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Information in support of a Recovery Potential Assessment of Lilliput (*Toxolasma parvum*) 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 2013, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of Lilliput (*Toxolasma parvum*) and determined the designation to be Endangered. The reason provided for this designation is that, “This species has a fairly restricted range in Canada, confined to tributaries of Lake St. Clair, Lake Erie, and Lake Ontario. Populations once found in the open Canadian waters of Lake St. Clair, Lake Erie and the Detroit River have disappeared. Overall, the species has lost 40% of its former range in Canada. The invasion of freshwater habitat by the exotic Zebra and Quagga mussels, combined with pollution from urban development and sedimentation are the main cause of populations disappearing and the range shrinking.” Lilliput is currently not listed under the *Species at Risk Act* (SARA).

This Recovery Potential Assessment (RPA) provides information and scientific advice needed to fulfill various requirements of SARA. This Research Document describes the current state of knowledge of the biology, ecology, distribution, population trends, and habitat requirements of Lilliput. Lilliput population sensitivity to perturbations, as well as the threats currently effecting known Lilliput populations is discussed. 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 Science Advisory Report 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 the 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 Lilliput in Canada.

Information à l’appui de l’évaluation du potentiel de rétablissement du toxolasme nain (*Toxolasma parvum*) au Canada

RESUME

En mai 2013, le Comité sur la situation des espèces en péril au Canada (COSEPAC) a évalué la situation du toxolasme nain (*Toxolasma parvum*) et lui a attribué le statut d'espèce « en voie de disparition ». La raison invoquée pour cette désignation était la suivante : « Cette espèce a une aire de répartition passablement restreinte au Canada, étant confinée aux affluents des lacs Sainte-Claire, Érié et Ontario. Les populations autrefois trouvées dans les eaux libres canadiennes du lac Sainte-Claire, du lac Érié et de la rivière Détroit ont disparu. Dans l’ensemble, l’espèce a disparu de 40 % de son ancienne aire de répartition au Canada. L’invasion de l’habitat d’eau douce par les moules exotiques zébrées et quagga, couplée à la pollution provenant du développement urbain et de la sédimentation, sont la principale cause de la disparition des populations et de la réduction de l’aire de répartition. » À l'heure actuelle, le toxolasme nain n'est pas inscrit en vertu de la *Loi sur les espèces en péril* (LEP).

La présente évaluation du potentiel de rétablissement (EPR) fournit les renseignements et les avis scientifiques nécessaires pour satisfaire à diverses exigences de la LEP. 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 et des besoins en matière d'habitat du toxolasme nain. On y aborde la vulnérabilité des populations de toxolasme nain aux perturbations ainsi que les menaces affectant actuellement les populations connues. Des mesures d'atténuation et d'autres activités associées aux menaces déterminées, qui peuvent être utilisées dans le but de protéger l'espèce, sont également présentées. Les renseignements contenus dans l'avis découlant de l'EPR et dans 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 du toxolasme nain au Canada.

SPECIES INFORMATION

Scientific Name – *Toxolasma parvum*
Common Name – Lilliput
Current COSEWIC Status (Year of Designation) – Endangered (May 2013)
Current *Species at Risk Act* Status (Schedule) – No status (No schedule)
Current Ontario *Endangered Species Act* Status (Year of Designation) – No status
Range in Canada – Ontario

BACKGROUND

DESIGNATION

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of Lilliput (*Toxolasma parvum*) as Endangered. The reason given for this designation was that, "This species has a fairly restricted range in Canada, confined to tributaries of Lake St. Clair, Lake Erie, and Lake Ontario. Populations once found in the open Canadian waters of Lake St. Clair, Lake Erie and the Detroit River have disappeared. Overall, the species has lost 40% of its former range in Canada. The invasion of freshwater habitat by the exotic Zebra and Quagga mussels, combined with pollution from urban development and sedimentation are the main cause of populations disappearing and the range shrinking." Lilliput 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 Lilliput to inform the RPA.

SPECIES DESCRIPTION

Lilliput is a small-sized freshwater mussel with an average shell length of approximately 25 mm (Metcalfe-Smith et al. 2005). A maximum shell length of 50 mm was reported (COSEWIC 2013), but this length has recently been surpassed by a Lilliput recorded from the Royal Botanical Gardens (RBG) with a shell length of 58 mm (P. Smith, unpubl. data). Lengths of Lilliput shells collected from RBG between 2004 and 2009, and live individuals collected from all other sites between 2008 and 2011 ranged in length from 13 to 49.5 mm (Figure 1).

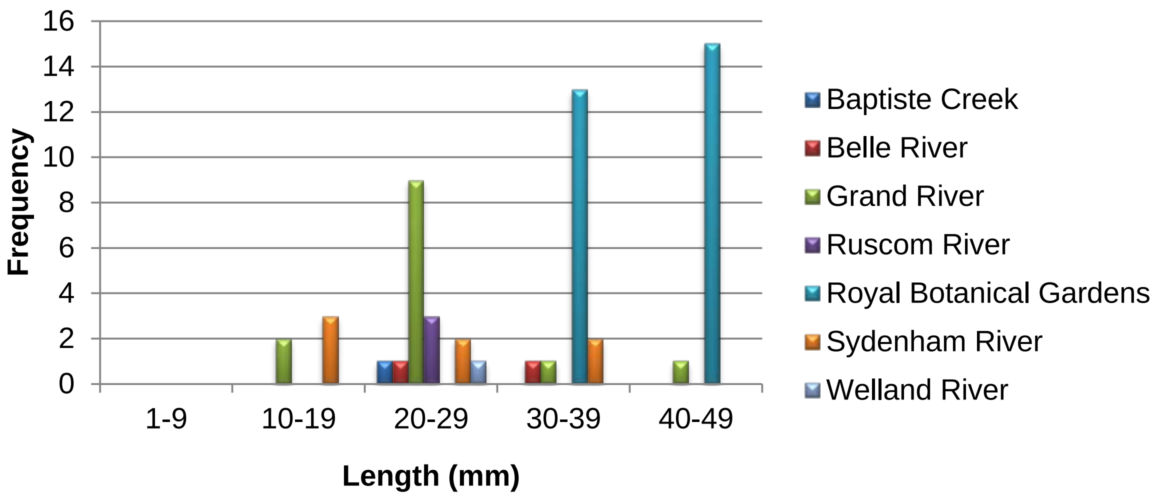
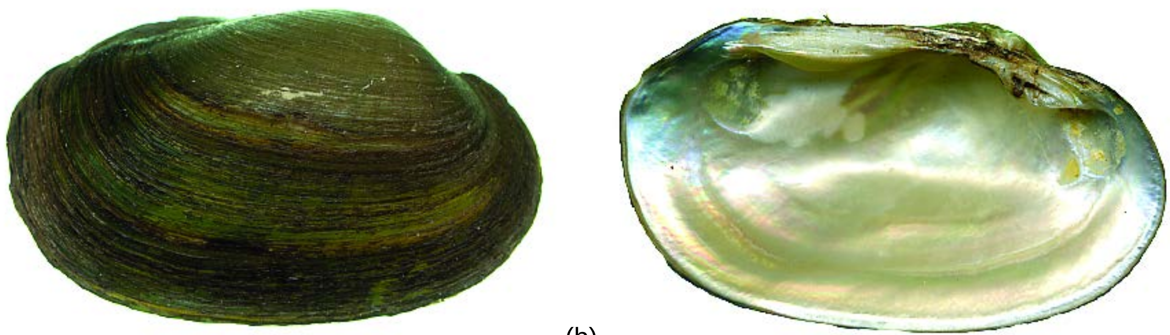


Figure 1. Size distribution of Lilliput from various sites recorded from 2008-2011.

The shell is described as thick, elliptical, moderately flattened in males and oval and more inflated in females (Figure 2; Metcalfe-Smith et al. 2005). The anterior end is rounded, and the posterior end is rounded in males, and squared in females (Metcalfe-Smith et al. 2005). The ventral margin is described as straight or slightly curved (Metcalfe-Smith et al. 2005). The beak is inflated, and slightly elevated about the hinge line, and generally consists of four to six coarse concentric ridges, aligned slightly obliquely so that the ridges open anterior to center (Metcalfe-Smith et al. 2005; Watters et al. 2009). The exterior of the shell (periostracum) varies from pale yellow, green, or gray, with a satin-like shine in younger individuals to darker, uniformly blackish-brown in large specimens (Watters et al. 2009). COSEWIC (2013) indicated that green rays may be present; although, Watters et al. (2009) describes Lilliput as being rayless. The nacre is white and iridescent posteriorly (Watters et al. 2009).



(a) (b)

Figure 2. Lilliput (a) exterior shell and (b) interior nacre. Photograph by Environment Canada, reproduced with permission.

SIMILAR SPECIES

Lilliput is the only member of the genus *Toxolasma* currently known to occur in Canada (COSEWIC 2013). Morphologically similar species include Rayed Bean (*Villosa fabalis*) and Salamander Mussel (*Simpsonaias ambigua*). Rayed Bean can be distinguished from Lilliput by its prominent rays and thick hinge line, while Salamander Mussel can be distinguished by its thinner shell and more elongate shape.

AGE AND GROWTH

Lilliput are considered to be a short-lived species, with maximum range estimates reported between four and five years (Haag and Rypel 2011). Although Watters et al. (2009) found similar results, in that most individuals were approximately five years old, they also reported a few individuals as old as 12 years. Successful sampling efforts from 2004 to 2009 at the RBG has allowed for a study to determine Lilliput size at age (Figure 3; Smith and Morris, unpubl. data). Two of the 26 mussels sampled (46 and 49.5 mm) were estimated to be over seven years of age (age 9 and age 12, respectively), while the remaining mussels were estimated to be between age 2 and age 7 (Figure 3). These findings support previous age estimates reported by Watters et al. (2009). No additional information on age and growth patterns is available, locally or globally for this species.

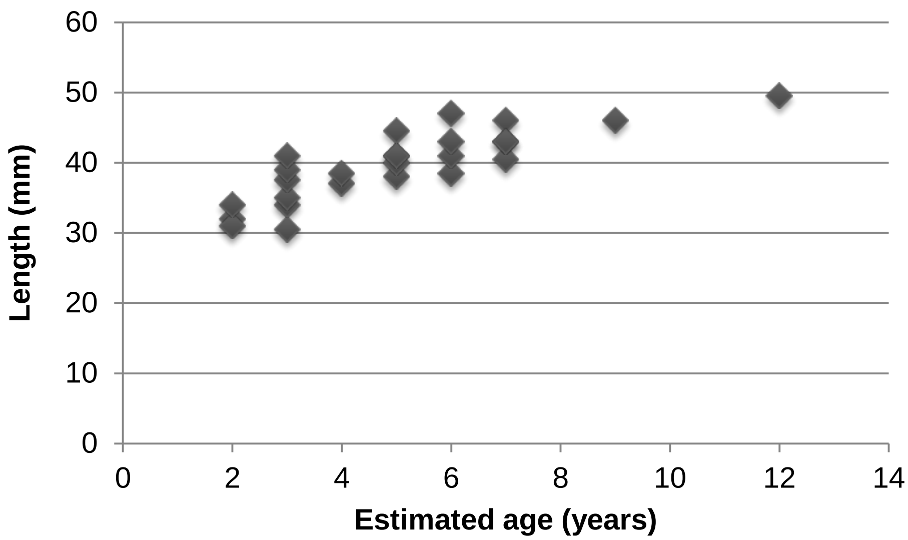


Figure 3. Length at age estimates for Lilliput collected from the Royal Botanical Gardens between 2004 and 2009 (Smith and Morris, unpubl. data).

