if populations of Round Hickorynut and Kidneyshell, respectively, are declining or are just less likely to be reliably detected using the quadrat approach. It is important to detect and thoroughly confirm these potential population trends as it may lead to alterations to the population and distribution objectives in the future, and consequently the feasibility of recovery for some populations.

Significant progress has also been made in terms of research focused on Kidneyshell including: life-history studies; host fish confirmation laboratory studies; genetic research to investigate population structure; and research regarding the culturing of Kidneyshell to facilitate potential repatriation measures in the future. In contrast, these same research measures were not undertaken for Round Hickorynut, and therefore should be conducted in the future to elucidate

these knowledge gaps. In addition, the habitat requirements of both species at each specific life stage remain to be characterized, and surveys have not been conducted to inventory and map suitable unoccupied habitat as was prescribed in the recovery strategy.

Management and coordination has been ongoing in terms of capacity building and inter-jurisdictional cooperation (for example, working with recovery teams and municipal planners); however, future efforts should be made to encourage municipalities to reduce chloride loading, educate individuals within the baitfish industry to reduce impacts to the host fish species for both Round Hickorynut and Kidneyshell and educate them regarding the unionid life cycle, and encourage wastewater treatment plants and stormwater management facilities to upgrade where appropriate to increase water quality at downstream locations.

Progress has also been made with regard to outreach and awareness activities, which have been conducted by DFO as well as external agencies through funding from the Habitat Stewardship Program (HSP), to inform the general public about freshwater mussels including Round Hickorynut and Kidneyshell, their status, the threats that are affecting them as well as best management practices that can be adopted to minimize impacts from human activities. In addition, habitat improvement activities have been conducted in the Ausable River (Ausable Bayfield Conservation Authority [ABCA]) and Sydenham River (St. Clair Region Conservation Authority [SCRCA] and Carolinian Canada Coalition [CCC]), which should reduce the threat of sedimentation and improve water quality downstream.

Future recovery efforts for these two species should be focused on implementing the monitoring, research, and management measures, which have not been adequately addressed in the last five years. Specifically, more effort may need to be focused on Round Hickorynut to make informed decisions on the management of this species when updating the recovery strategy in the future.

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