COSEWIC
Assessment and Status Report

on the

Lilliput
Toxolasma parvum

in Canada

ENDANGERED
2013

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Lilliput — Photo credit: Todd Morris (Fisheries and Oceans Canada).

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COSEWIC
Assessment Summary

Assessment Summary – May 2013

Common name
Lilliput

Scientific name
Toxolasma parvum

Status
Endangered

Reason for designation
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 44% 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.

Occurrence
Ontario

Status history
Designated Endangered in May 2013.

COSEWIC
Executive Summary

Lilliput
Toxolasma parvum

Wildlife Species Description and Significance

Lilliput are small freshwater mussels generally reaching 25 mm in adult length (maximum length of 50 mm). The shell is elliptical to ovate in shape and thick with an outer surface that is dull, smooth and appears cloth-like. Lilliput is the only member of the genus *Toxolasma* occurring in Canada.

Distribution

Lilliput is globally restricted to central North America where it occurs widely from the Gulf of Mexico to the Great Lakes basin. In Canada, this species is restricted to southern Ontario where it is known from the Lake St. Clair, Lake Erie and Lake Ontario drainages. Its current distribution is limited to the Sydenham River, lower Thames River (Baptiste Creek), Ruscom River, Belle River, Grand River, Welland River, 20 Mile Creek (Jordan Harbour) and Hamilton Harbour (Sunfish Pond).

Habitat

Lilliput are found in a variety of habitats including small to large rivers, wetlands, shallows of lakes, ponds and reservoirs. They are common in soft substrates such as mud, sand, and silt.

Biology

Lilliput are short-lived (maximum age of 12 years), benthic, burrowing filter-feeders. They have separate sexes but can also be hermaphroditic and lack strong sexual dimorphism. Like all unionids they are obligate parasites on vertebrate hosts during the transition from larvae to juvenile. Though not confirmed for Canadian populations, host fish are believed to be Johnny Darter, Green Sunfish and Bluegill.

Population Sizes and Trends

Little can be said about population sizes or trends for Lilliput. Population estimates are impossible as it has never been found during the quantitative sampling required to produce meaningful density estimates as these methods are ineffective in habitat types preferred by Lilliput. Due to the limited occurrence of Lilliput in the historical record (only 9 records from four waterbodies) it is also difficult to assess population trends, unless it can be inferred from trends in index of area of occupancy.

Threats and Limiting Factors

High-level threats to Lilliput populations include pollution (i.e., sediment loading, nutrient loading and contaminants and toxic substances) relating primarily to urban development. Medium-level threats include transportation and shipping corridors (i.e., shipping lanes, dredging), invasive species (i.e., Zebra and Quagga mussels, Round Goby), climate change (i.e., water level changes) residential and commercial development (i.e., in-stream works) and natural systems modifications (i.e., dams).

Protection, Status, and Ranks

The federal *Fisheries Act* historically represented the single most important piece of legislation protecting the Lilliput and its habitat in Canada. However, recent changes to the *Fisheries Act* have significantly altered protection for this species and it is unclear at this time if the *Fisheries Act* will continue to provide protection for this species. The collection of freshwater mussels requires a collection permit issued by the Ontario Ministry of Natural Resources under authority of the *Fish and Wildlife Conservation Act*.

Areas where the Lilliput occurs overlap with the distributions of several mussel species protected under Canada's *Species at Risk Act* and the Ontario *Endangered Species Act, 2007*. The Lilliput may therefore benefit indirectly from protection afforded to these species or by actions implemented (e.g., research, stewardship and outreach) under the direction of recovery strategies.

Though considered globally secure (G5) Lilliput are in decline throughout much of the Great Lakes basin. It is considered possibly extirpated (SH) in New York, critically imperiled (S2) in Pennsylvania and vulnerable (S3) in Indiana and Wisconsin. It is considered apparently secure (S4) in Illinois and secure (S5) in Ohio. The species is not ranked in either Michigan or Minnesota.

TECHNICAL SUMMARY

Toxolasma parvum
Lilliput — Toxolasme naine
Range of occurrence in Canada (province/territory/ocean): ON

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2008) is being used)	estimated at 6 yrs
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	N/A
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations]. The starting point for the current records has been selected as 1997 as it marks the beginning of a more intensive, and ongoing, survey effort throughout the range of the Lilliput.	decline of no more than 40% inferred from decline in IAO over 3 generations (18 years)
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	N/A
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past (1997-2011) and the future.	40% decline inferred from decline in IAO over 3 generations (18 years)
Are the causes of the decline clearly reversible and understood and ceased?	Causes of decline are not reversible, they are understood but have not ceased
Are there extreme fluctuations in number of mature individuals?	no

Extent and Occupancy Information

Estimated extent of occurrence	10221 km²
Index of area of occupancy (IAO) (Always report 2x2 grid value).	60 km²
Is the total population severely fragmented?	no
Number of locations∗ Lake St. Clair tributaries (Sydenham, Thames, Belle and Ruscom rivers) Lake Erie tributary (Grand River) Lake Ontario tributaries (Welland River, 20 Mile Creek) Hamilton Harbour (Sunfish Pond) If Sunfish Pond is included with Lake Ontario, there are three locations	3 to 4
Is there an [observed, inferred, or projected] continuing decline in extent of occurrence?	yes, inferred
Is there an [observed, inferred, or projected] continuing decline in index of area of occupancy?	yes, inferred
Is there an [observed, inferred, or projected] continuing decline in number of populations?	no
Is there an [observed, inferred, or projected] continuing decline in number of locations*?	no

∗ See Definitions and Abbreviations on COSEWIC website and IUCN 2010 for more information on this term.

Is there an [observed, inferred, or projected] continuing decline in [area, extent and/or quality] of habitat?	yes, inferred decline in quality of habitat based on continuing threats
Are there extreme fluctuations in number of populations?	no
Are there extreme fluctuations in number of locations∗?	no
Are there extreme fluctuations in extent of occurrence?	no
Are there extreme fluctuations in index of area of occupancy?	no

Number of Mature Individuals (in each population)

Population	**N Mature Individuals**
Sydenham River	unknown
Thames River	unknown
Ruscom River	unknown
Belle River	unknown
Grand River	unknown
Welland River	unknown
Hamilton Harbour (Sunfish Pond)	unknown
20 Mile Creek (Jordan Harbour)	unknown
Total	unknown

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	N/A

Threats (actual or imminent, to populations or habitats)

High-level threats to *Toxolasma parvum* populations include pollution (sediment loading, nutrient loading and contaminants and toxic substances) relating primarily to urban development. Medium-level threats include transportation and shipping corridors (shipping lanes, dredging), invasive species (Dreissenids, Round Goby), climate change (water-level changes), residential and commercial development (in-stream works) and natural systems modifications (dams)

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? Though considered globally secure (G5) *Toxolasma parvum* is in decline throughout much the Great Lakes basin. It is considered possibly extirpated (SH) in New York, critically imperiled (S2) in Pennsylvania and vulnerable (S3) in Indiana and Wisconsin. It is considered apparently secure (S4) in Illinois and secure (S5) in Ohio. The species is not ranked in Minnesota. It is considered Endangered in Michigan.	
Is immigration known or possible?	unknown, possible but not likely
Would immigrants be adapted to survive in Canada?	likely
Is there sufficient habitat for immigrants in Canada?	likely
Is rescue from outside populations likely?	no

∗ See Definitions and Abbreviations on COSEWIC website and IUCN 2010 for more information on this term.

Status History

COSEWIC: Designated Endangered in May 2013

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** B2ab(iii)
Reasons for designation: 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.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Threatened A2(c) is applicable as there has been a 40% decline in the IAO. The causes of the decline are not reversible and not understood, but not ceased.
Criterion B (Small Distribution Range and Decline or Fluctuation): B1 is applicable for Threatened as EO (10221 km^2) is below the threshold. Meets criteria for Endangered under B2ab(iii) because 1) IAO (56km^2) is below the threshold of 500km^2, 2) there are fewer than 5 locations, and 3) there is an inferred continuing decline in the quality of habitat based on continuing threats.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable as population size is unknown.
Criterion D (Very Small or Restricted Total Population): Meets D2 Threatened as there are fewer than 5 locations and because the species is prone to the effects of stochastic events and human activities that can rapidly alter its required habitat and area of occupancy.
Criterion E (Quantitative Analysis): Not performed.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2013)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Scientific name: *Toxolasma parvum* (Barnes, 1823)

English common name: Lilliput

French common name: Toxolasme naine

The recognized authority for the classification of aquatic molluscs in Canada is Turgeon *et al.* (1998). The currently accepted classification for this species is:

Kingdom: Animalia

Phylum: Mollusca

Class: Bivalvia

Subclass: Paleoheterodonta

Order: Unionoida

Superfamily: Unionoidea

Family: Unionidae

Subfamily: Lampsilinae

Tribe: Lampsilini

Genus: *Toxolasma*

Species *Toxolasma parvum*

Morphological Description

The following description is modified from Clarke (1981), Metcalfe-Smith *et al.* (2005a), Watters *et al.* (2009). Lilliput (Figure 1) is a small freshwater mussel generally reaching 25 mm in adult length (maximum length of 50 mm). The shell is elliptical to ovate in shape and thick with periostracum that is dull, sculptureless and appears cloth-like. The anterior end is rounded and the posterior end is either rounded (males) or squared (females), although this difference is subtle. The beaks are slightly elevated above the hinge line and sculpture consists of 4-6 heavy concentric ridges. Juvenile shells are thinner, more pointed posteriorly, more compressed, and have a coarser beak sculpture Utterback (1916). The shell is generally brown to brownish-black (especially in older individuals) or green. Green rays may be present and if so are mostly seen on the posterior slope. The hinge teeth are fully developed but compressed. The pseudocardinal teeth (two in the left valve, one in the right) are thin and serrated and the lateral teeth (two in the left valve, one in the right) are long, thin, and straight. Species that are similar include the Rayed Bean (*Villosa fabalis*) and the Salamander Mussel (*Simpsonaias ambigua*). The Rayed Bean is distinguished by the prominent rays and thick hinge line. The Salamander Mussel has a thinner shell and more elongate shape.

Figure 1. Live specimens of Lilliput (*Toxolasma parvum*) collected from the lower Grand River. Photo courtesy of Fisheries and Oceans Canada.

Population Spatial Structure and Variability

There is no information available on the genetic structure of Canadian populations of the Lilliput. However, the remaining populations (see **Canadian Range**) are isolated from one another by distances of 50 – 250 km, and Zanatta *et al.* (2007) have shown that genetic isolation in Canadian populations of freshwater mussels is possible over these spatial scales.

Designatable Units

All Canadian populations are found within the Great Lakes-Upper St Lawrence National Freshwater Biogeographic Zone. There are no known distinctions among populations that warrant consideration for designation below the species level.

Special Significance

Freshwater mussels in general play an integral role in the functioning of aquatic ecosystems. Unionids are responsible for numerous water column (size-selective filter-feeding; species-specific phytoplankton selection; nutrient cycling; control of phosphorus abundance) and sediment processes (deposit feeding decreasing sediment organic matter; biodeposition of feces and pseudofeces). Invertebrates and algae also colonize shells and benthic invertebrate densities have been shown to correlate with mussel densities (Welker and Walz 1998, Vaughn and Hakenkamp 2001, Newton *et al.* 2011). Neves and Odom (1989) reported that mussels also play a role in the transfer of energy to the terrestrial environment through predation by Muskrat (*Ondatra zibethicus*) and Raccoon (*Procyon lotor*) . However, given that Lilliput appears to have always been a minor component of the freshwater mussel community in Canada, its relative contribution to all of these processes is likely minor. The Lilliput is the only member of the genus *Toxolasma* found in Canada.

Aboriginal and Traditional Knowledge (ATK) is not available for *Toxolasma parvum* (Aboriginal Traditional Knowledge Subcommittee 2012).

DISTRIBUTION

Global Range

The global range (Figure 2) of Lilliput is limited to central North America where it is widely distributed, occurring in 22 American states: Alabama, Arkansas, Florida, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, West Virginia, and Wisconsin (NatureServe 2011). It is thought to be extirpated from Georgia and New York. It occurs in the Mississippi River system including its western drainages and the Ohio, Cumberland, and Tennessee rivers (Watters *et al.* 2009). In Canada, this species occurs only in southwestern Ontario. Overall, less than 5% of the Lilliput's global distribution occurs in Canada.

