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Information in support of a recovery potential assessment of Hickorynut (*Obovaria olivaria*) in Canada

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Canada

Foreword

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

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

In May 2011, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of Hickorynut (*Obovaria olivaria*) and determined the designation to be Endangered. The reason provided for this designation is that, “This freshwater mussel lives in mid-sized to large rivers in southern Ontario and Quebec. There has been an historical decline in the species’ distribution with losses of the populations in the Detroit and Niagara rivers. Other locations are threatened by the continuing invasion of dreissenid mussels. In addition, the one known host of this mussel, the Lake Sturgeon, is at risk and may be declining in some locations where the mussel is known to still occur. The species is also affected by degraded water quality in many freshwater systems in southern Ontario and Quebec”. Hickorynut is currently not listed under the *Species at Risk Act* (SARA).

The Recovery Potential Assessment (RPA) provides information and scientific advice needed to fulfill various requirements of SARA, including informing both scientific and socio-economic elements of the listing decision and permitting activities that would otherwise violate SARA prohibitions and the development of recovery strategies. This Research Document describes the current state of knowledge of the biology, ecology, distribution, population trends, habitat requirements, and threats to Hickorynut. Mitigation measures and alternative activities related to the identified threats, which can be used to protect the species, are also presented. The information contained in the RPA and this document may be used to inform the development of recovery documents and for assessing permits, agreements and related conditions, as per section 73, 74, 75, 77 and 78 of SARA. The scientific information also serves as advice to the Minister of Fisheries and Oceans Canada (DFO) regarding the listing of the species under SARA and is used when analyzing the socio-economic impacts of adding the species to the list as well as during subsequent consultations, where applicable. This assessment considers the available scientific data with which to assess the recovery potential of Hickorynut in Canada.

RÉSUMÉ

En mai 2011, le Comité sur la situation des espèces en péril au Canada (COSEPAC) a évalué la situation de l'obovarie olivâtre (*Obovaria olivaria*) et lui a attribué le statut d'espèce en voie de disparition. La raison invoquée pour cette désignation était la suivante : « Cette moule d'eau douce vit dans les moyennes et les grandes rivières du sud de l'Ontario et du Québec. Il y a eu un déclin historique de la répartition de l'espèce incluant la perte des populations dans les rivières Détroit et Niagara. D'autres localités sont menacées par l'invasion continue des dreissénidés. De plus, l'hôte connu de cette moule, l'esturgeon jaune, est en péril et pourrait être en déclin dans certaines localités que l'on sait encore fréquentées par la moule. L'espèce est également touchée par la dégradation de la qualité de l'eau dans bon nombre de réseaux dulcicoles du sud de l'Ontario et du Québec. » À l'heure actuelle, l'obovarie olivâtre n'est pas inscrite sur la liste de la *Loi sur les espèces en péril* (LEP).

L'évaluation du potentiel de rétablissement (EPR) fournit les renseignements et les avis scientifiques nécessaires pour satisfaire à diverses exigences de la LEP; notamment, cette évaluation permet d'éclairer les aspects scientifiques et socioéconomiques de la décision relative à l'inscription sur la liste, de réaliser des activités qui autrement enfreindraient les interdictions de la LEP et d'élaborer des stratégies de rétablissement. Le présent document de recherche fournit une description de l'état actuel des connaissances de la biologie, de l'écologie, de la répartition, des tendances démographiques, des besoins en matière d'habitat et des menaces relatives à l'obovarie olivâtre. Des mesures d'atténuation et d'autres activités associées aux menaces identifiées, qui peuvent être utilisées dans le but de protéger l'espèce, sont également présentées. Les renseignements que renferment l'EPR et ce document peuvent servir de base à l'élaboration de documents relatifs au rétablissement et à l'évaluation des permis, des ententes et des conditions connexes, conformément aux articles 73, 74, 75, 77 et 78 de la LEP. On se sert également de ces renseignements scientifiques pour conseiller le ministre de Pêches et Océans Canada (MPO) au sujet de l'inscription de l'espèce en vertu de la LEP, analyser les répercussions socioéconomiques de l'inscription de l'espèce sur la liste ainsi que pour les consultations subséquentes, le cas échéant. Cette évaluation tient compte de toutes les données scientifiques existantes permettant d'évaluer le potentiel de rétablissement de l'obovarie olivâtre au Canada.

SPECIES INFORMATION

Scientific Name – *Obovaria olivaria* (Rafinesque, 1820)
Common Name – Hickorynut
Current COSEWIC Status (Year of Designation) – Endangered (2011)
Current *Species at Risk Act* Status (Schedule) – No status (No schedule)
Current Ontario *Endangered Species Act* Status (Year of Designation) – Endangered (January 2012)
Range in Canada – Quebec and Ontario

BACKGROUND

DESIGNATION

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of Hickorynut (*Obovaria olivaria*) as Endangered. The reason given for this designation was that, "This freshwater mussel lives in mid-sized to large rivers in southern Ontario and Quebec. There has been an historical decline in the species' distribution with losses of the populations in the Detroit and Niagara rivers. Other locations are threatened by the continuing invasion of dreissenid mussels. In addition, the one known host of this mussel, the Lake Sturgeon (*Acipenser fulvescens*), is at risk and may be declining in some locations where the mussel is known to still occur. The species is also affected by degraded water quality in many freshwater systems in southern Ontario and Quebec." Hickorynut is currently not listed under the *Species at Risk Act* (SARA). A Recovery Potential Assessment (RPA) process has been developed by Fisheries and Oceans Canada (DFO) to provide information and scientific advice needed to fulfill SARA requirements, including the development of recovery strategies and authorizations to carry out activities that would otherwise violate SARA (DFO 2007). This document provides background information on Hickorynut to inform the RPA.

SPECIES DESCRIPTION

Hickorynut (*Obovaria olivaria*) is a medium-sized freshwater mussel with an average shell length of approximately 55 mm (Metcalfe-Smith et al. 2005). A maximum shell length of 80 mm (Metcalfe-Smith et al. 2005) and 100 mm (Cummings and Mayer 1992; Parmalee and Bogan 1998) have been reported; however, most individuals are generally less than 75 mm long (COSEWIC 2011). Voucher shell specimens stored at the Canadian Museum of Nature (CMN) were measured. Mean shell lengths were 45.3 mm (n=2) for the Mississagi River, 39.8 mm (n=28) for the Ottawa River and 35.9 mm (n=12) for the St. Lawrence River. The shell is described as being almost perfectly oval and inflated with rounded anterior and ventral margins (Metcalfe-Smith et al. 2005). Although sexual dimorphism is subtle, the posterior margin of males is described as being bluntly rounded, while that of the female is described as being broadly rounded (Metcalfe-Smith et al. 2005). The height/length ratio is usually 0.65 to 0.80 (Strayer and Jirka 1997). The shell is generally thicker anteriorly and thinner posteriorly (COSEWIC 2011). The beak is inflated, directed forward and very close to the anterior end of the shell (Metcalfe-Smith et al. 2005). The exterior of the shell (periostracum) varies from olive-green to yellowish-brown with faint greenish rays in juveniles, while older specimens tend have a dark brown periostracum (Metcalfe-Smith et al. 2005; COSEWIC 2011; Figure 1a). The nacre is bright white and often iridescent posteriorly (Metcalfe-Smith et al. 2005; Figure 1b).

(a) (b)

*Figure 1. Hickorynut (*Obovaria olivaria*) (a) exterior shell and (b) interior nacre. Photograph by Environment Canada, reproduced with permission.*

SIMILAR SPECIES

Globally, there are only four additional species in the genus *Obovaria* (*O. jacksoniana, O. retusa, O. subrotunda, and O. unicolor*). Of these additional four species, only the range of Round Hickorynut (*O. subrotunda*) extends into Canadian waters. Hickorynut is easily distinguished from all other freshwater mussels in Canada by its relatively small, nearly oval shell shape, its unique hinge-plate features and the peak of its shell located far anteriorly (COSEWIC 2011).

Morphologically similar species include Round Hickorynut, Round Pigtoe (*Pleurobema sintoxia*), and Mucket (*Actiononaias ligamentina*). Round Hickorynut can be distinguished from Hickorynut by its rounded shell and vertically aligned pseudocardinal teeth. Hickorynut pseudocardinal teeth are aligned horizontally. The shell of Round Pigtoe generally has a darker color and is more compressed with smaller beaks. Mucket can be distinguished from Hickorynut by the presence of green rays and heavy, well-developed teeth.

AGE AND GROWTH

Investigation into the age of Hickorynut in Canada by examination of the distinct dark bands on the external surface of the shells of individuals from the Ottawa River indicated that most Hickorynut adults ranged in age from seven to 14 years (A. Martel, unpubl. data *in* COSEWIC 2011). No additional information on age and growth patterns is available, locally or globally for this species.

DIET

Like most other unionid mussels, Hickorynut is considered to be a filter feeder. Cilia present on their foot may also be evidence that Hickorynut may be deposit feeders as these cilia direct particles towards the mouth. Filter feeding (also called suspension feeding) is accomplished by using cilia to pump water through their incurrent siphon and over the gills. Particles are subsequently sorted by cilia on the gills and directed towards the mouth for consumption. Food items may include phytoplankton, organic detritus, and bacteria (COSEWIC 2011). In the early juvenile stage, when the mussel is most commonly buried in the substrate, food is obtained directly from the substrate (COSEWIC 2011). Species-specific dietary information is not available for Hickorynut.

DISTRIBUTION

Hickorynut is currently found throughout most of the Mississippi River drainage, from portions of Pennsylvania and New York to Minnesota and Kansas, south to Missouri, Arkansas and Louisiana. It is thought to be extirpated from Alabama (Mirarchi et al. 2004), Kansas (Couch 1997 *in* Cummings and Cordeiro 2012), Nebraska (Hoke 2005), Pennsylvania (Bogan 1993) and Ohio (Watters et al. 2009). In Canadian waters, it is found exclusively in the St. Lawrence River basin from the Mississagi River (tributary of the North Channel of Lake Huron) to approximately 40 km east of Quebec City in the St. Lawrence River. It is thought to be extirpated from the Detroit River (Schloesser et al. 2006) and from the Niagara River.

CURRENT STATUS

In Canada, the current and historic known distribution of Hickorynut is limited to four confirmed populations, one of which is currently considered to be extirpated. Extant populations include the Mississagi River (Lake Huron drainage), the Ottawa River and its tributaries (Coulonge River), and the St. Lawrence River and its tributaries (Assomption River, Saint-Francois River and Batiscan River; Figure 2). The largest population of Hickorynut in Canada is located in the St. Lawrence River near the city of Grondines, Quebec where repeated sampling between 2007 and 2012 has yielded the capture of over 550 live individuals. It should be noted that the following maps represent all current and historic records of Hickorynut, and may not accurately represent the current distribution. Deep water, the habitat most often associated with Hickorynut, has not been extensively sampled and therefore the following maps may be an underrepresentation of the current distribution.

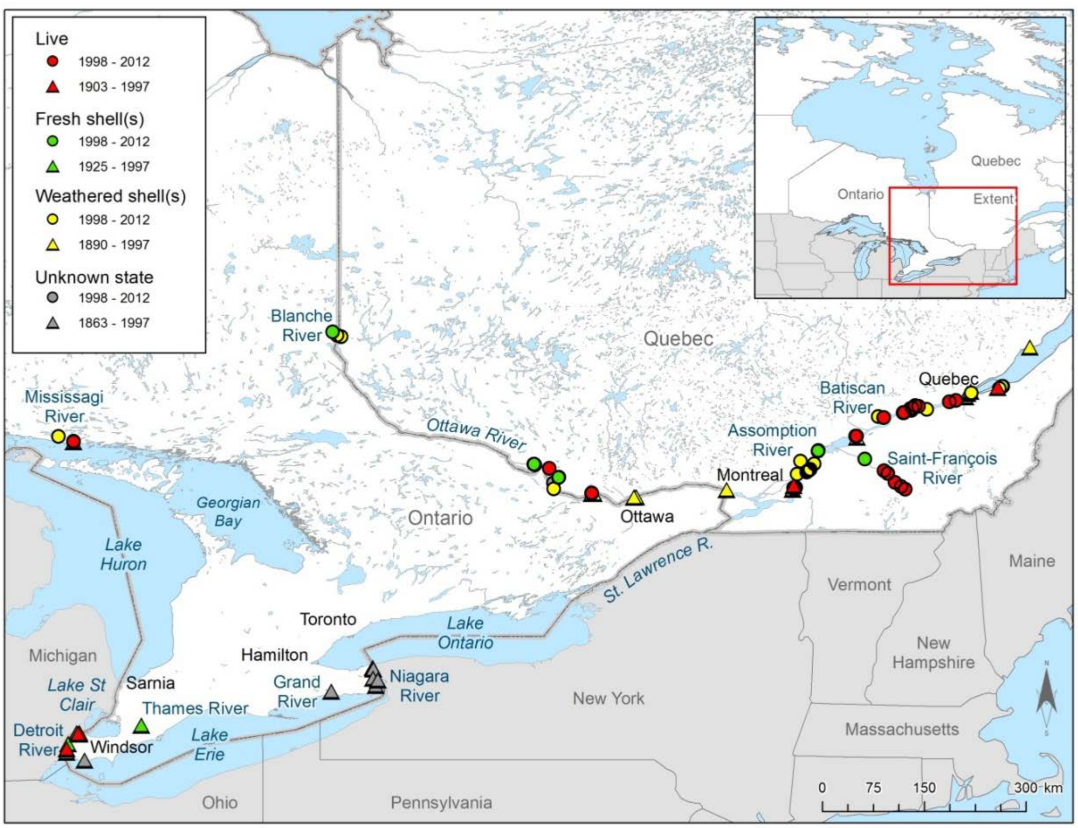

Figure 2. Distribution of Hickorynut in Canada.

