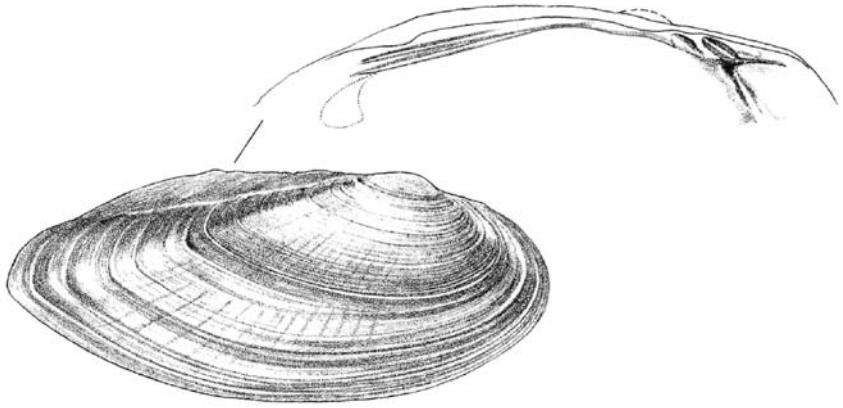
COSEWIC
Assessment and Status Report

on the

Eastern Pondmussel
Ligumia nasuta

in Canada



ENDANGERED
2007

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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Production note:

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Eastern Pondmussel — Line drawing reproduced with permission from Burch (1975).

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COSEWIC
Assessment Summary

Assessment Summary – April 2007

Common name
Eastern Pondmussel

Scientific name
Ligumia nasuta

Status
Endangered

Reason for designation
This was one of the most common species of freshwater mussel in the lower Great Lakes prior to the invasion of the zebra mussel (*Dreissena polymorpha*) in the late 1980s. Zebra mussels attach to the shells of native freshwater mussels in the hundreds or even thousands, causing the native mussels to suffocate or die from lack of food. Over 90% of historical records for the species are in waters that are now infested with zebra mussels and therefore uninhabitable. The species has declined dramatically and now occurs as two small, widely separated populations, one in the delta area of Lake St. Clair and one in a tributary of the upper St. Lawrence River. There is evidence that declines may be continuing at one location. Although zebra mussels appear to be declining in some areas, their impacts on this species may be irreversible if insufficient breeding adults have survived. Climate change is likely to cause a drop in water levels in the delta and further reduce the amount of habitat available to the mussel. Recent surveys in Lake St. Clair, which were conducted as a collaborative effort between Environment Canada and the Walpole Island First Nation, resulted in the identification of a significant refuge for this species within First Nation territory. The refuge is being managed by the First Nation for the protection of this and other aquatic Species at Risk with which it co-occurs.

Occurrence
Ontario

Status history
Designated Endangered in April of 2007. Assessment based on a new status report.

COSEWIC
Executive Summary

Eastern Pondmussel
Ligumia nasuta

Species information

The Eastern Pondmussel, *Ligumia nasuta* (Say, 1817), is a medium-sized freshwater mussel with an average length of about 70 mm. It has a compressed, elongate shell with a distinctive, bluntly pointed posterior end. The outside of the shell varies in colour from yellowish- or greenish-black in juveniles to dark brown or black in adults. Narrow green rays, concentrated at the posterior end of the shell, are often visible in juveniles and light-coloured adults. The nacre is usually silvery-white or bluish-white in specimens from the Great Lakes basin.

Distribution

The range of the Eastern Pondmussel is restricted to eastern North America where it extends from the lower Great Lakes east through New York to New Hampshire and south, in coastal rivers, to South Carolina. In Canada, *Ligumia nasuta* is known only from the Great Lakes region of Ontario where it historically occurred in Lakes St. Clair, Erie and Ontario, their connecting channels, and the lower reaches of some tributaries. The Eastern Pondmussel appears to have been lost from nearly all of its former range in Canada, but still occurs in the delta area of Lake St. Clair. Another population was recently discovered in Lyn Creek, a small tributary of the upper St. Lawrence River near the outlet of Lake Ontario.

Habitat

The Eastern Pondmussel occurs in sheltered areas of lakes, in slack-water areas of rivers and in canals, where it prefers substrates of fine sand and mud at depths ranging from 0.3 to 4.5 m. In Lake St. Clair, it is currently found on substrates composed of over 95% sand at the transition zone between the emergent wetlands and the open waters of the lake.

Biology

The Eastern Pondmussel has separate sexes, but males and females differ only slightly in shell shape and are often difficult to tell apart. The glochidia (larvae) of

Ligumia nasuta, like those of most other freshwater mussels, are obligate parasites of fishes. *Ligumia nasuta* is a long-term brooder that spawns in late summer, broods its glochidia over the winter and releases them in the spring. Fish hosts for the Eastern Pondmussel are unknown, but the occurrence of this mussel in coastal rivers along the Atlantic seaboard suggests that at least one of the hosts is tolerant of brackish water. Adult *L. nasuta* feed on bacteria, algae and other organic particles that are filtered from the water column. Juveniles live completely buried in the substrate and feed on similar food items obtained directly from the substrate or interstitial water.

Population sizes and trends

The Eastern Pondmussel was one of the most common species of freshwater mussel in the lower Great Lakes, numbering in the billions, prior to the invasion of the zebra mussel (*Dreissena polymorpha*) in the late 1980s. It has likely been extirpated from nearly all previously inhabited areas in Canada due to the impacts of zebra mussels. A remnant population of *Ligumia nasuta*, with an estimated size of 22,000 – 44,000 individuals, currently occupies shallow, nearshore areas of the Lake St. Clair delta within the territory of the Walpole Island First Nation. A second population of unknown size was discovered in Lyn Creek, a tributary of the upper St. Lawrence River, in 2006.

Limiting factors and threats

Zebra mussels constitute the most significant threat to the continued existence of the Eastern Pondmussel in Canada. More than 90% of historical records for *Ligumia nasuta* are from areas now infested with these aquatic invasive organisms. According to several climate change models, climate warming is likely to cause a drop in water levels in the lower Great Lakes which in turn could cause the shallow St. Clair delta to dry up and further reduce the amount of habitat available to native mussel communities.

Special significance of the species

The Eastern Pondmussel was a significant component of the Great Lakes mussel fauna historically, being the fourth most common species in the lower Great Lakes and connecting channels prior to 1990. It is reasonable to assume that this species contributed significantly to the function of freshwater mussel communities in the Great Lakes ecosystem up to that time.

Existing protection

Ligumia nasuta is ranked G4G5 globally, N4N5 in the United States and N2N3 in Canada. It is listed as Lower Risk-Near Threatened in North America on the IUCN Red List of Threatened Species. It has been designated as Endangered in Ohio and Delaware, Threatened in New Jersey and North Carolina and Special Concern in Massachusetts and Connecticut. The federal *Fisheries Act* protects freshwater mussels and their habitats in Canada because fishes are broadly defined under the Act to

include shellfishes. The collection of live mussels in Ontario is considered “fishing” and falls under the Ontario Fishery Regulations made under the *Fisheries Act*. The population of the Eastern Pondmussel that inhabits the Canadian portion of the Lake St. Clair delta is somewhat protected from human disturbance as user permits are required to access Walpole Island First Nation territory.

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

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.

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

COSEWIC Status Report

on the

Eastern Pondmussel

Ligumia nasuta

in Canada

2007

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SPECIES INFORMATION

Name and classification

Scientific name: *Ligumia nasuta* (Say, 1817)
English common name: Eastern Pondmussel
French common name: Ligumie pointue

The recognized authority for the classification of aquatic molluscs in the United States and Canada is Turgeon *et al*. (1998). The current accepted classification of this species is as follows:

Phylum:	Mollusca
Class:	Bivalvia
Subclass:	Paleoheterodonta
Order:	Unionoida
Superfamily:	Unionoidea
Family:	Unionidae
Subfamily:	Lampsilinae
Genus:	*Ligumia*
Species:	*Ligumia nasuta*

Morphological description

The following description of *Ligumia nasuta* was adapted from Clarke (1981), Strayer and Jirka (1997), Nedeau *et al*. (2000) and Bogan (2002). The Eastern Pondmussel (Figure 1) is a medium-sized to large mussel with a long-elliptical, laterally compressed shell that is thin but strong. The posterior ridge is well developed, distinct, and angled near the beak, but becoming rounded posteriorly. The anterior end is rounded; the ventral margin is broadly curved; and the posterior end is rounded and drawn out into a blunt point near the midline of the shell. Females can be distinguished from males by a swelling along the posterior ventral margin. The beaks are low, barely raised above the hinge line and located in the anterior quarter of the shell. Beak sculpture consists of 5-8 fine double-looped bars. Lateral and pseudocardinal teeth are well-developed and sharp, but delicate. The surface of the shell (periostracum) is rough with concentric wrinkles and clearly visible lines of growth. The colour of the periostracum varies from yellowish- or greenish-black in juveniles to dark brown or black in adults. Narrow green rays, concentrated posteriorly, are often visible in juveniles and light-coloured adults. The nacre is usually silvery-white or bluish-white in specimens from the Great Lakes basin, and pinkish or purple in specimens from the Atlantic drainage.