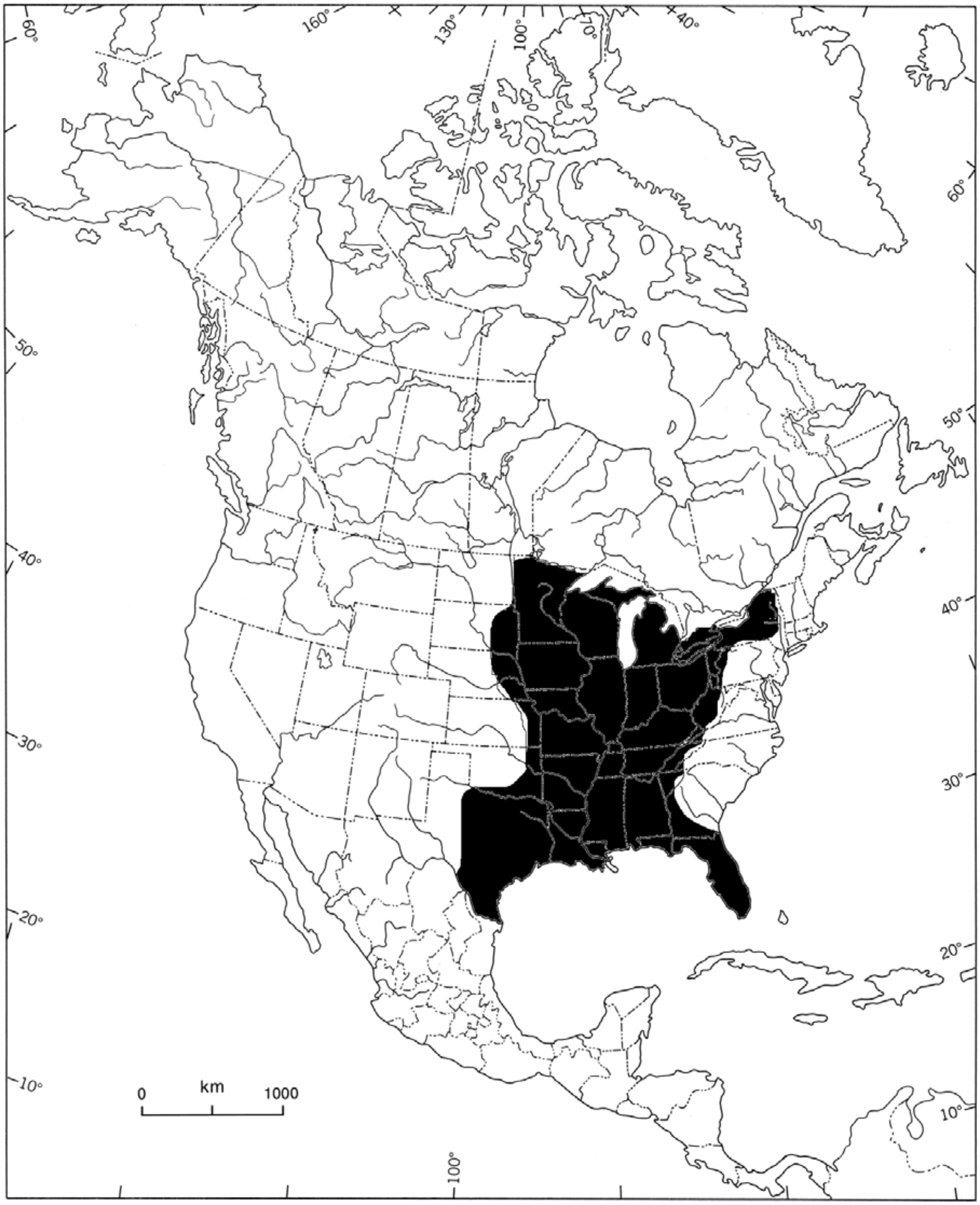

Figure 2. Global distribution of Lilliput (*Toxolasma parvum*).

Canadian Range

In Canada, Lilliput were historically (1943-1996) known to occur in the Lake St. Clair (specifically the Sydenham, Thames, and Detroit rivers) and Lake Erie (i.e., Grand River) drainages (Metcalfe-Smith and Cudmore-Vokey 2004; Lower Great Lakes Unionid Database 2011; Figure 3). Since 1997, live individuals have been found in the Sydenham, Thames, Belle, Ruscom, Grand, and Welland rivers and in Lake Ontario (Lower Great Lakes Unionid Database 2011). This species has a fairly restricted range as there are no records of the Lilliput from any other Canadian province or territory (Metcalfe-Smith and Cudmore-Vokey 2004). The Lilliput has always been a rare species in the faunal record for Canada. Thirty-five records exist for this species in the Lower Great Lakes Unionid Database dating back to 1943 when it was detected in the Grand River by F. R. Latchford (Lower Great Lakes Unionid Database 2011). The first documented live collection of the Lilliput in Canada was not made until 1991 when A. H. Clarke collected it from the Sydenham River (Clarke 1992).

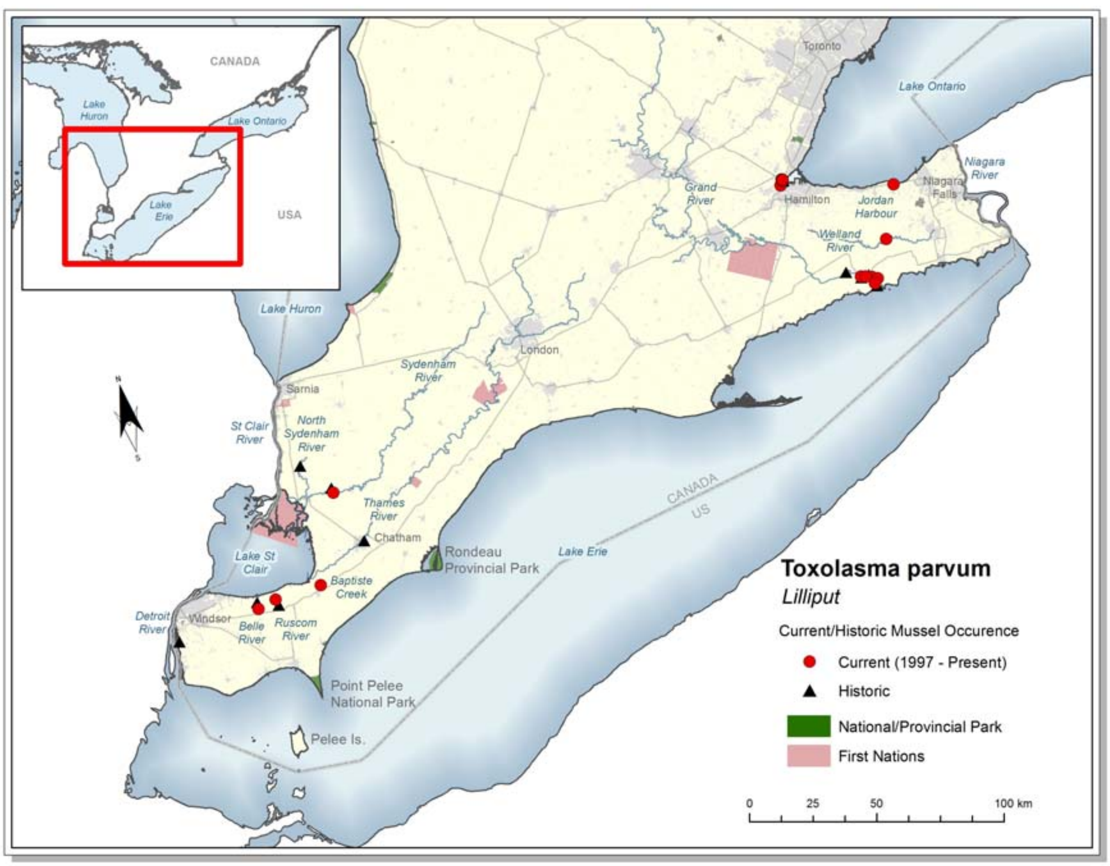

Figure 3. Historical (1943-1996) and current distribution (1997-2012) of Lilliput (*Toxolasma parvum*) in Canada. Records obtained from the Lower Great Lakes Unionid Database (2012). Note that weathered shells collected during the “current” time period are mapped as “historic” sites unless they overlap with collections of live animals or fresh shells as weathered shells do not indicate the recent presence of live animals.

Unionids are dependent on a host, generally a fish, to complete their complex lifecycle. Although hosts have not been identified for Canadian Lilliput populations, six fishes have been identified as hosts in the U.S.: (1) Johnny Darter (*Etheostoma nigrum*); (2) Green Sunfish (*Lepomis cyanellus*); (3) White Crappie (*Pomoxis annularis*); (4) Bluegill (*Lepomis macrochirus*); (5) Warmouth (*Lepomis gulosus*); and (6) Orangespotted Sunfish (*Lepomis humilis*; Watters *et al.* 2009). All of these species are found in Ontario and there is some distributional overlap among the first four fish species listed above (Holm *et al.* 2009) and the Lilliput (see **Lifecycle and Reproduction** for more detail).

The following discussion contains a review of historical (1934 – 1996) and current (1997 – 2011) distribution of the species throughout the Great Lakes basin, beginning with the Lake St. Clair drainage and moving downstream through the Great Lakes system.

The first Lilliput was found in the North Sydenham in 1967 by H. D. Athearn (Lower Great Lakes Unionid Database 2011). It was then found alive in the east Sydenham River in 1991 by Clarke (1992) and then in 2011 near Tupperville (1 site, 7 live individuals) (Lower Great Lakes Unionid Database 2011).

There is one historical record for the Lilliput in the Thames River (McGregor Creek) near Chatham, which was found by H. D. Athearn in 1963. One live individual was found in 2010 near Tilbury in another tributary (Baptiste Creek) during surveys by Fisheries and Oceans Canada (Lower Great Lakes Unionid Database 2011).

Lilliput was first observed in the Belle River (weathered shell), during surveys in 1999 by D. Zanatta at the University of Guelph (Lower Great Lakes Unionid Database 2011). Live specimens (1 site, 2 live individuals) were then found by Fisheries and Oceans Canada in 2010 (Lower Great Lakes Unionid Database 2011). Live individuals and shells were also found in the nearby Ruscom River during surveys in 2010 by Fisheries and Oceans Canada (2 sites, 3 live individuals) (Lower Great Lakes Unionid Database 2011).

The first specimen (unknown if live or shell) reported from the Canadian side of the Detroit River was in 1943 by F. R. Latchford (Lower Great Lakes Unionid Database 2011). No other individuals have been reported from the Detroit River, despite surveys by Schloesser *et al.* (1998) who surveyed 13 stations within the River (at least six of these on the Canadian side) in 1982-83 and then again in 1992 (plus four additional sites) and in 1998 (Schloesser *et al.* 2006).

The first observation of the Lilliput in Lake Erie was by Walker (1913). This was followed by La Rocque and Oughton (1937) who confirmed that specimens from the National Museum of Canada and the Royal Ontario Museum were those of the Lilliput. Unfortunately, no information was available as to the specific locations of these specimens (i.e., Canadian or American side); therefore, they cannot be included in Figure 3. There are no records for Lilliput in Lake Erie in the Lower Great Lakes Unionid Database although they have been found alive in the western basin of Lake Erie (U.S.A.) during recent surveys by Crail *et al.* (2011), Zanatta pers. comm. 2011); they found Lilliput at three of 12 stations, although in very low densities (<0.09/m^2). Most of the native mussels have been eradicated in Lake Erie by the Zebra and Quagga mussels. The last lake-wide survey for dreissenid densities in Lake Erie occurred in 2002 (Nalepa *et al.* 2011). Mean abundances in 2002 were little changed since 1992 (2,025 m^{-2} in 2002 compared to 2,636 m^{-2} in 1992), but mean biomass increased four-fold (24.7 g m^{-2} in 2002 compared to 6.8 g m^{-2} in 1992). Most dreissenid biomass (90%) occurs in the eastern basin. Populations in the central basin are limited because of seasonal hypoxia, and populations in the western basin are limited because of poor food quality (cyanophytes, inorganic particulates). Recent surveys (2005-2010) in the western basin indicate that dreissenid populations have fluctuated from year to year with no clear trends, and that Quagga Mussels have replaced Zebra Mussels as the dominant species (Nalepa *et al.* 2011).

Lilliput was first recorded from the Grand River at Byng, near Dunnville, sometime between 1934 and 1946 (Robertson and Blakeslee 1948) – it is unknown if the specimen(s) were live records or shells or where this collection occurred; therefore it is not included in Figure 3. Additional shells were found in 1963 by Stansbery, in 1966 by Oughton, and in 1971 by Kidd (1973), Lower Great Lakes Unionid Database 2011). The first live specimens were not found until 1997-98 by Metcalfe-Smith *et al.* (2000b). Further surveys of the Grand River produced 13 live specimens at five additional sites in 2010 and 2011 (Lower Great Lakes Unionid Database 2011).

One live Lilliput was found in the Welland River in 2008 during surveys by Fisheries and Oceans Canada (Lower Great Lakes Unionid Database 2011).

Eight live Lilliput were collected from 20 Mile Creek (Jordan Harbour) in the Lake Ontario watershed during targeted sampling in August 2012. No historical data exist for this watershed.

Lilliput shells have been collected periodically from several sites in Hamilton Harbour of the Lake Ontario drainage since 2006. Targeted surveys for this species in 2011 have confirmed the existence of an extant population at one of these sites (Sunfish Pond) (1 site, 2 live individuals) (Smith and Morris *in review*). This is the first record for this species in Lake Ontario (Lower Great Lakes Unionid Database 2011).

Extent of Occurrence and Index of Area of Occupancy

Extent of occurrence (EO) was estimated using a minimum convex polygon. The maximal historical extent of the species' distribution was estimated at 13,168 km^2 (Figure 4) with the current EO estimated at 10,221 km^2 (Figure 5) representing a 22% reduction. Index of area of occupancy (IAO) was estimated with a 2 km x 2 km grid. Maximal historical IAO was estimated at 100 km^2 (Figure 6) whereas the current IAO was estimated at 60 km^2 (Figure 7) representing a decline of 40%.

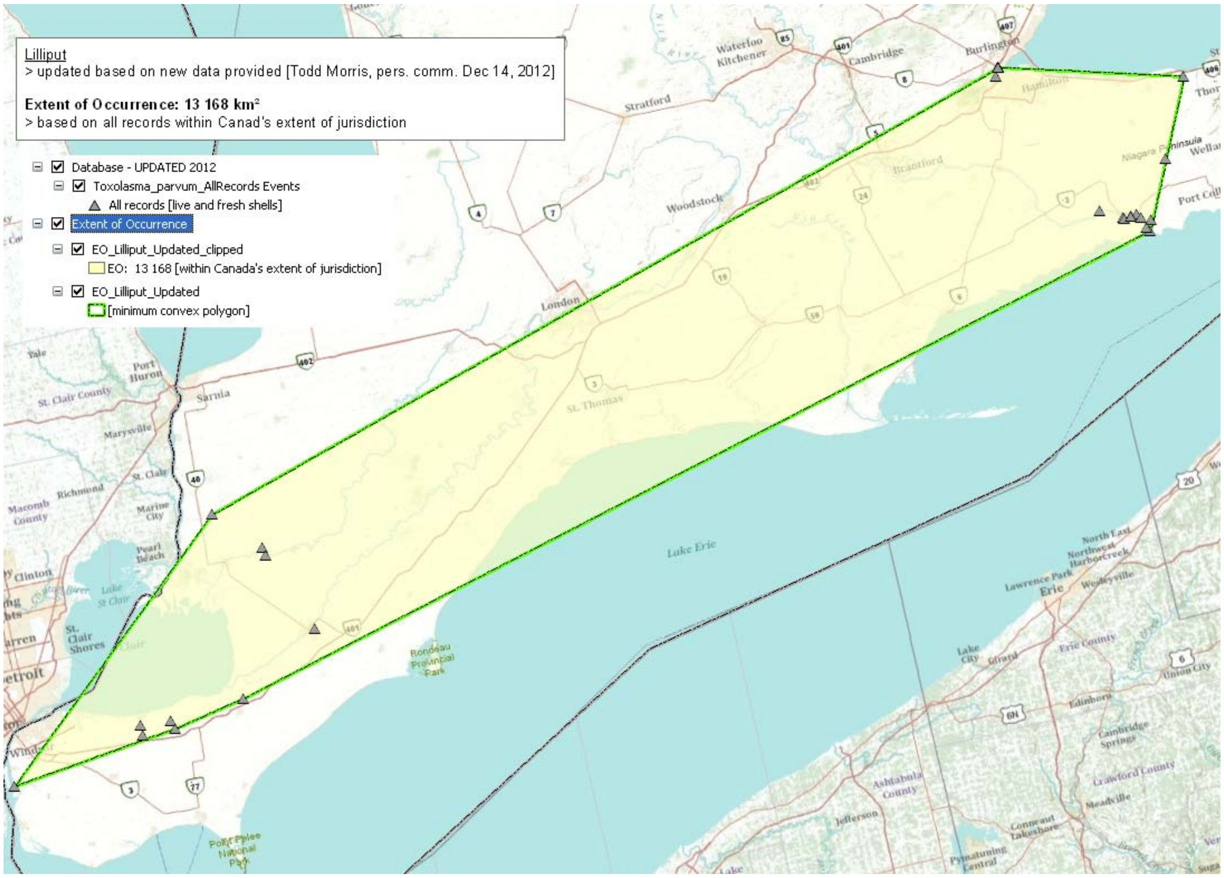

Figure 4. Extent of occurrence of Lilliput based on all records within Canada's extent of jurisdiction.