It is believed that Hickorynut is now extirpated from the Great Lakes and their connecting channels following the dreissenid mussel invasion, as Hickorynut has not been recorded from these areas since 1994. Hickorynut populations in both the Detroit and Niagara rivers have since disappeared. A historic Hickorynut record exists for the Thames River near Chatham, Ontario dated 1934. This record consists of a single shell located at the Royal Ontario Museum (ROM) and has been confirmed to be Hickorynut via photographs. This represents the only known Hickorynut record from this system. An additional Hickorynut record exists from the Grand River near Dunnville, Ontario dated 1963, collected by David H. Stansbery and Carol B. Stein (Ohio State University Museum of Zoology). No additional information is available for this record and it represents the only indication of Hickorynut from this system.

The loss of the Great Lakes and connecting channel populations has drastically affected the distribution of this species. The index of area of occupancy (IAO), based on 2 km x 2 km grid cells, considering both live and fresh dead shells from 1998 to 2010, was reported to be 92 km^2 (COSEWIC 2011). When this value was compared to the historic IAO (192 km^2), a 52.1% decline in mean IAO over the last three generations was reported (COSEWIC 2011).

MISSISSAGI RIVER

The Mississagi River originates in the Sudbury district in Ontario and flows approximately 226 km south to Lake Huron. The first Hickorynut record from this river was recorded near Blind River, Ontario in 1955 (UMMZ lot number 26921) (Figure 3). Two additional weathered shells have been confirmed from the Mississagi River, although the date associated with these shells was simply listed as prior to 1960 (CMN collection number 024979). Hickorynut was not recorded from this system again until 2000 when one fresh shell was incidentally collected while conducting botanical fieldwork (M. Oldham, Natural Heritage Information Centre, pers. comm.). This area was not revisited until September 2009 when SCUBA and snorkeling surveys were completed at five sites, two of which resulted in positive identifications for a total of ten Hickorynut (Zanatta and Woolnough 2011).

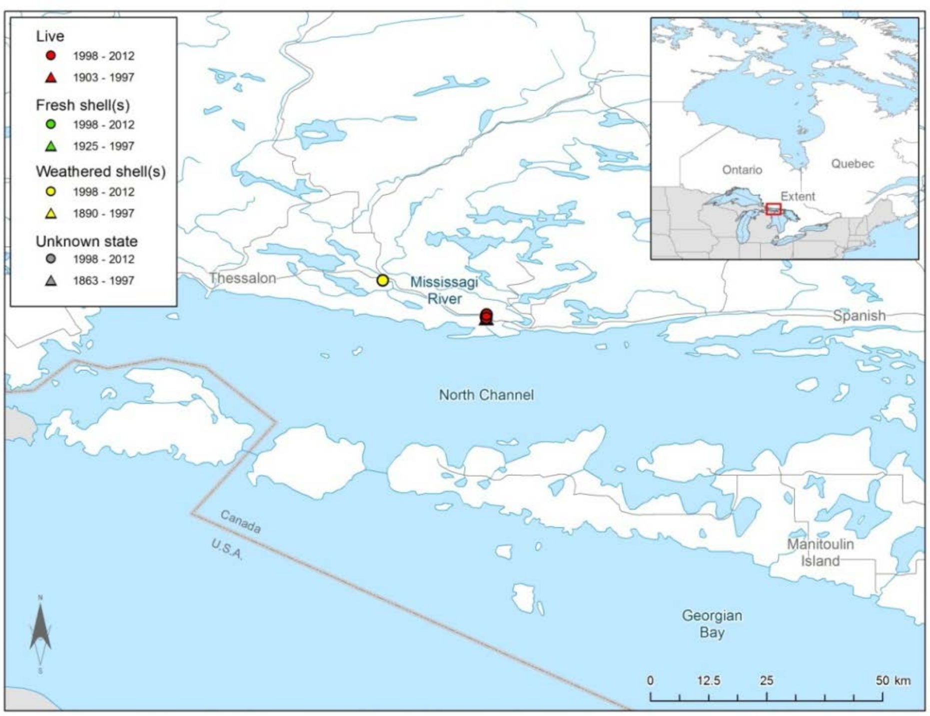

Figure 3. Distribution of all known current and historic Hickorynut records from the Mississagi River, Ontario.

OTTAWA RIVER

Historical museum records of Hickorynut from the Ottawa River are available from 1885, 1887, 1900, 1906, 1931, 1933, 1936, 1937, 1960, and 1962 (Figure 4). This species was not observed from this system again until 2000 when one fresh shell and two weathered shells were recorded during an observational study (F. Schueler, Bishop Mills Natural History Museum, unpubl. data). These observations, recorded from both the Blanche River (a tributary of the Ottawa River) and the Ottawa River proper in the Timiskaming District, Ontario represent the most northerly records of Hickorynut in Canada. Subsequent to this observational study, additional extensive targeted sampling by CMN, the Ministère des Ressources naturelle et de la Faune du Québec (MRNF), and the Bishop Mills Natural History Museum have occurred in 2001, 2002, 2004-2005, 2007, 2010 and 2012 throughout the Ottawa River. These studies resulted in the observation of live Hickorynut (n=6), fresh shells (n=52) and weathered shells (n=23) in the Ottawa River from the Chenal-de-la-Culbute in the vicinity of the Ile-aux-Allumettes, Quebec to Parc de Plaisance, Quebec. Hickorynut have also been found in a few tributaries of the Ottawa River. There is a single record of a weathered shell from the Madawaska River (CMN collection number 073989); although there was no date associated with this collection. In addition, one live individual was found in 2001 in the Coulonge River approximately 6 km from the confluence with the Ottawa River (I. Picard, unpubl. data).

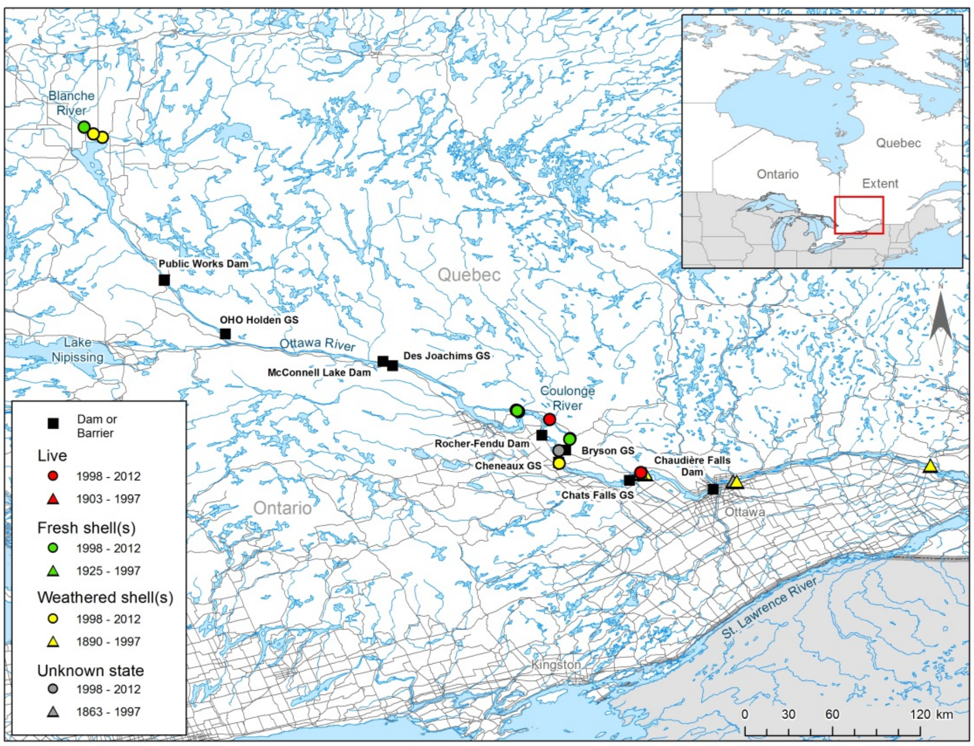

Figure 4. Distribution of all known current and historic Hickorynut records from the Ottawa River.

ST. LAWRENCE RIVER AND TRIBUTARIES

Evidence of the presence of Hickorynut populations is noted through the St. Lawrence River from the southern point of the Charron Island (near Montreal, Quebec) downstream to the town of Saint-Joseph-de-la-Rive, Quebec, as well as in three of its large river tributaries: the Saint-François River, the Batiscan River and the Assomption River (Figure 5).

St. Lawrence River

The first historical record of Hickorynut from the St. Lawrence River is from an 1863 account of the freshwater mussels of lower Canada (Whiteaves 1863). Subsequent to this initial account, there are historical records of Hickorynut from the St. Lawrence River from 1890, 1905, 1947, 1953, 1974 and 1982.

More recently, the MRNF have undertaken substantial sampling efforts to record the presence and estimate the abundance of Hickorynut throughout the St. Lawrence River. Most notable, was the discovery of what is considered to be the largest population of Hickorynut in Canada near the municipality of Deschambault-Grondines, Quebec. Sampling efforts at this site since 2007 have resulted in the capture of 586 live individuals, 17 fresh shells and 33 weathered shells (information on whether these live individuals were recaptures was not available). Surveys in 2007 resulted in an estimated abundance of 0.75 individuals/m^2 (A. Paquet and C. Laurendeau, MRNF in COSEWIC 2011). Surveys at Grondines from 2007 to 2012 recorded the presence of numerous juvenile Hickorynut providing evidence that recruitment is occurring at this site. In addition, 72 fresh shells were recorded in 2010 at Berthierville (I. Picard, unpubl. data).

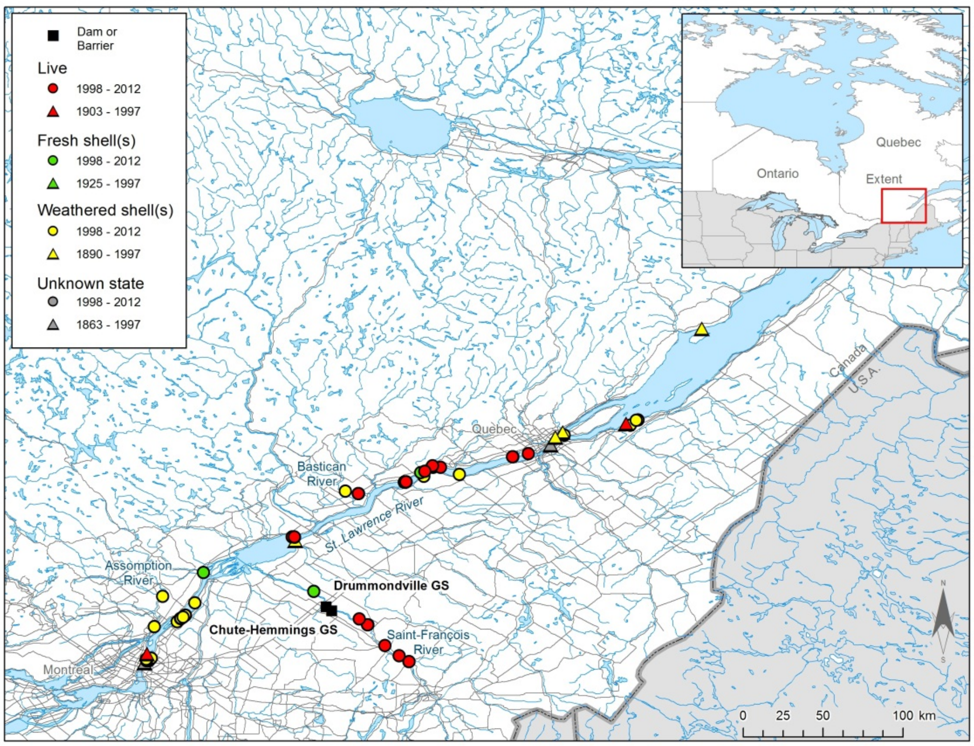

Figure 5. Distribution of all known current and historic Hickorynut records from the St. Lawrence River and its tributaries.

Extensive sampling for Hickorynut occurred throughout the St. Lawrence River in 2012 (MRNF, unpubl. data). It should be noted that live individuals were only observed from downstream sites (Grondines, 468 live individuals, 15 fresh shells and 19 weathered shells; Trois-Rivières, five live individuals), while only weathered shells were observed at upstream sites (Contrecoeur, 29 shells; Longueuil, four shells). Shell lengths from all live Hickorynut and fresh shells observed from 2005 to 2012 were recorded (A. Paquet, MRNF, unpubl. data; Figure 6).