Age at maturity is currently unknown for Lilliput, although generation time is estimated to be approximately 6 years in Canada (COSEWIC 2013). The only information currently available on Lilliput age at maturity is provided by Tepe (1943) who, during his examination of five individuals between 12 and 21 mm in length, found eggs and spermatozoa. Unfortunately, the length at age relationship was not available in Tepe (1943), making it difficult to estimate the age at maturity from this data.

DIET

Like most other unionid mussels, Lilliput is considered to be a filter feeder. Cilia present on their foot may also be evidence that Lilliput 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. In the early juvenile stage, when the mussel is most commonly buried in the substrate, food is obtained directly from the substrate in the form of algae and bacteria (Yeager et al. 1994). Species-specific dietary information is not available for Lilliput.

DISTRIBUTION

Globally, Lilliput is considered secure (G5) and is distributed throughout much of the central/eastern United States (NatureServe 2014). It is currently found throughout most of the Mississippian Region (NatureServe 2014). It is considered to be possibly extirpated in New York and Georgia, critically imperiled in Pennsylvania and Iowa, and imperiled in West Virginia and Kansas (NatureServe 2014). In Canadian waters, it is limited to south-western Ontario from tributaries of the southern shore of Lake St. Clair to Jordan Harbour, a wetland located along the south shore of Lake Ontario at Twenty Mile Creek.

CURRENT STATUS

Information contained within this report was drawn from data contained within the Lower Great Lakes Unionid Database as well as additional sources including the COSEWIC status report (COSEWIC 2013), and various unpublished reports. For a detailed description of the Lower

Great Lakes Unionid database and its historical data sources, see Metcalfe-Smith et al. (1998). Ontario records generally resulted from formal studies directed at sampling unionids using both qualitative and quantitative methods. Locations of all known sampling sites in Ontario (Figure 4) are shown to provide context of mussel sampling effort.

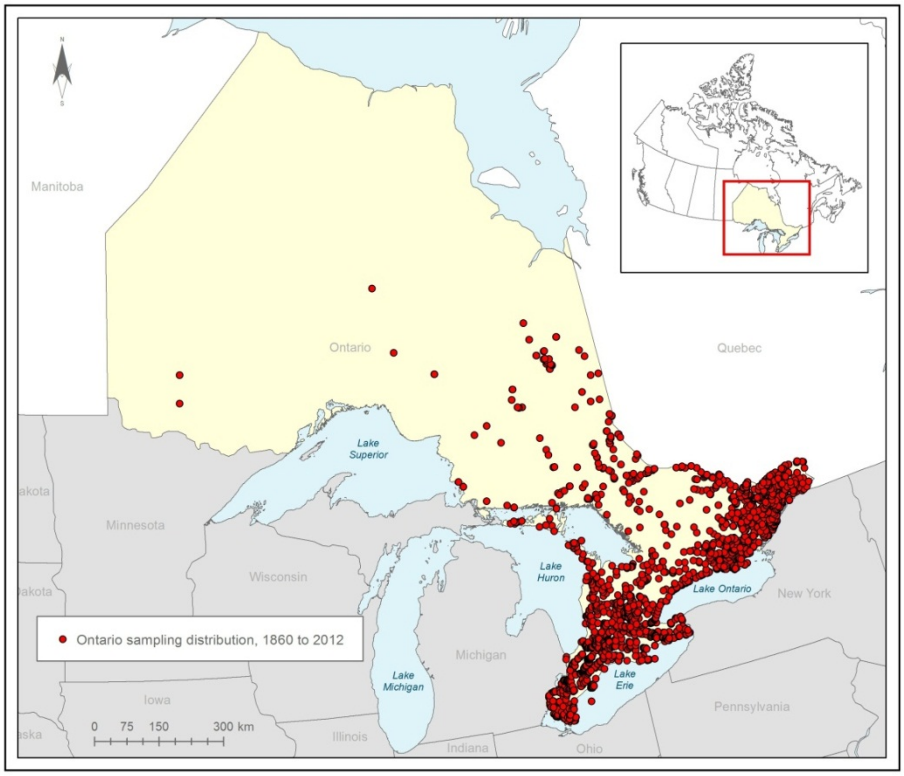


Figure 4. Distribution of all known historic and current freshwater mussel sampling sites in Ontario.

In Canada, the current and historic known distribution of Lilliput is limited to nine confirmed populations, one of which is currently considered to be extirpated. Extant populations include four tributaries of Lake St. Clair (East Sydenham, Thames, Belle and Ruscom rivers), Grand River (Lake Erie drainage), Welland River (tributary of the Niagara River), Jordan Harbour (a wetland at the mouth of Twenty Mile Creek) and Hamilton Harbour and surroundings (Cootes Paradise, Carroll's Bay, Grindstone Creek, Sunfish Pond) (Figure 5). Live individuals have been recorded from all extant sites, with the greatest number of Lilliput being recorded from the Grand River in 2011 (n=13). It should be noted that the following maps (Figures 5-13) represent all current and historic records of Lilliput, and may not accurately represent the current distribution. Substantial mussel sampling has occurred throughout Ontario (Figure 4); however, the habitat most often associated with Lilliput has not been extensively sampled and therefore the following maps may be an underrepresentation of the current distribution. Historically, Lilliput were recorded from the Detroit River (1943), Sydenham River (1967, 1991), Thames River (1963), and Grand River (1963, 1966, 1977). Historical records are comprised of museum records of valves or shells. Rarity of this species, in addition to difficulties in detecting this species due to inefficiencies in sampling its preferred habitat has yielded a mere 48 live individuals in Canada.

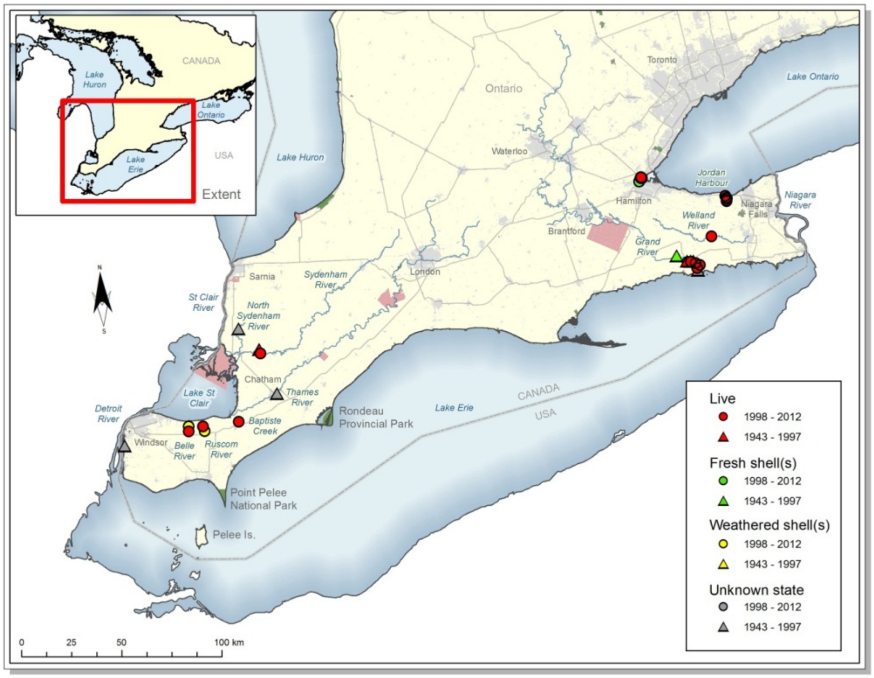


Figure 5. Distribution of Lilliput in Canada.

POPULATION CATEGORIZATION

Characteristics to be considered when delineating populations include movement of the individual mussel (including movement of the host fishes), availability of suitable habitat between two locations, state of the Lilliput recorded, and date of the record. In general, juvenile and adult mussels have very limited dispersal ability. Lilliput must rely on the dispersal abilities of their host fish to facilitate movement from one location to another. Therefore, for the purposes of this research document, populations have been delineated based on the ability of the host fish to move from one location where Lilliput is known to occur to another. The putative host fishes for Lilliput in Canada include Johnny Darter (*Etheostoma nigrum*), Green Sunfish (*Lepomis cyanellus*), White Crappie (*Pomoxis annularis*) and Bluegill (*Lepomis macrochirus*) (COSEWIC 2013). Refer to Host fishes section for additional information on host fish interactions and infestation experiments.

Movement of Green Sunfish and Bluegill has been well studied with the aim of investigating movement patterns and homing behaviour (Gatz and Adams 1994; Smithson and Johnston 1999; Gatz 2007). A mark and recapture study, reported by Smithson and Johnston (1999), indicated that of 679 marked Green Sunfish, 176 (88%) were recaptured in their home pool, and 25 (12%) were recaptured outside of their home pool. The majority of the 25 individuals recaptured outside of their home pool were recaptured in the pools adjacent to their home pool, and the most distant recapture was 453 m from the home pool (Smithson and Johnston 1999). In a similar experiment on Green Sunfish, Gatz (2007) reported that 56% of the recaptures were either in the same section of river as the initial capture location or in the adjacent section. Although some individuals moved greater distances (15% moved ≥ 400 m), very few individuals (3.5%) moved ≥ 1000 m from the initial point of release (Gatz 2007). Another movement study, this time focused on the movement of 822 marked Bluegill, indicated that of the 172 individuals recaptured only three individuals were recaptured at a distance between 17-17.6 km from the site of release, and an additional two were captured at a distance of 9-11 km from the site of release (Gatz and Adams 1994). All remaining recaptures occurred at sites less than 9 km from site of release (Gatz and Adams 1994). Funk (1957) reported Green Sunfish movement to be on average 9.17 km, while average White Crappie movement was 40.9 km. Similar results were reported from a White Crappie movement study, in which average movement over a one-year period was recorded to be 36 km (Thompson 1933). Johnny Darter appear to move the least when compared to all other putative hosts. Of the 340 Johnny Darter marked during a movement study, only 10 (3.24%) of recaptured fish (n=309) moved, and the average distance of those that did move was merely 55 m (Mundahl and Ingersoll 1983).

In addition to host fish movement, we considered the state of the Lilliput recorded (live individual, fresh shell, weathered shell), and the date of the sampling event. Records consisting of live or fresh shells were considered valid when determining relevancy of records in population categorization. Weathered shells were not considered valid as a weathered shell can persist at a location for an undetermined amount of time, and would not necessarily provide evidence of a current population. Also, shells may move passively downstream, and in general older shells are likely to have moved greater distances making it difficult to determine the location the mussel occupied when living. Passive movement of shells may not be relevant to Lilliput populations occupying wetlands with little flow, but would be relevant to any riverine population. The date of the sampling event was also considered when determining the likelihood of a current population at a site. A record was considered current if it was recorded from 1997 to present, as this timeframe represents the period of increased, targeted mussel sampling in Ontario.

Bearing in mind the review of putative host fish movement, Ruscom River and Belle River will be considered a single population. Due to age and state of the Lilliput record from the Detroit River (one record from 1943), we will not consider this location to represent a population. Therefore, the following will be considered separate populations for the purposes of this research document: Sydenham River, Thames River (including Baptiste Creek), Ruscom River/Belle River, Grand River, Welland River, Jordan Harbour, and Hamilton Harbour and surroundings (including Sunfish Pond, Carroll's Bay, Cootes Paradise, and Grindstone Creek).