Ligumia nasuta reaches a maximum length of approximately 100 mm in Canada. The average length of an adult shell is about 70 mm based on over 200 live specimens measured by the authors and their associates between 1997 and 2004. The Eastern Pondmussel can be distinguished from all other species of freshwater mussel in Canada by its elongate shell with distinctive, bluntly-pointed posterior end, rough periostracum and delicate hinge teeth.

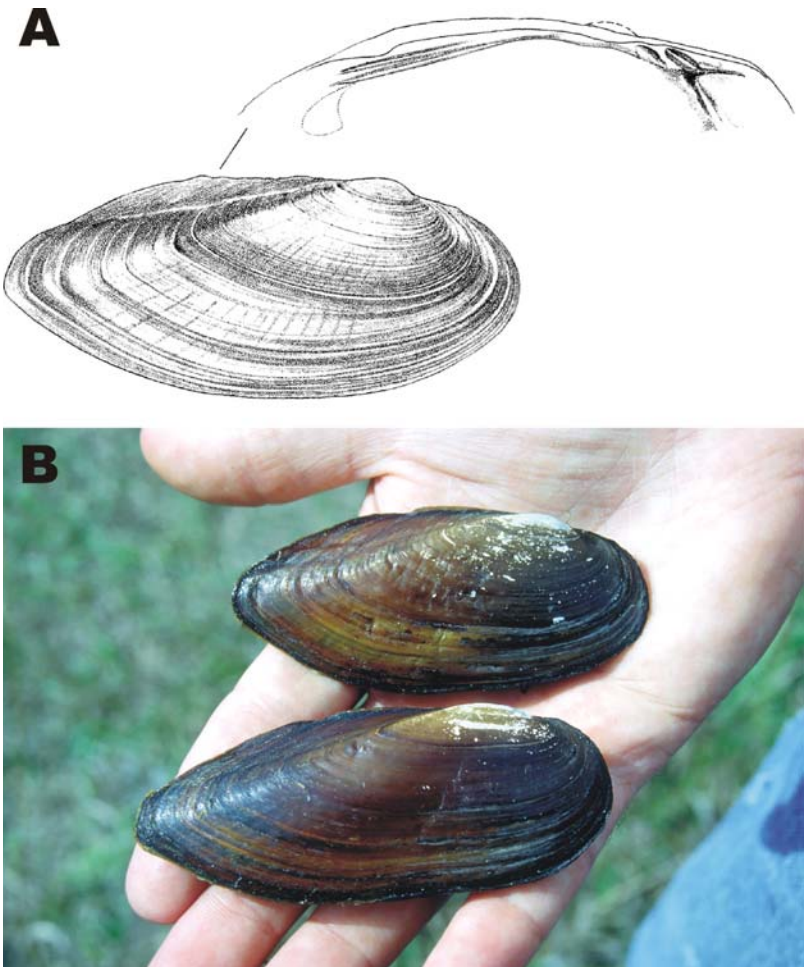

Figure 1. (A) Line drawing of the external features of the shell and internal structure of the left valve of *Ligumia nasuta*. Reproduced with permission from Burch (1975). (B) Photograph of live specimens collected from East Lake in Prince Edward County, Ontario in 1996. (Photo credit: S. Staton, NWRI)

Genetic description

There are no data available on the genetic structure of the Canadian population of *Ligumia nasuta.* The Eastern Pondmussel has been lost from over 90% of its former range in Canada (see Canadian range); thus, it is likely that genetic diversity has been greatly reduced. The remaining two populations of *L. nasuta* in Canada are separated by more than 800 km of zebra mussel-infested waters of the lower Great Lakes and their connecting channels. There would be no gene flow between these populations.

Ligumia nasuta was included in a recent study investigating the evolution of active host-attraction strategies in freshwater mussels. Zanatta and Murphy (2006) used mitochondrial DNA sequence data (COI, 16S and ND1) to create a molecular phylogeny for several species of unionids (freshwater mussels belonging to the Family Unionidae).

Their analyses revealed that *L. nasuta* was most closely related to members of *Potamilus* and *Leptodea* and not closely related to *Ligumia recta*. As *L. recta* is the type species of the *Ligumia*, Zanatta and Murphy (2006) concluded that *L. nasuta* should be re-designated into an existing or newly described genus.

DISTRIBUTION

Global range

The Eastern Pondmussel is restricted to eastern North America, having been recorded from 14 states and the Province of Ontario. It ranges from the lower Great Lakes east through New York to New Hampshire and south, in coastal rivers, to South Carolina. In the United States, *Ligumia nasuta* occurs in Michigan, Ohio, Pennsylvania, New York, New Hampshire, Massachusetts, Connecticut, New Jersey, Delaware, Maryland, District of Columbia, Virginia, North Carolina and South Carolina (Figure 2). NatureServe (2005) also lists the species as occurring in Vermont and Rhode Island, but this is believed to be erroneous (Nedeau pers. comm. 2005). *Ligumia nasuta* originated on the Atlantic coast of North America and reached the lower Great Lakes following the last period of glaciation (Nedeau *et al*. 2000). The post-glacial dispersal route for this species is believed to be unique among Great Lakes unionids. Most species reinvaded the Great Lakes from the Mississippian Refugium to the south, whereas several others originated in the Atlantic Refugium and entered the region from the northeast via the Champlain Sea/St. Lawrence River. Although *L. nasuta* is an Atlantic Slope species, it does not appear to have followed an east to west migration route. Stansbery (1961) proposed instead that the Eastern Pondmussel entered the Great Lakes via an eastward-flowing outlet of Lake Erie meltwater that would have provided access to host fishes from the Mohawk or Hudson Rivers to the east. Glacial geology has established the existence of this Mohawk-Hudson or Susquehanna Outlet (Hough (1950) cited in Stansbery 1961).

The current distribution of the Eastern Pondmussel is similar to its historical distribution, but the species is declining in many places, particularly the Great Lakes (NatureServe 2005). Populations of freshwater mussels in the Canadian and U.S. waters of the lower Great Lakes and connecting channels have been nearly extirpated due to the impacts of zebra mussels (*Dreissena polymorpha*). Zebra mussels attach to the shells of native freshwater mussels in the hundreds or even thousands, causing the native mussels to suffocate or die from lack of food. Small, isolated populations of native mussels can still be found in some nearshore areas where densities of zebra mussels have remained low; such locations have been termed “refuge sites.” There are four known refuge sites for unionids in U.S. waters along the south shore of Lake Erie. *Ligumia nasuta* was not among the species found alive in the western basin refuge in 1993 (Schloesser *et al*. 1997), in Metzger Marsh in 1996 (Nichols and Amberg 1999), or in Crane Creek Marsh in 2001 (Bowers and de Szalay 2004); however, it was one of the most abundant of nine species occupying the Thomson Bay refuge near Erie, PA in 2000 (Masteller pers. comm. 2002).