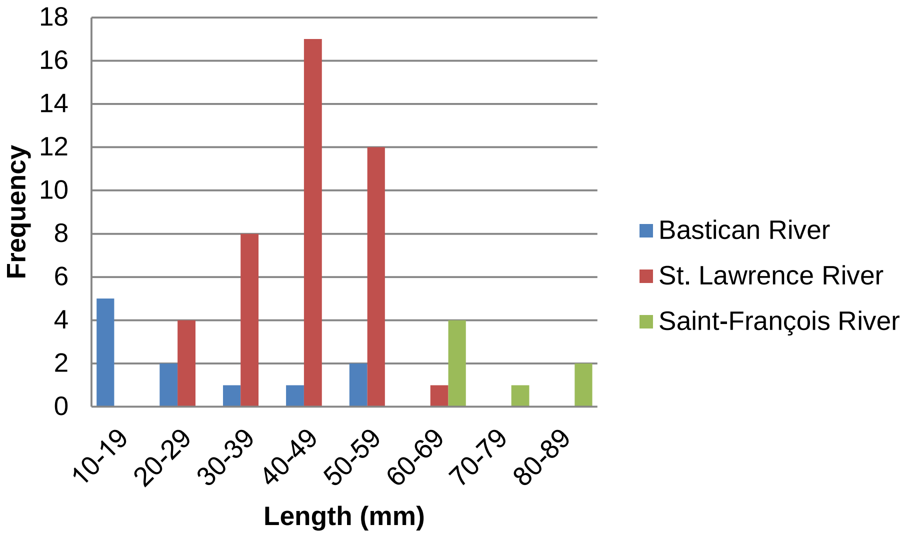

Figure 6. Size distribution for live Hickorynut and fresh shells recorded during field sampling between 2005-2012 in the Batiscan, St. Lawrence and Saint-François River.

Saint-François River

The Hickorynut population from the Saint-François River was first discovered in 2002, when one fresh shell and 23 weathered shells were recorded (I. Picard and A. Paquet, MRNF, unpubl. data). Since the initial discovery of this population, 15 live individuals and seven weathered shells have been recorded from this system. Of these records, one fresh shell and 13 weathered shells were recorded at a single site downstream of Drummondville, Quebec at Saint-Joachim-de-Courval, Quebec, while the remaining individuals were recorded from seven sites upstream of Drummondville. The upstream site is approximately 2 km north of the hydroelectric dam at Windsor.

Batiscan River

The Batiscan River is a large river system that flows into the St. Lawrence River at a point downstream and northeast of Trois-Rivières, Quebec. Hickorynut was first discovered in the Batiscan River in 2002 when 14 live individuals, two fresh shells, and one weathered shell was recorded from a site approximately 5 km downstream from its confluence with the St. Lawrence River (A. Paquet, MRNF, unpubl. data). Subsequent to its discovery, Hickorynut have been recorded from this site on the Batiscan River in 2003 (one fresh shell), 2005 (six live individuals, one weathered shell), and 2006 (five live individuals). Hickorynut is only known from one additional site in the Batiscan River, approximately 8 km upstream from the site of discovery. A single weathered shell was collected from this upstream site in 2006 (A. Paquet, MRNF, unpubl. data). Shell length was noted for 11 live individuals and two weathered shells recorded during the 2005-2006 surveys (A. Paquet, MRNF, unpubl. data; Figure 6).

Assomption River

There are only two records of Hickorynut from the Assomption River. The first consists of two weathered shells collected in 1998 (F. Cotton, MRNF, unpubl. data) and the second consists of a single weathered shell collected in 2001 (I. Picard, MRNF, unpubl. data). Limited information is available regarding Hickorynut at present in this system. Additional sampling is needed to determine whether an extant population of Hickorynut is present.

GREAT LAKES AND CONNECTING CHANNELS (EXTIRPATED)

It is important to provide context of the mussel sampling effort that has occurred in Ontario when considering the current state of Hickorynut in the Great Lakes and connecting channels; therefore, sampling locations of all known sampling sites in Ontario are illustrated in Figure 7. Information contained in this figure was drawn from data in the Lower Great Lakes Unionid Database (Metcalfe-Smith et al. 1998) as well as additional sources including COSEWIC reports, published and unpublished reports and information from the Bishops Mills Natural History Centre.

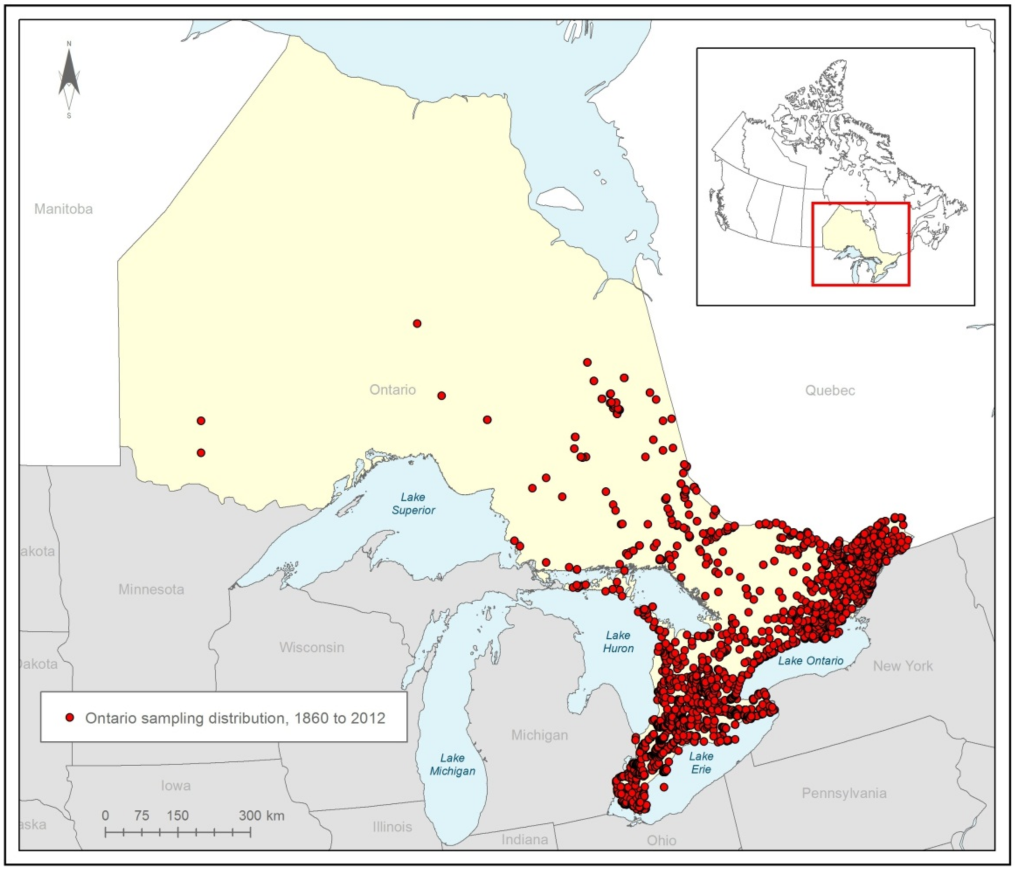

Figure 7. Distribution of all known historic and current freshwater mussel sampling in Ontario.

Prior to the introduction of the invading dreissenid mussels Hickorynut occurred at very low numbers throughout the Great Lakes and their connecting channels. The likely extirpation of Hickorynut from the Great Lakes and their connecting channels has been attributed to the introduction of dreissenid mussels.

Lake Erie

There is only a single record of Hickorynut from the Great Lakes proper, located in Lake Erie (1925) (Figure 8). The only record is from the north shore of Lake Erie near Oxley, Ontario. Very limited locational information is available for this record, and the state of the specimen (fresh or weathered shell) was not recorded.

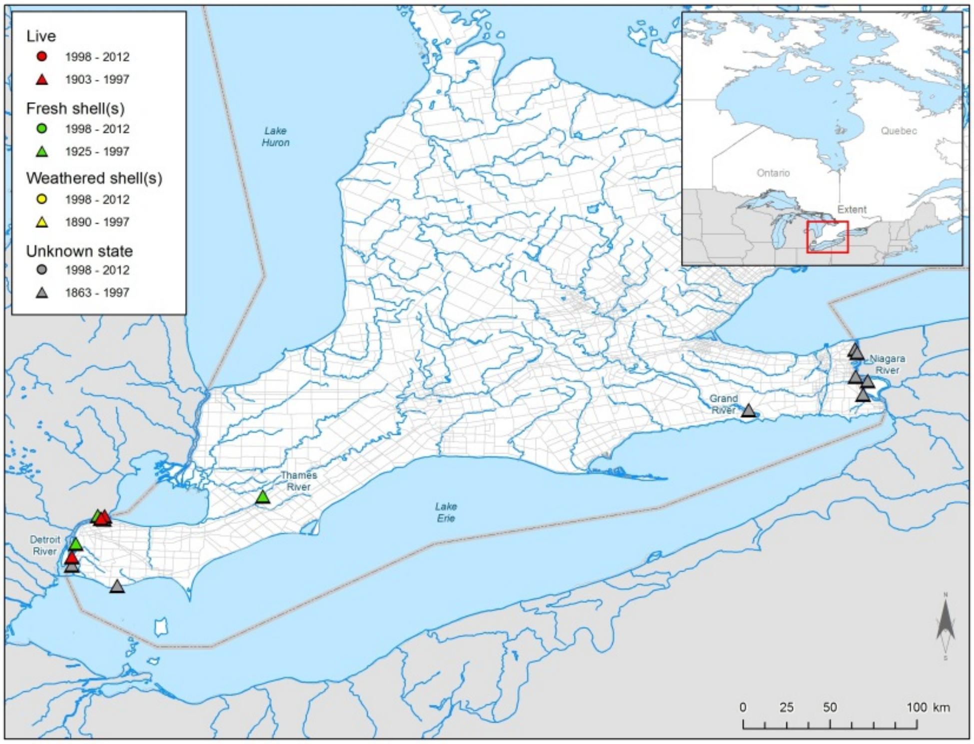

Figure 8. Distribution of all known current and historic Hickorynut records from Great Lakes and their connecting channels.

Detroit River

Hickorynut was first noted from the Detroit River in 1934. This species was subsequently reported from this system in 1982 (nine live individuals), 1992 (one live individual, five fresh shells), and 1994 (one fresh shell) (Schloesser et al. 2006; COSEWIC 2011). The 1994 record was to be the last Hickorynut record from the Detroit River. Additional sampling occurred in the Detroit River in 1996 but did not yield any Hickorynut (Schloesser et al. 2006).

Niagara River

Records from 1903, 1931, 1932, 1934 and 1935 provide supporting evidence of an historical Hickorynut population in the Niagara River. The New York Power Authority commissioned a study to the Riveredge Associates LLC aimed at surveying the mussel assemblage on the American side of the Niagara River in 2001 and 2002 (COSEWIC 2011). Although Hickorynut was not found alive, numerous weathered and sub-fossil shells were inventoried, indicating a once-productive population (COSEWIC 2011). Additional sampling of preferred habitat is necessary in Canadian waters to verify that Hickorynut is currently extirpated from the Niagara River.

Grand River

There is a single record of Hickorynut in the Grand River, Ontario from 1963. The record did not indicate the state of the shell, but only specifies that the individual was found directly below the dam at Dunnville, Ontario.

Thames River

A single record of Hickorynut exists for the Thames River, Ontario from 1934. This record consists of a single fresh shell (ROM accession number 115) and was verified to be Hickorynut by the authors. Extensive unionid sampling has occurred in this system over the past two decades, and it is believed that Hickorynut no longer exists in this system.

POPULATION SATUS ASSESSMENT

POPULATION CATEGORIZATION

For the purposes of this RPA, populations have been delineated based on the ability of the host fish to move from one location where Hickorynut is known to exist to another. The putative host for Hickorynut is Lake Sturgeon (Brady et al. 2004). Lake Sturgeon distribution in Canada directly overlaps that of Hickorynut. A thorough review of Lake Sturgeon abundance and distribution in various reaches of the Ottawa River is available (Haxton 2002). The ability of Hickorynut to disperse via its host fish during the obligate parasitic phase was considered when determining the population structure used for the Population Status Assessment.

Lake Sturgeon have the ability to migrate over long distances but this movement in both the Ottawa and Saint-François rivers may be impeded by the presence of numerous dams. Natural and man-made barriers within the known Hickorynut distribution in the Ottawa River include the Otto Holden Generating Station (GS), the Des Joachims GS, the Cheneaux GS, the Chats Falls GS, the Chaudière Falls Dam, and the Carillon GS (Haxton 2002). Barriers to movement on the Saint-François River within the known Hickorynut distribution include the Chute-Hemming GS, and the Drummondville GS. A literature review was completed to categorize Lake Sturgeon movement, upstream and downstream of all dams within the known distribution of Hickorynut (Haxton 2002; Haxton and Chubbuck 2002; Haxton 2008; T. Haxton, Ontario Ministry of Natural Resources, pers. comm.; S. Roy, Unité de gestion des Ressources naturelles et de la Faune de l'Estrie, pers. comm.; Table 1).

Table 1. Summary of all known man-made barriers to Lake Sturgeon movement on the Ottawa and Saint-François rivers within the distribution of Hickorynut, and categorization of whether Lake Sturgeon are likely to move through these barriers both upstream and downstream.

Population	Name of Barrier	Lake Sturgeon Movement Upstream	Lake Sturgeon Movement Downstream
Ottawa River	Otto Holden GS	Impassable	Passable
	Des Joachims GS	Impassable	Passable through sluice gates
	Rocher Fendu Dam	Impassable	Passable
	Chenaux GS	Impassable	Passable through sluice gates
	Chats Falls Dam	Impassable	Passable through tail race
	Chaudière Falls Dam	Impassable	Passable
	Carillon GS	Passable through boat locks	Passable through boat locks
Saint-François River	Drummondville GS	Impassable	Passable through sluice gates
	Chute-Hemming GS	Impassable	Passable

Downstream passage of Lake Sturgeon through hydroelectric facilities may cause harm or mortality from exposure to changes in water pressure, cavitation, shear, turbulence or mechanical injury (Cada 1998 *in* Golder Associates Ltd. 2011). The level of mortality of adult Lake Sturgeon passage through sluice gates, as well as juvenile Lake Sturgeon movement through turbines is currently unknown. Intakes of hydroelectric facilities are generally covered by grates spaced to prevent the passage of adult Lake Sturgeon, but this does not exclude juveniles (Golder Associates Ltd. 2011). It is also possible that Lake Sturgeon of all age classes move downstream over the weir, or through pipe flows (S. Roy, pers. comm.).