A comparison between the current extent of occurrence, and index of area of occupancy to historic values indicate that the spatial extent of the records has declined over the last 10 years (COSEWIC 2013). The extent of occurrence, which was estimated using a minimum convex polygon has declined by 22%, while the index of area of occupancy has declined 44% (COSEWIC 2013).

SYDENHAM RIVER

The first historical record of Lilliput from the North Sydenham River was dated 1967 and collected by H.D. Athearn and M.A. Athearn. A second record, this one of a live individual was recorded in 1991 from the East Sydenham River (collector: A.H. Clarke). Recent sampling efforts to verify the presence of this species in the Sydenham River yielded seven live individuals at a site east of Tupperville Bridge (Tupperville, Ontario; Figure 6; McNichols-O'Rourke et al. 2012).

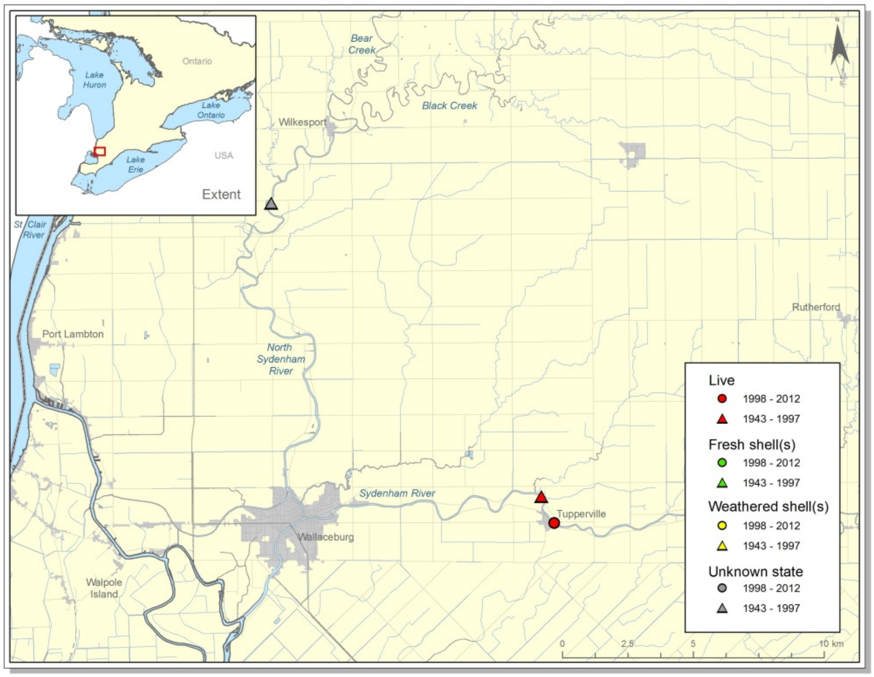


Figure 6. Distribution of all known current and historic Lilliput records from the Sydenham River.

THAMES RIVER

There are currently two records of Lilliput in the Thames River. The first record originates from H.D. Athearn's 1963 collection in Chatham, Ontario. The second record is represented by a single live individual recorded from Baptiste Creek (a tributary of the Thames River) in 2010 (Figure 7; McNichols-O'Rourke et al. 2012).

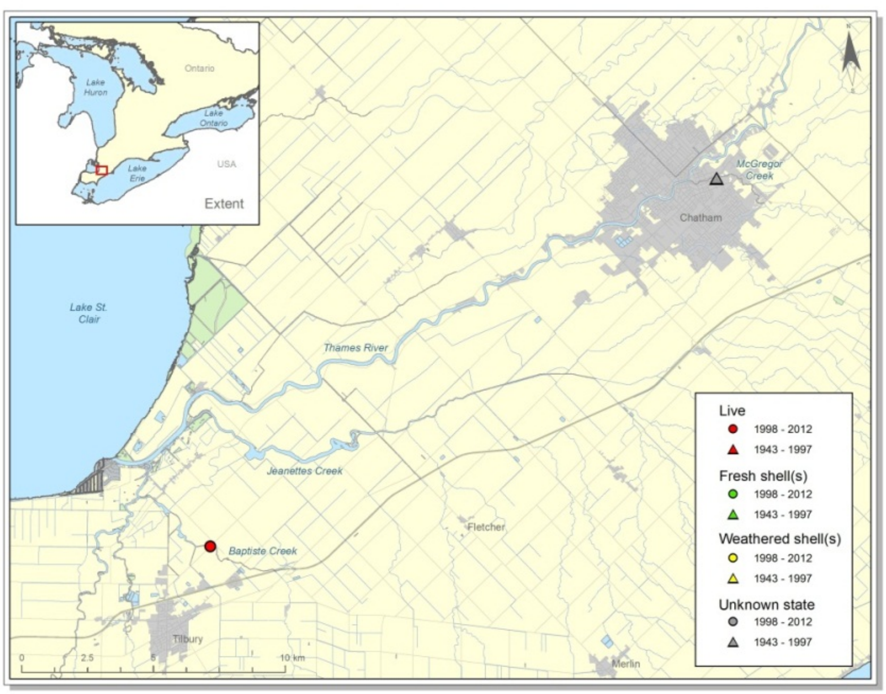


Figure 7. Distribution of all known current and historic Lilliput records from the Thames River.

RUSCOM RIVER

Ruscom River represents one of two Lake St. Clair southern shore tributaries known to be occupied by Lilliput (Figure 8). Three live Lilliput and two weathered shells were recorded from two sites in 2010 (McNichols-O'Rourke et al. 2012). The first site was located at Saint Joachim, and the second was approximately 4 km upstream. No additional mussel sampling has occurred in this system.

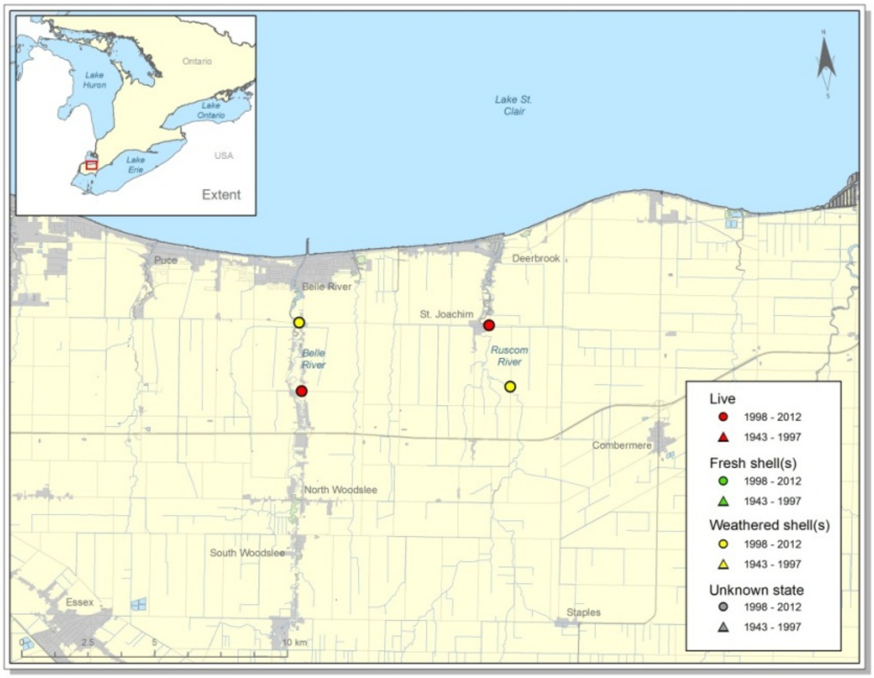


Figure 8. Distribution of all known current and historic Lilliput records from the Ruscom and Belle rivers.

BELLE RIVER

Bell River is the second of two Lake St. Clair southern shore tributaries occupied by Lilliput (Figure 8). The first record of Lilliput in this system originates from a single weathered shell collected in 1999 (D. Zanatta, unpubl. data), while the second record consists of two live individuals recorded from the road crossing upstream of Lions Club road (McNichols-O'Rourke et al. 2012).

DETROIT RIVER

The only record of Lilliput from Canadian waters of the Detroit River is dated 1943 (collector: F.R. Latchford; UM186265). This historical record is lacking information on the state of the individual; therefore, the quality of the specimen is unknown. Additional mussel surveys have occurred in the Detroit River since this time but have not detected Lilliput (Figure 9; Schloesser et al. 1998; Schloesser et al. 2006). The Detroit River will not be considered in the Population Status Assessment.

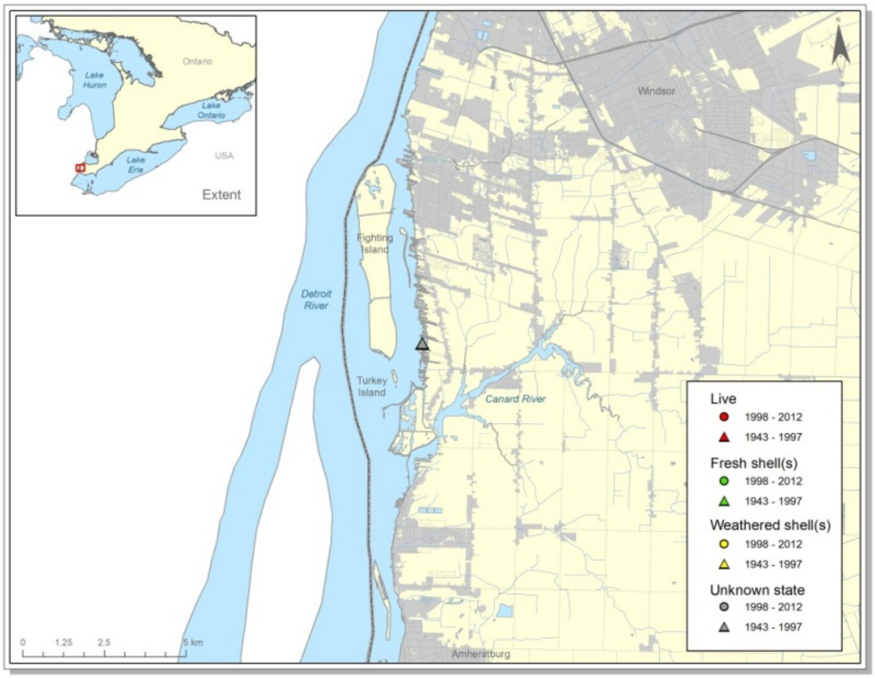


Figure 9. Distribution of all known current and historic Lilliput records from the Detroit River.

GRAND RIVER

All Lilliput records from the Grand River originate from the mouth of the river to approximately 15 km upstream, with the majority occurring within the first 8 km of river (Figure 10). Historically, Lilliput shells were recorded from the Grand River in 1952 by A. Clarke and L. Clarke (CMNML 014332), in 1963 by D.H. Stansbery and C.B. Stein (OSUM 1963:0060), in 1966 by J.G. Oughton (CMNML 070974; CMNML 0709746) and in 1971 by Kidd (1973). The first detection of live individuals occurred in 1997 when two live individuals were recorded from Byng Park (DFO, unpubl. data). Additional surveys of the river in 2011 resulted in 13 live individuals and nine weathered shells (DFO, unpubl. data).