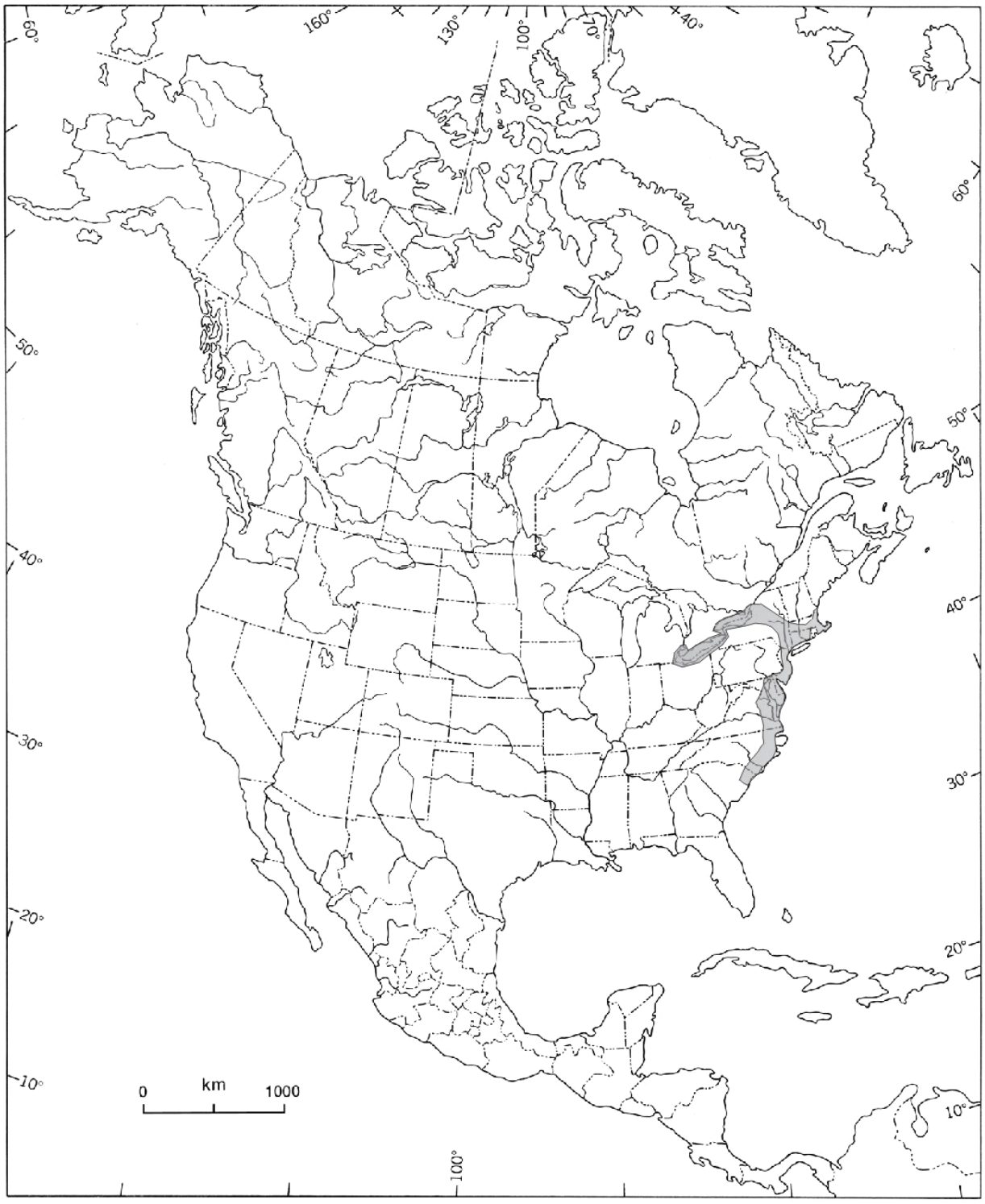

Figure 2. North American distribution (shaded area) of the Eastern Pondmussel, *Ligumia nasuta*, based on records from the Lower Great Lakes Unionid Database and data obtained from www.natureserve.org and jurisdictional authorities.

Canadian range

In Canada, *Ligumia nasuta* is known only from the lower Great Lakes region of southern Ontario. There are no records of this mussel from Quebec (Gagnon pers. comm. 2005). The National Water Research Institute's Lower Great Lakes Unionid Database was used to identify occurrence records for *L. nasuta* in Ontario. For a detailed description of the database and its data sources, see **COLLECTIONS EXAMINED**. In the Lake Ontario drainage basin, *L. nasuta* was historically collected from the Bay of Quinte and its watershed including the Moira River, Consecon Lake and East Lake, and at scattered locations along the north shore of Lake Ontario to Hamilton Harbour. In the Lake Erie drainage, it was found in the Niagara and Welland Rivers, at various locations along the north shore of the eastern basin including the mouth of the Grand River, at Long Point and Rondeau Bay in the central basin, and at numerous locations in the shallow western basin, including Point Pelee, Pelee Island, Middle Sister Island and East Sister Island. It also occurred in the Detroit River and Lake St. Clair. The earliest well-documented records of this species in Canada were collected in the 1890s by J. Macoun, who found specimens in the Detroit River near Windsor and in Lake Erie near Rondeau Provincial Park (specimens held by the Canadian Museum of Nature). Figure 3 shows the historical distribution of the Eastern Pondmussel in Ontario based on 149 records collected between 1860 and 1996. Only about 15% of these records are for known live occurrences; the rest are for shells that, in many cases, could have washed up on the shore from deeper water. The current distribution of the species is shown in Figure 4 and is based on 64 records (live animals and shells) collected between 1997 and 2006. Live specimens were most recently collected from Lyn Creek in the upper St. Lawrence River drainage in August, 2006. It should be noted that Figure 4 shows the locations of all 531 sites that were surveyed for unionids between 1997 and 2006. Although many of these sites are outside the historical range of *L. nasuta*, it is useful to show them because they give an indication of recent survey effort throughout the region. Over 90% of the sites were surveyed using intensive semi-quantitative (timed search) or quantitative sampling methods.

Lake St. Clair and the Detroit River have been intensively surveyed for unionids in recent years. Zanatta *et al*. (2002) surveyed 95 sites in nearshore areas around Lake St. Clair between 1999 and 2001 and found live mussels at 33 sites, most of which were in the Canadian waters of the St. Clair delta. The Eastern Pondmussel was found at 16 (48%) of these sites. Metcalfe-Smith *et al*. (2004, 2005b) surveyed 15 sites in the Canadian waters of the delta in 2003 and 2005 and found live Eastern Pondmussels at 6 (40%) of these sites, although 59 of the 82 live animals were found in a single sheltered bay approximately 0.37 km^2 in size. Five live animals were also collected from 4 of 17 sites surveyed in the U.S. waters of the delta. *Ligumia nasuta* was collected from the offshore waters of Lake St. Clair prior to the dreissenid invasion (1986-1990), but by 1994 it had been eliminated (Nalepa *et al*. 1996). Similarly, *L. nasuta* was found alive in the Detroit River between 1987 and 1992 (Schloesser *et al*. 1998), but no specimens were found during follow-up surveys in 1997-98 (Schloesser *et al*. 2006).

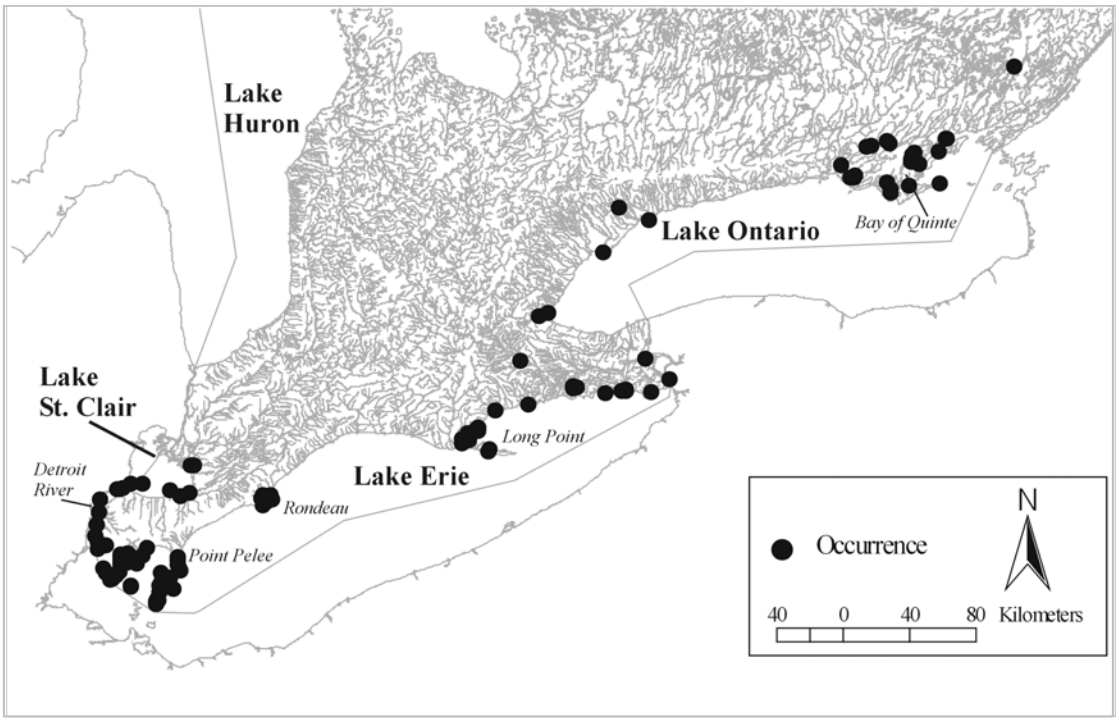

Figure 3. Historical distribution (1860-1996) of *Ligumia nasuta* in Ontario, based on records from the Lower Great Lakes Unionid Database. Only 15% of the records are for known live occurrences; the rest are for shells (see text).