Fish movement across hydroelectric dams has been recorded. Knights et al. (2002) successfully tracked the movement of Lake Sturgeon both upstream and downstream past dams in the Mississippi River. In addition, Thuemler (1985) tracked Lake Sturgeon movement downstream over dams in the Menominee River, Wisconsin/Michigan. During a study commissioned by Manitoba Hydro in 2006 to determine fish movement between and across the Pointe du Bois GS and the Slave Falls GS it was found that one Lake Sturgeon was tagged upstream of the Pointe du Bois GS and was later recaptured downstream of the GS (DFO 2010b). Two additional Lake Sturgeon tagged downstream of the Pointe du Bois GS, were later recaptured downstream of the Slave Falls GS (DFO 2010b) providing evidence that adult Lake Sturgeon movement downstream across a GS is possible.

Currently, there have been no studies tracking Lake Sturgeon in the Ottawa or Saint-François rivers; however, Walleye (*Sander vitreus*) have been successfully tracked over the Chenaux GS (T. Haxton, Ontario Ministry of Natural Resources, pers. comm.). Considering Lake Sturgeon's natural ability to move downstream over substantial natural barriers (Welsh and McLeod 2010) and evidence indicating the movement of adult Lake Sturgeon across GS (DFO 2010b), it is possible that Lake Sturgeon infested with Hickorynut glochidia are making such movements. Therefore, for the purposes of the Recovery Potential Assessment, the Ottawa River Hickorynut population is considered a continuous population, as well, the Saint-François River Hickorynut population is considered continuous with the St. Lawrence River population via Lake Sturgeon movement.

Despite the ability of Lake Sturgeon to move across the Carillon GS (Ottawa River; see Table 1) and potentially migrate to the St. Lawrence River, zoogeography and morphological differences suggest distinctness between Lake Sturgeon stocks from the Ottawa and St. Lawrence rivers (Haxton 2008). Specifically, it is believed that Ottawa River Lake Sturgeon colonized through the Fossmill outlet and later the North Bay outlet during the retreat of the Wisconsin glacier (Mandrak and Crossman 1992). Also, the existence of the marine Champlain Sea (up to 7000 years ago) precluded colonization from the St. Lawrence River (Mandrak and Crossman 1992). In addition, morphological difference in head measurements indicated differences between Lake Sturgeon from these two systems (Guénette et al. 1992). This was further supported by mitochondrial DNA variations between Ottawa River and St. Lawrence River Lake Sturgeon (Guénette et al. 1993).

Bearing in mind the review of Lake Sturgeon movement, and due to similarities in both habitat characteristics and threats affecting Hickorynut throughout the various reaches of the Ottawa River, all Hickorynut along the Ottawa River will be considered a single population. The Batiscan, Assomption and St. Lawrence rivers will be considered a single population as Lake Sturgeon movement between these sites is free of dams or barriers. These three sites, within the range of Hickorynut distribution, are also very similar in terms of habitat and the threats providing additional support for a single population. From this point forward, this population will be referred to as the St. Lawrence River population. Although Lake Sturgeon downstream movement across the generating stations on the Saint-François River is possible, both the habitat characteristics and the various threats affecting Hickorynut at this site vary considerably from those of the St. Lawrence River; therefore, the Saint-François River will be considered a separate population.

ASSESSMENT

To assess the Population Status of Hickorynut populations in Canada, each population was ranked in terms of its abundance (Relative Abundance Index) and trajectory (Population

Trajectory) (Table 2). The Relative Abundance Index was assigned as Extirpated, Low, Medium, High, or Unknown. Sampling parameters considered included sampling method, area sampled, sampling effort, and whether the study was targeting Hickorynut. The number of individual Hickorynut caught during each sampling period was then considered when assigning the Relative Abundance Index. The Relative Abundance Index is a relative parameter in that the values assigned to each population are relative to the most abundant population. In the case of Hickorynut, all populations were assigned an Abundance Index relative to the Hickorynut population from the St. Lawrence River. It is important to remember that the Relative Abundance Index is based on Hickorynut records currently available. There is a need for species-targeted sampling to allow for further refinement of the assessment.

The Population Trajectory was assessed as Decreasing, Stable, Increasing, or Unknown for each population based on the best available knowledge about the current trajectory of the population. The number of individuals caught over time for each population was considered. Trends over time were classified as Increasing (an increase in abundance over time), Decreasing (a decrease in abundance over time) and Stable (no change in abundance over time). If insufficient information was available to inform the Population Trajectory it was listed as Unknown.

Certainty has been associated with the Relative Abundance Index and Population Trajectory rankings and is listed as: 1=quantitative analysis; 2=CPUE or standardized sampling; 3=expert opinion.

Table 2. Relative Abundance Index and Population Trajectory of each Hickorynut population in Canada. Certainty has been associated with the Relative Abundance Index and Population Trajectory rankings and is listed as: 1=quantitative analysis; 2=CPUE or standardized sampling; 3=expert opinion.

Population	Relative Abundance Index	Certainty	Population Trajectory	Certainty
Mississagi River	Low	2	Unknown	3
Ottawa River	Medium	2	Unknown	3
St. Lawrence River	Medium	2	Unknown	3
Saint-François River	Low	2	Unknown	3
Great Lakes and connecting channels	Extirpated	2	-	-

The Relative Abundance Index and Population Trajectory values were then combined in the Population Status matrix (Table 3) to determine the Population Status for each population. Population Status was subsequently ranked as Poor, Fair, Good, Unknown, or Not applicable (Table 4). Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index, or Population Trajectory).

Table 3. The Population Status Matrix combines the Relative Abundance Index and Population Trajectory rankings to establish the Population Status for each Hickorynut population in Canada. The resulting Population Status has been categorized as Extirpated, Poor, Fair, Good, or Unknown.

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

Table 4. Population Status of all Hickorynut populations in Canada, resulting from an analysis of both the Relative Abundance Index and Population Trajectory. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index, or Population Trajectory).

Population	Population Status	Certainty
Mississagi River	Poor	3
Ottawa River	Poor	3
St. Lawrence River	Poor	3
Saint-François River	Poor	3
Great Lakes and connecting channels	Extirpated	3

HABITAT REQUIREMENTS

GLOCHIDIUM

To fully understand the habitat requirements of freshwater mussels, we must first understand their unique life cycle. During the spawning period, males located upstream release sperm into the water column via the excurrent siphon (COSEWIC 2011). Females subsequently utilize their gills to filter the sperm from the water column, and the sperm is deposited in the posterior portion of the female gill, in a specialized region, where the ova are fertilized. The fertilized ova are held until they reach a larval stage. Although some freshwater mussels are obviously sexually dimorphic (mature females characterized by a swelling of the posterior-ventral margin), there is very subtle sexual dimorphism in Hickorynut.

Freshwater mussels are often categorized in terms of their brooding and glochidial release patterns (Watters and O'Dee 2000). Two brooding categories are long-term brooders (bradytictic) and short-term brooders (tachytictic). Hickorynut is classified as a long-term brooder, spawning in late summer, brooding their glochidia over the winter and subsequently releasing their glochidia the following summer. Gravid females with glochidia have been found from August to June of the following summer (COSEWIC 2011). Gravid females have been observed during September surveys of the Mississagi River, as well during October surveys in the Ottawa River (COSEWIC 2011; A Martel, pers. comm. in COSEWIC 2011). Regardless of brooding strategy, once females release their glochidia they must encyst on the gills of an appropriate host fish (Kat 1984).

Shovelnose Sturgeon (*Scaphirhynchus platorynchus*) is the only host fish recorded to have been successfully infested by Hickorynut glochidia in a non-laboratory setting (Howard (1914) and Coker et al. (1921) *in* Watters et al. 2009). A subsequent laboratory experiment provided evidence that Lake Sturgeon may also act as a host fish for this species (Brady et al. 2004). A study conducted by Brady et al. (2004) placed eight juvenile Lake Sturgeon in a bucket containing one litre of water and glochidia from two female Hickorynut for approximately five minutes. Lake Sturgeon were subsequently moved to a 38-litre aquarium and surveyed for juveniles every other day (Brady et al. 2004). Juveniles were siphoned and removed from the system once found, which occurred 15 days post-infestation (Brady et al. 2004).

This relationship was further explored in additional Hickorynut infestation experiments where Shovelnose Sturgeon, Pallid Sturgeon (*S. albus*) and Lake Sturgeon were all found to be suitable hosts, transforming a significant number of juveniles in a laboratory setting (B. Sietman, Minnesota Department of Natural Resources, unpubl. data; M. Hove, University of Minnesota, unpubl. data). Additional hosts that were tested but only produced a few juveniles included Brook Stickleback (*Culea inconstans*), Central Mudminnow (*Umbra limi*), Mosquitofish (*Gambusia affinis*), Guppy (*Poecilia reticulata*) and Goldeye (*Hiodon alosoides*) (B. Sietman, pers. comm.). Although a few transformations did occur with these hosts, it is thought that these fishes would be unlikely hosts in a natural environment (B. Sietman, pers. comm.). Additional successful infestation experiments, with Lake Sturgeon as the host, have been conducted at the Genoa National Fish Hatchery, Genoa, Wisconsin (N. Eckert, U.S. Fish and Wildlife Service, unpubl. data). Typically, 15-20 cm Lake Sturgeon are used in the infestation experiments and as many as 1200 juvenile Hickorynut have been recovered from a single fish (N. Eckert, pers. comm.). When held at approximately 21°C, juveniles release 20 to 25 days post-infestation (N. Eckert, pers. comm.).

Shovelnose and Pallid sturgeons do not occur in Canadian waters, while the distribution of all remaining Canadian Hickorynut populations directly overlap with those of Lake Sturgeon (Pratt 2008). This overlap in distribution provides circumstantial evidence to the probable host-mussel relationship between Hickorynut and Lake Sturgeon. Many factors must be considered when discussing the suitability and probability of a successful host fish encounter. The host fish must not only be present in the system in sufficient numbers, but must be of appropriate age, health and immunity to be susceptible to infestation and act as a candidate host fish. Specific criteria related to these factors are currently unknown for the Hickorynut and Lake Sturgeon interaction and should be the focus of future studies.

Many species of freshwater mussels have evolved complex host attraction strategies to increase the probability of encountering a suitable host (Zanatta and Murphy 2006). Hickorynut do not seem to utilize any active host-attraction strategy and do not appear to have a lure (Zanatta and Murphy 2006). However, Hickorynut do have a specialized brooding behavior, in that they position themselves so that the posterior-ventral shell margin is about flush with the sediment surface, the mantle covers a modest shell gape, and the mantle will retract, exposing the gills, in response to being touched by a finger (B. Sietman, pers. comm.). One could imagine that this type of behavior would lend itself well to successful infestation of a benthic feeding host fish, such as Lake Sturgeon. Natural infestation of Lake Sturgeon by Hickorynut glochidia has never been observed in a natural setting, and the details of this interaction are currently unknown. Attachment times in the field are also currently unknown.

Regardless of the method of exposure and attachment, glochidia will remain encysted on the host fish until they metamorphose into juveniles. Encystement is an obligate step in the life cycle of Hickorynut and development will not occur in the absence of this phase. The gills of the appropriate host fish can be considered a habitat requirement for the glochidial life stage of Hickorynut.

JUVENILE

Subsequent to metamorphosis, juvenile freshwater mussels are released from the gills of the host fish and bury themselves in the substrate until maturity. Time to maturity can vary from one mussel species to another and accurate estimates are not known for most species. The proportion of glochidia that survive to the juvenile stage is estimated to be as low as 0.000001% (Jansen and Hanson 1991; COSEWIC 2006b, 2007). A survival tactic to overcome this increased level of mortality is to produce very high numbers of glochidia. It is difficult to classify required habitat for juvenile mussels because they are difficult to detect and because they have a tendency to burrow. Once sexually mature they emerge from the substrate to participate in gamete exchange (Watters et al. 2001).

ADULT

Adult Hickorynut habitat is generally described as sand or mixed sand gravel substrate in relatively deep water with moderate to fast water velocity in large river systems (Metcalfe-Smith et al. 2005).

Stream characteristics

Hickorynut is generally categorized as occupying large, deep, wide river systems, relative to other Canadian freshwater mussel species (COSEWIC 2011). They are generally recorded at depths ranging from 2 to 5 m. On the Ottawa River, a SCUBA dive survey conducted at MacLaren's Landing, and the Mohr Island area, recorded Hickorynut at depths between 1.5 and 6 m (Martel et al. 2006; COSEWIC 2011). Another SCUBA dive survey along the north shore of the Chenal-de-la-Culbute (Ottawa River) recorded shells in 3 to 4 m of water, but did not record any live individuals (COSEWIC 2011). In the Mississagi River, a total of ten live individuals were captured in water ranging from 1.5 to 4 m deep (Zanatta and Woolnough 2011).