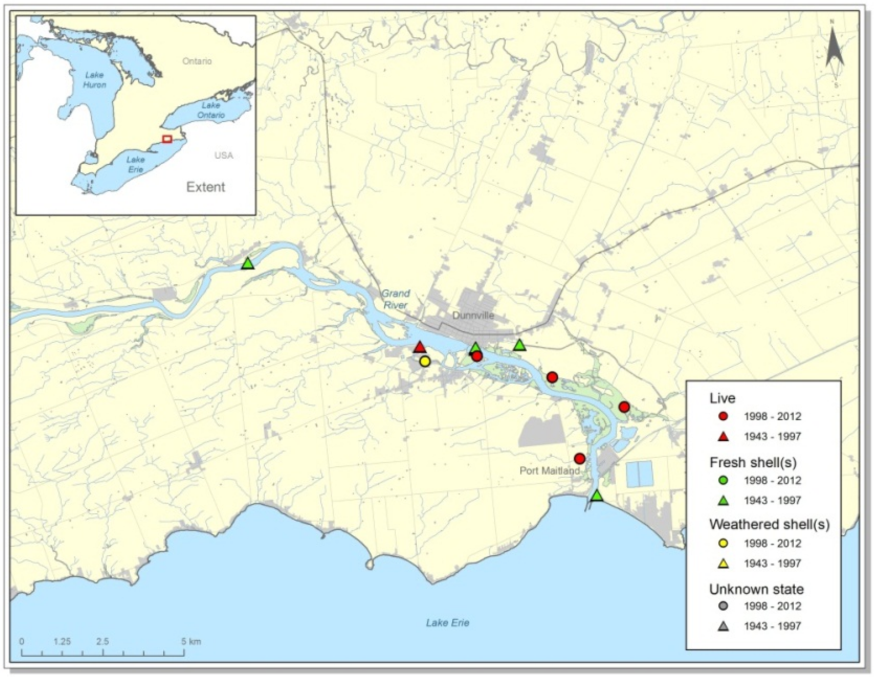


Figure 10. Distribution of all known current and historic Lilliput records from the Grand River.

WELLAND RIVER

A single live individual was recorded from the Welland River in 2008 (Figure 11; McNichols-O'Rourke et al. 2012). A total of eight sites were visited during this sampling event and only a single individual was detected. Additional sampling in the Welland River to confirm the presence of a Lilliput population has yet to be completed.

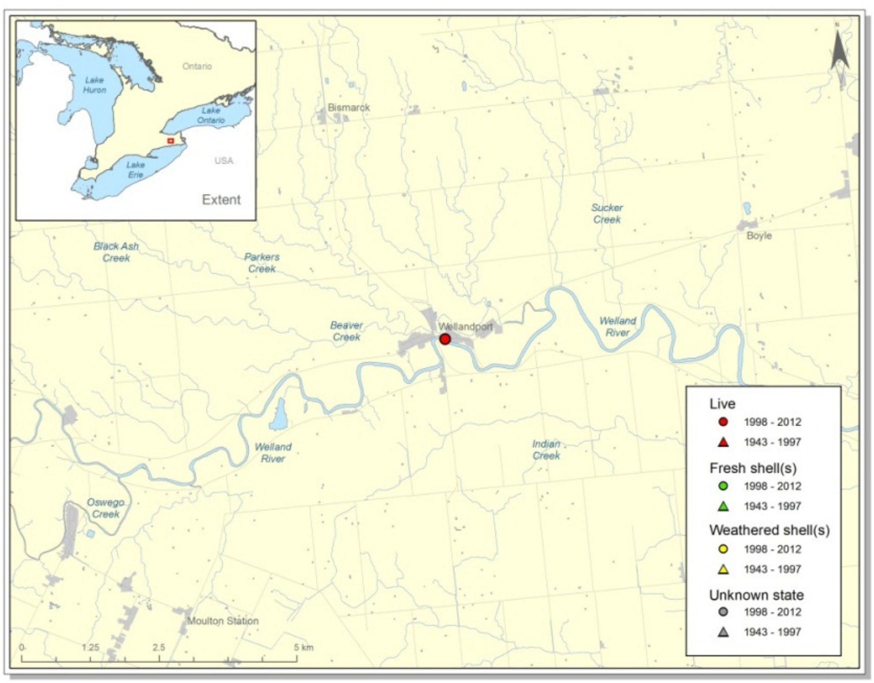


Figure 11. Distribution of all known current and historic Lilliput records from the Welland River.

JORDAN HARBOUR

In 2012, Lilliput targeted sampling, by means of visual timed search and clam rakes, occurred in Jordan Harbour, a wetland located along the south shore of Lake Ontario at Twenty Mile Creek [Figure 12; Ontario Ministry of Natural Resources (OMNR) and DFO, unpubl. data]. This sampling event detected the presence of nine live Lilliput at five sites. There are no historical records for Lilliput at Jordan Harbour.

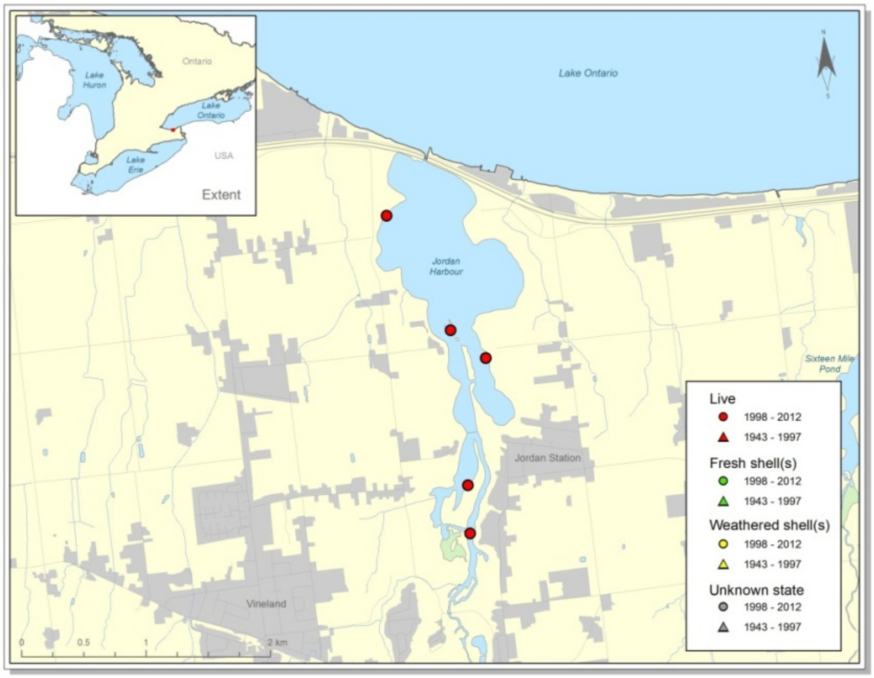


Figure 12. Distribution of all known current and historic Lilliput records from Jordan Harbour.

HAMILTON HARBOUR AND SURROUNDINGS

Lilliput has been detected throughout western Hamilton Harbour (Carroll's Bay), the lower Grindstone estuary (Sunfish Pond, Blackbird Marsh) and Cootes Paradise (Figure 13). A total of 155 fresh shells (whole and valves) and 11 weathered shells (whole and valves) have been recorded from these areas since 2000. Lilliput targeted sampling occurred in 2011 to determine the presence of an extant population. Two live individuals were detected from a single site in Sunfish Pond (Smith and Morris, unpubl. data). Mussel sampling by visual search in 2012 resulted in the observation of live individuals in Sunfish Pond (n=2), Grindstone Creek (n=1) and Cootes Paradise (n=4) (T. Theysmeyer, RBG, unpubl. data). These observations represent the first time live individuals were recorded from both Grindstone Creek and Cootes Paradise.

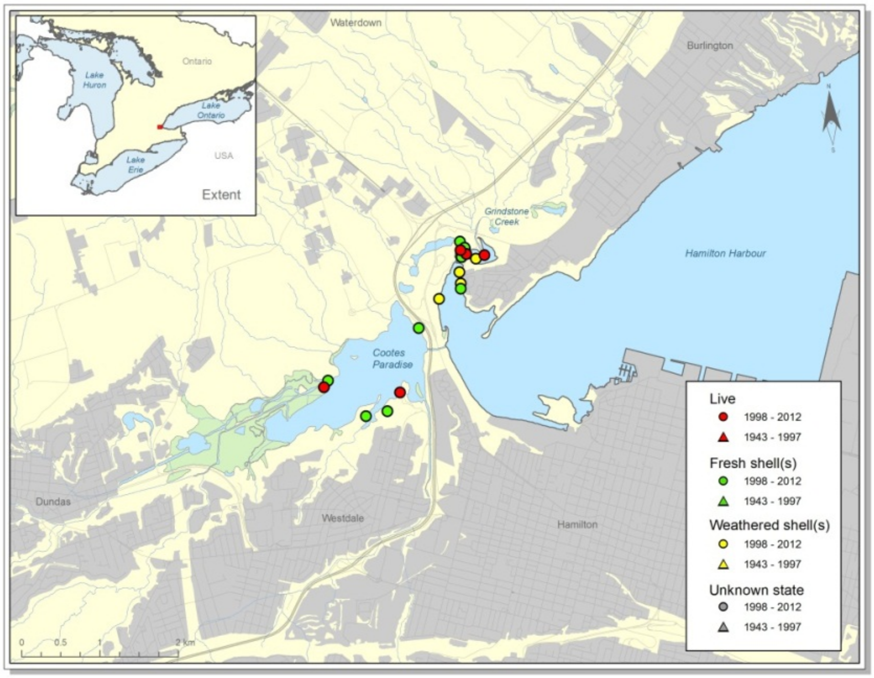


Figure 13. Distribution of all known current and historic Lilliput records from Hamilton Harbour and its surroundings.

POPULATION STATUS ASSESSMENT

ASSESSMENT

To assess the Population Status of Lilliput populations in Canada, each population was ranked in terms of its abundance and population trajectory (Table 1). Abundance 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 Lilliput. The number of individual Lilliput caught during each sampling period, as well as the state of the individual (live, fresh shell or weathered shell) was then considered when assigning abundance. It is important to remember that abundance is based on Lilliput records currently available.

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 1. Relative Abundance Index and Population Trajectory of each Lilliput 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
Sydenham River	Low	2 (timed search)	Unknown	3
Thames River (Baptiste Creek)	Low	2 (timed search)	Unknown	3
Ruscom River/Belle River	Low	2 (timed search)	Unknown	3
Grand River	Low	2 (timed search)	Unknown	3
Welland River	Low	2 (timed search)	Unknown	3
Jordan Harbour	Low	2 (timed search)	Unknown	3
Hamilton Harbour and surroundings	Low	2 (timed search & observation)	Unknown	3

The Relative Abundance Index and Population Trajectory values were then combined in the Population Status matrix (Table 2) to determine the Population Status for each population. Population Status was subsequently ranked as Poor, Fair, Good, Unknown, or Not applicable (Table 3). 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 2. The Population Status Matrix combines the Relative Abundance Index and Population Trajectory rankings to establish the Population Status for each Lilliput 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 3. Population Status of all Lilliput 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
Sydenham River	Poor	3
Thames River (Baptiste Creek)	Poor	3
Ruscom River/Belle River	Poor	3
Grand River	Poor	3
Welland River	Poor	3
Jordan Harbour	Poor	3
Hamilton Harbour and surroundings	Poor	3

HABITAT REQUIREMENTS

GLOCHIDIUM

To fully understand the habitat requirements of freshwater mussels, we must first understand their unique life cycle. Some believe Lilliput to be wholly hermaphroditic (Ortmann 1912), while others believe that the relative proportion of hermaphrodites may increase under low population densities to help increase population numbers (Watters et al. 2009). Regardless of reproductive strategy, Lilliput are believed to express very little sexual dimorphism. During the spawning period, males located upstream release sperm into the water column via the excurrent siphon. 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.