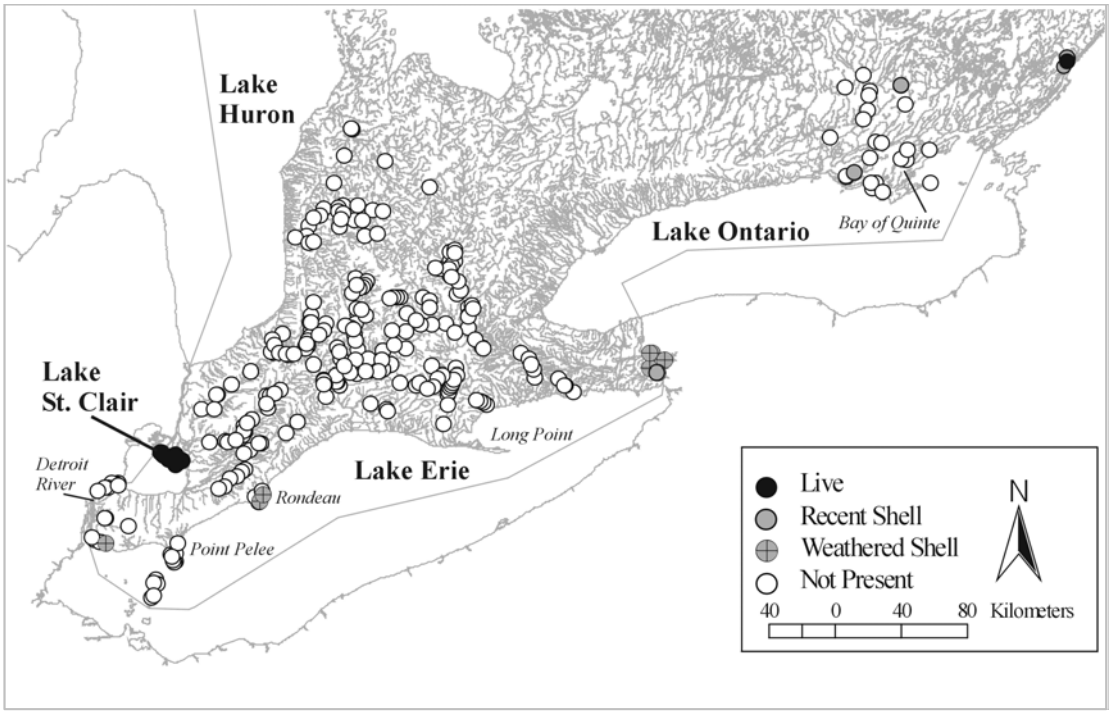

Figure 4. Current distribution (1997-2006) of *Ligumia nasuta* in Ontario, based on records from the Lower Great Lakes Unionid Database. The locations of all 531 sites surveyed for unionids during this time period are shown.

Many of the historical sites for *Ligumia nasuta* in Lake Erie have been revisited in recent years and no live specimens were found. Metcalfe-Smith *et al*. (2000b) surveyed 94 sites throughout the Grand River watershed in 1995 and 1997-98 and found a single weathered valve of *L. nasuta* in MacKenzie Creek, a tributary to the lower reach of the river. Zanatta and Woolnough surveyed 6 sites in Rondeau Bay in 2001 while working for J.L. Metcalfe-Smith and found many weathered shells and valves of *L. nasuta* but no live specimens. The New York Power Authority commissioned Riveredge Associates to survey 15 sites around Grand Island in the Niagara River for rare, threatened and endangered mussels in 2001 and 2002. Only 46 mussels of six species were found alive at two sites in U.S. waters (New York Power Authority 2003). Thirty-one species are known from the river historically. The Eastern Pondmussel was not found alive during these surveys, but shells were observed at many of the sites. The authors of the present report surveyed 17 historical sites in the western basin of Lake Erie, including sites around Point Pelee and Pelee Island, in July 2005 and did not find any live unionids. Four weathered valves of *L. nasuta* were found near the historical site of Holiday Beach Park in Essex County. Researchers at the University of Waterloo who are studying the effects of dreissenids on food webs and nutrient cycling in Lake Erie conducted benthic invertebrate surveys at about 60 sites along the north shore of the eastern basin of the lake in 2001 and 2002 using either a Ponar dredge or airlift sampler. The project was expanded to include the central and western basins in 2004, and 220 sites ranging in depth from 2 to 63 m were sampled. No live unionids were found in any of the samples (Barton pers. comm. 2005). Historical sites around Middle Sister Island and East Sister Island in the western basin have not been surveyed recently, but 33 sites in U.S. waters around the nearby Bass Islands were surveyed in 1998 and no live unionids were found (Ecological Specialists 1999).

The Eastern Pondmussel has not been reported alive in the Lake Ontario drainage since 1996, when it was collected from two inland lakes (Consecon Lake and East Lake) in Prince Edward County (Metcalfe-Smith *et al*. unpublished data). No zebra mussels were present in the lakes at the time. *Ligumia nasuta* was not present at any of seven sites surveyed in the Moira River, Moira Lake, Skootamatta River and Salmon River in the same year. Three fresh shells were collected from Beaver Lake near Erinsville, Ontario, in the Salmon River watershed in 1998 (Schueler pers. comm. 2005). When the site was revisited in 2006, the lake was found to be infested with zebra mussels (Schueler pers. comm. 2006). The authors of the present report surveyed 15 sites in Consecon Lake, East Lake, West Lake and the Bay of Quinte in 2005. All sites were heavily infested with zebra mussels and not a single live unionid of any species was found. Based on conversations with the owner of a resort on Consecon Lake and the president of the Consecon Lake Cottagers' Association, zebra mussels began to appear in the lake around 1999 and native mussels, which were once very abundant, have now disappeared. In 2006, several live specimens of *L. nasuta* were found in Lyn Creek, a tributary of Jones Creek which flows into the upper St. Lawrence River near Brockville, Ontario (Schueler pers. comm. 2006). The Lyn Creek record represents the easternmost occurrence of the Eastern Pondmussel in Canada.

The available data suggest that *Ligumia nasuta* has likely been lost from ~ 93% of its former range (in terms of extent of occurrence) in Canada due to the impacts of zebra mussels. The current extent of occurrence (EO) is approximately 3,400 km^2 as compared with 50,500 km^2 historically. The current area of occupancy (AO) is approximately 45 km^2, which was calculated using scales based on the current IUCN guidelines (Standards and Petitions Working Group 2006) as recommended by COSEWIC's Criteria Working Group (Boles pers. comm. 2006). A 2×2 km grid (the standard grid size) was applied for estimating the AO of the Lake St. Clair population, but a 1×1 km grid was applied for estimating the AO of the Lyn Creek population because the Criteria Working Group recognizes that a smaller grid might be more appropriate for linear habitats such as rivers. In both cases, only live occurrences of the species were considered in the calculation of AO.

HABITAT

Habitat requirements

The Eastern Pondmussel occurs in sheltered areas of lakes, in slack-water areas of rivers and in canals, where it prefers substrates of fine sand and mud at depths ranging from 0.3 to 4.5 m (Clarke 1981; Strayer and Jirka 1997; Bogan 2002). It is found on substrates composed of over 95% sand in the delta area of Lake St. Clair (Metcalfe-Smith *et al*. 2004). In rivers, the species is restricted to the lowermost reaches (Strayer 1983 and see Figure 3). van der Schalie (1938) reported the presence of *Ligumia nasuta* in the mouth of the Huron River as "evidently a Lake Erie intrusion."

Habitat trends

The invasion of the Great Lakes by dreissenid mussels began in 1986 (Hebert *et al*. 1989) and resulted in the near extirpation of native unionids from Lake Erie, Lake St. Clair and the Detroit and Niagara Rivers by the mid-1990s (Schloesser and Nalepa 1994; Nalepa *et al*. 1996; Schloesser *et al*. 2006; Schneider pers. comm. 2002). Only isolated communities with reduced species richness and low abundance still survive in several bays and marshes along the U.S. shore of Lake Erie and in the delta area of Lake St. Clair where zebra mussel densities are low. As 93% of historical records for the Eastern Pondmussel in Canada are from areas now infested with dreissenid mussels, there has been a near total loss of habitat for this species. There is, however, some reason for optimism. Zebra mussel densities declined by 50% between 1994 and 1997 in Lake St. Clair (Nalepa *et al*. 2001) and by about 3-fold between 1992-94 and 1998 in the Detroit River (Schloesser *et al*. 2006). Hunter and Simons (2004) reported continuing declines in Lake St. Clair in 2001 and concluded that "If the present biomass levels are sustained or reduced further we would expect the impact of zebra mussels on the Lake St. Clair ecosystem to become considerably moderated."