It is difficult to discuss preferred water depth for most St. Lawrence River sampling, as sites are greatly influenced by tidal water movements, and are typically sampled during low tide. For example, three live Hickorynut were recorded from Grondines, Quebec (St. Lawrence River) during low water levels at a depth of 0.5 m (A. Paquet, MRNF, unpubl. data). Although this water depth would not be considered typical for this species, it should be noted that it has adapted to survive in areas that undergo substantial daily fluctuations in water levels. Caution must be taken when interpreting depth preferences for Hickorynut from a system greatly influenced by tidal water movements. On the opposite end of this spectrum, live Hickorynut have been recorded from a maximum sampling depth of 9.7 m near Portneuf, Quebec on the St. Lawrence River when two live individuals were incidentally captured in two nets during fish surveys (8.6 and 9.7 m) (P.-Y., Collin, MRNF, unpubl. data). These incidental captures provide evidence that Hickorynut may also be found at water depths greater than previously sampled. Also, the maximum water depth where this species can survive is currently unknown. Sampling has not occurred at very great depths, and it is not known if a maximum depth preference exists for this species.

Water velocity

It is difficult to discuss water velocity preferences as most of the data collected during Hickorynut surveys only provided qualitative estimates of water velocity. Descriptors such as occupying water of 'good current' (Metcalfe-Smith et al. 2005), 'moderate to strong current' (Parmalee and Bogan 1998; COSEWIC 2011) and 'moderate current' (Martel et al. 2006) have been used in the literature. Water velocity was recorded during the 2012 sampling of Hickorynut from Grondines, Quebec and ranged from 0.0 to 0.3 m/s at sites where live Hickorynut was recorded (A. Paquet, MRNF, unpubl. data). Although it is difficult to assess the range of preferred water velocity, it is important that a natural flow regime is maintained in systems where Hickorynut is known to occur. A natural flow regime is required to maintain clean substrate by decreasing silt deposits, provide a source of food to this filter-feeding species, and distribute gametes to aid in reproduction.

Substrate

Substrate at sites where Hickorynut has been recorded is generally described as sandy (Parmalee and Bogan 1998), muddy sand or gravel (Watters et al. 2009), sand or mixed sand

and gravel (Metcalfe-Smith et al. 2005) or sandy and silty sand bottom areas (D. Zanatta and A. Martel, pers. obs. in COSEWIC 2011). Substrate estimates (percent composition), were recorded at sites where live Hickorynut were recorded between 2002 and 2012 on the St. Lawrence, Batiscan and Saint-François rivers (A. Paquet, MRNF, unpubl. data; Figure 9). Sites on the St. Lawrence River follow classic descriptions provided in the literature in that many of the sites were composed of a mixture of sand, silt and gravel. Sites in the Batiscan River were categorized as being sand-dominated (≥ 85% at all sites), while sites in the Saint-François River differed significantly from the conventional habitat description. Sites in the Saint-François River were categorized as having very little sand (≤ 20% at all sites) and all sites were categorized as having relatively similar levels of bedrock, boulder and rubble, and trace amounts of gravel. This not only represents a significant divergence from the conventional substrate description provided for Hickorynut, but also indicates a larger range of substrate tolerances. It should be noted that although Hickorynut was found in areas dominated by larger substrates, pockets of finer substrate (sand, and silt) are necessary and Hickorynut is generally found within these pockets.

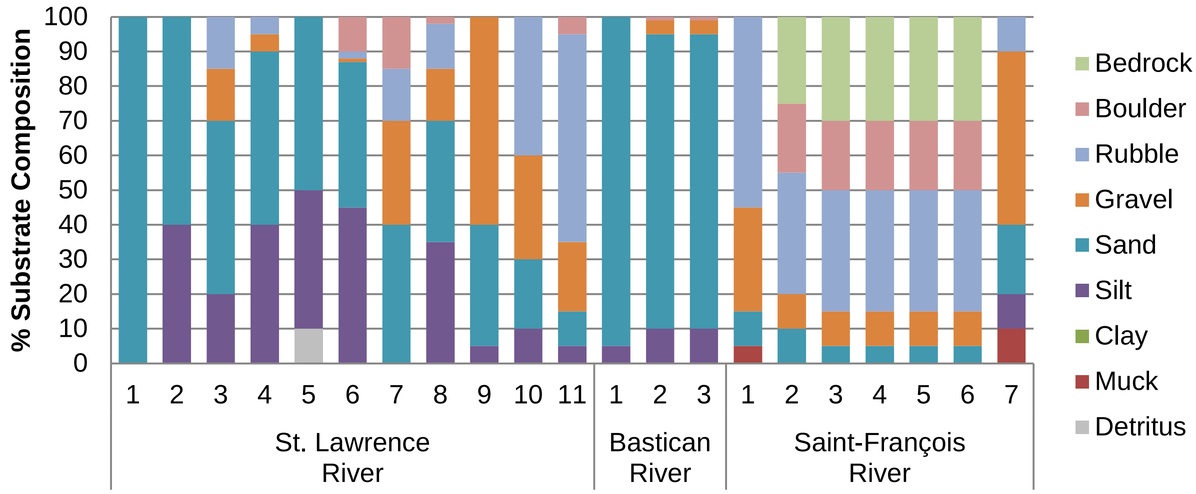

Figure 9. Substrate composition (%) recorded at sites where live Hickorynut was recorded from 2002-2012 in the St. Lawrence, Batiscan and Saint-François rivers.

FUNCTIONS, FEATURES AND ATTRIBUTES

A description of the functions, features, and attributes associated with Hickorynut habitat can be found in Table 5. The habitat required for each life stage has been assigned a function that corresponds to a biological requirement of Hickorynut. In addition to the habitat function, a feature has been assigned to each life stage. A feature is considered to be the structural component of the habitat necessary for the survival or recovery of the species. Habitat attributes have also been provided, which describe how the features support the function for each life stage. Optimal habitat attributes from the literature for each life stage have been combined with habitat attributes from current records (records from 2002 to present) to show the maximum range in habitat attributes within which Hickorynut may be found (see Table 5, and references therein). This information is provided to guide any future identification of critical habitat for this species. It should be noted that habitat attributes associated with current records may differ from those presented in the scientific literature as Hickorynut may be currently occupying areas of sub-optimal habitat where optimal habitat is no longer available.

Table 5. Summary of the essential functions, features and attributes for each life stage of Hickorynut. Habitat attributes from published literature, and habitat attributes recorded during recent Hickorynut surveys (captured over the last 10 years or since 2002) have been combined to derive the habitat attributes required for the delineation of critical habitat (see text for a detailed description of categories).

			Habitat Attributes		
Life Stage	**Function**	**Feature(s)**	**Scientific Literature**	**Current Records**	**For Identification of Critical Habitat**
Spawning and fertilization (long-term brooder: gravid females with glochidia found between August to June; COSEWIC 2011)	Reproduction	Large river systems		• Gravid females observed at the same locations as other non-spawning adult Hickorynut in the Mississagi and Ottawa rivers (COSEWIC 2011)	• Same habitat as adults
Encysted glochidial stage on host fish until drop off	Development	Appropriate host fish	• Natural infestation of Hickorynut on gills of Shovelnose Sturgeon (Howard 1914 and Coker et al. 2001 *in* Watters et al. 2009) • There are no historic records of natural infestation of Lake Sturgeon by Hickorynut • Hickorynut successfully transformed in Lake Sturgeon infestation experiments (Brady et al. 2004; B. Sietman, unpubl. data; M. Hove, unpubl. data; N. Eckert, unpubl. data) • Lake Sturgeon distribution directly overlaps Hickorynut distribution (Pratt 2008) providing circumstantial evidence of host fish interaction	• There are no records of natural infestations of Hickorynut glochidia on gills of Lake Sturgeon	• Presence of sufficient host fish (putative host fish in Canadian waters is Lake Sturgeon)
Adult/juvenile	Feeding Cover Nursery	Large river systems with flow within the range of natural variability	**Stream characteristics** • Categorized as occupying large, deep, wide river systems, relative to other Canadian freshwater mussel species (COSEWIC 2011) • Recorded at depths ranging from 0.5 to 9.7 m	• Ottawa River: SCUBA dive survey recorded live Hickorynut at depths between 1.5 and 6 m (Martel et al. 2006; COSEWIC 2011) • Mississagi River: total of ten live individuals were captured in water ranging from 1.5 to 4	• Occupy a wide range of water depths, ranging from 0.5 to 9.7 m

			Habitat Attributes		
Life Stage	**Function**	**Feature(s)**	**Scientific Literature**	**Current Records**	**For Identification of Critical Habitat**
				m (Zanatta and Woolnough 2011) • St. Lawrence River (Grondines): Three live Hickorynut were recorded from at a depth of 0.5 m during low tide (A. Paquet, MRNF, unpubl. data) • Portneuf, Quebec (St. Lawrence River: Two live Hickorynut were recorded from a maximum sampling depth of 9.7 m (incidentally captured in two nets during fish surveys; 8.6 and 9.7 m) (P.-Y., Collin, MRNF, unpubl. data)	
			Water velocity • Descriptors such as occupying water of 'good current' (Metcalfe-Smith et al. 2005), 'moderate to strong current' (Parmalee and Bogan 1998; COSEWIC 2011) and 'moderate current' (Martel et al. 2006) have been used in the literature.	• Water velocity recorded during the 2012 sampling of live Hickorynut from Grondines, Quebec ranged from 0.0 to 0.3 m/s (A. Paquet, MRNF, unpubl. data).	
			Substrate • Substrate at sites where Hickorynut has been recorded is generally described as sandy (Parmalee and Bogan 1998), muddy sand or gravel (Watters et al. 2009), sand or mixed sand and gravel (Metcalfe-Smith et al. 2005) or sandy and silty sand bottom areas (D. Zanatta and A. Martel, pers. obs. in COSEWIC 2011)	• St. Lawrence River: composed of a mixture of sand, silt, and gravel (similar to scientific literature) • Batiscan River: sand-dominated (≥ 85% at all sites), • Saint-François River: very little sand (≤ 20% at all sites) and all sites were categorized as having relatively similar levels of bedrock, boulder and rubble, and trace amounts of gravel (differed significantly from description provided in scientific literature).	• Ability to survive in a wide range of substrate types, with the exception of muck and clay.

			Habitat Attributes		
Life Stage	**Function**	**Feature(s)**	**Scientific Literature**	**Current Records**	**For Identification of Critical Habitat**
			Presence of dreissenid mussels • Introduction and establishment of dreissenid mussels has led to the decline of Hickorynut (COSEWIC 2011)	• Recent sampling (2004-12) has found the presence of Zebra Mussel attached to the shell of five live Hickorynut, and an additional four Hickorynut with byssal threads on their shells (A. Paquet, unpubl. data)	

RESIDENCE

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

THREATS

In the past 30 years, species diversity and abundance of native freshwater mussels has declined throughout Canada and the United States (Williams et al. 1993). It appears that the greatest limiting factors to the stabilization and growth of freshwater mussel populations in Canada are largely attributed to the introduction and establishment of dreissenid mussels and decreases in the quality of available freshwater mussel habitat. The historic vast distribution of freshwater mussels in the Great Lakes and their connecting channels has been devastated by the introduction of dreissenid mussels, and many of the areas once inhabited by freshwater mussels no longer provide suitable habitat. In addition, evidence suggests that decreases in water quality, specifically increased turbidity and suspended solids, increased nutrient loading, and increased levels of contaminants and toxic substance are also limiting the distribution of freshwater mussels. These declines in water quality are the result of activities such as dam construction and impoundments, channel modifications (e.g., channelization, dredging, snagging) and land-use practices (e.g., farming, mining, construction) (Bogan 1993; Williams et al. 1993; Watters 2000). Impoundments typically result in siltation, pollutant accumulation and nutrient-poor water, while dams alter flow and temperature regimes and separate mussels from their host fish (Bogan 1993; Watters 2000). Land-use practices such as farming, “logging, mining and construction usually result in the runoff of sediments, pollutants and salt into streams (Bogan 1993; Watters 2000).

Due to the obligate glochidial encystement stage, Hickorynut is directly affected by host fish abundance and indirectly affected by the threats affecting the host fish. The distribution of many freshwater mussel species can be limited by the distribution of their host fish. Lake Sturgeon is the only putative host fish for Hickorynut in Canada (see Habitat Requirements section) and Lake Sturgeon [designatable unit (DU) 8 Great Lakes-Upper St. Lawrence populations, which overlaps the entire Canadian Hickorynut distribution] is currently designated as Threatened by COSEWIC (COSEWIC 2006a). Declines in Lake Sturgeon abundance throughout DU 8 have been attributed to a historical, large commercial fishery that existed in the Great Lakes between the mid-1800s to early 1900s (COSEWIC 2006a). In addition, dam construction in the Ottawa River and overexploitation, despite recovery efforts, in the St. Lawrence River, have contributed to the decline of this species throughout its range (COSEWIC 2006a).

A wide variety of threats negatively affect Hickorynut across its range. Our knowledge of threat impacts on Hickorynut populations is limited to general documentation, as there is a paucity of threat-specific cause and effect information in the literature. It is important to note the threats discussed below may not always act independently on Hickorynut populations; rather, one threat may directly affect another, or the interaction between two threats may introduce an interaction effect. It is quite difficult to quantify these interactions; therefore, each threat is discussed independently.