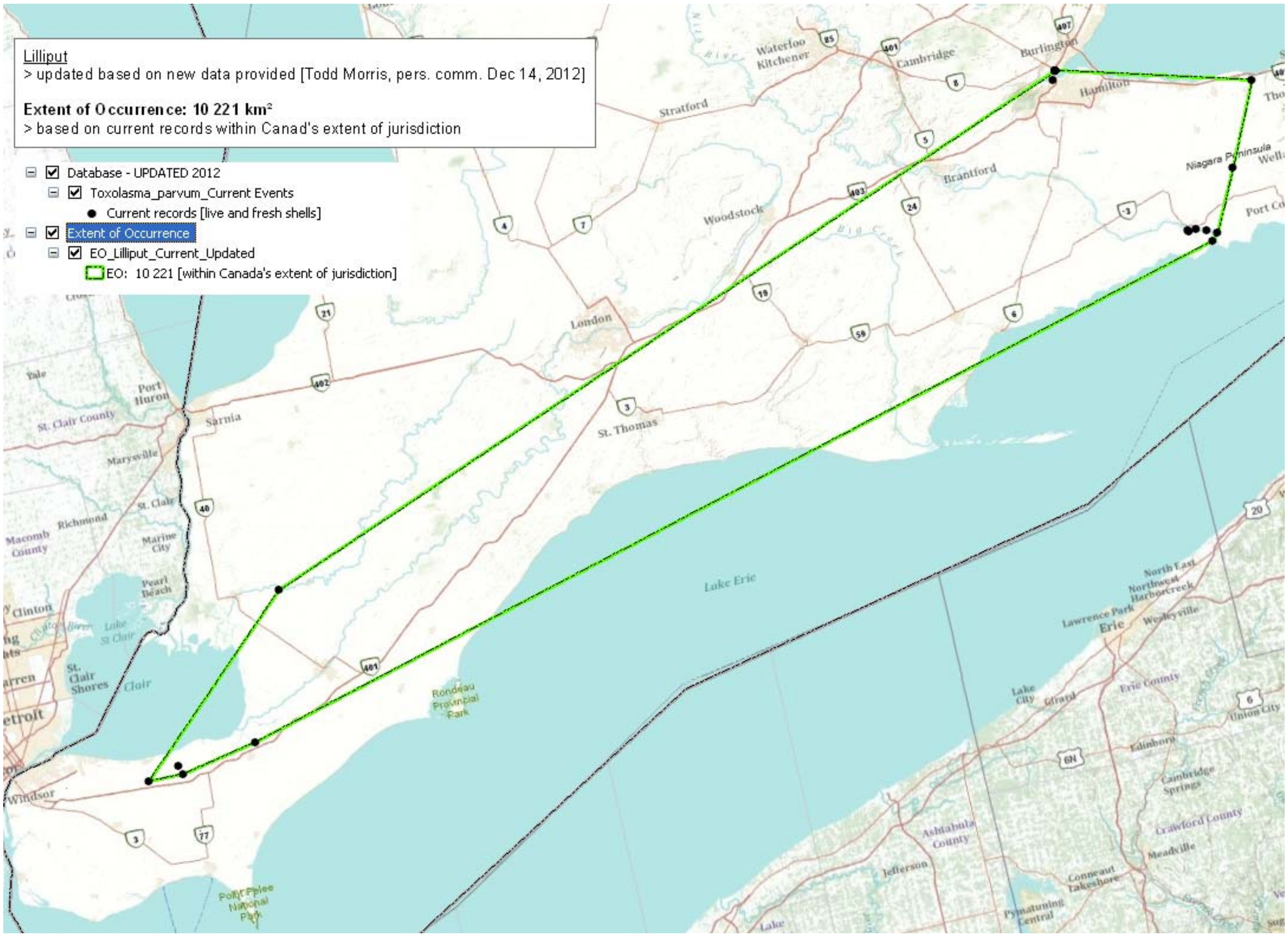

Figure 5. Current (2011) extent of occurrence of Lilliput within Canada's extent of jurisdiction.

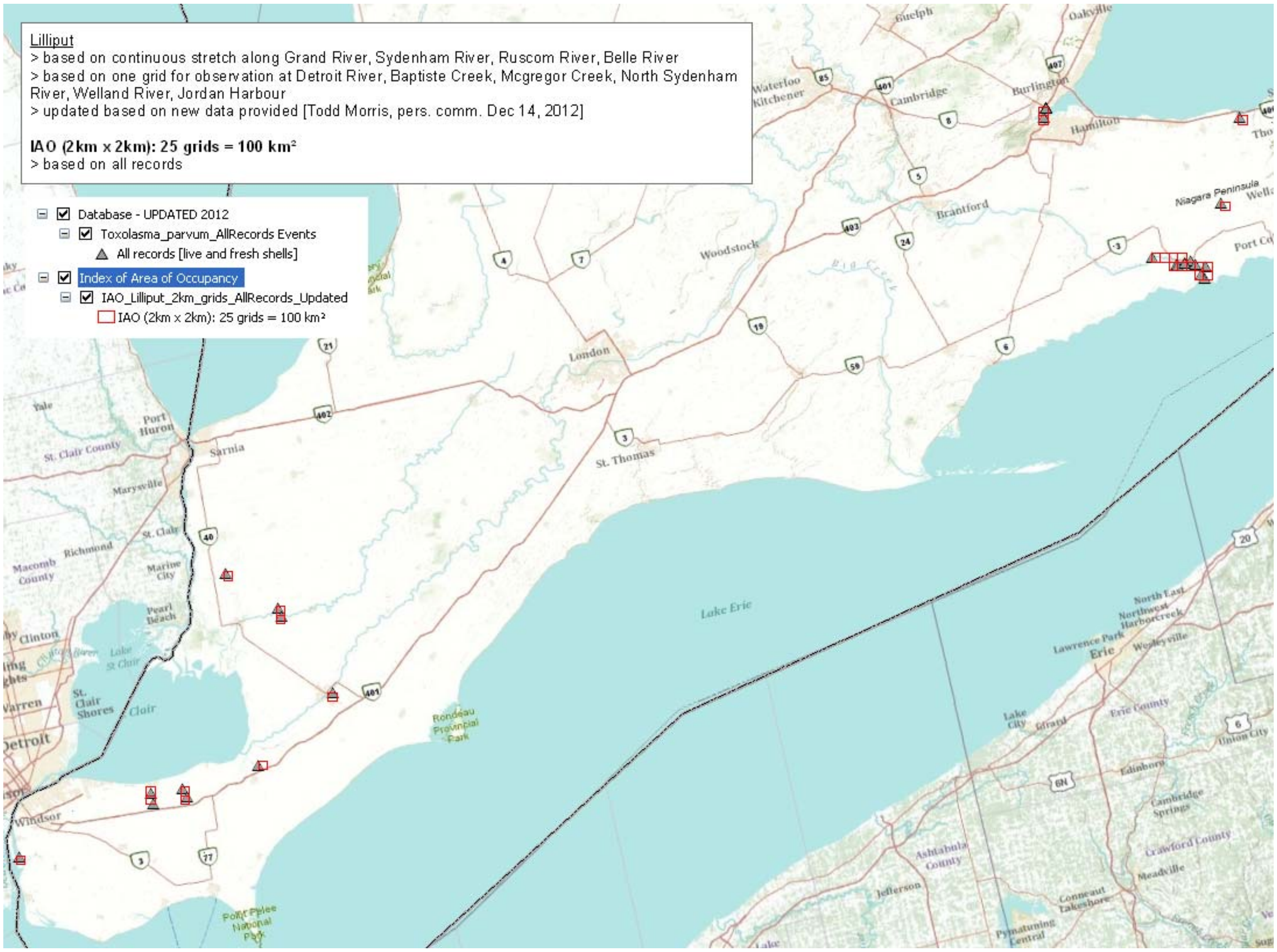

Figure 6. Index of area of occupancy of Lilliput using 2 km x 2 km grids for all records within Canada’s extent of jurisdiction.

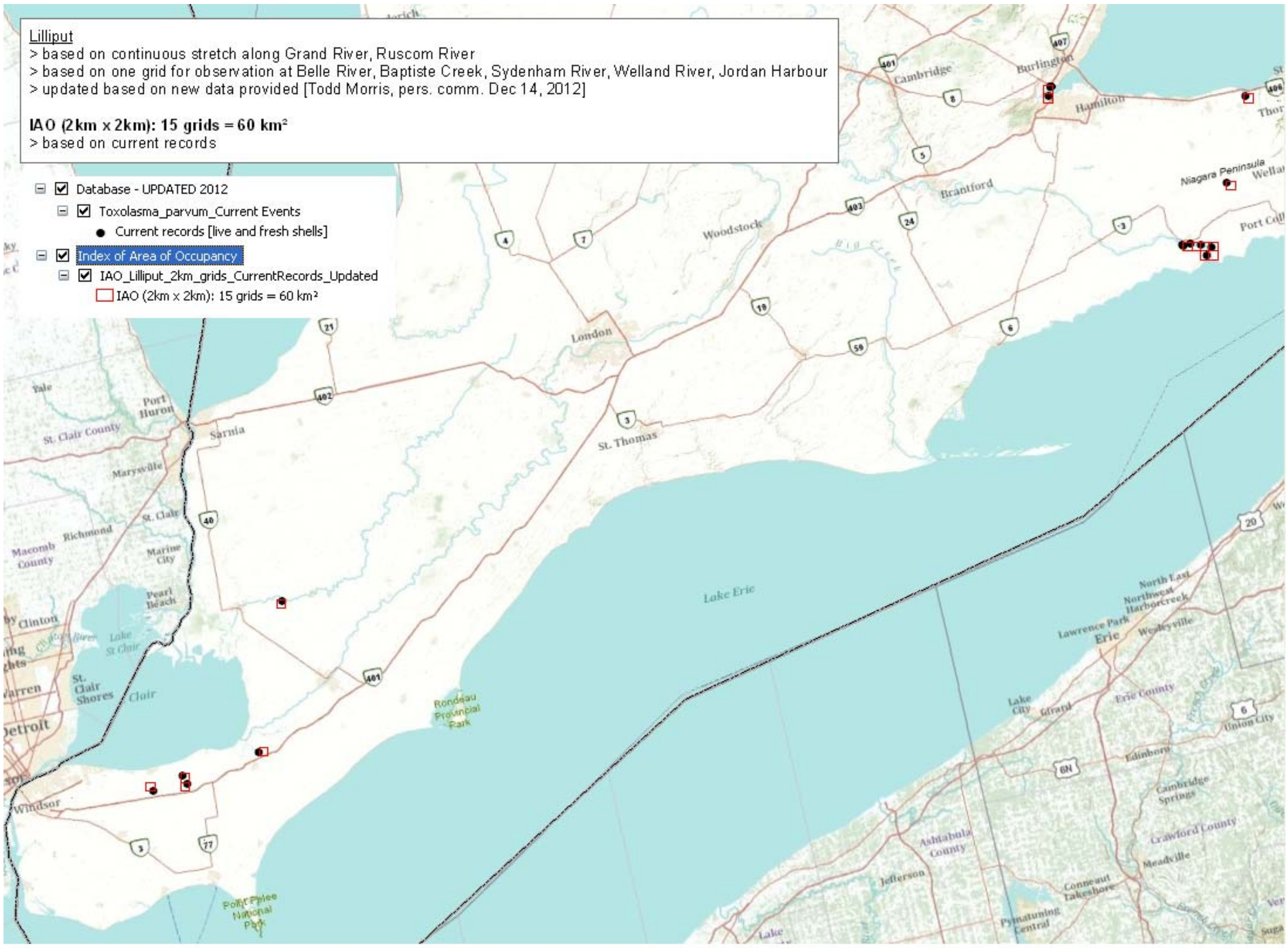

Figure 7. Current (2011) index of area of occupancy of Lilliput within Canada's extent of jurisdiction.

Search Effort

Based on records from the Lower Great lakes Unionid Database the Lilliput historically occurred in the Grand, Detroit, Thames, and Sydenham rivers. This distribution is based on nine records (Lower Great Lakes Unionid Database 2011). No information was available as to the method of collection or search effort for these records as all but one of the historical records are from museum specimens.