Whether or not conditions in Lake St. Clair will improve enough to allow recolonization by unionids is unknown. Unionids and zebra mussels have coexisted in

Europe at sites where zebra mussels have been present for decades to millennia, but this may be due to their long shared evolutionary history (Strayer and Malcom 2007). Closer to home, Strayer and co-workers have been studying the interaction between zebra mussels and native bivalves in the Hudson River in eastern New York since zebra mussels first appeared in 1991. Population sizes of three unionids and one sphaeriid declined by 65-100% by 1999, but by 2005 all four species had stabilized or recovered and simple exponential decay models predict that these species may persist at population densities about an order of magnitude below their pre-invasion densities (Strayer and Malcom 2007). It should be noted that this is the only North American study to date that has documented recovery of native bivalves after an extended period of post-invasion decline, and it may not be applicable to Lake St. Clair because the impacts of zebra mussels in the Hudson River were more related to competition for food than to biofouling.

Habitat protection/ownership

To the best of our knowledge, there are only two populations of *Ligumia nasuta* left in Canada. One population is located in delta area of Lake St. Clair, mainly within the territory of the Walpole Island First Nation. These waters are primarily used for hunting and fishing by the Walpole community and are protected from urban development as well as certain recreational uses (e.g., jet skis are prohibited). Walpole Island contains over 12,000 ha of World Class Wetlands, one of the largest wetland complexes in the Great Lakes Basin (The Nature Conservancy 1995 cited in Bowles 2005), and freshwater mussels occupy the transition zone between these wetlands and the open waters of Lake St. Clair. A second population of *L. nasuta* was recently discovered in Lyn Creek, a tributary of the upper St. Lawrence River near Brockville, Ontario. Lands adjacent to Lyn Creek are mostly under private ownership. However, there are no bridges or settlements along the stretch of river where live animals and fresh shells were found in 2005-06 and the habitat is relatively undisturbed compared to other areas in eastern Ontario (BMNHC 2006).

BIOLOGY

Ligumia nasuta, like all freshwater mussels, is a sedentary animal that buries itself partially or completely in the substrates of rivers or lakes. Adult freshwater mussels are filter-feeders that obtain nourishment by siphoning particles of organic detritus, algae and bacteria from the water column and, as recently shown, sediments (Nichols *et al*. 2005). Juveniles of most species of freshwater mussels live completely buried in the substrate where they feed on similar foods obtained directly from the substrate or from interstitial water (Yeager *et al*. 1994; Gatenby *et al*. 1997). Aspects of the life history of *L. nasuta* summarized in the following sections were derived from a review of the available literature as well as the authors' own knowledge of the species.

Life cycle and reproduction

The life cycle of the Eastern Pondmussel is similar to that of all freshwater mussels and is described as follows (adapted from Clarke 1981, Kat 1984 and Watters 1999): during spawning, males release sperm into the water and females living downstream filter the sperm out of the water with their gills. Ova are fertilized in a specialized region of the female gills, called marsupia, where they are held until they reach a larval stage called the glochidium. The female mussel then releases the glochidia, which must attach to an appropriate vertebrate host, usually a fish. The glochidia become encysted on the host and are nourished by the host's body fluids until they metamorphose into juveniles. The juveniles then release themselves from the host and fall to the substrate to begin life as free-living mussels. The proportion of glochidia that survive to the juvenile stage is estimated to be as low as 0.000001%. Mussels overcome the extremely high mortality associated with this life cycle by producing large numbers of glochidia – often more than a million. Juvenile mussels are difficult to find because of their small size and because they quickly burrow into the sediment upon release. Juvenile mussels remain buried until they are sexually mature, at which point they move to the surface for the dispersal/intake of gametes (Watters *et al*. 2001).

Ligumia nasuta is dioecious and there are subtle differences in the external shell features of males and females (see Morphological description). Eastern Pondmussels are bradytictic (long-term brooders); that is, fertilization occurs in late summer and glochidia are released the following spring (Ortmann (1919) cited in Bogan 2002). Glochidia are subovate with an undulate hinge line and measure approximately 250 µm in length and 290 µm in height (Clarke 1981). According to Hoggarth (1993), glochidia with valve heights greater than valve lengths have a wide valve gape and large area of sweep and are most likely gill parasites. The age at maturity is unknown for this species, but the average age of maturity for unionids is 6-12 years (McMahon 1991).

Glochidial hosts for the Eastern Pondmussel are unknown, but the occurrence of this mussel in coastal rivers along the Atlantic seaboard of North America suggests that at least one of the hosts is tolerant of brackish water. Hosts for the other two species of *Ligumia*, i.e., *Ligumia subrostrata* (Pondmussel) and *Ligumia recta* (Black Sandshell) have been identified using evidence from natural and/or laboratory infestations (OSUM 2005). The Pondmussel uses several centrarchid species as hosts and the more widely distributed Black Sandshell uses a variety of centrarchids, percids and cyprinids as well as the American eel (*Anguilla rostrata*) and the banded killifish (*Fundulus diaphanus*). Virtually all hosts for these two species are established in the Great Lakes (Cudmore-Vokey and Crossman 2000) and could theoretically be used by the Eastern Pondmussel in Ontario. Stansbery (1961) suggests the yellow perch (*Perca flavescens*) as a possible host for the Eastern Pondmussel because "the distribution of *L. nasuta* along the Atlantic coast lies entirely within and all but duplicates that of *P. flavescens*." He goes on to say that the distribution of the yellow perch in Ohio in the early 1800s indicates that it used the same post-glacial dispersal route as the Eastern Pondmussel, which provides further circumstantial evidence of a parasite-host relationship between these two species.

Female Eastern Pondmussels use a visual display to attract their hosts. The display behaviour was described by Corey and Strayer (1999) as follows: “While displaying, the female positioned itself upright in the substrate, with valves gaped and mantle exposed. White papillae rippled up and down the mantle margin in an uninterrupted, synchronized rippling, the appearance of which resembled a swimming amphipod. A complete down and back motion along the mantle margin took an average of 0.8 seconds.” This display was observed to strongly attract fish in both natural and laboratory settings (Corey *et al*. 2006). When a fish struck at the lure, the female mussel would expel a stream of glochidia in close proximity to the fish, thus facilitating the attachment of glochidia to the fish’s gills.

Predation and parasitism

River otter (*Lontra canadensis*), mink (*Mustela vison*) and muskrat (*Ondatra zibethicus*) have been identified as feeding “more or less heavily” on freshwater mussels (Fuller 1974). The impacts of these predators on mussels in Ontario waters have not been investigated and the extent to which they limit the distribution of *Ligumia nasuta* in Canada is not known (see **LIMITING FACTORS AND THREATS**). Freshwater mussels are often parasitized by helminths (Order Digenea) and mites (Hydrachnidia), which may have detrimental effects on the infected mussels and the overall population (Esch and Fernandez 1993; Di Sabatino *et al*. 2000). The impacts of parasitism on *L. nasuta* have not been investigated.

Physiology

Freshwater mussels are sensitive indicators of environmental conditions in rivers and lakes because many species require optimal water and habitat quality for survival. The specific environmental requirements of *Ligumia nasuta* are unknown.

Dispersal/migration

Freshwater mussels are basically sedentary as adults, with movement limited to a few metres of the lake or river bottom. The only time that significant dispersal can take place is during the parasitic phase. Infected host fishes can transport larval unionids into new habitats and replenish depleted populations with new individuals. Dispersal is particularly important for genetic exchange between populations.

Interspecific interactions

The larvae of *Ligumia nasuta* are obligate parasites on fishes. Specific fish hosts for this species have not yet been identified.

Adaptability

Freshwater mussels are particularly sensitive to environmental perturbations because of their complex life cycle. Not only are they threatened by disturbances that

impact them directly, but also by those that affect their host fish populations. Recent successes in the captive-rearing of several species of freshwater mussels have been reported (e.g., Hanlon and Neves 2000); however, the authors are not aware of any programs involving the Eastern Pondmussel. The release of artificially reared juvenile mussels of other species is underway in the United States, but the long-term outcome of such releases is still being evaluated.

POPULATION SIZES AND TRENDS

Search effort

Historical surveys

Approximately 85% of the historical records (1860-1996) for *Ligumia nasuta* in Canada are based on either museum specimens or occurrence data. For most of these records, there is little if any information on sampling method, search effort, numbers of sites visited where the species did *not* occur, or even if the animals were dead or alive when collected. Data on relative abundance or density of unionids are available for the remaining 15% of records from the western basin of Lake Erie (Nalepa *et al*. 1991; Schloesser and Nalepa 1994; Schloesser *et al*. 1997), the Detroit River (Schloesser *et al*. 1998), Lake St. Clair (Nalepa *et al*. 1996) and East Lake and Consecon Lake in Prince Edward County (Metcalfe-Smith *et al*. unpublished data). Sampling techniques and efforts for these surveys are described below.