INVASIVE SPECIES

The biggest direct threat to Hickorynut in Canada is infestation by invasive dreissenid mussels (Zebra Mussel, *Dreissena polymorpha*; Quagga Mussel, *Dreissena rostriformis*). The invasion and spread of these invasive species through the Great Lakes and their tributaries has devastated many native freshwater mussel populations (Haag et al. 1993; Schloesser and Nalepa 1994; Nalepa et al. 1996; Ricciardi et al. 1996; Schloesser et al. 1996; Schloesser et al. 1998; Zanatta et al. 2002). Within approximately ten years of their initial invasion (Zebra Mussel 1986; Quagga Mussel 1991) native unionids had been almost completed eradicated from the Great Lakes and their connecting channels (COSEWIC 2011). This included the destruction of habitat previously occupied by Hickorynut in both the Detroit and Niagara rivers, which lead to the likely extirpation of Hickorynut from these two systems. Zebra Mussel compete with native mussel species for space and food and can attach to freshwater mussel shells, impairing movement, burrowing, feeding, respiration, reproduction and other physiological activities (Mackie 1991; Haag et al. 1993; Baker and Hornbach 1997). This typically results in the death of the unionid mussel. Zebra Mussel exhibit rapid population growth and are able to eliminate entire unionid populations in a very short time.

This threat is particularly relevant to remnant Hickorynut populations occupying the St. Lawrence River as Zebra Mussel are now present in the upper St. Lawrence River and appear to be affecting the presence of Hickorynut in this portion of the St. Lawrence River system. During extensive sampling completed in 2012, live Hickorynut was only observed at downstream sites (Grondines and Trois-Rivières) while upstream sites (Contrecoeur and Longueuil) were devoid of live individuals (MRNF, unpubl. data). Although live individuals were collected at downstream sites, Zebra Mussel were still recorded at these sites (MRNF, unpubl. data). At Grondines two adult, and one juvenile Hickorynut were recorded as having a single Zebra Mussel attached to their shells, while an additional two individuals were recorded as having byssal threads on their shells (MRNF, unpubl. data). A 2004 Hickorynut record from Saint-Augustin-De-Desmaures (a site approximately 50 km downstream from Grondines) also recorded the presence of a single Zebra Mussel attached to the shell of a live Hickorynut (MRNF, unpubl. data). Evidence of past Zebra Mussel attachment on live Hickorynut (presence of byssal threads) was recorded during sampling at Contrecoeur (n=7), Grondines (n=4), Portneuf (n=1), Sainte-Croix (n=15), Trois-Rivières (n=2) and Verchères (n=1) (MRNF, unpubl. data; I. Picard, unpubl. data; Figure 10).

Figure 10. Evidence of Zebra Mussel attachment on a live Hickorynut recorded from a site at Trois-Rivières, Quebec in 2012 (© A. Paquet, reproduced with permission).

Despite the catastrophic effects of the dreissenid invasion, there are portions of the St. Lawrence River that, due to hydrology, water movements and water quality appear to act as a refuge for native Unionid mussels, including Hickorynut. This type of refuge is similar to that described from the Lake St. Clair delta, Ontario (McGoldrick et al. 2009). In areas of the Lower St. Lawrence River, such as Grondines, Zebra Mussel densities are maintained at low levels allowing Hickorynut and Zebra Mussel to coexist (A. Paquet, pers. obs.). Although Zebra Mussel have been recorded from other portions of the Hickorynut distribution (e.g., Ottawa and Mississagi rivers), the water chemistry in these areas, namely the relatively low levels of calcium, may not lend itself to rapid colonization of Zebra Mussel through these systems (Jokela and Ricciardi 2008).

A risk assessment was recently completed to determine the ecological risk associated with both Zebra and Quagga mussel invasions across 108 Canadian sub-drainages (Therriault et al. 2013). This risk assessment considered the probability of arrival and survival based on habitat suitability. The water quality thresholds limiting Zebra and Quagga mussel distribution have been well-studied and are available in the literature (Mackie and Claudi 2010). Specifically, calcium concentrations and water temperature were used in the habitat suitability analysis to inform the probability of survival, reproduction and the ability of the Zebra or Quagga mussel to reach densities that would be considered invasive (Therriault et al. 2013).

The results of the risk assessment indicated that the upper Ottawa River, the lower St. Lawrence River and the Mississagi River sub-drainages were at low environmental risk of both Zebra Mussel and Quagga Mussel invasion, while the central Ottawa River and the upper and central St. Lawrence River sub-drainages were at high risk (Therriault et al. 2013; Table 6).

Table 6. Results of Zebra Mussel and Quagga Mussel risk assessment incorporating both risk of probability of invasion and environmental impact at the sub-watershed level. Results indicate the overall risk to the environment (modified from Therriault et al. 2013).

Hickorynut Population	Sub-drainage	Zebra Mussel	Quagga Mussel
Ottawa River	Upper Ottawa River	Low	Low
	Central Ottawa River	High	High
St. Lawrence River	Upper St. Lawrence River	High	High
	Central St. Lawrence River	High	High
	Lower St. Lawrence River	Low	Low
	St. Lawrence River proper	High	High
Mississagi River	Northern Lake Huron	Low	Low

Invasive species, notably Round Goby (*Neogobius melanostomus*) and Sea Lamprey (*Petromyzon marinus)* may also negatively affect the host fish. Round Goby may be predating on Lake Sturgeon eggs, while Sea Lamprey attachment may cause mortality in Lake Sturgeon with juveniles showing increased vulnerability.

THREATS TO HOST FISH

The obligate glochidial encystement stage necessitates access to a suitable host fish. Therefore, the distribution of many freshwater mussel species is limited by the distribution of their host fish. If host fish populations decline, recruitment will not occur, and the mussel species may become functionally extinct (Bogan 1993). Due to the obligate parasitic nature of the mussel reproductive cycle, any threat leading to the separation of mussel and host fish during reproduction can be detrimental to the mussel population. Movement is minimal in adult freshwater mussels and therefore mussels rely on host fish for dispersal into new habitats, and ultimately for genetic exchange with other populations. Please see ‘Habitat Requirements’ for a detailed description of the Hickorynut life cycle.

Table 7. Lake Sturgeon estimated population size, conservation status (critical, cautious or healthy), population trajectory (unknown, stable, increasing, or decreasing) certainty associated with both conservation status and trajectory (1=quantitative population data; 2=catch per effort data; 3=expert opinion), and population-specific threats (ranked based on expert opinion). Table modified from Pratt (2008). See Pratt (2008) for a complete description of categorization.

RPA Population Categorization	Population	Population Size	Conservation Status	Certainty	Trajectory	Certainty	Threats	Source
Mississagi River	Mississagi River	~ 500	Cautious	2	Stable	1,2	1-Changes in flow regimes; 2-Exploitation; 3-Sea lamprey predation	Mohr et al. (2007) *in* Pratt (2008)
Ottawa River	Lake Timiskaming	Unknown	Cautious	2,3	Decreasing	2,3	1-Habitat loss to dams; 2-Habitat fragmentation due to dams; 3-Exploitation; 4-Agricultural activities; 5-Changes in flow regimes; 6-Introduction of exotics	D. Nadeau, pers. comm. (*in* Pratt 2008)
Ottawa River	Mid Ottawa River (Lac Coulonge, Lower Allumette Lake, Upper Allumette Lake)	>5000	Healthy	2,3	Increasing	2,3	1-Exploitation	T. Haxton, and H. Fournier, pers. comm. (*in* Pratt 2008)
Ottawa River	Lac des Rocher Fendu	Unknown	Cautious	2,3	Unknown	2,3	No information	T. Haxton, and H. Fournier, pers. comm. (*in* Pratt 2008)
Ottawa River	Lac des Chats	Unknown	Cautious	2,3	Decreasing	2,3	1-Habitat loss due to dams; 2-Habitat fragmentation due to dams; 3-Changes in flow regimes; 4-Exploitation	T. Haxton, and H. Fournier, pers. comm. (*in* Pratt 2008)
Ottawa River	Lac Deschênes	>500	Cautious	2,3	Decreasing	2,3	1-Habitat loss due to dams; 2-Habitat fragmentation due to dams; 3-Changes in flow regimes; 4-Urbanization; 5-Exploitation; 6-Agricultural activities; 7-Industrial activities; 8-Introduction of exotics	T. Haxton, and H. Fournier, pers. comm. (*in* Pratt 2008)
St. Lawrence River	From Lake St. Louis to upper estuary	>100 000	Cautious	2,3	Decreasing	1,2	1-Exploitation (commercial, First Nation, illegal); 2-Habitat	P. Dumont and Y. Mailhot pers. comm. (*in* Pratt

RPA Population Categorization	Population	Population Size	Conservation Status	Certainty	Trajectory	Certainty	Threats	Source
							fragmentation due to dams; 3-Changes in flow regimes; 4-Water quality; 5-Introduction of other diseases (VHS); 6-Urbanization; 7-Agricultural activities; 8-Industrial activities; 9-Introduction of exotics	2008)

Lake Sturgeon is the only putative host fish for Hickorynut in Canada (see Habitat Requirements section). Threats to Lake Sturgeon have been well examined in the Lake Sturgeon DU8 Recovery Potential Assessment (DFO 2008; Pratt 2008; Table 7). Lake Sturgeon threats have been ranked from greatest to lowest threat as follows: presence of dams, exploitation, agriculture, urbanization, invasive species, climate change, and dredging (Pratt 2008). See Pratt (2008) for a detailed discussion of the threats affecting Lake Sturgeon DU8 populations.

CONTAMINANTS AND TOXIC SUBSTANCES

Freshwater mussel life history characteristics also make them particularly sensitive to increased levels of sediment contamination and water pollution. Adult mussels feed primarily by filter feeding, while juveniles remain burrowed deep in the sediment feeding on particles found within the sediment. Toxic chemicals from both point and non-point sources, especially agriculture, are believed to be one of the major threats to mussel populations today (Strayer and Fetterman 1999). In addition, much of the harm to the freshwater mussel assemblages in highly urbanized centres has been attributed to anthropogenic stressors, such as sewage pollution from outflows and toxic pollutants that enter the sewer system from industrial operations. The city of Ottawa has recognized sewage overflow has a major problem and are currently investing in the creation of underground storage tanks that will prevent sewage-tainted rainwater from entering the river (Brownlee 2012).The effect of chronic exposure to heavy metals on freshwater mussels has been reviewed (Naimo 1995). Findings indicate that the effects of metals on feeding, growth, and reproduction could significantly affect mussel populations (Naimo 1995). It was concluded that exposure to high concentrations of Cadmium, Copper, Mercury, and Zinc in the laboratory has caused mortality, alterations in weight, changes in enzyme activity and filtration rate and behavioural modifications (Naimo 1995). Studies have considered the influence of biological factors on concentrations of metals (Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, and Zn) in the tissues of Eastern Elliptio (*Elliptio complanata*) and Eastern Lampmussel (*Lampsilis radiata*) collected from the St. Lawrence River (Metcalfe-Smith et al. 1996) but this type of work has not been completed for Hickorynut. The toxic effects of copper on freshwater mussels and specifically on the early life stages are well known and documented (Keller and Zam 1991; Jacobsen et al. 1997; Gillis et al. 2008), This may be particularly relevant to those Hickorynut populations in the Saint-François River where old mines and mine tailings are present in the upper portion of the watershed and leaching of metals, such as copper is known to occur (Painchaud 2007).

The application of road salts as a de-icing or anti-icing chemical has been highlighted as an increasing area of concern for our lakes and streams (Environment Canada 2001). Road salts enter the surface water and groundwater after snow melt and can lead to the salinization of our lakes, rivers, and streams (Demers and Sage Jr. 1990). A study was recently completed assessing the long-term trend in chloride concentrations in areas known to be inhabited by mussel species at risk in southwestern Ontario, indicating that a significant increase in chloride concentration was observed at 96% of the 24 long-term (1975-2009) monitoring sites (Todd and Kalteneckerm 2012). An additional study completed by Gillis (2011) determining the level of acute toxicity of NaCl for glochidia of various species of mussel (including two species endangered in Canada), reported that chloride data collected from mussel habitats reached levels of acute toxicity for glochidia. It has been recorded that the application rates have decreased; however, the number of roads salted has increased (International Joint Commission 1977).

NUTRIENT LOADING

Agriculture appears to be contributing to poor water quality through agricultural runoff and manure seepage. Particularly relevant to freshwater mussels are the indirect effects of increased nutrient loading, such that, increases in nutrient levels can lead to increased algal growth and eutrophication. Once algal masses senesce, the oxygen supply in the water column is used for the decomposition process, leading to decreased levels of available oxygen. Strayer and Fetterman (1999) identified increased nutrient loads from non-point sources, and especially from agricultural activities as a primary threat to freshwater mussels. Tile drainage, wastewater drains, manure storage and spreading have contributed to poor water quality in many aquatic systems.

Nutrient loading may play an important role for Hickorynut populations in the lower St. Lawrence, lower Saint-Francois, and Batiscan rivers as these rivers face increased pressure from agricultural activities. The National Agri-Environmental Health Analysis and Reporting Program (NAHARP) assess the agriculture sector's performance. Results from their 2006 water quality analysis indicated that the lower St. Lawrence, Saint-Francois and Batiscan rivers were at a 'very high' risk of water contamination from nitrogen on farmlands (Figure 11). In the Saint-Francois River watershed, 23% of the land is used for agricultural purposes such as crops and livestock rearing, with the majority of agriculture activities occurring in the lower portion of the watershed, corresponding to areas where Hickorynut is known to occur (COGESAF 2006). The major land use in the Mississagi River sub-basin is forest (occupying 95% of the sub-basin area), with very limited land being used for agricultural purposes (International Joint Commission 1977). Nutrient loading from both agricultural sources and sewage outflow would be minimal in this area (International Joint Commission 1977).