The current distribution (1997-2011) as shown in Figure 3 is based on 27 records (12 records for live individuals) reporting 39 live animals. The starting point for the current records has been selected as 1997 as it marks the beginning of a more intensive, and ongoing, survey effort throughout the range of the Lilliput. This species is currently reported alive in the Sydenham, Thames, Ruscom, and Belle rivers of the Lake St. Clair watershed, the Grand and Welland rivers of the Lake Erie watershed, and in Lake Ontario (Lower Great Lakes Unionid Database 2011). During the current time period, intensive, targeted surveys have been conducted at over 280 sites in 6 systems (Lakes Erie and St. Clair, Thames, Sydenham, Grand and Detroit rivers; Figure 8). Table 1 provides a summary of the current sampling methods and search effort used in these surveys. It should be noted that different sampling techniques may provide different types of information. Semiquantitative methods (timed-search surveys while wading, snorkelling or using SCUBA gear) provide data on the presence/absence of species and their relative abundance. Quantitative methods, i.e., methods that sample a defined area of the substrate surface using quadrats, grabs, circular plots or line transects, provide additional data on mussel densities. This is a time-consuming technique that detects both adult mussels occurring at the sediment surface and juvenile mussels that tend to burrow deeply in the substrate. The latter method can therefore provide additional data on recruitment.

Table 1. Summary of current (1997-2011) mussel sampling effort within the range of the Lilliput. PH refers to the number of person-hours searched. Raccooning refers to excavation of substrate using hands. SAR is species at risk.

Waterbody	# of sites where live individuals occurred/Total # of sites surveyed	Year	Effort	Notes	Source
Lake St. Clair	0/30	1998	10 transects at 1, 2.5, and 4 m depths with 5 x 1 m^2 quadrats and 20 Ekman grabs in each transect		(Zanatta *et al.* 2002)
	0/77	1999	Sites < 2 m deep employed 0.75 PH of snorkeling effort and if mussels present an additional 0.75 PH was spent; sites > 2 m deep employed 0.5 PH of SCUBA effort	Includes 10 locations surveyed in 1998	Zanatta *et al.* (2002)
	0/10	2000	1.5 PH of snorkeling, 10 x 1m^2 quadrats	Includes 10 most abundant sites from 1999	Zanatta *et al.* (2002)
	0/9	2001	5-21 x 65 m^2 circular plots surveyed using snorkelers	Includes 4 previously sampled sites	Zanatta *et al.* (2002)
	0/18	2003	10 x 65 m^2 circular plots surveyed using snorkelers	9 sites in Canadian waters of delta, 9 sites in U.S. waters, includes 9 previously sampled sites from 2001	(Metcalfe-Smith *et al.* 2004)
	0/10	2003	0.5 PH (snorkeling)	2 sites in Canadian waters of delta, 8 sites in U.S. waters	Metcalfe-Smith *et al.* (2004)
	0/4	2005	3-4 PH (snorkeling)		(Metcalfe-Smith *et al.* 2005b)

Waterbody	# of sites where live individuals occurred/Total # of sites surveyed	Year	Effort	Notes	Source
	0/2	2006	~ 9 PH (snorkeling)	Searching for gravid SAR females, both sites previously surveyed (Metcalfe-Smith *et al.* 2005b)	(McNichols pers. comm. 2010)
	0/8	2011	10 x 65 m^2 circular plots surveyed using snorkelers at all sites; 0.5 Ha plots searched by snorkelers at 3 sites	Includes 8 sites surveyed by Metcalfe-Smith *et al.* in 2003.	Fisheries and Oceans Canada, unpublished data
Lake Erie	0/6	2001	2 PH snorkeling		D. Zanatta and D. Woolnough unpublished data
	0/17	2005	Timed search (1.5 PH of snorkeling)		D. McGoldrick unpublished data
	0/1	2009	~ 4.5 PH timed search (viewing boxes while wading)	Searching for gravid Eastern Pondmussel (*Ligumia nasuta*)	McNichols pers. comm. (2010)
	3/17[2]	2011	20-60 minutes of searching, 1 site = 4 x 100 m^2 quadrats	US side	Crail *et al.* (2011)
Lake Ontario	1/3	2011	0.5 hectare search	Royal Botanical Gardens	Fisheries and Oceans Canada, unpublished data
Sydenham River	0/17	1997-98	4.5 PH timed search (wading)		(Metcalfe-Smith *et al.* 2003), Lower Great Lakes Unionid Database (2011)
	0/15	1999-2003	60-80 x 1 m^2 quadrats with excavation	Includes 12 sites surveys in 1997-98	(Metcalfe-Smith *et al.* 2007)
	0/11	2002	> 110 PH timed search (excavation)	Searching for gravid SAR females, 10 sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/7	2003	~ 212 PH timed search (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/7	2004	~ 176 PH timed (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/6	2005	120.5 PH (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/2	2005	Excavation	Mussel identification course (field portion), all sites previously surveyed in 1999-2003	Fisheries and Oceans Canada, unpublished data
	0/4	2006	47.5 PH timed search (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/2	2006	Excavation	Mussel identification SAR course (field), all sites previously surveyed in 1999-2003	Fisheries and Oceans Canada, unpublished data

Waterbody	# of sites where live individuals occurred/Total # of sites surveyed	Year	Effort	Notes	Source
	0/4	2007	~ 20 PH timed search (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/2	2007	Excavation	Mussel identification course (field portion), all sites previously surveyed in 1999-2003	Fisheries and Oceans Canada, unpublished data
	0/4	2008	~ 41 PH timed search (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/2	2008	Excavation	Mussel identification course (field portion), all sites previously surveyed in 1999-2003	Fisheries and Oceans Canada, unpublished data
	0/3	2009	~ 35 PH timed search (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/2	2009	Excavation	Mussel identification course (field), all sites previously surveyed in 1999-2003	Fisheries and Oceans Canada, unpublished data
	0/2	2010	Excavation	Mussel identification course (field), all sites previously surveyed in 1999-2003	Fisheries and Oceans Canada, unpublished data
	0/3	2010	~ 39 PH timed search (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/2	2011	~ 61 PH timed search (excavation)	Searching for gravid SAR females, all sites previously surveyed in 1999-2003	McNichols pers. comm. (2010)
	0/2	2011	Excavation	Mussel identification course (field), all sites previously surveyed in 1999-2003	Fisheries and Oceans Canada, unpublished data
	1/2	2011	4.5 PH timed search (wading or excavation)	Targeted surveys for *T. parvum*	Fisheries and Oceans Canada
Thames River	0/11	1997	4.5 PH timed search (wading or excavation)		(Metcalfe-Smith *et al.* 1998)
	0/5	1998	4.5 PH timed search (wading or excavation)		(Metcalfe-Smith *et al.* 1999)
	0/48	2004-2005	4.5 PH timed search (wading)	27 sites on Upper Thames River, 10 sites on lower Thames River	Fisheries and Oceans Canada, unpublished data
	0/37	2004-2005	60 – 80 x 1m^2 quadrats	Sites included in Morris and Edwards (2007)	(Morris and Edwards 2007)
	0/2	2006	720 x 1 m^2 quadrats (360 at each site)	Medway Creek Relocation Project (Stantec)	(Mackie 2011) pers. comm.
	0/1	2006	~ 3 PH timed search (viewing boxes)	Searching for gravid SAR females	McNichols pers. comm. (2010)

Waterbody	# of sites where live individuals occurred/Total # of sites surveyed	Year	Effort	Notes	Source
	0/2	2007	729 x 1 m^2 quadrats (561 quadrats at 1 site and 168 quadrats at the other site)	Medway Creek Relocation Project (Stantec)	Mackie pers. comm. (2011)
	0/1	2008	1 x 444m^2	Plot sampled 14 times between May and October	Morris unpublished data, TM-10 of Morris and Edwards (2007)
	0/2	2008	16 PH timed search		Zanatta unpublished data, Woolnough and Morris unpublished data
	0/1	2008	3 PH timed search (viewing boxes or excavation)	Searching for gravid SAR females, sites previously surveyed in Morris and Edwards (2007)	McNichols pers. comm. (2010)
	0/1	2009	Viewing boxes	Searching for gravid SAR females, sites previously surveyed in Morris and Edwards (2007)	McNichols pers. comm. (2010)
	0/6	2010	408 x 1 m^2 quadrats	sites previously surveyed in Morris and Edwards (2007)	Fisheries and Oceans Canada, unpublished data
	0/3	2010	1830 x 1 m^2 quadrats (630, 750, and 450 at each site respectively)	Medway Creek Relocation Project (Stantec)	Mackie pers. comm. (2011)
	0/1	2010	1 PH timed search (viewing boxes)	Searching for gravid SAR females	McNichols pers. comm. (2010)
	1/3	2010	4.5 PH timed search (wading)	Baptiste Creek	Fisheries and Oceans Canada, unpublished data
	0/4	2011	32 PH timed search (excavation and viewing boxes)	Searching for gravid SAR females	McNichols pers. comm. (2010)
	0/1	2011	999 x 1 m^2 quadrats	Thames River Relocation Project (County of Middlesex)	Mackie pers. comm. (2011)
Ruscom River	2/6*	2010	2 PH	Inventory survey (focusing on Mapleleaf Mussel (*Quadrula quadrula*)	Fisheries and Oceans Canada, unpublished data
Belle River	0/~10	1999	0.5 - 1 PH timed search (wading)		Zanatta unpublished data (Zanatta 2000)
	1/3	2010	2.25 PH timed search (wading)	Inventory survey (focusing on Mapleleaf Mussel	Fisheries and Oceans Canada, unpublished data
Welland River	1/8	2008	Timed Search		Fisheries and Oceans Canada, unpublished data
Grand River	1/17	1997	4.5 PH timed search (wading)		Metcalfe-Smith *et al.* (1998)
	0/7	1998	4.5 PH timed search (wading)		Metcalfe-Smith *et al.* (1999)
	0/2	2005	Viewing boxes (effort unknown)	Searching for gravid SAR females	McNichols pers. comm. (2010)

Waterbody	# of sites where live individuals occurred/Total # of sites surveyed	Year	Effort	Notes	Source
	0/2	2007	Viewing boxes (effort unknown)	Searching for gravid SAR females, sites previously surveyed in 2005	McNichols pers. comm. (2010)
	4	2007	48-65 x 1 m^2 quadrats with excavation	All sites included in Metcalfe-Smith *et al.* (2000)	Fisheries and Oceans Canada, unpublished data
	0/2	2007	720 x 1 m^2 quadrats (360 at each site)	Grand River relocation project (Thurber Engineering Ltd.)	Mackie pers. comm. (2011)
	0/1	2008	825 x 1 m^2 quadrats	Grand River relocation project (Region of Waterloo)	Mackie pers. comm. (2011)
	0/1	2008	Viewing boxes	Searching for gravid SAR females, previously surveyed in 2005	McNichols pers. comm. (2010)
	0/1	2009	Viewing boxes	Searching for gravid SAR females, previously surveyed in 2005	McNichols pers. comm. (2010)
	0/1	2009	1200 x 1 m^2 quadrats	Grand River relocation project (BOT construction)	Mackie pers. comm. (2011)
	0/2	2010	171 x 1 m^2 quadrats (96 at 1 site, 78 at 1 site)	Grand River relocation project (Region of Waterloo)	Mackie pers. comm. (2011)
	0/2	2010	8.5 PH timed search (viewing boxes)	Searching for gravid SAR females, previously surveyed in 2005	McNichols pers. comm. (2010)
	0/3	2011	18 PH timed search (viewing boxes)	Searching for gravid SAR females, previously surveyed in 2005	McNichols pers. comm. (2010)
	0/1	2011	431 x 1 m^2 quadrats	Grand River relocation project (Natural Resource Solutions)	Mackie pers. comm. (2011)
	4/13[1]	2011	5.5-6 PH	Targeted surveys for Lilliput	Fisheries and Oceans Canada, unpublished data
Detroit River	1	1997	4 x 120 m^2 line transects	sites where live unionids were observed in 1990	Schloesser *et al.* (2006) and unpublished data
	4	1998	500 m^2 area searched for 60 minutes using SCUBA; second 500 m^2 area searched for 25 minutes	sites where live unionids were observed in 1992 and 1994	(Schloesser *et al.* 2006)
	1	1998	10 random quadrats within a 10 m x 10 m grid, excavated to a depth of 30 cm	sites where live unionids were observed in 1987	Schloesser *et al.* (2006) and unpublished data

[*] Shells found at site
[1] Shells found at one additional site
[2] Shells found at two additional sites

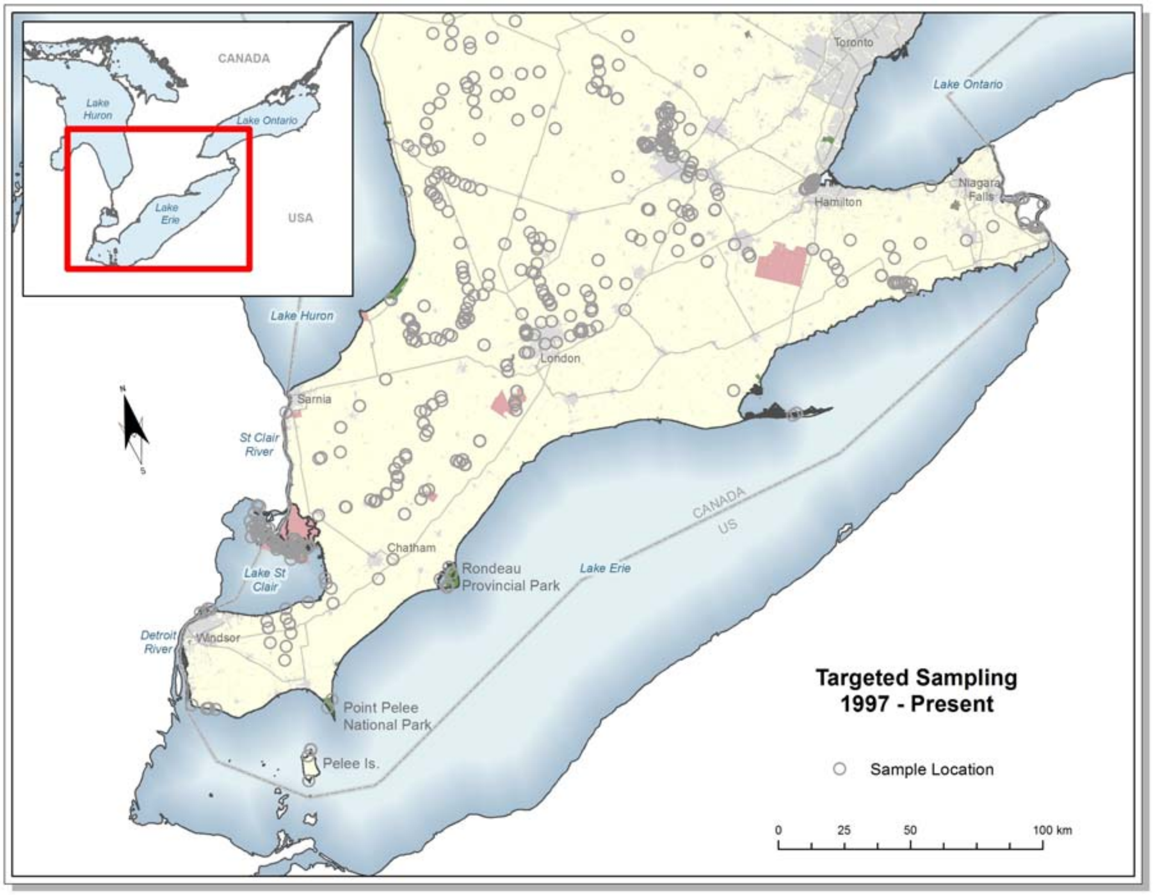

Figure 8. Recent (1997-2012) targeted mussel sampling sites within the range of Lilliput (*Toxolasma parvum*) in Canada. Records obtained from the Lower Great Lakes Unionid Database (2011). Methods employed at these sites would have a high likelihood of detecting Lilliput if present.