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). Lilliput is classified as a long-term brooder, with eggs being reported in June to August, and glochidia present in July (Watters et al. 2009; COSEWIC 2013). Although gravid individuals have not been observed in Ontario, they have been observed in April (Texas), June (Pennsylvania and Arkansas), and August (Indiana and Wisconsin) in the United States (Williams et al. 2008; COSEWIC 2013). Regardless of brooding strategy, once females release their glochidia they must encyst on the gills of an appropriate host fish (Kat 1984). Glochidial mortality is currently unknown but it is estimated that as little as 0.001% of glochidia successfully attach to an appropriate host fish (Bauer 2001). Metamorphosis from glochidia to juvenile cannot occur without a period of encystement, which has been recorded to occur at 12 days post infestation on Johnny Darter (Watters et al. 2005), and 30-35 days post infestation on Green Sunfish (Hove 1995).

Host fishes

Infestation experiments to determine host fish for Lilliput in Canada have not occurred, but Johnny Darter, Green Sunfish, White Crappie, Bluegill, Warmouth (*Lepomis gulosus*) and Orangespotted Sunfish (*Lepomis humilis*) have been identified to be appropriate host fish in the United States (see Watters et al. 2009 for species-specific references). Complete distributional overlap with the extant range of Lilliput in Canada does exist for Johnny Darter, Green Sunfish, White Crappie, and Bluegill, providing circumstantial evidence of host fish interaction (Scott and Crossman 1973; Holm et al. 2010; DFO, unpubl. data). There is no distributional overlap between Lilliput and Warmouth or Orangespotted Sunfish; therefore, these species do not appear to be functional hosts for Lilliput in Canada. Green Sunfish, Bluegill and White Crappie tend to have similar preferred habitat, tending towards areas of warm water in lakes, wetlands or slow moving streams with some aquatic vegetation, while Johnny Darter are more often found in streams and lakes, particularly those with little to moderate current, and substrate ranging from sand/silt to gravel (Scott and Crossman 1973; Holm et al. 2010). The overlap in distribution provides circumstantial evidence to the probable host-mussel relationship between Lilliput and Johnny Darter, Green Sunfish, White Crappie and Bluegill.

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 Lilliput and these four probable host fishes 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). Lilliput have evolved a complex strategy, in that they appear to use active lures to attract their host. Zanatta and Murphy (2006) indicate that Lilliput utilize both a worm-like caruncle (a finger-like projection of the mantle; Howells et al. 1996) and an active mantle flap to attract it's host. Lilliput also releases club-shaped conglutinates (Utterback 1916 *in* Watters et al. 2009). The glochidia are untethered and embedded in a core of unfertilized eggs (Watters et al. 2009). A predatory response from the host fish causes the host to ingest the conglutinate, resulting in the release, and subsequent attachment, of the glochidia. (COSEWIC 2013).

Regardless of the method of exposure and attachment, glochidia will remain encysted on the host fish until they metamorphose into juveniles. It should be noted that not all glochidia successfully metamorphose as some drop off and an estimate of the proportion of glochidia that successfully metamorphose is currently unknown. Encystement is an obligate step in the life cycle of Lilliput 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 Lilliput.

JUVENILE

Subsequent to metamorphosis, juvenile freshwater mussels are released from the gills of the host fish and burrow 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 (Schwalb and Pusch 2007). Once sexually mature they emerge from the substrate to participate in gamete exchange (Watters et al. 2001).

ADULT

General characteristics

Although Lilliput is found in a variety of habitats (e.g., small rivers, larger rivers, wetlands, shallow areas of ponds and backwaters), it is mostly commonly found in the lower reaches of large rivers, wetlands, and backwater areas with little current (Metcalfe-Smith et al. 2005; Watters et al. 2009).

Depth

Lilliput is generally categorized as occupying relatively shallow areas, and they have been recorded from areas ranging from 0.5 to 1.5 m in depth (McNichols-O'Rourke et al. 2012; Morris et al. 2012). It is difficult to discuss preferred water depth, as is the case for many freshwater mussels, due to imposed biases related to sampling techniques. The maximum water depth where Lilliput can survive, and its preferred water depth is currently unknown.

Substrate

Lilliput is most often found in soft substrates composed of mud, sand, silt and clay (Parmalee and Bogan 1998; Watters et al. 2009; COSEWIC 2013). Limited habitat information is available from the 16 sites where live Lilliput have been recorded between 1997-2012 from Baptiste Creek, Belle River, Grand River, Jordan Harbour, Ruscom River, Sunfish Pond, Sydenham River and Welland River (Figure 14; McNichols-O'Rourke et al. 2012; Morris et al. 2012; DFO, unpubl. data; S. Reid, OMNR, unpubl. data).The percent composition of various substrate types were estimated during site visits and it was found the majority of sites were composed of a combination of sand, silt, clay, muck and detritus (14 of 16 sites had greater than 80% of this combination; McNichols-O'Rourke et al. 2012; Morris et al. 2012; DFO, unpubl. data; S. Reid, OMNR, unpubl. data). The remaining two sites, one from the Grand River and one from Sydenham River, had a higher composition of gravel (35 and 40%; McNichols-O'Rourke et al. 2012). Twenty (of the 40 live Lilliput recorded) were found at sites where the sand, silt, clay and detritus combination was recorded to be 100%.

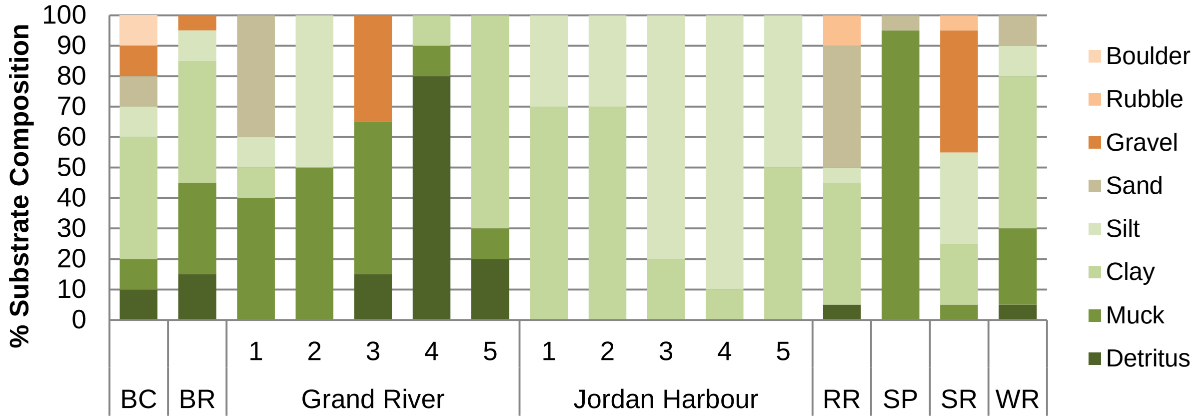


Figure 14. Substrate composition (%) recorded at sites where live Lilliput were recorded from 1997-2012 in Baptiste Creek (BC), Belle River (BR), Grand River, Jordan Harbour, Ruscom River (RR), Sunfish Pond (SP), Sydenham River (SR) and Welland River (WR).

FUNCTIONS, FEATURES AND ATTRIBUTES

A description of the functions, features, and attributes associated with Lilliput habitat can be found in Table 4. The habitat required for each life stage has been assigned a function that corresponds to a biological requirement of Lilliput. 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 (recorded from 1997 to present) to show the maximum range in habitat attributes within which Lilliput may be found (see Table 4 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 Lilliput be currently occupying areas where optimal habitat is no longer available.

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 (DFO 2010). In the context of the above narrative description of habitat requirements during glochidial, juvenile and adult life stages, Lilliput does not construct a residence during its life cycle.

Table 4. Summary of the essential functions, features and attributes for each life stage of Lilliput. Habitat attributes from published literature, and habitat attributes recorded during recent Lilliput surveys (recorded since 1997) 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 eggs found in June to August, and glochidia present July)	Reproduction	Lower reaches of large rivers, small rivers, wetlands, and shallow backwater areas		• There are no records of Lilliput spawning in Canada	• Same habitat as adult
Encysted glochidial stage on host fish until drop off	Development	Appropriate host fish	• Infestation experiments reported that Johnny Darter, Green Sunfish, White Crappie, Bluegill, Warmouth and Orangespotted Sunfish are appropriate host fish for Lilliput in the United States (Watters et al. 2009) • In Canada, distributional overlap does exist between Lilliput and Johnny Darter, Green Sunfish, White Crappie and Bluegill, providing circumstantial evidence of host fish interaction • There are no records from the literature of infestation of putative host fishes by Lilliput in Canada	• There are no records of natural infestations of Lilliput glochidia on gills of putative host fishes	• Presence of sufficient host fish (putative host fishes in Canadian waters are Johnny Darter, Green Sunfish, White Crappie and Bluegill)
Adult/juvenile	Feeding Cover Nursery	Lower reaches of large rivers, small rivers, wetlands, and shallow backwater areas	**General** • Categorized as occupying small rivers, large rivers, wetlands, shallow areas of ponds and backwaters (Metcalfe-Smith et al. 2005; Watters et al. 2009) **Depth** • Lilliput is generally categorized as occupying relatively shallow areas (Watters et al. 2009)	• General characteristics taken from the literature supported by recent reports of live individuals • Live Lilliput recorded at depths ranging from 0.5 to 1.5 m (McNichols-O'Rourke et al. 2012; Morris et al. 2012) • Maximum depth may be	• Known to occupy water ranging from 0.5 to 1.5 m in depth

			Habitat Attributes		
Life Stage	**Function**	**Feature(s)**	**Scientific Literature**	**Current Records**	**For Identification of Critical Habitat**
				imposed by biases related to sampling technique	
			Substrate • Lilliput is most often found in soft substrates composed of mud, sand, silt and clay (Parmalee and Bogan 1998; Watters et al. 2009; COSEWIC 2013)	• The majority of sites where live Lilliput were recorded were composed of a combination of sand, silt, clay, muck and detritus (McNichols-O'Rourke et al. 2012; DFO, unpubl. data; S. Reid, OMNR, unpubl. data; Morris et al. 2012)	• Most often found in areas where the substrate is composed of sand, silt, clay, muck and detritus, or a combination thereof
			Presence of dreissenid mussels • Introduction and establishment of dreissenid mussels has negatively affected freshwater mussels in the Great Lakes	• During a sampling event at Baptiste Creek in 2011 at a site where a live Lilliput was recorded, it was noted that there were many Zebra Mussel shells present (McNichols-O'Rourke et al. 2012) • Zebra Mussel present in the Grand River up to the Dunnville Dam (G. Mackie, pers. comm.)	

POPULATION SENSITIVITY TO PERTURBATION

There was insufficient information on the life history of Lilliput to complete a population model of the species. For use in such data-poor scenarios, Young and Koops (2011) used a population matrix model framework to explore the sensitivity of Unionid mussel populations to perturbations.