Nalepa *et al*. (1991) reported data from unionid surveys conducted in soft substrates at 17 offshore sites (3.0 - 20.0 km from shore) in the western basin of Lake Erie in 1961, 1972 and 1982 using either a Peterson or Ponar grab (3 - 5 replicate grabs/site). Data from an additional 23 offshore sites surveyed in 1961 and 1982 and 40 offshore sites surveyed in 1930 (all of the above sites) were also discussed, as were data from another survey conducted in 1951-52 using a drag-dredge that was repeated in 1973-74. The 17 offshore sites were re-surveyed by Schloesser and Nalepa (1994) in 1991 after the zebra mussel invasion using a 46 × 26 cm epibenthic sled (one 5-minute tow per site) and 3 replicate 0.05 m^2 Ponar grabs. Schloesser *et al*. (1997) surveyed 15 nearshore sites (max. 1.5 km from shore) with firm substrates in the western basin in 1983 (pre-zebra mussels), 1991 and 1993 using a 30-minute SCUBA search within a 50 m diameter circle at each site. Schloesser *et al*. (1998) conducted surveys along the length of the Detroit River in 1982-83 (pre-zebra mussels, 13 sites), 1992 (17 sites) and 1994 (9 sites). Sampling effort was a 60-minute search of a 500 m^2 area by one SCUBA diver. If live unionids were found, an additional 15 to 30-minute search was conducted in an area adjacent to the site. Nalepa *et al*. (1996) surveyed 29 sites in the offshore waters of Lake St. Clair in 1986 (pre-zebra mussels), 1990, 1992 and 1994; ten 0.5 m^2 quadrats were sampled at each site. Gillis and Mackie (1994) conducted intensive surveys at two of these sites in 1990-92. They sampled 20-1m^2 quadrats at depths of 1, 2, 3 and 4 m once a month between June and September at Puce, ON in 1990 and 1991 and at Grosse Pointe, MI in 1991. They also sampled both sites in July 1992. Metcalfe-Smith *et al*. (unpublished data) conducted 4.5 person-hour (p-h) timed-search

surveys using waders, polarized sunglasses and underwater viewers at 7 sites in the Moira River, Moira Lake, Skootamatta River and Salmon River, one site in East Lake and one site in Consecon Lake in 1996. The sampling technique is described in detail in Metcalfe-Smith *et al*. (2000a).

Recent surveys

In contrast to the historical data, almost all of the recent records (1997-2005) for *Ligumia nasuta* in Canada include information on sampling method and sampling effort, data on both presence and absence, and descriptions of the condition of the specimens collected (i.e., live animals, fresh shells or weathered shells). Surveys conducted within the range of the species during this time period used either semi-quantitative (timed-search) or quantitative sampling methods, thus providing data on relative abundance or density, respectively. Sampling techniques and efforts for these surveys are described below.

Lake St. Clair:

Zanatta *et al*. (2002) surveyed 95 sites in various nearshore areas around Lake St. Clair between 1998 and 2001. In 1998, 3 sites were surveyed at depths of 1, 2.5 and 4 m along 10 transects in the vicinity of Puce and Belle River, ON. Five 1 m^2 quadrats and 20 Ekman grabs were taken at each of the 30 sites. Ten of these sites (depths of 2.5 and 4 m along 5 transects) were re-surveyed in 1999 along with 12 new sites (depths of <1, 2-3 and 4 m along 4 transects) near Grosse Pointe, MI. Another 48 sites at depths of <1 to >3 m along the eastern shore of the lake and in the Canadian waters of the delta were also surveyed in 1999. Searches at water depths greater than 2 m were conducted by two SCUBA divers for a total effort of 0.5 p-h whereas searches at depths less than 2 m were conducted by three people using mask and snorkel for a total of 0.75 p-h. At sites where live mussels were found (all were ≤ 1.5 m deep), snorkel searches were extended to a total of 1.5 p-h. Ten of the sites where unionids were most abundant were re-surveyed in 2000 using 1.5 p-h timed-searches. Four of the best sites from 2000 and 5 new sites, including 4 in U.S. waters, were surveyed quantitatively in 2001 using the following technique: each of two snorkelers searched the area until a live unionid was found, and then surveyed a 65 m^2 circular area around the animal and collected any other live unionids encountered. Ten such “circle plots” (total area = 650 m^2) were searched at 7 of the 9 sites, 5 were searched at one site, and 21 were searched at the most productive site.

Metcalfe-Smith *et al*. (2004) surveyed 18 sites throughout the St. Clair delta in 2003, including 9 sites in Canadian waters and 9 sites in U.S. waters using the circle plot technique described above, except that three divers were used and each diver searched 10 plots for a total search area of 1950 m^2/site (fewer plots were searched at a few sites). Nine of these sites had been surveyed in 2001. Timed-search surveys were also conducted at 10 sites in 2003, including 8 sites in U.S. waters and 2 sites in Canadian waters. Sampling effort was ~ 1.0 p-h/site (Metcalfe-Smith *et al*. 2004). Four additional sites in Canadian waters were surveyed in 2005 using 3-4 p-h search effort/site (Metcalfe-Smith *et al*. 2005b).

In 2004, Metcalfe-Smith *et al*. (2005a) conducted intensive quantitative surveys at two sites in the Canadian waters of the delta that were found to support the richest and most abundant unionid communities in the area. The circle plot technique was used to survey 29 points along 10 transects in Pocket Bay (covering ~ 1% of the 170,000 m^2 area of the bay), and 138 points along 16 transects in Bass Bay (covering ~ 2% of the 370,000 m^2 area).

In all of the surveys described above, all live native mussels found were identified, counted, measured, sexed (if sexually dimorphic) and returned to the lake bottom.

Detroit River:

In 1998, Schloesser *et al*. (2006) re-surveyed four sites in the upper Detroit River where live unionids were observed in 1992 and 1994. They searched a 500 m^2 area for 60 minutes and a second 500 m^2 area for 25 minutes at each site. Excavated quadrat searches consisting of 10-1 m^2 quadrats within a 10 m × 10 m grid were also conducted at one site in 1998 for comparison with pre-zebra mussel data available from 1987, and at a second site in 1998 only. Line-transect searches were conducted at one site in 1997 for comparison with data from 1990. A total of 480 m^2 along four 120-m transects were sampled in 1997 and 180 m^2 along three 60-m transects were sampled in 1990.

Lake Erie:

Metcalfe-Smith *et al*. (2000b) surveyed two sites near the mouth of the Grand River in 1997 using 4.5 p-h timed searches. Zanatta and Woolnough (unpublished data) surveyed 6 sites in Rondeau Bay in 2001 using mask and snorkel for ~ 2 p-h/site. The authors of the present report surveyed 17 historical sites in the western basin of Lake Erie, including sites around Point Pelee and Pelee Island, in 2005. Snorkel searches (1.5 p-h) were conducted at depths of < 3 m at 12 sites. At 5 sites where the water was too rough or turbid for snorkeling, the beach was searched for shells instead.

Lake Ontario/Eastern Ontario:

The authors of the present report surveyed 15 historical sites in East Lake, Consecon Lake, the Bay of Quinte and a few other nearby locations in 2005 using 0.75 to 2 p-h snorkel searches at 5 sites, <0.5 to 1.5 p-h visual searches while wading at 8 sites and a beach search for shells at the remaining sites. Frederick W. Schueler of the Bishops Mills Natural History Centre in Bishops Mills, Ontario, surveyed 2 sites in Lyn Creek in 2006 and one site in Golden Creek, a tributary of Lyn Creek, in 2005. Search effort ranged from 1 to 2.8 p-h/site and searches were tactile, as water clarity was greatly reduced when the soft, muddy substrate was disturbed by the searchers (Schueler pers. comm. 2006).

Abundance

To the best of our knowledge, the only locations in Canada where *Ligumia nasuta* still survives are the delta area of Lake St. Clair and Lyn Creek near Brockville, Ontario.

Lake St. Clair

Information on relative abundance is available from timed-search surveys conducted between 1999 and 2005. In 1999-2001, *Ligumia nasuta* was found alive at 48% of 33 sites (29 in Canadian waters) that supported unionid communities, accounting for 3% of the 2356 live unionids collected (Zanatta *et al*. 2002). Overall catch per unit effort (CPUE) at the 28 sites surveyed in 2000 (all in Canadian waters) was 43 unionids/p-h for all species and about 1.5/p-h for *L. nasuta*. Fourteen additional sites were surveyed in 2003 and 2005, including 6 sites in Canadian waters (Metcalfe-Smith *et al*. 2004, 2005b). The Eastern Pondmussel was found alive at 3 or 21% of these sites (2 in Canadian waters) where it accounted for 2% of the 367 live unionids collected. Overall CPUE for this species was 0.3/p-h. These data suggest that the Eastern Pondmussel is widely distributed throughout the delta but sparse in numbers.