HABITAT

Habitat Requirements

Lilliput are found in a variety of habitats including small to large rivers, wetlands, shallows of lakes, ponds and reservoirs. They are common in soft substrates such as mud, sand, and fine gravel (Parmalee and Bogan 1998; Metcalfe-Smith *et al.* 2005a; Watters *et al.* 2009). Estimates of substrate type (%) were reported during timed searches in the Grand River at five sites and in the Sydenham, Thames, Ruscom, Belle, and Welland rivers as well as Lake Ontario at one site each. Over 50% of the substrate type was sand and a mud/muck/silt combination. Boulder, rubble and gravel made up < 10%, clay made up ~ 24% and detritus 11% of the remaining substrate (Department of Fisheries and Oceans unpubl. data).

Host fish species have yet to be identified for Canadian populations; however, they have been identified for US populations (see **Lifecycle and Reproduction** below). Most species are from the centrachidae family (Green Sunfish, Warmouth, Bluegill, White Crappie, and Orangespotted Sunfish), which prefer warm waters of either lakes, wetlands or slow-moving streams, with some aquatic vegetation. One species from the Percidae family, Johhny Darter, has also been identified as a host and it is widespread throughout Ontario preferring a variety of habitat bottoms in streams and lakes particularly those with moderate or no current and sand, gravel and/or silt bottoms (Scott and Crossman 1998; Holm *et al.* 2009). The most likely functional hosts, based on distributions alone are the Green Sunfish, Bluegill, White Crappie, and Johnny Darter.

Habitat Trends

Over 85% of the land in the Sydenham River watershed is in agricultural use, with 60% of this land in tile drainage (Dextrase *et al.* 2003). Only 12% of the original forest cover remains and large areas of the river have little to no riparian vegetation. Agricultural lands, particularly those with little riparian vegetation and large amounts of tile drain, allow large inputs of sediments to the watercourse. The Sydenham River has had high nutrient levels with total phosphorus levels consistently exceeding provincial water quality objectives (0.03 mg• L^{-1}) over the last 30 years (SCRCA 2008). Mean levels on the East Sydenham River range from approximately 0.075 to 0.13 mg/L and the levels in the North Sydenham basin are two-three times higher (Dextrase *et al.* 2003; SCRCA 2008). Not surprisingly, nitrogen has replaced phosphorus as the limiting nutrient in the system. Chloride levels in the East Sydenham River rarely exceed 50 mg•L^{-1} which is below the threshold for the Canadian Water Quality Guidelines for the Protection of Aquatic Species at Risk for (120 mg•L^{-1}; CCME 2011); however, they are increasing, most likely as a result of increased use of road salts for de-icing (Dextrase *et al.* 2003; SCRCA 2008). The human population is over 162,000 and although not densely populated, the lower portion of the river is subject to commercial shipping activities that tend to fluctuate in response to economic conditions (SCRCA 2011). Non-native species have also invaded the Sydenham River. Dreissenid mussels are found in the lower portion of the river (below the site where Lilliput were collected) and since there are no large reservoirs (which provide a continuous source of veligers) in this system it is not significantly at risk from further invasion. Round Goby (*Neogobius melanostomus*), on the other hand, are present with a distribution extending throughout the range occupied by Lilliput. Although Common Carp (*Cyprinus carpio*) are present in the Sydenham River, they are not abundant (Barnucz pers. comm. 2011). See **Threats and Limiting Factors** for more details on invasive species.

The lower Thames River watershed, including Baptiste Creek is subject to intense agricultural pressure with 88% of the land in agricultural use (Taylor *et al.* 2004). Less than 5% of the historical forest cover still remains (Taylor *et al.* 2004). Water quality in the Thames River basin has historically suffered greatly from agricultural activities. Tile drainage, wastewater drains, manure storage and spreading, and insufficient soil conservation have all contributed to poor water quality within the Thames River basin (Taylor *et al.* 2004). Phosphorus and nitrogen loadings have increased steadily and range from 0.032 – 0.22 $mg \bullet L^{-1}$ and 8-13 $mg \bullet L^{-1}$ respectively, which are some of the highest inputs for the entire Great Lakes basin (WQB 1989; UTRCA 2004; 2007). Mean concentrations of copper (0.97-4 $\mu g \bullet L^{-1}$) have decreased over the past three decades (UTRCA 2004; Morris *et al.* 2008) and most are at or below the 5 $\mu g \bullet L^{-1}$ provincial water quality objective (Ontario Ministry of Environment and Energy 1994). Chloride levels in the Thames River range from 25-220 $mg \bullet L^{-1}$ and appear to be rising throughout the watershed (UTRCA 2004). Some of these concentrations are above the 120 $mg \bullet L^{-1}$ threshold for the Canadian Water Quality Guidelines for the Protection of Aquatic Species at Risk for chloride (CCME 2011). Although Dreissenid shells were abundant at the site in the Thames River (Baptiste Creek) where Lilliput were found, no live individuals were observed (Fisheries and Oceans pers. obs. 2010). Round Goby and Common Carp are present in the Thames River and appear to be at low abundances; however, further surveys are required to confirm distributions and abundances (Barnucz pers. comm. 2011 (Dextrase pers. comm. 2011).

The Ruscom and Belle rivers drain into Lake St. Clair and are part of the Essex Region watershed. Land uses in these areas are similar to that of the Sydenham and Thames rivers being predominantly agriculture with wetlands, riparian forest and forest cover making up approximately 2% of land use in the Ruscom River and 4% in the Belle River watersheds (ERCA 2010). The Ruscom and Belle rivers consistently exceed the provincial benchmark of 25 $mg \bullet L^{-1}$ for total suspended solids (ERCA 2010) with the Ruscom having the highest total suspended sediment concentration (68 $mg \bullet L^{-1}$) in the Essex region (ERCA 2010). Total phosphorus concentration in the Essex region exceeds the Provincial Water Quality Objectives (0.03 $mg \bullet L^{-1}$), with Ruscom River having a mean total phosphorus concentration of 0.272 $mg \bullet L^{-1}$ (ERCA 2010). To date, dreissenid mussels in these two rivers are contained to the mouths and do not occur at the sites where Lilliput were found. Round Goby are abundant in the Ruscom River and are most likely present in the Belle River (Barnucz pers. comm. 2011). Further research is required to determine if carp are present.

Mussel communities in the Grand River have undergone a significant decline and subsequent recovery over the last 35 years (Kidd 1973, Mackie 1996, Metcalfe-Smith *et al.* 2000b). When Kidd (1973) sampled the river in 1970-72, he reported a 55% decrease in species diversity. Much of this loss was attributed to impaired water quality related to agricultural activity, and habitat fragmentation resulting from the construction of three large and 11 small impoundments. Currently 93% of the watershed is considered rural, and there are more than 132 dams (GRCA 2011). Mackie (1996) found a total of 18 species and indicated that anthropogenic stressors, particularly below urban centres, were likely driving the species' declines. Although only 7% of the watershed is considered urban, approximately 81% of the population occurs in this area (GRCA 2011). Metcalfe-Smith *et al.* (2000b) found 25 species, representing a 50% increase in species richness compared with Kidd's (1973) results from 25 years earlier. Morris (2006b) reports that the Grand River is now believed to be home to one of the two largest populations of the Wavyrayed Lampmussel, which is assessed as Special Concern (by COSEWIC) in Canada. Metcalfe-Smith *et al.* (2000b) relate much of the improvement in mussel communities of the Grand River to improved water quality and the addition of fish ladders promoting fish movement (allowing dispersal through host activity) and reconnection of formerly fragmented habitat. Unfortunately, further improvements are required as median total phosphorus levels in areas where Lilliput occur are approximately four times (0.128 $mg \cdot L^{-1}$) the provincial objective during high spring flows, and they can be as high as 12 times the objective (Water Quality Working Group 2011). The dams in Caledonia and Dunnville most likely play a large role in the phosphorus level as they alter the hydraulic character of the river (Water Quality Working Group 2011). The primary means of phosphorus loading in the Grand River is soil erosion from cropland, but other sources are runoff from manure, tile drainage, and livestock access to the watercourse, and the presence of dams (GRCA 1998; Water Quality Working Group 2011). Dreissenids in the Grand River are found downstream of the Dunnville dam, which includes the Lilliput distribution (Morris pers. obs. 2005). Round Goby are found both above and below the dam at Dunnville; however, abundances are higher above the dam (Barnucz pers. comm. 2011). Common Carp are also present but appear to be in low abundance (Barnucz pers. comm. 2011).

The Welland River is the largest watershed in the Niagara Peninsula Conservation Authority jurisdiction, and part of the Niagara River Area of Concern (NPCA 2010b; a). Over 70% of this area is designated as rural, with agriculture focusing on poultry and egg, grain, and oilseed production (NPCA 2010b). Only 15% of the watershed is forest cover (NPCA 2010b). There are 10 water quality monitoring stations on the Welland River and nine of these have been designated with “poor” water quality and one with “marginal” water quality based on the Water Quality Index (WQI) (NPCA 2010a). The WQI descriptions incorporate “…the number of parameters where water quality objectives have been exceeded, the frequency of exceedances within each parameter, and the amplitude of each exceedance” (NPCA 2010a). The provincial total phosphorous objectives are not met in the Welland River where total phosphorus concentrations range from approximately 0.09 – 0.27 mg•L^{-1} (NPCA 2010a). Suggested causes of high phosphorus concentrations are related to animal waste, sewage discharges, soil erosion, and agricultural land use (NPCA 2010a). In addition, Zebra Mussels have become established in the lower portion of the Welland River including the site where live Lilliput have been observed (Fisheries and Oceans Canada unpubl. data; NPCA 2010a). As of 2007 no Round Gobies have been caught in the Welland; however, Common Carp are present (Yagi and Blott 2008).

In 1985, Hamilton Harbour was identified as an *Area of Concern* by the International Joint Commission (IJC) as it was one of the most degraded areas in the Great Lakes region (Hall *et al.* 2006; O'Conner 2010). Loading sources in the area come from wastewater treatment plants, steel mills, urban runoff, combined sewer overflows, creeks (Red Hill and Grindstone), and Cootes Paradise (O’Conner 2010). The Hamilton Harbour watershed is approximately 36% agriculture, 28% urban, 17% forest and 8% wetlands with over 650,000 people living in the area (Bowlby *et al.* 2010). Phosphorus concentrations are decreasing since the implementation of the Remedial Action Plan; however, they still range from 30-50 µg•L^{-1} (Bowlby *et al.* 2010), which is well above the 0.03 mg•L^{-1} Provincial Water Quality Objectives. The decreased water clarity in Hamilton Harbour has been attributed to increased nutrient levels which have lead to algal growth and its subsequent use of dissolved oxygen in the harbour (Hamilton Harbour Technical Team 2007). Toxic chemicals that are present in the harbour and exceed the provincial and/or federal guidelines (water, sediment or tissue thresholds) for the protection of aquatic species are: polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), arsenic, cadmium, iron, lead, zinc and mercury (O’Conner 2010).

For populations of Lilliput occurring in the Great Lakes, the most significant change in habitat is associated with the invasion of the dreissenid mussels (*Dreissena polymorpha* and *D*. *rostriformis*) which have almost completely eradicated native freshwater mussels from the open waters of Lake St. Clair, Lake Erie and the Detroit River (Schloesser and Nalepa 1994, Nalepa *et al.* 1996, Schloesser *et al.* 2006). No dreissenid mussels were observed at the site where Lilliput were collected in the Lake Ontario drainage (Sunfish Pond). Although they are present in Lake Ontario, their burdens do not appear to be high – Ricciardi *et al.* (1995) predicted that Zebra Mussel densities reaching 1000•m^{-2}, where burdens are 100 Zebra Mussels per unionid, will lead to accelerated unionid mortality. Round Goby and Common Carp are both present in Lake Ontario (specifically Hamilton Harbour; Bowlby *et al.* 2010, Barnucz pers. comm. 2011).

BIOLOGY

The Lilliput is a small, short-lived species. Haag and Rypel (2011) found that the maximum age for Lilliput was between four and five years old. Watters *et al.* (2009) noted that most individuals were approximately five as well but also that the oldest individuals observed were approximately 12 years old. These results are similar to length-age estimates of the Lilliput from shells found in Sunfish Pond (Lake Ontario) – most were below seven years of age but two of the 26 examined were nine and 12 years old (Smith pers. comm. 2010). Mussels are relatively sedentary as adults. Adults feed by siphoning algae from the water column but may also engage in some pedal feeding (Nichols *et al.* 2005). Unionids have a complex reproductive cycle that involves a period of obligate parasitism on a vertebrate host. Juvenile mussels burrow below the substrate surface where they will remain until mature (Balfour and Smock 1995; Schwalb and Pusch 2007). As free-living juveniles their food source is suspected to be a combination of detritus, algae and bacteria obtained from the interstitial pore water or through pedal feeding (Yeager *et al.* 1994; Gatenby *et al.* 1997). Growth is rapid during the juvenile stage (Watters *et al.* 2009). During the summer months, adult mussels migrate to the substrate surface and are known to burrow below the surface during the winter months – most likely in response to decreasing water temperatures or changing flow regimes (Schwalb and Pusch 2007). The following discussion is based on a survey of the available literature.