Sensitivity was quantified using elasticities, which can be used to describe the expected percent change in the long-term population growth rate as a result of a percent change in a vital rate (Caswell 2001). A range of possible Unionid life histories were classified into groups with similar elasticities. It was found that sensitivity groups could be predicted if certain vital rates were known to be on either the high or the low end of the parameter range. Life histories were classified into the following groups:

- Reproduction dominant: population growth was most sensitive to perturbation or uncertainty in age at maturity; glochidial survival and fecundity were more influential in this group than in others.
- Adult survival dominant: adult survival influenced population growth much more than juvenile survival. Remaining vital rates were relatively less important.
- Juvenile survival dominant: population growth was most influenced by juvenile survival.

The relative fecundity of Lilliput is unknown. However, Lilliput is thought to be a relatively short-lived species (maximum observed age of 12 years) (Watters et al. 2009), with early maturity (COSEWIC 2013). Using the classification system from Young and Koops (2011), Lilliput falls into either the reproduction dominant group (if fecundity is high) or the adult survival dominant group (if fecundity is low). An updated version of this classification system (DFO, unpubl. data) also suggests that if fecundity is low, Lilliput may fall into a fourth “low sensitivity” group. This group is similar to the adult survival dominant group but with lower sensitivity to adult survival (i.e., population growth is less sensitive to all vital rates compared to other groups). In this group, population growth is equally sensitive to changes in adult survival, juvenile survival, and lifespan. It is thought that Lilliput produce a small number of conglutinates with relatively low numbers of glochidia (G. Watters, pers. comm.). We therefore conclude that Lilliput belongs to the fourth “low sensitivity” group.

Note that sensitivity analyses are meant to compare expected responses in population growth to changes in vital rate. Pertinent threats to the species may affect life stages not identified as being most sensitive to perturbation.

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). 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 its 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). Urbanization and both residential and commercial development may be negatively affecting Lilliput across much of its known distribution, contributing to further decreases in water quality by increasing sedimentation from land development, increasing nutrient and contaminant inputs and modifying natural systems (e.g., creation of dams).

A wide variety of threats negatively affect Lilliput across its range. Our knowledge of threat impacts on Lilliput 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 Lilliput 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.

CONTAMINANTS AND TOXIC SUBSTANCES

Freshwater mussel life history characteristics 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. As mussels generally display little movement, they tend to accumulate deleterious substances from their environment, one of the reasons they are prime candidates for studies in environmental ecotoxicology. Toxic chemicals from both point and non-point sources are believed to be one of the major threats to mussel populations today (Strayer and Fetterman 1999). In rural areas contaminants and toxic substances can originate from agricultural practices, while inputs in urbanized areas generally include sewage pollution from outflows or stormwater runoff, and toxic pollutants that enter the sewer system from industrial operations. Of increasing concern is the application of road salts as a de-icing or anti-icing chemical.

A study conducted by Environmental Canada in 2001 and 2002 analyzed the sediment quality in the mouths of all tributaries to Lake Erie and Lake Ontario (Table 5; Dove et al. 2002, 2003; Bejankiwar 2009). From the results of this study, we can see that many of the tributaries within the known distribution of live Lilliput records showed exceedances of both federal and provincial standards for polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), various metals and pesticides.

The effects of heavy metals on mussels have been reviewed by Fuller (1974) and it was concluded that substances such as arsenic, cadmium, chlorine, copper, mercury and zinc can be toxic to freshwater mussels because they accumulate these substances from their environment. This toxicity may be increasingly relevant to glochidia and juveniles. Interestingly, a study on the sensitivity of freshwater mussels to copper indicated that conglutinates were found to provide significant protection from acute copper exposure when compared to freed glochidia (Gillis et al. 2008); therefore, this reproductive strategy, utilized by Lilliput, may afford the glochidia some protection from contaminants. There is also an ever-growing body of literature indicating that freshwater mussels are sensitive to ammonia (Augspurger et al. 2003; Bartsch et al. 2003; Mummert et al. 2003).

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

Table 5. Summary of sediment contamination at the mouths of various tributaries of Lake Ontario and Lake Erie within, or in close proximity to, the known distribution Lilliput (TEL=federal threshold effect level, PEL=federal probable effect level, LEL=provincial lowest effect level and SEL=provincial severe effect level). Table reproduced from Dove et al. (2002, 2003). Blank cells represent samples where there was no detection.

		Exceedance of standards*			
River	**Lilliput population affected**	**Total PAHs**	**Total PCBs**	**Metals**	**Pesticides**
Baptiste Creek	Thames River (Baptiste Creek)			Arsenic, Cadmium, Zinc: TEL Iron: LEL and TEL Copper, Nickel: LEL	Total DDE: TEL
Belle River	Ruscom/Belle rivers	TEL		Arsenic: TEL and LEL Iron and Nickel: LEL Lead and Zinc: LEL	Total DDD: TEL Total DDE: TEL
Ruscom River	Ruscom/Belle rivers			Arsenic, Iron, Nickel, Lead, Zinc: TEL and LEL	Total DDE: TEL
Chedoke Creek	Hamilton Harbour and surroundings	LEL		Arsenic, Cadmium, Chromium, Copper, Lead: TEL Zinc: PEL Mercury, Manganese, Nickel: LEL	
Grindstone Creek	Hamilton Harbour and surroundings			Arsenic and Cadmium, Zinc: TEL Manganese: SEL	Total DDD: TEL Total DDE: PEL Total DDT: PEL
Spencer Creek	Hamilton Harbour and surroundings		LEL	Cadmium, Lead: TEL Manganese: LEL Zinc: PEL	Total DDE: TEL
Twenty Mile Creek	Jordan Harbour			Arsenic and Cadmium: TEL Iron, Manganese, Nickel: LEL	Total DDE: PEL Total DDT: TEL

*Federal levels (TEL, PEL) set out by Environment Canada; Provincial levels (LEL, SEL) set out by the Ministry of the Environment

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.

Effluents from municipal treatment plants are known as a major source of pollution, releasing metals, PAHs, pharmaceuticals and various endocrine-disrupting compounds into waterways (Chambers et al. 1997). In addition, numerous studies have reported the negative effects of municipal effluents on freshwater mussel health (Gagné and Blaise 2003; Gagné et al. 2004; Gagné et al. 2011). Gagné and Blaise (2003) reported that freshwater mussels caged downstream from a municipal water treatment facility with primary treatment were exposed to estrogenic chemicals present in the municipal effluent, which may alter the normal metabolism of serotonin and dopamine, two chemicals involved in sexual differentiation. This is further supported by Gagné et al. (2011) who presented evidence that exposure to municipal effluent may lead to feminization of wild freshwater mussels and be disrupting gonadal physiology (Gagné et al. 2011). In the Grand River, Flutedshell (*Lasmigona costata*) downstream of a municipal wastewater outfall were shown to have reduced condition factor as well as exhibited negative immune status when compared to mussels upstream of the outfall (P. Gillis, Environment Canada, pers. comm. *in* COSEWIC 2013).

Increased levels of per- and poly-fluorinated compounds (a broad class of substances often used in industrial and consumer products) have been shown at elevated levels in Lake Niapenco, in the upper watershed of the Welland River (de Solla et al. 2012). This may be of particular importance to freshwater mussels as it has been shown through acute toxicity tests that perfluoroctanesulfonic acid significantly reduces the duration of glochidia viability and reduces the probability of glochidial metamorphosis (Hazelton et al. 2012).

NUTRIENT LOADING

Agriculture, the primary land use in many southwestern Ontario watersheds, appears to be contributing to poor water quality through agricultural runoff and manure seepage (Grand River Conservation Authority 1997; Thames River Recovery Team 2005; Veliz et al. 2007; MacDougall and Ryan 2012). 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. 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 may contribute to poor water quality in watersheds dominated by agricultural lands. Increased application of nutrients (nitrogen and phosphorus) as fertilizer and manure was the main driver for the declining trend in the performance index for water quality throughout Canada (Agricultural Atlas; Accessed: 3 September 2013). Specifically, the Thames, Sydenham, Ruscom, Belle and Grand rivers face increased pressure from agricultural activities, and often show high nutrient levels with total phosphorus levels often exceeding the provincial water quality objective (PWQO) of 30 µg/L (St. Clair Region Conservation Authority 2009; MacDougall and Ryan 2012). Water quality monitoring in Sydenham River reported total phosphorus concentrations from 30 µg/L to 200 µg/L (St. Clair Region Conservation Authority 2009). Concentrations of total phosphorous, associated with agricultural runoff, continue to increase in the east branch of the Sydenham River, and may be affecting Lilliput. Thick layers of green algae are often observed at the Belle and Ruscom rivers water quality monitoring sites by Essex-Region Conservation Authority (ERCA) staff (Bejankiwar 2009). An intensive water quality monitoring study focusing on the lower Grand River was conducted in 2003 and 2004 (MacDougall and Ryan 2012). This study indicated that of the 402 water samples collected throughout the Grand River that only six of these samples fell below the PWQO for total phosphorus (MacDougall and Ryan 2012). In Cootes Paradise, high algal biomass is thought to be the result of excessive nutrient loads from sewage effluent and surface runoff (Chow-Fraser 1998).

TURBIDITY AND SEDIMENT LOADING

Increases in turbidity, and the subsequent decrease in silt-free habitats has reduced the quantity and quality freshwater habitat across southwestern Ontario. 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. Furthermore, the reproductive cycle of Lilliput requires a visual predator to be attracted to a lure, and subsequently become infested with glochidia. Extreme levels of siltation would decrease the likelihood that the host fish will be able to locate 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 (COSEWIC 2008). On a much smaller scale, in-water projects without sedimentation controls may cause temporary turbidity increases in the waterway.

Portions of the Thames and Sydenham rivers flow through areas of prime agricultural land in southwestern Ontario. It is estimated that over 85% of the land in the Sydenham River and 88% of the land in the lower Thames River is used for agricultural purposes and large extents of these rivers have little to no riparian vegetation (Dextrase et al. 2003). Dextrase et al. (2003) reported suspended solid levels in the Sydenham River to be as high as 900 $mg \cdot L^{-1}$, which would undoubtedly negatively affect the freshwater mussel assemblage.

Another watershed greatly affected by increased turbidity is the Grand River. It is believed that poor water quality and increased sediment loads in this watershed have resulted from riparian vegetation clearing and increased livestock access to the river (Water Quality Branch 1989). The effects of increases in agricultural land use in the Grand River on Lilliput are not known.

Turbidity readings from the Belle River Wastewater Treatment Plant (WTP) were reviewed between the period of 2002 and 2006, and it was found that turbidity levels were commonly between 20 to 100 NTU (Bejankiwar 2009). A turbidity level of 200 NTU is considered very high and is often used as a benchmark to indicate a change in standard procedures is necessary (Bejankiwar 2009). Data from the Belle River WTP revealed that 4.8% of readings exceeded 200 NTU between 2002 and 2006 (Bejankiwar 2009).

Although, it is known that increases in turbidity and decreases in silt-free habitats reduce water quality for freshwater mussels, it is difficult to determine the effects that these environmental changes may have on Lilliput, as this species is often associated with areas of increased turbidity (i.e., Jordan Harbour, Grindstone Creek, Sunfish Pond). It has been suggested that sedimentation effects (i.e. the accumulation of silt on the streambed that may reduce flow rates and dissolved oxygen concentrations below the surface) may have a greater impact on Lilliput as they tend to burrow in the substrate (Österling et al. 2010; COSEWIC 2013). Experiments are necessary to determine the turbidity tolerance levels of Lilliput. However, increased turbidity will undoubtedly affect the host fish’s ability to locate the mussel, and would decrease the probability of a host fish encounter and glochidial transfer.