Density estimates for the St. Clair delta population of *Ligumia nasuta* are available from quantitative surveys conducted between 2001 and 2004. Nine sites were surveyed in 2001 and *L. nasuta* was found at 2 sites, both in Canadian waters, at low densities of 0.001 and 0.002 individuals/m^2 (Zanatta *et al*. 2002). Eighteen sites were surveyed in 2003 – nine sites in Canadian waters and nine in U.S. waters (Metcalfe-Smith *et al*. 2004). *Ligumia nasuta* was found at 3 Canadian sites at a mean density of 0.014/m^2 and at 3 U.S. sites at a mean density of 0.0008/m^2. These results suggest that U.S. waters of the delta support a smaller population of *L. nasuta* than Canadian waters. Two of the sites in Canadian waters, Bass Bay and Pocket Bay, supported the richest and most abundant unionid communities in the delta. Intensive quantitative surveys were conducted at these sites in 2005 (Metcalfe-Smith *et al*. 2005b), allowing the calculation of precise estimates of density and abundance for the Eastern Pondmussel in these two bays (Table 1). The estimate of abundance for *L. nasuta* in the remainder of the delta was based on an occupied area of 17 km^2, which is the proportion of the 44 km^2 AO that represents actual mussel habitat (~ 27 km^2 of the AO is either on dry land or in water deeper than 1.5 m, which does not support mussels). The total size of the population of *L. nasuta* in the St. Clair delta is estimated to be 22,000 – 44,000 individuals (Table 1).

Table 1. Estimates of population size for the Eastern Pondmussel (*Ligumia nasuta*) in the Canadian waters of the delta area of Lake St. Clair, based on surveys conducted at 15 sites between 2003 and 2005.

	Mean density (±SE) (# individuals/m^2)	Occupied area (m^2)	Correction factor for occupied area	Estimated abundance (# individuals)
Pocket Bay	0.001 ± 0.0006	170,000	0.30[a]	20 – 82
Bass Bay	0.020 ± 0.003	370,000	1.00[b]	6,290 – 8,510
Remainder of the delta	0.005 ± 0.002	17,000,000	0.30[c]	15,300 – 35,700
Total				**21,610 – 44,292**

[a]correction factor of 0.30 applied, as *L. nasuta* was found in 3 of 10 transects surveyed.
[b]no correction factor applied, *as L. nasuta* was found in all 16 transects surveyed.
[c]correction factor of 0.30 applied, as *L. nasuta* was found at 4 of 13 sites surveyed.

Shell lengths of all live mussels collected during timed-search and quantitative surveys in the Canadian waters of the delta in 2003, 2004 and 2005 were recorded. A total of 235 live *Ligumia nasuta* were captured, 209 of which were in Bass Bay. The size frequency distribution of the Bass Bay specimens is shown in Figure 5. Lengths of these specimens ranged from 49-99 mm with good representation in several size classes, suggesting that regular recruitment is occurring. Very small specimens were not encountered, but this is probably because juveniles tend to burrow deeply in the substrate where they would not be detected using visual searches. Size class distributions could not be determined for other sites in the delta because too few specimens were collected. *Ligumia nasuta* exhibits subtle sexual dimorphism, with the female shell being more rounded or swollen along the posterior ventral margin than the male shell. In the authors' experience most specimens cannot be reliably sexed on the basis of shell shape; therefore, sex ratios have not been presented.

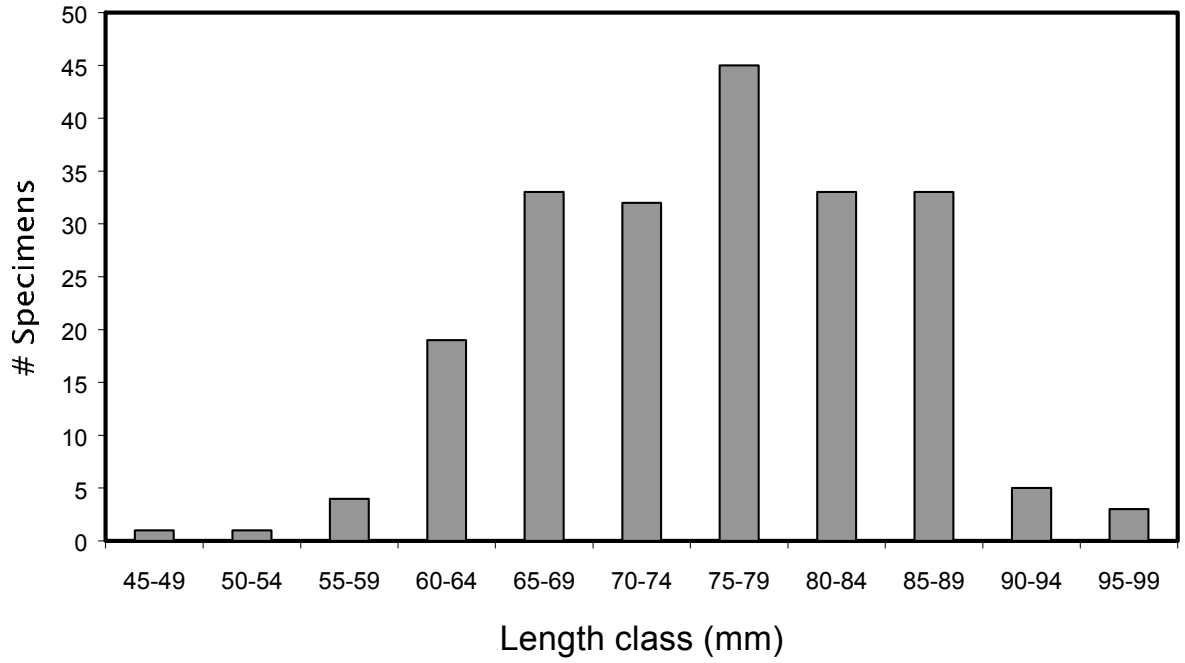

Figure 5. Size frequency distribution of 209 live *Ligumia nasuta* collected from Bass Bay in the Canadian waters of the Lake St. Clair delta in 2003 and 2004.

Lyn Creek

Several fresh shells of *Ligumia nasuta* were discovered in Golden Creek, a tributary to Lyn Creek near Lyn, Ontario in September 2005 (Schueler pers. comm. 2005). In 2006, 4 live specimens and several fresh shells were found in Lyn Creek at a site just downstream of the confluence with Golden Creek, and a single fresh valve was found in a muskrat midden at another site ~ 5 km downstream. Based on information provided by F.W. Schueler, the Eastern Pondmussel is thought to occupy a 6 km stretch of Lyn Creek from the town of Lyn to Younge Mills. Live specimens have only been found at one site to date; thus, the current AO for the Lyn Creek population is estimated

at 1 km^2. As there are no density estimates for *L. nasuta* in Lyn Creek, the total size of the population cannot be determined.

Fluctuations and trends

Ligumia nasuta was one of the most common species of freshwater mussel in the lower Great Lakes and connecting channels prior to the invasion of dreissenid mussels in the late 1980s. The National Water Research Institute's Lower Great Lakes Unionid Database consists of over 8700 occurrence records for 40 species of unionids collected from over 2500 sites in the lower Great Lakes drainage basin between 1860 and 2006. A query of this database showed that *L. nasuta* was the 4th most common species in Lake St. Clair, Lake Erie, Lake Ontario and the Detroit and Niagara Rivers prior to 1990, accounting for 7.5% of the 1591 records for 39 species. The Eastern Pondmussel is now found only in a small portion of Lake St. Clair, where it accounted for ~ 6% of the 5359 live unionids collected between 1999 and 2005. Thus, the current population of *L. nasuta* in Canada is undoubtedly many orders of magnitude smaller than it once was.

Ligumia nasuta was the second most abundant species (after *Lampsilis siliquoidea*, the Fatmucket) in surveys conducted in the offshore waters of the western basin of Lake Erie in 1930, 1951-52, 1961, 1972, and 1982 and the 3rd most abundant in 1973-74 (Nalepa 1994). Mean density of all unionids at the 17 sites surveyed in 1961, 1972 and 1982 declined from 9.8 to 5.6 to 4.1/m^2, respectively, most likely due to a general decline in water quality. *Ligumia nasuta* accounted for 25.6% of the community in 1961 and the overall density of unionids was 9.8/m^2. The authors of the present report used these data to calculate a density of 2.5 individuals/m^2 for *L. nasuta* in 1961, 0.46/m^2 in 1972 and 0.95/m^2 in 1982. It follows that the abundance of *L. nasuta* declined by about 60% between 1961 and 1982. As the area of the western basin is approximately 1354 km^2, abundance of *L. nasuta* in the western basin in 1982 was calculated to be 1,286,550,000 individuals. Schloesser and Nalepa (1994) surveyed the same 17 sites in 1991 after the dreissenid invasion and found only four live animals, none of which was *L. nasuta*. Schloesser *et al*. (1997) reported a decline in unionids at 15 nearshore sites in the western basin from 85 specimens and 12 species in 1983 to 97 specimens and 9 species in 1991 and 5 specimens of 4 species in 1993; however, the Eastern Pondmussel was not found during any of these surveys.