Life Cycle and Reproduction

Although Lilliput are believed to be predominantly hermaphroditic, the reproductive biology is thought to follow the general reproduction of most mussels. During spawning, male mussels release sperm into the water and it is filtered out by the gills of females living downstream. Female mussels brood their young from the egg to the larval stage in specialized regions of their gills known as marsupia. In the Lilliput, the marsupium is formed by the posterior half of the outer gill (Ortmann 1912). Larvae, known as glochidia, develop within the marsupial gills and are released by the female mussel into the water column to undergo a period of parasitism on a suitable host fish species.

Natural glochidial mortality is difficult to estimate but assumed to be extremely high. (Bauer 2001) has suggested that 0.001% of glochidia successfully attach to a host. Further development to the juvenile stage cannot continue without this period of encystment. During encystment the immature juvenile will feed on the host tissue enclosed in the shell of the glochidia and their own larval adductor muscle (Fisher and Dimock 2002) – here they undergo significant differentiation. Generally, there is no increase in size during encystment on the host (Watters 2007). Juvenile Lilliput metamorphosis and excystment occurred between 12 and 30-35 days post-infestation on the Johnny Darter and Green Sunfish respectively at approximately 20ºC (Hove 1995; Watters *et al.* 2005). After excystment from the host, the juveniles settle to the river bottom and begin life as free-living mussels. Generally, juvenile mussels remain burrowed in the sediment for several years until sexual maturity is reached at which point they migrate to the substrate surface and begin the cycle again (Watters *et al.* 2001). Age at maturity is unknown for the Lilliput. McMahon (1991) indicates average age at maturity for unionids is 6 – 12 years; however, given the relatively young maximum age reported above (12 years) and the observation that most animals found are less than 6, it seems likely that age at maturity is much lower than McMahon's (1991) estimate. Furthermore, Tepe (1943) examined five individuals between 12 and 21 mm in length and all contained eggs and spermatozoa, which according to length-age relationships (Smith pers. comm. 2010) in Ontario would estimate these mussels to be less than one year old. Further research is required to determine age at maturity. Generation time for Lilliput in Canada is estimated at 6 years.

According to Utterback (1916), van der Schalie (1970) and Campbell (pers. comm. 2011), Lilliput are predominantly hermaphroditic (i.e., presence of both male and female gonads). Some studies suggest that dioecious populations do occur (Utterback 1916; Ortmann 1919; Baker 1928; van der Schalie 1966); however, others believe that this species is wholly hermaphroditic and that if males are observed, it is most likely a different species (Campbell pers. comm. 2011). If dioecious populations exist, the shell does not exhibit a pronounced sexual dimorphism (Watters *et al.* 2009). Whether this species is wholly hermaphroditic in Canada is unknown. This species is believed to be bradytictic (long-term brooder), with eggs being reported in June to August (Utterback 1916; Ortmann 1919) and glochidia are present to the following July (Watters *et al.* 2009). Gravid (presence of glochidia) individuals have not been observed in Ontario; however, they have been observed in April (Texas), June (Pennsylvania and Arkansas), and August (Indiana and Wisconsin) in the United States (Williams *et al.* 2008). Glochidia are hookless, sub-elliptical in shape and approximately 180 μm in length and 200 μm in height (Watters *et al.* 2009).

Lilliput have evolved a complex host attraction strategy to increase the probability of encountering a suitable host (Zanatta and Murphy 2006). Worm-like caruncles (on the posterior mantle margin) and mantle flaps have been observed in different populations and it is likely that these are active lures (Zanatta and Murphy 2006; Watters *et al.* 2009). The Lilliput forms and releases conglutinates (bundles of glochidia bound in mucus). These conglutinates are white and club-shaped with glochidia embedded among unfertilized eggs (Williams *et al.* 2008; Watters *et al.* 2009). When the conglutinate is released by the mussel, it elicits a predatory response from its host species, causing the host to ingest the conglutinate. Once ruptured, the glochidia will be released and attach to the host and undergo metamorphosis.

Host fishes have not been identified for Lilliput populations in Canada; however, six fish species have been identified as hosts in the United States. These are: Johnny Darter, Green Sunfish, Bluegill, White Crappie, Warmouth, and Orangespotted Sunfish (Fuller 1978; Hove 1995; Watters *et al.* 2005; as well as Fuller 1978 as cited in Watters *et al.* 2009). The most likely hosts in Canada (based on distributional overlap) are the Bluegill, Green Sunfish, White Crappie and Johnny Darter. The first three species are typical of slow-moving lakes, streams, and wetlands (Green Sunfish) and are present throughout most of the Lilliput range (Scott and Crossman 1998; Holm *et al.* 2009). The Johnny Darter is most common in areas of moderate to no current and substrates of sand, gravel and silt. There is some distributional overlap with that of the Lilliput (Scott and Crossman 1998; Holm *et al.* 2009). The Warmouth and Orangespotted Sunfish do not share distributional overlap with current Lilliput populations (Holm *et al.* 2009; Lower Great Lakes Unionid Database 2011). The Warmouth has been assessed by COSEWIC and listed under the *Species at Risk Act* as Special Concern (COSEWIC 2009; Species at Risk Public Registry 2011).

Physiology and Adaptability

The presence of freshwater mussels of the family Unionidae is indicative of the overall good health of an aquatic ecosystem. This family, especially the glochidia and juveniles, has been shown to be sensitive to heavy metals (Keller and Zam 1991) ammonia (Goudreau *et al.* 1993; Mummert *et al.* 2003), acidity (Huebner and Pynnonen 1992), salinity (Liquori and Insler 1985; Gillis 2011), and copper (Gillis *et al.* 2008).

Host fish identification experiments have been completed in the United States; however, there have been no attempts to identify host fishes or artificially rear this species in Canada. No studies were found that address Lilliput adaptability.

Dispersal and Migration

In general, adult mussels have very limited dispersal abilities. Although adult movement can be directed upstream or downstream, studies have found a net downstream movement through time (Balfour and Smock 1995; Villella *et al.* 2004). Small-scale vertical and horizontal movement can be affected by mussel diversity, reproduction, current velocity, substrate type, temperature, and dreissenid infestations (Kat 1982; Lewis and Riebel 1984; Amyot and Downing 1998; Watters *et al.* 2001; Schwalb and Pusch 2007; Allen and Vaughn 2009). Utterback (1916) found that Lilliput had a rapid heartbeat (38 beats per minute), making it one of the most actively moving species. However, the primary means for large-scale dispersal, upstream movement, and the movement into novel habitats occurs during the encysted glochidial stage on the host fish.

Most Centrarchids tend to exhibit home pool (remain in the same area) or homing behaviour (Matthews 1998). Paukert *et al.* (2004) estimated that the Bluegill's core home range was 0.01 – 27.2 hectares in Pelican Lake, Nebraska and Thompson (1933) found that they moved approximately 23 km in one year in Illinois streams. The Green Sunfish also has a restricted home range and most tend to remain in certain areas or pools moving very little (approximately 100 m; Thompson 1933; Gerking 1953; Gatz and Adams 1994; Smithson and Johnston 1999). Funk (1957) did observe movement of greater than 40 km for a few individual Green Sunfish; however, this was rare. Funk (1957) also noted that the overall movement patterns of the White Crappie varied seasonally; however, they could cover up to 42 km in 3 months. Thompson (1933) found similar results with white crappie moving ~ 36 km over a one-year period.

Mundahl and Ingersoll (1983) found that Johnny Darters moved very little (mean = 55 m) from the initial capture point in early autumn; however, it may expand during the reproductive season.

Interspecific Interactions

Immature Lilliput are obligate parasites on vertebrate hosts. The suspected hosts for Canadian populations are Bluegill, Green Sunfish, White Crappie and Johnny Darter (see **Lifecycle and Reproduction** and **Dispersal and Migration**).

Freshwater mussels of the Great Lakes region have been severely impacted by negative interactions with invasive species. Dreissenid mussels (*D. polymorpha* and *D. bugensis*) can colonize unionids in large numbers. This leads to severe impacts on feeding, respiration, movement and reproduction. The Round Goby is another invasive species that may be impacting Lilliput populations both directly and indirectly. They have been labelled as "voracious consumers of benthic organisms" (Ray and Corkum 1997; Poos *et al.* 2010), and as such may directly affect the mussels via predation. Indirect effects are caused by the competition and predation with other fish species, which may act as hosts for Lilliput. See **Threats and Limiting Factors** for more details.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Historical surveys (1943 – 1996)

Based on nine records from the Lower Great lakes Unionid Database, Lilliput were historically (1943 -1996) found in Sydenham, Thames, Grand and Detroit rivers. Search effort and/or sampling methods are limited for historical records as most are based on the presence of valves or shells.

Recent Surveys (1997 – 2011)

There are 26 current records (live and shells) in the Lower Great Lakes Unionid Database. These records indicate that Lilliput are currently found in the Lake St. Clair watershed (Thames, Sydenham, Belle, and Ruscom rivers), Lake Erie watershed (Grand and Welland rivers) and in Lake Ontario. Table 1 provides a summary of the current information available on search effort and sampling methods. Data were collected using two basic methods:

(1) Timed-Searches

Timed searches refer to the number of hour(s) searched x number of people searching. This qualitative survey method provides data on species presence/absence and relative measures of abundance. When visibility is clear, searches are conducted using the naked eye, viewing boxes, snorkelling, or SCUBA diving. When turbidity is high the substrate is manually sieved using hands or scopes (raccooning). Mussels are collected, held in the water (mesh diver bags, or bucket) until the end of the sampling period and then identified to species, sexed (if sexually dimorphic), counted, measured, and returned to the substrate alive. A period equal to 4.5 person-hours of searching generally detects rare species (Metcalfe-Smith *et al.* 2000a).

(2) Quadrat surveys

Quantitative surveys involve the excavation of 1 m^2 quadrats to a depth of approximately 10 cm where all mussels are removed. As with the timed-search method, individuals are identified, sexed, counted and measured before being returned to the substrate alive. This method provides information on species composition, density estimates, sex ratios, size frequencies and estimates of recruitment. If sediments are sifted through 7-mm mesh, the likelihood of finding juveniles is greatly enhanced. However, quadrat surveys are ineffective in very soft substrates such as silt, often occupied by Lilliput.

Abundance

To the best of our knowledge, Lilliput no longer occur in the Detroit River (Schloesser *et al.* 2006). Extant occurrences in Ontario are restricted to the Sydenham, Thames, Ruscom, Belle, Grand and Welland rivers and Lake Ontario.

A total of 13 live Lilliput have been collected from tributaries of Lake St. Clair (Lower Great Lakes Unionid Database 2011). Seven Lilliput were found at one of two sites sampled in the Sydenham River in 2011 (Fisheries and Oceans unpubl. data). This species was not observed in any other surveys in the east branch of the Sydenham River between Florence and Dresden despite over 1000 person-hours of searching (between 1997 and 2011). One live individual was collected at one of three sites sampled via timed searches in Baptiste Creek (Thames River tributary) in 2010. Two individuals were found in the Belle River and three individuals in the Ruscom River in surveys conducted by Fisheries and Oceans Canada in 2010. In addition to the small number of individuals observed, all were found during qualitative timed searches, which is not conducive to abundance estimates.

Lilliput have been collected in two tributaries of Lake Erie: the Grand River and the Welland River. Fisheries and Oceans Canada (unpubl. data 2011) surveyed 13 sites on the Grand River in 2011, and found a total of 13 live Lilliput at four of these sites. Shells were found at one additional site (Lower Great Lakes Unionid Database 2011). Figure 9 shows the length of the individuals found in the Grand River. A total of eight sites were surveyed in the Welland River in 2008 and one live Lilliput was found at one site. Again due to the low numbers, abundance estimates are not possible.

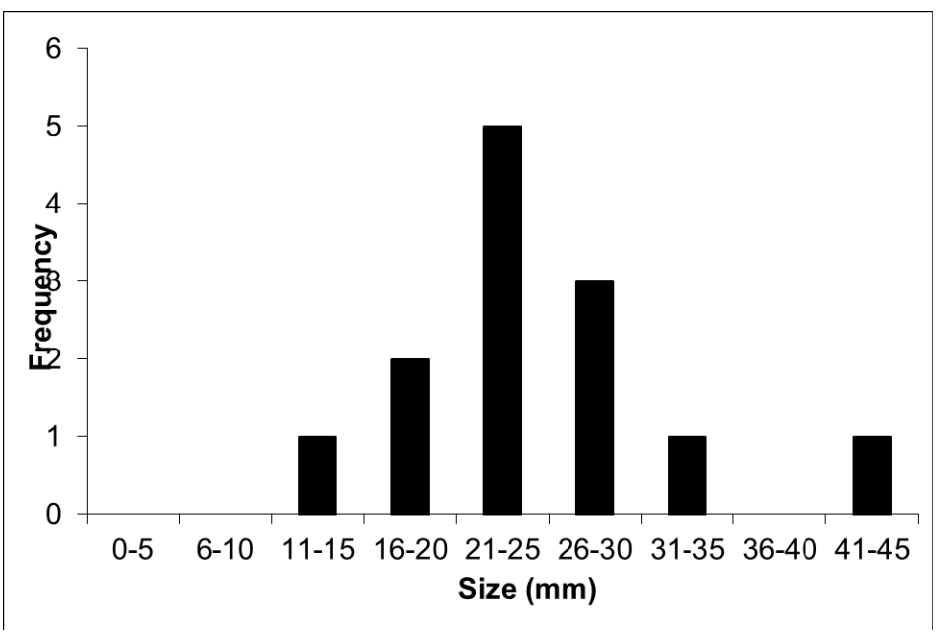

Figure 9. Size distribution of Lilliput (*Toxolasma parvum*) in the Grand River in 2011 (n = 13; Morris unpub. data).

A total of two Lilliput were found at one (sunfish pond) of three sites surveyed in Lake Ontario (Royal Botanical Gardens) in 2011. This is the first time that this species has been found in Lake Ontario. Abundance estimates could not be determined because of the low number of individuals found and the collection method (qualitative timed search).