INVASIVE SPECIES

Dreissenid mussels, Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena bugensis*), have severely affected native, lacustrine freshwater mussel populations. The invasion and spread of these invasive species throughout the Great Lakes and their tributaries has decimated many native freshwater mussel populations (Schloesser and Nalepa 1994; Nalepa et al. 1996; Ricciardi et al. 1996; Schloesser et al. 1996; Schloesser et al. 1998; Zanatta et al. 2002). 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 over a very short time period.

This threat may have been particularly relevant to Lilliput population in the Detroit River; although it has not been confirmed that a Lilliput population once existed in this system. Zebra Mussel are not only a threat for lacustrine freshwater mussel populations but do pose a threat to riverine populations should they become established in reservoirs. Impoundments behind reservoirs act to increase water retention times, allowing time for Zebra Mussel veligers to settle and act as a seed population. Infestation may occur if water retention time is greater than the life span of the larval stage of the Zebra Mussel (G. Mackie, University of Guelph Emeritus, pers. comm.). Zebra Mussel have already been reported in two reservoirs on the Thames River (Upper Thames River Conservation Authority 2003), and have been noted to occur throughout the lower Thames River from Fanshawe Reservoir to the mouth of the river (Morris and

Edwards 2007). Zebra Mussel shells have also been observed during field sampling in Baptiste Creek, a tributary of the lower Thames River, where a live Lilliput was recorded in 2010 (McNichols-O'Rourke et al. 2012). Another highly susceptible population is that of the Grand River, which is heavily impounded with a total of 34 dams/weirs (Grand River Conservation Authority 1998). Zebra Mussel infestation in the Luther, Bellwood, Guelph, Conestogo reservoirs could seriously impact the freshwater mussel populations of the Grand River (Metcalfe-Smith et al. 2000); although, the effect of Zebra Mussel in the Grand River may not be detrimental to Lilliput as its current distribution is concentrated in the lower Grand River.

Round Goby (*Neogobius melanostomus*), another invasive species that is now prolific throughout the lower Great Lakes and tributaries, may also be negatively affecting Lilliput. Round Goby have been shown to predate on Zebra Mussel (Ghedotti et al. 1995; Ray and Corkum 1997) but it is unknown whether Round Goby are currently utilizing native unionid mussels as a food source. Round Goby gape size limitations may be restricting Round Goby predation on Lilliput. Ray and Corkum (1997) indicated that only large, adult Round Goby (8.5-10.3 cm in length) had the ability to prey on Zebra Mussel with shell sizes ranging from 10-12.9 mm, while smaller Round Goby size classes could only predate on smaller mussel size classes (<10 mm shell length). Therefore, gape size limitations (maximum 12.9 mm; Ray and Corkum 1997) may be restricting the ability of Round Goby to prey on adult Lilliput, while juvenile Lilliput may remain susceptible to predation. In addition to negatively affecting Lilliput through predation, Round Goby may also be inhibiting unionid recruitment by acting as a host. Tremblay (2012) tested the infestation and metamorphosis rates of four mussel species at risk and compared them to rates obtained from known host fish in a laboratory setting. It was concluded that Round Goby serves more as a sink for glochidia than as a host, and may be negatively affecting freshwater mussels by disrupting their reproductive cycle (Tremblay 2012). In addition to the direct affect that Round Goby may have on Lilliput, Round Goby may be negatively affecting Lilliput through competition with, and predation of host fishes (see subsection on Host fishes in Threats section).

The feeding behaviour of Common Carp (*Cyprinus carpio*) is known to have serious negative impacts on aquatic systems by uprooting aquatic vegetation and increasing turbidity levels (Lougheed et al. 1998; Lougheed et al. 2004). This feeding behaviour, known to cause significant alterations to native wetland habitats, may impact Lilliput. In addition, Common Carp has been shown to be the cause of bottom sediment re-suspension, increasing nutrient levels, leading to hypereutrophic conditions (Mayer et al. 1999). A study at Point Pelee National Park (Sanctuary Pond) was completed in 1994 to determine the cause of elevated nutrient concentrations leading to prolific algal growth (Mayer et al. 1999). It was determined that organic matter decomposition was an important mechanism leading to high concentrations of nutrients, and that re-suspension of bottom sediment, primarily by Common Carp foraging behaviour, were most likely responsible for the hypereutrophic conditions (Mayer et al. 1999). The negative effects of Common Carp may be particularly relevant to Lilliput populations in Hamilton Harbour and surroundings, Jordan Harbour and the lower Grand River where they are known to be prolific.

To facilitate the threat level assessment, and to provide context on which invasive species is being considered for each Lilliput population, Table 6 was created to highlight the current known distribution of dreissenid mussels, Round Goby and Common Carp.

Table 6. Current known distribution of dreissenid mussels, Round Goby and Common Carp in areas where live Lilliput have been recorded to occur. It should be noted that the presence of the invasive species is only being considered within the known range of Lilliput (see Current Status for additional information).

	Invasive Species		
	Dreissenid mussels	**Round Goby**	**Common Carp**
Sydenham River		X	X
Thames River (Baptiste Creek)	X	X	X
Ruscom River/Belle River		X	X
Grand River	X	X	X
Welland River	X		X
Jordan Harbour	X	X	X
Hamilton Harbour and surroundings	X*	X	X

* Dreissenid present but no established population in Cootes Paradise (Tys Theysmeyer, RBG, pers. comm.).

HABITAT LOSS 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 or moved to areas that may be comprised of less suitable habitat. In a study on the effects of dredging on freshwater mussel populations, Aldridge (2000) noted that 3-23% of the mussel population (depending on species) was displaced by dredging activities. This threat may be particularly important to Lilliput populations in the Ruscom and Belle rivers, which undergo yearly dredging to maintain both recreational and commercial access; although dredging typically occurs downstream of the currently known range of Lilliput in these two systems. 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 streams and rivers has been shown to negatively affect mussel communities (Vaughn and Taylor 1999; Parmalee and Polhemus 2004). 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 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. Man-made alterations to the environment have also been detrimental to mussel communities (Watters 2000). For example, channelization, dredging and snagging activities result in the disruption of the riffle-run-pool sequence, as well as alterations to circulation patterns and substrate composition (Watters 2000).

The Grand River is a highly altered system with a number of water control structures (e.g., dams and weirs). The most significant dam found within the Lilliput range is the Dunnville Dam. Although it is plausible that this water control structure is negatively affecting mussel habitat, the effects of this dam on freshwater mussels is currently unknown.

HOST FISHES

Due to the obligate glochidial encystement stage, Lilliput is also directly affected by host fish abundance and indirectly by the threats affecting the host fish. The distribution of many freshwater mussel species can be limited by the distribution of its host fish. Johnny Darter, Green Sunfish, White Crappie and Bluegill are the putative host fishes for Lilliput in Canada (see subsection on Host fishes in the Habitat Requirements section of this report).

Invasive species

Although suspected to have little direct negative effect on Lilliput (Poos et al. 2010), Round Goby has been reported to negatively affect Johnny Darter (Lauer et al. 2004), one of the putative host fish of Lilliput. Round Goby is known to negatively impact Johnny Darter through competition (Lauer et al. 2004) and is suspected to impact Johnny Darter through predation (Poos et al. 2010). Corkum et al. (1998) predicted that Round Goby reproductive behaviour may be out-competing other cavity spawners, such as Johnny Darter, Brindled Madtom (*Noturus miurus*), and Northern Madtom (*Noturus stigmosus*). This prediction is supported by a trend reported by Thomas and Haas (2004) who observed declining abundances of three native benthic species [Johnny Darter, Logperch (*Percina caprodes*) and Trout-Perch (*Percopsis omiscomaycus*)] over a six year study, attributing this decline to competitive interactions with Round Goby. In addition, Thomas and Haas (2004) noted the presence of Johnny Darter in the stomach content of Round Goby; although, this was found in <1% of samples examined. There are currently no studies suggesting that Round Goby negatively affect Green Sunfish, Bluegill, or White Crappie.

Barriers to movement

Threats to fish hosts include barriers to movement such as impoundments and dams, which limits the dispersal ability of the host fish. For example, improvements of the Grand River mussel community have been linked to the addition of fish ladders in this system, allowing for mussel dispersal via the host fish (Metcalfe-Smith et al. 2000). Fish passage at the Dunnville Dam (the most significant dam within the known Lilliput distribution) was thought to have improved in 1994 with the creation of a Denil-type fishway, allowing for movement of non-jumping fish across the Dunnville Dam (Grand River Conservation Authority 2013). A review of ten years (1995-2005) of monitoring data indicated that this may not be the case for Lilliput putative host fish [N. Ward, Grand River Conservation Authority (GRCA), pers. comm.]. In this ten-year period the monitoring program only recorded the presence of a Lilliput host fish on three occasions (once for White Crappie, and twice for Bluegill). In addition, the fishway is currently damaged and lack of maintenance has resulted in a system that is filled with debris (N. Ward, GRCA, pers. comm.). It is unlikely that Lilliput putative host fishes are currently able to move across this dam; therefore, it should be considered a barrier to fish movement.

PREDATION

There is observational evidence that predation by raccoons (*Procyon lotor*) may negatively affect Lilliput in urbanized wetlands, such as Hamilton Harbour and surroundings, as fresh Lilliput shells are often found in raccoon middens (Tys Theysmeyer, RBG, pers. comm.). Although raccoons would be considered a natural predator, urban wetlands may have a disproportionately higher number of raccoons as they are often used as a release location for raccoons trapped in urbanized areas. This anomalous increase in levels of natural predation may be negatively affecting Lilliput populations in urbanized wetlands.

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). These alterations may be particularly relevant to Lilliput as it often inhabits shallow systems. Large water level fluctuations may result in increased time of exposure, and ultimately may result in the creation of inhabitable environments. 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 assessment.

THREAT LEVEL ASSESSMENT

Each threat was ranked in terms of the Threat Likelihood and Threat Impact for all locations where it is believed that a Lilliput population currently exists. 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 or fresh shells were recorded since 1997 were included) was also applied to the Threat Level assessment.

The Threat Likelihood was assigned as Known, Likely, Unlikely, or Unknown, and the Threat Impact was assigned as High, Medium, Low, or Unknown (Table 7-10). Threat Likelihood was classified for the extent of the known distribution for each population. 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 9) resulting in the final Threat Level assessment for each location (Table 10).

Table 7. 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.
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 8. Threat Likelihood and Threat Impact of each Lilliput 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 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. Gray cells indicate that the threat is not applicable to the population due to the nature of the aquatic system where the population is located.