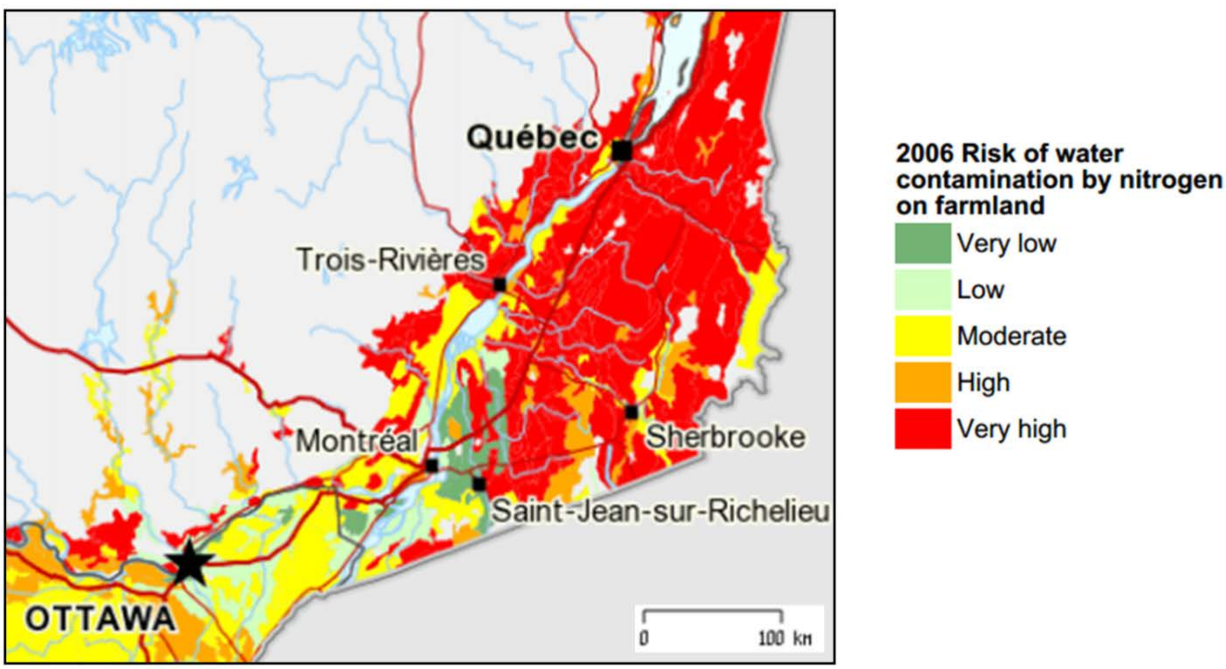

Figure 11. Results of 2006 water quality analysis indicating level of risk of water contamination by nitrogen on farmland © Her Majesty the Queen in Right of Canada 2013, Agriculture and Agri-Food Canada (http://atlas.agr.gc.ca; Accesssed 3 January 2013).

Increased nutrient inputs may not only come from agricultural sources, but may also be elevated in urbanized areas from sewage overflow and outflows from sewage treatment facilities that do not implement tertiary treatment. In the Ottawa River watershed there are over 90 wastewater treatment facilities with varying types and levels of treatment; only four of which provide tertiary treatment (Ottawa Riverkeeper 2006).

TURBIDITY AND SEDIMENT LOADING

Increases in turbidity, and the subsequent decrease in silt-free habitats has reduced the quantity and quality of freshwater mussel habitat. Increased siltation affects freshwater mussels by clogging siphons, hindering the intake of oxygen and impeding reproductive functions (Strayer and Fetterman 1999). Increased suspended solids in the water column can clog the gill structures and ultimately suffocate the mussel.

Increased sediment loading is often associated with increased agricultural land use. Increased agricultural land use can also lead to riparian vegetation clearing or unrestricted livestock access to the river leading to poor water quality with increased sediment loads (Water Quality Branch 1989). Agricultural practices and increased tile drainage results in large inputs of sediments to the watercourse. On a much smaller scale, in-water projects without sedimentation controls may cause temporary turbidity increases in the waterway. Sedimentation from not only poor agricultural practices, but also poor land development practices, could also contribute to increased sediment loading in waterways where Hickorynut is known to exist.

HABITAT REMOVAL AND ALTERATION

Physical loss of freshwater mussel habitat can occur as a result of many activities, such as dredging, infilling, construction of impoundments, marinas and docks, and channelization. Mussels may not only be negatively affected by the physical act of dredging but may also be buried under the dredgeate. This threat may be of particular importance to the St. Lawrence River Hickorynut population in light of considerations to expand the Port de Montréal to Contrecoeur; although, sampling from this location has only recorded the presence of weathered Hickorynut shells. Also, a trend towards decreased water levels may necessitate dredging to maintain marina operations. There is no quantitative information available regarding the number of freshwater mussel affected by these human activities; however, it is conceivable that removal or alteration of preferred habitat could have a direct effect on the recovery or survival of freshwater mussels.

ALTERED FLOW REGIMES

The presence of impoundments and dams on freshwater rivers has been shown to negatively affect mussel communities by altering the physiochemical characteristics of these systems (Vaughn and Taylor 1999; Parmalee and Polhemus 2004; Galbraith and Vaughn 2011; Addy et al. 2012). Impoundments typically result in siltation, stagnation, loss of shallow water habitat, pollutant accumulation and water of poor quality due to high nutrient concentrations, while dams alter flow regimes, and can affect the natural thermal profile (Bogan 1993; Vaughn and Taylor 1999; Watters 2000). In addition, poor management of water control structures can potentially dewater areas, leading to unsuitable habitat for mussels as the bottom of the watercourse may become exposed. Dams can also cause sediment retention upstream and scouring downstream. Increased pressures from urbanization can include increased water taking from rivers as well as storm water management that greatly alter flow regimes surrounding urbanized centers. A recent study relating the native mussel community to a hydroelectric power facility noted that sites immediately downstream of the hydroelectric facility had increased bed compaction. This increase in bed compaction created a non-functional area in the river that was limiting the recruitment of juvenile mussels (Addy et al. 2012). An additional mussel community study observed a mussel extinction gradient downstream of impoundments, with rare species only found at sites the furthest away from the impoundment (Vaughn and Taylor 1999). Vaughn and Taylor (1999) concluded that considerable stream length is necessary to overcome the effects of the impoundment on the mussel community. Another study examining the effects of water management regimes on freshwater mussels found that sites downstream from dams with unnatural flow regimes had lower mussel density, higher hermaphroditism and parasitism rates, and reduced body condition, when compared to sites downstream from dams with more naturally regulated water flow regimes (Galbraith and Vaughn 2011).

The populations of Hickorynut in the Ottawa and Saint-François rivers may be particularly vulnerable to this threat as dams and hydropower generating stations are present on both systems. Seven hydroelectric dams were constructed on the Ottawa River between Carillon and Lake Temiscaming between the 1880s and 1964 (Haxton and Chubbuck 2002), while there are two hydroelectric facilities on the Saint-François River within the Hickorynut range (Hydro Québec 2010). It is quite plausible that water control structures are negatively affecting mussel habitat in these systems although the effects are currently unknown.

CLIMATE CHANGE

Through discussions on the effects of climate change on aquatic species, impacts such as decreases in water levels, increases in water and air temperatures, increases in the frequency of extreme weather events, and emergence of diseases have been highlighted, all of which may negatively impact native freshwater mussels (Lemmen and Warren 2004). Although the various climate models provide differing projections on the long-term effects of climate change, many scenarios indicate that there will be a decrease in average annual water levels and changes in the seasonal hydrograph (Lofgren and Hunter 2011). Impacts of decreased water levels will be particularly important to those Hickorynut populations occupying the regions of the St. Lawrence already affected by tidal water level fluctuations. Climate change is also often related to an increase in extreme weather events, and has been circumstantially linked to an increase in ice scours in the St. Lawrence River. Although ice scouring does occur naturally, the fluctuation in ice scour, which erodes Hickorynut habitat, appears to have increased in recent years (N. Desrosiers, Ministère des Ressources naturelles et de la Faune du Québec, pers. obs.). Since the effects of climate change on freshwater mussels are speculative, it is difficult to determine the likelihood and impact of this threat on each population; therefore, the threat of climate change is not included in the following population-specific Threat Level analysis.

THREAT LEVEL ASSESSMENT

Each threat was ranked in terms of the Threat Likelihood and Threat Impact for all river systems where it is believed that a population of Hickorynut may exist. The criteria used to determine whether a site would be included in the Population Status assessment [i.e., only populations where one or more live individuals, fresh whole shells or fresh valves were recorded since 1995 (i.e., post-Zebra Mussel invasion) were included in the assessment] was also applied to the Threat Level analysis.

The Threat Likelihood was assigned as Known, Likely, Unlikely, or Unknown, and the Threat Impact was assigned as High, Medium, Low, or Unknown (Table 8-11). Threat Likelihood was classified for the extent of the known distribution at each location. If location-specific information was not available, knowledge of the threat throughout the watershed was applied. Location-specific information was used to categorize the Threat Impact for each location. If location-specific information was not available, the highest Threat Impact ranking for all known populations was used. Certainty of the Threat Impact was classified and is based on: 1= causative studies; 2=correlative studies; and, 3=expert opinion. The Threat Likelihood and Threat Impact for each location were subsequently combined in the Threat Level matrix (Table 10) resulting in the final Threat Level for each location (Table 11).

Table 8. Definition of terms used to describe Threat Likelihood and Threat Impact.

Term	Definition
Threat Likelihood	
Known (K)	This threat has been recorded to occur at site X.
Likely (L)	There is a > 50% chance of this threat occurring at site X.
Unlikely (U)	There is a < 50% chance of this threat occurring at site X.
Unknown (UK)	There are no data or prior knowledge of this threat occurring at site X.
Threat Impact	
High (H)	If threat was to occur, it would jeopardize the survival or recovery of this population.
Medium (M)	If threat was to occur, it would likely jeopardize the survival or recovery of this population.
Low (L)	If threat was to occur, it would be unlikely to jeopardize the survival or recovery of this population.
Unknown (UK)	There is no prior knowledge, literature or data to guide the assessment of the impact if it were to occur.

Table 9. Threat Likelihood and Threat Impact of each Hickorynut population in Canada. The Threat Likelihood was assigned as Known (K), Likely (L), Unlikely (U), or Unknown (UK), and the Threat Impact was assigned as High (H), Medium (M), Low (L), or Unknown (UK). Certainty (C) is associated with Threat Impact (TI) and is based on the best available data (1= causative studies; 2=correlative studies; and 3=expert opinion). References (Ref) are provided.

	Mississagi River				Ottawa River			
	TLH	TI	C	Ref	TLH	TI	C	Ref
Invasive species	U	H	2	1,22,23	K	L	2	1,5,6,7,8,9,21,23
Host fish	L	M	2	2,21	K	H	2	3,10
Contaminants and toxic substances	L	L	3	4,21	K	L	3	11,12,13,21
Nutrient loading	U	L	3	4,21	K	L	2	14,15, 21
Turbidity and sediment loading	U	L	3	21	L	U	2	14,16, 21
Habitat removal and alteration	U	M	2	21	K	L	2	14, 21
Altered flow regimes	U	L	1	18,19,20,21	K	H	1	18,19,20

	St. Lawrence River				Saint-François River			
	TLH	TI	C	Ref	TLH	TI	C	Ref
Invasive species	K	H	2	6,7,8,17,23	L	H	2	6,7,8,21,23
Host fish	K	H	2	10,14	K	H	2	10,14
Contaminants and toxic substances	K	M	3	11,12,13	K	M	2	11,12,13,24
Nutrient loading	K	M	3	14,15,21	K	L	3	14,15
Turbidity and sediment loading	K	M	3	14,16	K	M	3	14,16
Habitat removal and alteration	K	H	2	14	K	H	2	14
Altered flow regimes	U	H	1	18,19,20	K	H	1	18,19,20

References:

1. Ontario's Invading Species Awareness Program (www.invadingspecies.com; Accessed: 4 January 2012)
2. Pratt (2008)
3. Haxton (2002; 2008)
4. IJC (1977)
5. MRNF (2013)
6. Ricciardi et al. (1996)
7. Hebert et al. (1991)
8. Martel et al. (2001)
9. Bergeron (1995)
10. Dumont et al. (2012)
11. Gagné et al. (2011)
12. Naimo (1995)
13. Keller and Lydy (1997)
14. McMahon (1991)
15. Allan and Flecker (1993)
16. Aldridge et al. (1987)
17. Simard et al. (2011)
18. Addy et al. (2012)
19. Vaughn and Taylor (1999)
20. Galbraith and Vaughn (2011)
21. Hickorynut Recovery Potential Assessment Participants (29-30 January 2013)
22. Ontario Ministry of the Environment, unpubl. data
23. Therriault et al. (2013)
24. Painchaud (2007)

Table 10. The Threat Level Matrix combines the Threat Likelihood and Threat Impact rankings to establish the Threat Level for each Hickorynut population in Canada. The resulting Threat Level has been categorized as Poor, Fair, Good, or Unknown.

		Threat Impact			
		Low (L)	**Medium (M)**	**High (H)**	**Unknown (UK)**
Threat Likelihood	**Known (K)**	Low	Medium	High	Unknown
	Likely (L)	Low	Medium	High	Unknown
	Unlikely (U)	Low	Low	Medium	Unknown
	Unknown (UK)	Unknown	Unknown	Unknown	Unknown

Table 11. Threat Level for Hickorynut populations, resulting from an analysis of both the Threat Likelihood and Threat Impact. The number in brackets refers to the level of certainty assigned to each Threat Level, which relates to the level of certainty associated with Threat Impact. Certainty has been classified as: 1= causative studies; 2=correlative studies; and 3=expert opinion.