Fluctuations and Trends

It is very difficult to evaluate population fluctuations associated with the Lilliput as there are very few records available. Of the nine historical records, one refers to a single live animal. There are only 26 current records for this species in the Lower Great Lakes Unionid Database representing 31 live individuals.

No comments can be made on the fluctuations of Lilliput distributions in the Sydenham, Thames, Belle or Ruscom rivers as very few records exist (6 records with a total of 13 live Lilliput).

Similarly, fluctuations in the Grand or Welland rivers are unknown. Historically, Lilliput were known from six records (all shells) in the Grand River. Recent surveys (Lower Great Lakes Unionid Database 2011) have found 13 live specimens at four sites and shells at one other site. Only one live individual has been found in the Welland River. Therefore there is not enough information to determine fluctuations in the Grand and Welland rivers.

No comments can be made on the fluctuations in Lake Ontario as this population was only confirmed in 2011 when two live individuals were first detected (Lower Great Lakes Unionid Database 2011).

Trends in all populations appear to be negative, with an inferred 40% decline based on the decrease in IAO and an inferred decline of 22% in EO (see **Extent of Occurrence** and **Index of Area of Occupancy** under **DISTRIBUTION**).

Rescue Effect

Lilliput populations are currently isolated from one another and from American populations by large areas of unsuitable habitat. This makes the likelihood of re-establishment of extirpated populations by immigration small. The four suspected hosts of the Lilliput, Bluegill, Green Sunfish, White Crappie and Johnny Darter are generally not capable of large-scale movements. Lilliput populations do occur in adjacent U.S. states; however, they could not act as source populations because they are not considered abundant. It has been found at several locations; however, it is not common (Zanatta pers. comm. 2011). In the four U.S. states of the Lake St. Clair-Lake Erie corridor, populations in Ohio are not ranked, those in Michigan are Endangered, those in Pennsylvania are S1S3 (critically imperilled to vulnerable) and those in New York are SH (possibly extirpated; NatureServe 2011).

THREATS AND LIMITING FACTORS

In 2011 a multi-species Recovery Potential Assessment (RPA) for four mussel species: Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadrula*), and Rainbow (*Villosa iris*) was conducted by Fisheries and Oceans Canada (DFO 2011). This peer-reviewed RPA addresses threats in some of the watersheds where Lilliput populations occur. The following threats are in compliance with this RPA document. Threats were addressed and ranked using the threats calculator (Table 2) following the methods and terminology of Salafsky *et al.* (2008) and Master *et al.* (2009).

Table 2. Description of threats and their impacts on current Lilliput (*Toxolasma parvum*) populations – calculated using the threats calculator. Threats have been arranged from highest to lowest severity.

Threat no.	Threat description	Threat impact		Scope	Severity	Timing
9	Pollution	A	Very High	Pervasive	Extreme	
9.1	Household sewage & urban waste water	B	High	Pervasive	Serious	High
9.2	Industrial & military effluents	C	Medium	Restricted	Extreme	High
9.3	Agricultural & forestry effluents	C	Medium	Pervasive	Moderate	High
4	Transportation & service corridors	C	Medium	Pervasive	Moderate	
4.3	Shipping lanes	C	Medium	Pervasive	Moderate	High
8	Invasive & other problematic species & genes	C	Medium	Pervasive	Moderate	
8.1	Invasive non-native/alien species	C	Medium	Pervasive	Moderate	High
11	Climate change & severe weather	C	Medium	Pervasive	Moderate	
11.1	Habitat shifting & alteration	C	Medium	Pervasive	Moderate	Moderate
1	Residential & commercial development	C	Medium	Restricted	Serious	
1.1	Housing & urban areas	C	Medium	Restricted	Serious	High
7	Natural system modifications	C	Medium	Restricted	Serious	
7.2	Dams & water management/use	C	Medium	Restricted	Serious	High
6	Human intrusions & disturbance	D	Low	Large	Slight	
6.1	Recreational activities	D	Low	Large	Slight	High
1.2	Commercial & industrial areas	D	Low	Small	Serious	High
5	Biological resource use	D	Low	Small	Moderate	
5.4	Fishing & harvesting aquatic resources	D	Low	Small	Moderate	Insignificant /Negligible
6.3	Work & other activities	D	Low	Small	Slight	High

The following emphasizes the principal threats that may be currently acting on Lilliput populations. It is important to note that these threats may also directly impact the feeding, respiration, reproduction, and movement of host fishes which can lead to severe consequences for the remaining Lilliput populations.

Very High to High Threats

Pollution (9.1 Household sewage and urban wastewater, 9.2 Industrial and military effluents, & 9.3 Agriculture and forestry effluents)

Pollution has been deemed one of the most prominent threats affecting mussel populations. Although it is unclear as to the impact of pollution on Lilliput populations, it has been shown to affect mussel populations throughout North America. There are a variety of threats associated with “household sewage and urban waste water”, “industrial and military effluents” and “agricultural effluents” including: sediment loads (siltation), nutrient loads, contaminants and toxic substances (e.g., run-off of lawn fertilizers and pesticides, road salts, and spills). Freshwater mussels, particularly glochidia and juveniles, are sensitive to a number of aquatic pollutants (Bringolf *et al.* 2007a; Bringolf *et al.* 2007b); therefore the current levels of pollution observed in these watersheds may have negative effects on the remaining populations of the Lilliput. Below is a brief description of how these threats affect mussels.

Sediment loading

Loading of suspended solids causing turbidity and siltation is presumed to be one of the primary limiting factors for most aquatic SAR in southern Ontario. Lilliput, however, appear to prefer muddy or silty substrates (Metcalfe-Smith *et al.* 2005a; Watters *et al.* 2009), therefore increased turbidity may not impact Lilliput populations as much as other mussel species. It is important to note that the transport and increase in abundance of fine particles can degrade the stream as well as negatively impact feeding, growth, respiration and reproduction (Wood and Armitage 1997; Strayer and Fetterman 1999). Because Lilliput tend to burrow completely in the substrate, sedimentation effects may be more severe in that the accumulation of silt on the streambed may reduce flow rates and dissolved oxygen concentrations below the surface by clogging interstitial spaces in the stream substrate (Österling *et al.* 2010). In addition, increased turbidity and/or siltation would decrease the likelihood that a host fish will be able to visually locate a Lilliput or its conglutinate. Further research is required to determine if sediment loading is having any negative effects on Lilliput populations. Turbidity alone does not appear to be a major threat; however, it may affect the presence of the host species, whereas siltation may be a larger threat if levels are high.

Nutrient loading

Strayer and Fetterman (1999) identified increased nutrient loads from non-point sources, especially from agricultural activities as a primary threat to freshwater mussels. Other sources include municipal wastewater discharges, domestic septic systems and runoff associated with lawn maintenance in areas of urban and residential development. Increase nutrient loads have indirect effects on freshwater mussels. For example, decreased levels of oxygen are often associated with increased concentrations of phosphorus and nitrogen and this can stimulate growth and decomposition of algae and plants (NPCA 2010a). This, in turn, reduces respiration and can cause death (Tetzloff 2001), as well as changes in fish communities (Jackson *et al.* 2001).

Contaminants and toxic substances

Exposure to contaminants and toxic substances can come from a variety of sources including industrial processes, wastewater treatment plants, steel mills, and sewage and storm water runoff. Toxic chemicals from both point and non-point sources, especially agriculture, are believed to be one of the major threats to mussel populations today (Strayer and Fetterman 1999). Due to the nature of the freshwater mussel lifecycle, they are particularly sensitive to increased levels of contaminants and toxic substances (Cope *et al.* 2008). Because mussels are unable to move large distances, they accumulate these substances from their environment. Freshwater mussels appear to be sensitive to PCBs, DDT, Malathion, and Rotenone, which can inhibit respiration and accumulate in mussel tissue (Fuller 1974; USFWS 1994). Glochidia and juveniles are particularly sensitive to heavy metals (Keller and Zam 1991; Bringolf *et al.* 2007a; Bringolf *et al.* 2007b; Gillis *et al.* 2008), acidity (Huebner and Pynnonen 1992), salinity (Liquori and Insler 1985), and chloride (Gillis 2011). Newton (2003) and Newton *et al.* (2003) showed that juvenile freshwater mussels are among the most sensitive aquatic organisms to un-ionized ammonia toxicity. They tend to exhibit adverse responses at levels below those used as guidelines for aquatic safety in U.S. waterways. Increased agricultural activities and urban area runoff lead to increased levels of pesticides and fertilizers running off the land into the river (COSEWIC 2006). Roads and urban areas can also contribute significant contaminants to waterways, including oil and grease, heavy metals, and chlorides.

Exposure to municipal effluent has been shown to negatively affect unionid health (Havlik and Marking 1987; Gagné *et al.* 2004; Gagnon *et al.* 2006; Gagné *et al.* 2011). Pharmaceuticals enter aquatic ecosystems largely via effluent from sewage treatment plants and are being shown to disrupt gonad physiology and reproduction in mussels. Gagné *et al.* (2011) determined that Eastern Elliptios (*Elliptio complanata*) in Quebec have shown a dramatic increase in the number of females downstream of a municipal effluent outfall. In addition, males are showing a female-specific protein (Gagné *et al.* 2011). Flutedshell mussels (*Lasmigona costata*) living downstream of a municipal wastewater outfall in the Grand River have shown significantly reduced condition factor and mussel age as well as impacts on immune status when compared to individuals living upstream of the outfall (Gillis pers. comm. 2011). Experiments using three mussel species (Flutedshell, Eastern Elliptio and Giant Floater (*Pyganodon grandis*)) are underway in Canada to assess biomarkers of stress and immune status of field-deployed mussels upstream and downstream of municipal wastewater effluent outfall – results are pending (Gillis pers. comm. 2011).

Oil spills can result in limited oxygen exchange, interference with respiration, blanketed substrates, consumption effects (Crunkilton and Duchrow 1990) and changes in fish communities – all of which affect the survival of mussels. A spill in a tributary of the Kalamazoo River in Michigan released over 800 000 gallons of crude oil affecting many of the organisms in the area (Murray and Korpalski 2010). Oil transmission trunk lines run through the Grand, Welland and Thames rivers and some of their tributaries (Natural Resources Canada 2011). Lilliput populations in the Grand River would be severely impacted if a spill were to occur as they are located just downstream of the trunk line. Populations in the Thames or Welland rivers are located well downstream of the trunk lines (which occur in the headwaters whereas Lilliput occur in the lower portions of these rivers), therefore a spill would not have a great impact on extant populations.

Medium Threats

<u>Transportation and service corridors (4.3 Shipping lanes)</u>

Dredging for shipping purposes can result in environmental, physical, and biological consequences (Ebert 1995). Specific effects of dredging on Lilliput populations are unknown; however, it has caused the direct destruction of mussel habitat leading to siltation and sand accumulation of local and downstream mussel beds, created unstable substrate, re-suspended contaminants, caused changes in benthic and fish communities and lowered water velocity (Watters 2000). In addition, it can lead to removal of mussels and the redistribution of these individuals into sub-optimal habitat (Miller and Payne 1998; Aldridge 2000). Grace and Buchanan (1981 as cited in Watters 2000) found that no mussels were present in an area that had been dredged 15 years earlier. Whereas, Miller and Payne (1998) found that mussels present in a barge turning basin were tolerant to disturbances such as dredging. Dredging occurs at the mouths of the Thames, Belle, and Ruscom rivers as there are a number of marinas and residential homes in this area. These dredging events can occur on an annual basis but most occur downstream of extant Lilliput populations (Balint pers, comm. 2011).

Aquatic populations can also be impacted by navigation, which occurs in the commercialized areas near the mouths of some of these (e.g., Grand River) (Nielsen *et al.* 1986; Aldridge *et al.* 1987). The effects of navigation and their impact on mussels have not been studied in Canada. A lab experiment on the effects of intermittent suspended solids and turbulence exposure of three species of mussels suggested that frequent exposure to turbulence and high levels of suspended solids significantly lowered food clearance rates, oxygen uptake, and nitrogenous excretion rates, as well as cause changes to alternate catabolic substrates – indicating environmental stress (Aldridge *et al.* 1987). In one study, Miller and Payne (1995), however, found that the changes associated with navigation velocity were too small and the duration too short to have any negative effect on the mussel bed.

Invasive and other problematic species and genes (8.1 Invasive non-native/alien species)

The presence of dreissenid mussels (*Dreissena polymorpha* and *D*. *rostriformis*) is the most significant threat to mussels in the Great lakes. Zebra and Quagga mussels attach to a mussel's shell and interfere with feeding, respiration, reproduction, excretion and locomotion (Haag *et al.* 1993; Baker and Hornbach 1997). They have almost completely eradicated native unionid mussels from Lake St. Clair, Lake Erie and the Detroit River (Schloesser and Nalepa 1994; Nalepa *et al.* 1996; Schloesser *et al.* 2006). Dreissenids mussels have caused significant changes to the ecosystems in the Great Lakes; however, their threat is not as pronounced as it was a decade ago and some species (other than mussels) are showing signs of recovery (Crail *et al.* 2011; Strayer *et al.* 2011).

The invasion of the Round Goby has the potential to both directly and indirectly impact native mussel populations (Ray and Corkum 1997; Poos *et al.* 2010). Direct effects include predation as this fish species has been observed preying on juvenile mussels in the Sydenham River. Indirectly, this species has been implicated in the declines of native benthic fishes by competition and egg predation. Fish species that appear to be impacted by Round Goby presence include Logperch (*Percina caprodes*), Mottled Sculpin (*Cottus bairdii*), Johnny Darter (*Etheostoma nigrum*), Trout-perch (*Percopsis omiscomaycus*), Channel Darter (*P. copelandi*), Fantail Darter (*E. flabellare*), Greenside Darter (*E. blenniodes*), and Smallmouth Bass (*Micropterus dolomieu*) (French and Jude 2001; Steinhart *et al.* 2004; Thomas and Haas 2004; Baker 2005; Reid and Mandrak 2008). Of importance is the decline of the Johnny Darter as it is a suspected host for Lilliput. Although there are no specific studies that show Round Goby negatively affect Green Sunfish, Bluegill, or White Crappie, they do change the ecosystem where they occur, which could lead to disruptions in the Lilliput reproductive cycle.

The invasive Common Carp (*Cyprinus carpio*) may also be impacting Lilliput populations. Although they may consume juvenile mussels and dislodge adult mussels, it is their uprooting of plants and feeding on sediment-associated fauna that significantly alter habitat and this habitat destruction will have a far greater impact (Dextrase *et al.* 2003).