	Sydenham River				Thames River (Baptiste Creek)			
	TLH	TI	C	Ref	TLH	TI	C	Ref
Contaminants and toxic substances	K	H	3	12	K	H	3	13
Nutrient loading	K	H	3	12	K	M	3	13
Turbidity	K	UK	3	4	K	UK	3	17
Sediment loading	K	M	3	17	K	M	3	17
Invasive species	K	L	2	1,3,11,17	K	H	2	1,3,18
Altered flow regimes	U	M	3	17	U	M	3	13
Habitat removal and alteration	K	H	3	13	L	H	3	13
Host fish (barriers to movement)	U	H	3	17	U	H	3	17
Host fish (invasive species)	K	UK	3	2	K	UK	3	2
Predation								

	Belle/Ruscom rivers				Grand River			
	TLH	TI	C	Ref	TLH	TI	C	Ref
Contaminants and toxic substances	K	H	3	10,16	K	H	3	5,16,20
Nutrient loading	K	M	3	10	K	M	3	13,20
Turbidity	K	UK	3	6	K	UK	3	5
Sediment loading	K	M	3	17	K	M	3	17
Invasive species	K	H	2	1,3,9	K	H	2	1,3
Altered flow regimes	U	M	3	10	K	M	3	13
Habitat removal and alteration	K	H	3	9	K	H	3	13
Host fish (barriers to movement)	U	H	3	17	K	H	3	17,21
Host fish (invasive species)	K	UK	3	17	K	UK	3	17
Predation								

	Welland River				Jordan Harbour			
	TLH	TI	C	Ref	TLH	TI	C	Ref
Contaminants and toxic substances	K	H	3	7,8	K	H	3	7,8,15
Nutrient loading	K	M	3	7,8	K	M	3	7,8
Turbidity	K	UK	3	7	K	UK	3	7
Sediment loading	K	M	3	17	K	M	3	17
Invasive species	K	H	2	1,3,19	K	H	2	1,3
Altered flow regimes	K	L	3	7,17				
Habitat removal and alteration	U	H	3	7	U	H	3	7
Host fish (barriers to movement)	U	H	3	17				
Host fish (invasive species)	UK	UK	3	17	K	UK	3	17
Predation					L	UK	3	17

	Hamilton Harbour and surroundings			
	TLH	**TI**	**C**	**Ref**
Contaminants and toxic substances	K	H	2	15
Nutrient loading	K	M	3	14
Turbidity	K	UK	3	14
Sediment loading	K	M	3	17
Invasive species	K	H	2	1,3
Altered flow regimes				
Habitat removal and alteration	U	H	3	17
Host fish (barriers to movement)	U	H	3	17
Host fish (invasive species)	K	UK	3	17
Predation	L	M	3	17

References:

1. Ontario's Invading Species Awareness Program (www.invadingspecies.com; Accessed: 29 August 2013)
2. DFO, unpubl. data
3. Therriault et al. (2013)
4. Dextrase et al. (2003)
5. Water Quality Branch (1989)
6. Bejankiwar (2009)
7. J. Baker, Niagara Peninsula Conservation Authority (NPCA), pers. comm. *in* Bouvier and Morris (2010)
8. NPCA (2010)
9. M. Nelson, ERCA, pers. comm. *in* Bouvier and Morris (2010)
10. Proposed Assessment Report, ERCA (unpubl. data) *in* Bouvier and Morris (2010)
11. M. Andreae, St. Clair Region Conservation Authority, pers. comm. *in* Bouvier and Morris (2010)
12. Bouvier and Morris (2010)
13. COSEWIC (2006a)
14. Chow-Fraser (1998)
15. Dove et al. (2003)
16. Dove et al. (2002)
17. Lilliput Recovery Potential Assessment participants; Meeting held 24 September 2013 in Burlington, Ontario
18. McNichols-O'Rourke et al. (2012)
19. Morris et al. (2012)
20. MacDougall and Ryan (2012)
21. N. Ward, GRCA, pers. comm.

Table 9. The Threat Level Matrix combines the Threat Likelihood and Threat Impact rankings to establish the Threat Level for each Lilliput 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 10. Threat Level for Lilliput 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	Sydenham River	Thames River (Baptiste Creek)	Belle/Ruscom rivers	Grand River	Welland River	Jordan Harbour	Hamilton Harbour and surroundings
Contaminants and toxic substances	High (3)	High (3)	High (3)	High (3)	High (3)	High (3)	High (3)
Nutrient loading	High (3)	Medium (3)	Medium (3)	Medium (3)	Medium (3)	Medium (3)	Medium (3)
Turbidity	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)
Sediment loading	Medium (3)	Medium (3)	Medium (3)	Medium (3)	Medium (3)	Medium (3)	Medium (3)
Invasive species	Low (3)	High (3)	High (3)	High (3)	High (3)	High (3)	High (3)
Altered flow regimes	Low (3)	Low (3)	Low (3)	Medium (3)	Low (3)		
Habitat removal and alteration	High (3)	High (3)	High (3)	High (3)	Medium (3)	Medium (3)	Medium (3)
Host fish (barriers to movement)	Medium (3)	Medium (3)	Medium (3)	High (3)	Medium (3)		Medium (3)
Host fish (invasive species)	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)	Unknown (3)
Predation						Unknown (3)	Medium (3)

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 Lilliput habitat. Lilliput has been assessed as Endangered by COSEWIC and is not currently listed nor protected under the *Endangered Species Act 2007.*

Within Lilliput habitat, a variety of works, undertakings, and activities have occurred in the past few years with project types including: water crossings (e.g., bridge maintenance), shoreline and streambank works (e.g., stabilization), instream works (e.g., channel maintenance) and the placement or removal of structures in water. Research has been completed summarizing the types of work, activity, or project that have been undertaken in habitat known to be occupied by Lilliput (Table 11). 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 a three-year period from 2010-2012. Only 25 projects were identified in Lilliput habitat. It is likely that this number does not represent a comprehensive list of activities have impacted Lilliput as projects occurring in the proximity of current Lilliput records but not in the area of occurrence were not included in the summary. Some projects may not have been reported to partner agencies or DFO if they occurred under conditions of an Operational Statement. It was noted that five projects were completed under conditions of Operational Statements primarily for bridge maintenance.

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 impacted Lilliput (e.g., increased turbidity or sedimentation from upstream channel works). The most frequent project type (7) was for shoreline stabilization works with most of these occurring in the Ruscom and Belle rivers. As well, maintenance dredging (6) at the river mouths in these systems also occurred annually. 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 Lilliput habitat in the future. The primary project proponents were local municipalities.

As indicated in the Threat Analysis, numerous threats affecting Lilliput populations are habitat-related threats that have been linked to the Pathways of Effects developed by DFO Fish Habitat Management (FHM) (Table 11). 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 11. Summary of works, projects and activities that have occurred during the period of January 2010 to December 2012 in areas known to be occupied by Lilliput. 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 Lilliput 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 2010-2012)						
	Contaminants and toxic substances	**Nutrient loading**	**Turbidity and sediment loading**	**Altered flow regimes**	**Habitat removal and alteration**	**Host fish (barriers to movement)**	**Sydenham River**	**Thames River (Baptiste Creek)**	**Ruscom/ Belle River**	**Grand River**	**Welland River**	**Jordan Harbour**	**Hamilton Harbour and surroundings**
Applicable pathways of effects for threat mitigation and project alternatives	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	10,16, 17	1,2,3,4,5,7,8, 10,11,13,14, 15,16,18	10,16, 17							
Water crossings (bridges, culverts, open cut crossings)	✓		✓	✓	✓	✓	4			1			
Shoreline, streambank work (stabilization, infilling, retaining walls, riparian vegetation management)	✓		✓	✓	✓				5	1			2
Dams, barriers, structures in water (maintenance, modification, hydro retrofits)			✓	✓	✓								
Instream works (channel maintenance, restoration, modifications, realignments, dredging, aquatic vegetation removal)	✓	✓	✓	✓	✓	✓	2		7				1

Work/Project/Activity	**Threats** (associated with work/project/activity)						**Watercourse / Waterbody** (number of works/projects/activities between 2010-2012)						
	Contaminants and toxic substances	**Nutrient loading**	**Turbidity and sediment loading**	**Altered flow regimes**	**Habitat removal and alteration**	**Host fish (barriers to movement)**	**Sydenham River**	**Thames River (Baptiste Creek)**	**Ruscom/ Belle River**	**Grand River**	**Welland River**	**Jordan Harbour**	**Hamilton Harbour and surroundings**
Water management (stormwater management, water withdrawal)	✓	✓	✓	✓									
Structures in water (boat launches, docks, effluent outfalls, water intakes)	✓	✓	✓	✓	✓					1			1

INVASIVE SPECIES

As discussed in the Threats section, aquatic invasive species (e.g., dreissenid mussels) introduction and establishment may have a negative effect on Lilliput 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 Lilliput populations directly, or negatively affect Lilliput 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 introductions
    - None.
- Authorized introductions
    - Use only native species.
    - Follow the National Code on Introductions and Transfers of Aquatic Organisms for all aquatic organism introductions (DFO 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 decrease the likelihood that a fish-mussel encounter will occur.

Mitigation

- If putative host fish populations appear to be decreasing, a management plan for the appropriate host fish should be implemented. This would increase the host's survival, increasing the number of hosts available, creating a healthy host population and subsequently increasing the likelihood that the host fish would encounter a gravid freshwater mussel.

Alternatives

- None.

PREDATION

As discussed in the Threats section, raccoon predation may have negative effects on Lilliput populations in urbanized wetlands. It should be noted that if this threat were to occur, it would be localized.

Mitigation

- If predators were identified at a local scale to have an impact on Lilliput populations, predator control should be considered.

Alternatives

- None.

SOURCES OF UNCERTAINTY

Despite concerted efforts to increase our knowledge of Lilliput 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 Lilliput 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 the Sydenham River, Baptiste Creek, Ruscom River, Belle River and Welland River, as very few live individuals have been recorded from these systems. Exploratory sampling should be completed in systems with habitat characteristics similar to those areas where Lilliput is known to occur to determine the extent of their distribution. Candidate areas would include tributaries on the southern shore of Lake St. Clair with similar habitat to the Belle and Ruscom rivers. In addition, supplementary sampling is necessary for all populations that were assigned a low certainty in completing the population status assessment. As is now common practice, 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 Lilliput distribution and population trends as well as the success of any recovery measures implemented.

Additional studies on habitat requirements are imperative to determine critical habitat for all Lilliput life stages. 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 on Lilliput as this species may be particularly negatively affected by low water levels, resulting from climate change. Laboratory experiments, and if feasible field experiments, should be completed to determine the host fish of Lilliput in Canada. Currently, putative host fish species are inferred from experiments on this species in the United States. Infestation experiments, using samples from Canadian populations, should be completed to verify the usage of Bluegill, Johnny Darter, White Crappie, Green Sunfish, Orange-spotted Sunfish and Warmouth as host fishes for Lilliput. Sampling of putative host fish should be completed in areas known to be inhabited by Lilliput, during which the gills should be inspected and sampled for Lilliput glochidia. Once host fish species have been confirmed, additional investigations to determine the glochidial carrying capacity, as well as the relationship between mussel attachment probability and host-mussel density should be completed.

Many of the life history characteristics required to inform population modelling efforts are currently unknown, and should be considered a priority when collecting additional information on this species. At minimum, order of magnitude fecundity estimates are required to properly classify Lilliput as being most sensitive to changes in age at maturity, fecundity and glochidial survival (reproduction dominant) or in adult survival (adult survival dominant). In addition, survival rates of all life stages are unknown.

Numerous threats have been identified for Lilliput populations in Canada, although the direct impact that these threats may have is currently unknown. There is a need for more quantitative studies to evaluate the direct impact of each threat on Lilliput 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 effect of contaminants and toxic substances on Lilliput, as these pollutants are known to occur in areas where Lilliput is currently found. This type of research would provide insight on the factors currently limiting Lilliput populations. Thresholds for other water quality parameters (e.g., nutrients, turbidity) should also be investigated.

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