Threat	Mississagi River	Ottawa River
Invasive species	Medium (2)	High (2)
Host fish	High (2)	High (2)
Contaminants and toxic substances	Medium (3)	Medium (3)
Nutrient loading	Low (3)	Low (2)
Turbidity and sediment loading	Low (3)	Low (2)
Habitat removal and alteration	Medium (2)	High (2)
Altered flow regimes	Medium (1)	High (1)

Threat	St. Lawrence River	Saint-François River
Invasive species	High (2)	Medium (2)
Host fish	High (2)	High (2)
Contaminants and toxic substances	Medium (3)	Medium (2)
Nutrient loading	Low (3)	Low (3)
Turbidity and sediment loading	Medium (3)	Medium (3)
Habitat removal and alteration	High (2)	High (2)
Altered flow regimes	Medium (1)	High (1)

MITIGATIONS AND ALTERNATIVES

Threats to species survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects that could result from works or undertakings associated with projects, or activities in Hickorynut habitat. Hickorynut has been assessed as Endangered by COSEWIC and is currently listed as Endangered and protected under Ontario's *Endangered Species Act 2007*, which necessitates the preparation of a formal provincial recovery strategy for Hickorynut to manage the species and prevent further decline.

The Hickorynut is also a candidate species for listing under the *Species at Risk Act* and a RPA must be performed to inform the listing decision. The RPA process includes the information on works and undertakings in Hickorynut habitat and on mitigation measures. As the Hickorynut is present in Ontario and Quebec, the results will be presented by province in the text, but by Hickorynut population in the tables. Note that pathways of effects are the same for both provinces but Quebec does not have a referrals streamlining process as extensive as the Ontario one which is used to provide relevant information on threats and mitigations in the RPA.

Within Hickorynut habitat, a variety of works, undertakings, and activities have occurred in the past few years including: water crossings (e.g., bridges and culverts); shoreline and streambank works (e.g., stabilization); in-stream works (e.g., channel maintenance, modifications or realignments); the placement of structures in water (e.g., boat launches, docks, effluent outfalls, water intakes); and, water management activities (e.g., stormwater management). Research has been completed summarizing the types of work, activity, or project that have been undertaken in habitat known to be occupied by Hickorynut (Table 12). The DFO Program Activity Tracking for Habitat (PATH) database, as well as summary reports of fish habitat projects reviewed by partner agencies (e.g., conservation authorities), have been reviewed to estimate the number of projects that have occurred during the three-year period, 2009-2011. Approximately 133 projects were identified in Ontario and 55 in Quebec but likely do not represent a comprehensive list of activities that have occurred in these areas (Table 12). Some projects may not have been reported to partner agencies or DFO if they occurred under conditions of an Operational Statement. However, 9 were completed under conditions of Operational Statements primarily for structures in water (such as docks and boat launches) and shoreline or streambank works (such as stabilization).

The remaining projects were deemed low risk to fish and fish habitat and were addressed through letters of advice with standard mitigation. Without appropriate mitigation, projects or activities occurring adjacent or close to these areas could have affected Hickorynut (e.g., increased turbidity or sedimentation from upstream channel works). The majority of projects (42 percent) were for shoreline stabilization works. Based on the assumption that historic and anticipated development pressures are likely to be similar, it is expected that similar types of projects will likely occur in or near Hickorynut habitat in the future. The primary project proponents were individual landowners in Ontario and municipalities in Quebec.

As indicated in the Threat Analysis, numerous threats affecting Hickorynut populations are habitat-related threats that have been linked to the Pathways of Effects developed by DFO Fish Habitat Management (FHM) (Table 12). DFO FHM has developed guidance on mitigation measures for 19 Pathways of Effects for the protection of aquatic species at risk in the Central and Arctic Region (Coker et al. 2010). This guidance should be referred to when considering mitigation and alternative strategies for habitat-related threats. At the present time, we are unaware of mitigation that would apply beyond what is included in the Pathways of Effects.

Table 12. Summary of works, projects and activities that have occurred during the period of January 2009 to December 2011 in areas known to be occupied by Hickorynut. Threats known to be associated with these types of works, projects, and activities have been indicated by a checkmark. The number of works, projects, and activities associated with each Hickorynut population, as determined from the project assessment analysis, has been provided. Applicable Pathways of Effects have been indicated for each threat associated with a work, project or activity (1 - Vegetation clearing; 2 – Grading; 3 –Excavation; 4 – Use of explosives; 5 – Use of industrial equipment; 6 – Cleaning or maintenance of bridges or other structures; 7 – Riparian planting; 8 – Streamside livestock grazing; 9 – Marine seismic surveys; 10 – Placement of material or structures in water; 11 – Dredging; 12 – Water extraction; 13 – Organic debris management; 14 – Wastewater management; 15 – Addition or removal of aquatic vegetation; 16 – Change in timing, duration and frequency of flow; 17 – Fish passage issues; 18 – Structure removal; 19 – Placement of marine finfish aquaculture site).

Work/Project/Activity	**Threats** (associated with work/project/activity)							**Watercourse / Waterbody** (number of works/projects/activities between 2009-2011)			
	Invasive species	**Host Fish (Barriers to movement)**	**Contaminants & toxic substances**	**Nutrient loading**	**Turbidity and sediment loading**	**Habitat removal and alteration**	**Altered flow regimes**	**Mississagi River**	**Ottawa River**	**St. Lawrence River**	**St. François River**
Applicable pathways of effects for threat mitigation and project alternatives		10, 16, 17	1, 4, 5, 6, 7, 11, 12, 13, 14, 15, 16,18	1, 4, 7, 8, 11, 12, 13, 14, 15, 16	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 18	1, 2, 3, 4, 5, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18	10, 11, 12, 16, 18				
Water crossings (bridges, culverts, open cut crossings)		✓	✓		✓	✓		6	9	2	1
Shoreline, streambank work (stabilization, infilling, retaining walls, riparian vegetation management)			✓		✓	✓			63	15	1
Dams, barriers, structures in water (maintenance, modification, hydro retrofits)	✓	✓			✓	✓	✓	1	1	1	

Work/Project/Activity	Threats (associated with work/project/activity)							Watercourse / Waterbody (number of works/projects/activities between 2009-2011)			
	Invasive species	Host Fish (Barriers to movement)	Contaminants & toxic substances	Nutrient loading	Turbidity and sediment loading	Habitat removal and alteration	Altered flow regimes	Mississagi River	Ottawa River	St. Lawrence River	St. François River
Instream works (channel maintenance, restoration, modifications, realignments, dredging, aquatic vegetation removal)			✓	✓	✓	✓			8	12	
Water management (stormwater management, water withdrawal)			✓	✓	✓		✓		6		
Structures in water (boat launches, docks, effluent outfalls, water intakes)			✓	✓	✓	✓		2	43	16	1
Baitfishing											
Invasive species introductions (accidental and intentional)	✓										

Additional mitigation and alternative measures, specific to Hickorynut, related to invasive species, and host fish.

INVASIVE SPECIES

As discussed in the **THREATS** section, aquatic invasive species (e.g., dreissenid mussels) introduction and establishment have had negative effects on Hickorynut populations. Mitigation and alternatives should not only be considered for current established invasive species but species that may invade in the future.

Mitigation

- Evaluate the likelihood that a waterbody will be invaded by an invasive species.
- Monitor watersheds for invasive species that may negatively affect Hickorynut populations directly, or negatively affect Hickorynut habitat.
- Develop a plan to address potential risks, impacts, and proposed actions if monitoring detects the arrival or establishment of an invasive species.
- Introduce a public awareness campaign on proper boat cleaning methods when transferring boats from an infested waterway, and on the proper identification of native and invasive freshwater mussels. The public awareness campaign could include an educational fact sheet to better educate the public on native and invasive species.
- Encourage the use of existing invasive species reporting systems
- Restrict the use of boats in areas particularly susceptible to Zebra Mussel introduction and infestation.

Alternatives

- Unauthorized
  - None.
- Authorized
  - Use only native species.
  - Follow the National Code on Introductions and Transfers of Aquatic Organisms for all aquatic organism introductions (DF0 2003).

HOST FISH

As discussed in the ‘Threats’ section, decreases in the number of individual host fish or decreases in the area of overlap between host fish and freshwater mussel may be decreasing the likelihood that a fish-mussel encounter will occur.

Mitigation

- Implement a management plan for the appropriate host fish species. This would increase the host’s survival, increasing number of host individuals, creating a healthy host population and subsequently increasing the likelihood that the host fish would encounter a gravid freshwater mussel.
- Immediate release of host fish if caught angling in areas where freshwater mussels of concern are known to occur.

Alternatives

- Seasonal or zonal restrictions applied to Lake Sturgeon harvest if period of Hickorynut glochidial attachment can be confirmed for natural infestations.

SOURCES OF UNCERTAINTY

Despite concerted efforts to increase our knowledge of Hickorynut in Canada, there are still a number of key sources of uncertainty for this species related to population distribution, structure, habitat preferences and to the factors limiting their existence.

There is a need for a continuation of quantitative sampling of Hickorynut in areas where it is known to occur to determine population size, current trajectory, and trends over time. There is also a need for additional targeted sampling in Mississagi, Ottawa and Saint-François rivers to confirm the current population status assessment, and to determine population sizes. Exploratory sampling should be completed in systems with habitat characteristics similar to those areas where Hickorynut is known to occur to determine the extent of their distribution. Candidate systems for exploratory surveys would include the Mattawa, French and Gatineau rivers, and Lake Nipissing which are in close proximity to locations where Hickorynut have been recorded and may contain suitable habitat. Additional sampling is necessary for all populations that were assigned a low certainty in completing the population status assessment. Many of the historic Hickorynut sites in the Ottawa River have yet to be recently surveyed. Areas of particular interest in the Ottawa River include areas north of the Timiskaming records, including the Blanche River, the Ottawa River between the Timiskaming region and the Ile-aux-Allumettes, and the length of river between MacLaren's Landing and the confluence of the Ottawa River with the St. Lawrence River. Sampling efforts in the Saint-François River should be continued and expanded both upstream of the Domtar generating station, and downstream of the Drummondville generating station. Tributaries of the North Channel (Lake Huron) and potentially Lake Superior with habitat characteristics similar to those of the Mississagi River, and inhabited by Lake Sturgeon, should be sampled to determine if the Hickorynut population in the Mississagi represents a disjunct population. As Hickorynut is often found in deeper water, SCUBA surveys are required for all populations. Additional experimental sampling methods should be investigated to sample deep water habitats, including the use of brails. Brails are boards with a fringe of short chains to which hooks are attached, and each hook generally has four prongs with a bead at the end of each prong. When the brail is lowered in the river and pulled along the river bottom, the mussel clamps down on the beaded end and is pulled out of the substrate. During surveys, the shell length of all live individuals should be recorded to gain information on population structure and to understand recruitment within each population. These baseline data are required to monitor Hickorynut distribution and population trends as well as the success of any recovery measures implemented. If live Hickorynut can be successfully captured, there is a need to determine abundance estimates to properly interpret population modelling (see Young and Koops 2013). Certain life history characteristics also required to inform Hickorynut population modeling efforts are currently unknown. Studies to validate stage specific survival, fecundity, age at maturity, longevity, and population abundance are required. Further studies should focus on acquiring details about host infestation on all sizes of host (such as numbers of glochidia), as well as the relationship between mussel attachment probability and host-mussel density.

Additional studies on habitat requirements are imperative to determine critical habitat for all Hickorynut life stages. Additional studies on the preferred habitat of this species may also help to determine possible candidate areas for relocation. Additional sampling should include a quantitative habitat assessment including substrate categorization, water depth, and water velocity. There is a need to better understand the effects of water level variation and changes to natural flow regimes on Hickorynut. Supplementary laboratory experiments, and if feasible field experiments, should be completed to determine if Lake Sturgeon is indeed the host fish for Hickorynut in Canada. Laboratory infestation experiments, using samples from Canadian populations, should be completed to verify the usage of Lake Sturgeon as the host fish for

Hickorynut. Lake Sturgeon sampling should be completed, during which the gills should be inspected and sampled for Hickorynut glochidia. If Lake Sturgeon is confirmed as the host fish for Canadian populations of Hickorynut, Lake Sturgeon movement and migratory patterns should be investigated to determine Hickorynut dispersal within and between populations. Also, once Lake Sturgeon is confirmed to be the host fish for Hickorynut, additional modelling efforts should be completed to estimate the number of Lake Sturgeon required to support the Hickorynut population. Other potential host fish, such as Freshwater Drum (*Aplodinotus grunniens*), should be included in infestation experiments to determine if additional species may act as suitable host fish for Hickorynut. Numerous threats have been identified for Hickorynut populations in Canada, although the direct impact that these threats might have is currently unknown. There is a need for more quantitative studies to evaluate the direct impact of each threat on Hickorynut populations with greater certainty. In the literature, the threat impacts are generally discussed at a broad level (i.e., mussel assemblage level). It is important to further our knowledge on threat likelihood and impact at the species level. Research is needed to determine the direct and indirect effects that dreissenid mussels may have on Hickorynut. This type of species-specific threat research of invasive species on native mussels is needed to better inform decisions on the management of invasive species. There is a need to determine threshold levels for water quality parameters (e.g., nutrients, turbidity).

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