Climate change and severe weather (11.1 Habitat shifting and alteration)

Impacts of climate change such as decreases in water levels, increases in water and air temperatures, increases in the frequency of extreme weather events, and emergence of diseases may negatively impact native freshwater mussels (Lemmen and Warren 2004). There are many climate models that have different predictions regarding the long-term effects of climate change; however, most predict a drop in water levels (COSEWIC. 2007). A drop in water level may be particularly important to freshwater mussel populations inhabiting shallow wetlands, such as the Lilliput. Decreased water levels may cause local extinction or a forced movement into deeper waters where unionid mussels are likely to be outcompeted by dreissenid mussels. Because the effects of climate change on freshwater mussels are speculative, it is difficult to determine the likelihood and impact of this threat on Lilliput populations.

Residential and commercial development (1.1 Housing and urban areas)

Although there is no quantitative information available regarding the number of Lilliput affected by residential and commercial development activities in Canada, removal or alteration of preferred habitat, for either the mussel or its host, could have a direct effect on the recovery or survival of this species. Instream works (dock construction, marina development, hardening of shoreline) associated with human settlements that have a substantial footprint may pose a threat to extant Lilliput populations. For example, shoreline hardening and tidying in the Ruscom and Belle rivers is a major concern regarding changing ecosystems. Modification of the shoreline can cause loss of woody debris and aquatic vegetation and cause changes in wave action, current direction and sediment erosion patterns, as well as impede energy exchanges between the aquatic and terrestrial parts of the shore (Nodwell *et al.* 2007; Strayer and Findlay 2010). All of these can have negative effects on Lilliput and/or its host species.

Natural systems modifications (7.2 Dams and water management/use)

The presence of impoundments and dams on freshwater streams and rivers has been shown to negatively affect mussel communities (Blalock and Sickel 1996; Vaughn and Taylor 1999; Watters 2000; Parmalee and Polhemus 2004). Impoundments and dams typically result in siltation, stagnation, loss of shallow water habitat, pollutant accumulation, poor water quality, flow alteration and temperature changes (Bogan 1993; Vaughn and Taylor 1999; Watters 2000). Dams also disrupt habitat connectivity and may create barriers that prevent host fish movement and therefore mussel distributions, and cause sediment retention upstream and scouring downstream (Watters 1996; Gardner *et al.* 2011). 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. The only significant dam within the range of Lilliput is the dam at Dunnville on the Grand River. This dam is located within the lake-effect zone and its removal is unlikely to result in significant changes to flow or substrate conditions. In addition, the Grand River Conservation Authority does not have plans to remove the Dunnville Dam (Allan pers. comm. 2011). As a result, potential impact on Lilliput is minimal.

Low Threats

Human intrusions and disturbance (6.1 Recreational activities)

Recreational activities, such as boating, may negatively impact mussels by increasing total suspended solids. For example, the Ruscom and Belle rivers provide easy access to Lake St. Clair for recreational boating and fishing purposes. The effects of recreational boating have not been studied in Canada; however, there have been a few studies on how large vessels affect mussels (see **Transportation and service corridors**). Further research is required to determine if Lilliput populations may be at risk due to this particular human intrusion or disturbance.

Residential and commercial development (1.2 Commercial and industrial areas)

The Lilliput populations in Ontario appear to be restricted to the lower portions of these rivers and as such are susceptible to the commercial developments that are associated with these portions of the watershed. Examples of how commercial developments change habitat include: shoreline hardening, water use, lack of riparian zone, pollution and toxic chemicals, and dredging. The lower Sydenham and Grand rivers and Hamilton Harbour (Lake Ontario) are commercially developed and any of the above examples will undoubtedly impact the aquatic habitat by changing water chemistry, substrate composition, host fish communities, and pollution (see above sections for details).

Biological resource use (5.4 Fishing and harvesting aquatic resources)

Freshwater mussels have been used as food, knives, scrapers, utensils and currency (Stewart 1992). The pearl button industry was alive and well in Ontario with industries occurring on both the Thames and the Grand rivers. From 1935 into the 1950s approximately 100 tons of mussels were harvested per year from the Thames River (Stewart 1992). Detweiler (1918) stated that the Grand River had more commercially valuable mussels than any other river in Ontario. A small shelling industry was established in the early 1900s on the Grand River and although Lilliput were not likely a target species for the pearl button industry it may have been potential by-catch. This industry on the Grand River near Dunnville removed at least 260 tonnes of mussels from the Grand River in 1915 and in 1916 (Detweiler 1918). The removal of thousands of tons of mussels from these systems has undoubtedly shaped the current abundance and distributions of unionids in Ontario.

Human intrusions and disturbance (6.3 Work and other activities)

The collection of Lilliput for scientific research can be included in “Work and other activities” that may have some impact on extant populations. Although there may be some impacts (dislodgement, handling effects; Haag and Commens-Carson 2008), scientific research is required to advance knowledge of the population and its status.

Number of Locations

The number of locations was determined following IUCN guidelines by first selecting the most serious plausible threat that affects all of the taxon’s distribution; where the most serious plausible threat does not affect all of the taxon’s distribution, other threats can be used to define and count locations in those areas not affected by the most serious plausible threat. If there are two or more serious plausible threats, the number of locations should be based on the threat that results in the smallest number of locations. In the case of the Lilliput, high-impact threats include pollution (from sediment and nutrient loading, contaminants and toxic substances) relating primarily to urban development resulted in as many as seven locations: Lake St. Clair and Sydenham River, Thames River, Ruscom River, Belle River, Lake Erie and its tributary the Grand River, Lake Ontario and neighbouring Hamilton Harbour and its tributaries 20 Mile Creek, and Sunfish Pond, and the seventh, the Welland River (Table 2). The Lake Erie tributary (Grand River) location is influenced mostly by urban/industrial threats and is spatially isolated from all other locations. The Lake Ontario, Welland River, and 20 Mile Creek locations are influenced by agricultural threats but are spatially isolated from Lake St. Clair and its tributaries locations. Although the Hamilton Harbour (Sunfish Pond) location could be considered spatially similar to the Lake Ontario location it is primarily affected by urban/industrial threats and not likely to be impacted by similar threats to the other water bodies considered part of that location.

Using medium-level threats, especially invasive dreissenids, which invade tributaries in the downstream direction, and the Round Goby, which can invade tributaries in the upstream direction, resulted in three to four locations: Lake St. Clair and its tributaries (Sydenham, Thames, Ruscom and Belle rivers); Lake Erie and its tributary, Grand River; Lake Ontario and its tributaries, Welland River, and 20 Mile Creek; and Hamilton Harbour (Sunfish Pond). Three locations result if Hamilton Harbour is included with Lake Ontario. Dreissenids and Round Goby are threats that can rapidly affect all populations of Lilliput.

PROTECTION, STATUS, AND RANKS

Legal Protection and Status

The federal *Fisheries Act* historically represented the single most important piece of legislation protecting the Lilliput and its habitat in Canada. However, recent changes to the *Fisheries Act* have significantly altered protection for this species and it is unclear at this time if the *Fisheries Act* will continue to provide protection for this species. Three significant changes are: All explicit references to fish habitat have been removed; “harmful alteration, disruption, or destruction of fish habitat” has been replaced by “serious harm to fish”; general prohibitions against harm to fish habitat have been replaced by those that apply now only to fish that are important to a “commercial, recreational, or Aboriginal fishery”. The collection of freshwater mussels requires a collection permit issued by the Ontario Ministry of Natural Resources under authority of the Fish and Wildlife Conservation Act. Other indirect protections are realized through the habitat protections identified below in **Habitat Protection and Ownership**.

Several mussel species are protected under Canada’s *Species at Risk Act* and the Ontario *Endangered Species Act, 2007* including: Round Hickorynut (*Obovaria subrotunda*) and Kidneyshell (*Ptychobranchus fasciolaris*) (Morris 2006a), Northern Riffleshell (*Epioblasma torulosa rangiana*), Snuffbox (*E. triquetra*), Round Pigtoe (*Pleurobema sintoxia*), Salamander Mussel (*Simpsonaias ambigua*) and Rayed Bean (*Villosa fabalis*) (Morris and Burridge 2006) and Wavyrayed Lampmussel (*Lampsilis fasciola*) (Morris 2006b). The Lilliput may therefore, benefit indirectly from protection afforded to these species or by actions implemented (e.g., research, stewardship and outreach) under the direction of the above recovery strategies.

Non-Legal Status and Ranks

Lilliput are considered globally secure (G5) and is listed as nationally secure (N5) in the United States but critically Imperilled (N1) in Canada (NatureServe 2011) (NatureServe 2011). It is not on the IUCN's (International Union for Conservation of Nature) Red List. The most current Canadian and Ontario status ranks are both 2 (may be at risk; Wild Species 2010). In the United States, the Lilliput is considered possibly extirpated in two jurisdictions, critically imperilled and imperilled in two each, vulnerable in five, apparently secure in seven, and secure in two – it has not been ranked in four jurisdictions (Table 3).

Table 3. Subnational conservation rankings for Lilliput in North American jurisdictions. All information taken from NatureServe (2011).

Conservation rank	Description	Jurisdiction
S1	Critically imperilled	Ontario
SH	Possibly extirpated	Georgia, New York
S1	Critically imperilled	Iowa, Pennsylvania (S1S2)
S2	Imperilled	Kansas (S2S3), West Virginia
S3	Vulnerable	Alabama, Indiana, South Dakota, Texas, Wisconsin
S4	Apparently secure	Arkansas, Illinois, Kentucky (S4S5), Louisiana, Mississippi, Missouri, Oklahoma
S5	Secure	Ohio, Tennessee
SNR	Not ranked	Florida, Michigan, Minnesota, Nebraska

Alabama (S3), Arkansas (S4), Florida (SNR), Georgia (SH), Illinois (S4), Indiana (S3), Iowa (S1), Kansas (S2S3), Kentucky (S4S5), Louisiana (S4), Michigan (SNR), Minnesota (SNR), Mississippi (S4), Missouri (S4), Nebraska (SNR), New York (SH), Ohio (S5), Oklahoma (S4), Pennsylvania (S1S2), South Dakota (S3), Tennessee (S5), Texas (S3), West Virginia (S2), Wisconsin (S3)

Alabama (S3), Arkansas (S4), Florida (SNR), Georgia (SH), Illinois (S4), Indiana (S3), Iowa (S1), Kansas (S2S3), Kentucky (S4S5), Louisiana (S4), Michigan (SNR), Minnesota (SNR), Mississippi (S4), Missouri (S4), Nebraska (SNR), New York (SH), Ohio (S5), Oklahoma (S4), Pennsylvania (S1S2), South Dakota (S3), Tennessee (S5), Texas (S3), West Virginia (S2), Wisconsin (S3) Alabama (S3), Arkansas (S4), Florida (SNR), Georgia (SH), Illinois (S4), Indiana (S3), Iowa (S1), Kansas (S2S3), Kentucky (S4S5), Louisiana (S4), Michigan (SNR), Minnesota (SNR), Mississippi (S4), Missouri (S4), Nebraska (SNR), New York (SH), Ohio (S5), Oklahoma (S4), Pennsylvania (S1S2), South Dakota (S3), Tennessee (S5), Texas (S3), West Virginia (S2), Wisconsin (S3)

Habitat Protection and Ownership

The Ontario *Lakes and Rivers Improvement Act* prohibits the impoundment or diversion of a watercourse if siltation will result. Streamside development in Ontario is managed through floodplain regulations enforced by local conservation authorities.

Other acts that will improve overall water quality for all mussel species include: (1) *Nutrient Management Act*, which regulates the storage and use of nutrients; (2) *Clean Water Act*, which protects Ontario's source water via local committees that list existing and potential threats and implement actions that will reduce or eliminate these threats (OME 2011); (3) *Water Resource Act*, which is directed toward both ground and surface water throughout the province of Ontario with the goal of conserving, protecting and managing Ontario's water resources (OME 2011); and (4) *Environmental Protection Act*, which prohibits the discharge of any contaminants (causing negative effects) into the environment, and requires that any spills of pollutants be reported and cleaned up in a timely fashion (OME 2011).

A majority of the land adjacent to the rivers where Lilliput are found is privately owned; however, the river bottom is generally owned by the provincial Crown. Some of the occurrences in the Grand River extend to the Byng Conservation Area owned by the Grand River Conservation Authority. Lilliput found in the Welland River are within the Chippewa Creek Conservation Area which is owned by the Niagara Peninsula Conservation Authority.

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COLLECTIONS EXAMINED

The following description of the creation of the Lower Great Lakes Unionid Database was modified from COSEWIC (2006).

Fisheries and Oceans Canada's Great Lakes Laboratory for Fisheries and Aquatic Sciences in Burlington, Ontario is home to a computerized, GIS-linked database known as the Lower Great Lakes Unionid Database. It was created in 1996 and contains all of the available information on historical and current records of freshwater mussel species found throughout the lower Great Lakes drainage. Original data sources included the primary literature, natural history museums, federal, provincial, and municipal government agencies (and some American agencies), conservation authorities, Remedial Action Plans for the Great Lakes Areas of Concern, university theses and environmental consulting firms. Mussel collections held by six natural history museums in the Great Lakes region (Canadian Museum of Nature, Ohio State University Museum of Zoology, Royal Ontario Museum, University of Michigan Museum of Zoology, Rochester Museum and Science Center, and Buffalo Museum of Science) were the primary sources of information, accounting for over two-thirds of the initial data acquired. Janice Metcalfe-Smith (Biologist, Environment Canada) personally examined the collections held by the Royal Ontario Museum, University of Michigan Museum of Zoology and Buffalo Museum of Science, as well as smaller collections held by the Ontario Ministry of Natural Resources. The database continues to be updated with new field data and now contains over 8500 records of unionids from Lake Ontario, Lake Erie, Lake St. Clair and their drainage basins as well as several of the major tributaries to lower Lake Huron. The majority of records in the database are now from recent (post-1990) field collections made by Fisheries and Oceans Canada, Environment Canada, provincial agencies, universities and conservation authorities. This database is the source for all information on Canadian populations of the Lilliput discussed in this report. The status report writers have personally verified live specimens from all populations described in this report.