Schloesser *et al*. (1998) surveyed 13 sites in the Canadian and U.S. waters of the Detroit River in 1982-83 before the dreissenid invasion, 17 sites in 1992, and 9 sites in 1994. *Ligumia nasuta* accounted for 3.7% of 1279 live unionids of 23 species collected in 1982-83, 0.2% of 1653 unionids of 25 species collected in 1992 and none of the 58 live animals of 13 species collected in 1994. Abundance of *L. nasuta* at the 9 sites sampled on all three occasions declined from 37 to 4 to 0. Schloesser *et al*. (2006) surveyed four of these sites again in 1998; only 4 unionids of 4 species were found alive and none were *L. nasuta*.

Nalepa *et al*. (1996) surveyed 29 sites in the offshore waters of Lake St. Clair in 1986 (pre-zebra mussels), 1990, 1992 and 1994 using the same method in all years;

18 sites were in Canadian waters. Unionid abundance declined from 281 specimens of 18 species in 1986 to 6 specimens of 5 species in 1994. Relative abundance of *Ligumia nasuta* in these years was 2.8%, 2.0%, 5.1% and 0%, respectively. Mean density of all unionids in 1986 was 1.9/m^2, and since *L. nasuta* represented 2.8% of specimens it follows that the mean density of *L. nasuta* was probably ~ 0.05/m^2. As the area of Lake St. Clair is 1110 km^2, abundance of *L. nasuta* in the offshore waters of Lake St. Clair in 1986 was calculated by the authors of the present report to be 55,500,000 individuals. There are virtually none left. Gillis and Mackie (1994) conducted intensive surveys at two of Nalepa *et al*.'s (1996) sites that were relatively close to shore in 1990-92. Density of *L. nasuta* at the site in Canadian waters near Puce, Ontario, declined from 0.01/m^2 to 0.004/m^2 to 0/m^2 over this period. No live unionids of any species were found in 1992. Nearshore waters of the Lake St. Clair delta were not surveyed prior to 1999, so there is little information on changes in population size over time for *L. nasuta* in the delta area. However, a decline in unionids, including *L. nastuta*, is known to have occurred at one site in Johnston Bay. Zanatta *et al*. (2002) collected 137 live unionids of 7 species from the site in 1999 using 1.5 p-h survey effort; 19 specimens were *L. nasuta*. They resurveyed the site in 2000 using the same effort and found only 12 live unionids of 4 species, including one *L. nasuta*. Metcalfe-Smith *et al*. (2004) surveyed the site again in 2003 using 1.3 p-h survey effort and found only 10 live unionids, 2 of which were *L. nasuta*. Zanatta *et al*. (2002) noted that zebra mussel infestation rates in Johnston Bay and nearby Goose Lake (mean = 177 zebra mussels/unioinid) were higher than elsewhere in the delta in 1999.

Timed-search surveys were conducted at one site in each of East Lake and Consecon Lake in Prince Edward County (Bay of Quinte area, Lake Ontario) in 1996. A total of 167 live unionids were collected from Consecon Lake, 14 of which were *Ligumia nasuta*, whereas East Lake yielded 16 live unionids, including 2 *L. nasuta* (Metcalfe-Smith *et al*. unpublished data). The authors of the present report re-surveyed these sites in 2005 and searched an additional site in Consecon Lake and four sites in nearby West Lake. No live unionids of any species were found. Similarly, Schueler (pers. comm. 2006) visited Consecon Lake and Beaver Lake in the Salmon River watershed in 2006 and found both lakes to be heavily infested with zebra mussels and no longer likely to support live unionids. As there are no historical records for *Ligumia nasuta* in Lyn Creek, changes over time in the size of the Lyn Creek population are unknown.

Rescue effect

The Eastern Pondmussel occurs in four Great Lakes states (Michigan, New York, Ohio and Pennsylvania) that are connected to Ontario waterways via Lakes Ontario, Erie, St. Clair and Huron. Populations of *Ligumia nasuta* are generally not doing well in these jurisdictions. The species is listed as Endangered in Ohio and a Species of Conservation Concern in New York and Pennsylvania. Its status in Michigan is unknown. In New York, Strayer and Jirka (1997) describe the Eastern Pondmussel as not very widespread but still encountered regularly and sometimes abundant, being most common in the western part of the state where it is found at scattered locations in the Erie-Niagara drainage, central New York and the St. Lawrence drainage. The only location in the U.S. waters of

the Great Lakes where *L. nasuta* is known to persist is Thompson Bay, a small (~ 1km^2) bay just outside of Presque Isle Bay along the south shore of Lake Erie near Erie, PA. There were an estimated 20,000 unionids of 22 species, including *L. nasuta*, living in the larger (15km^2) Presque Isle Bay before the dreissenids arrived, but by 1995 all were believed to have died (Masteller pers. comm. 2002).

It is unlikely that extirpated populations of *L. nasuta* in Canada could become re-established by natural immigration of animals from the United States because there are few potential source populations and the distance is vast. The St. Clair delta population may be an exception: if the population in the Canadian portion of the delta were to disappear, it is possible that the species could return naturally through the movement of host fishes from U.S. waters of the delta, especially if the yellow perch is found to be one of the hosts. Yellow perch are shallow water fish that are not usually found at depths below 9.2 m (Scott and Crossman 1973). As the navigation channel that bisects the delta along the Canada/U.S.A. border is only 8.3 m deep (Edsall *et al*. 1988), yellow perch should be able to move freely throughout the delta. It should be noted, however, that the U.S. population of *L. nasuta* is smaller than the Canadian population and that unionid communities in U.S. waters are not as healthy (less diverse and abundant; individuals have lower energy reserves) as those in Canadian waters (Metcalfe-Smith *et al*. 2005a).

LIMITING FACTORS AND THREATS

The introduction and spread of non-native dreissenid mussels throughout the Great Lakes and connecting channels has led to dramatic declines of native freshwater mussels in colonized areas (see Habitat trends). Over 90% of historical records for the Eastern Pondmussel – the most for any species of unionid in Canada – are from areas now infested with zebra mussels and, thus, uninhabitable. Dreissenid mussels continue to threaten and limit the distribution of this species in the delta area of Lake St. Clair where most specimens collected between 2003 and 2005 were found in one small sheltered bay. Results of an unpublished study on the impacts of zebra mussels on five species of native mussels in Lake St. Clair showed that *Ligumia nasuta* had the lowest rate of survival (30%) and carried the heaviest load of attached zebra mussels relative to their size (Hunter pers. comm. 2004). Prior to the zebra mussel invasion, a general decline in water quality coupled with periods of low oxygen levels is believed to have been responsible for the decline in unionid densities from 10/m^2 in 1961 to 4/m^2 in 1982 in the western basin of Lake Erie (Nalepa *et al*. 1991). It is unlikely that zebra mussels could be introduced into the Lyn Creek drainage because the only standing waterbodies in the system are two small, wetland-surrounded ponds (Lambs Pond south of New Dublin and Lees Pond north of Lillies) with no boat access (BMNHC 2006).

Impacts of climate change on remaining populations of *Ligumia nasuta* and other unionids in the Great Lakes are likely to be severe. The potential impact of climate variability and change on the Great Lakes ecosystem is a topic of considerable research effort at present. Although a clear warming trend is indicated, the various climate models do not always agree on the magnitude and direction of other components, such

as precipitation, and their effects on lake levels. Likely responses of the Great Lakes to climate variability and change are discussed in a recent Environment Canada report on threats to water availability in Canada (Environment Canada 2004). According to one model, net basin supply (precipitation plus runoff minus evaporation) to the lower lakes shows large decreases, with Lake St. Clair showing a dramatic decrease. Other simulations show decreases or even slight increases, but there is general agreement that climate warming will cause lake levels to drop. Impacts of lower lake levels on remnant unionid communities clinging to survival in the shallow (1.5 m or less) “flats” area of the St. Clair delta are likely to be significant. If the flats dry up, these communities would either be lost entirely or the mussels would move out of the flats and into deeper water where they would encounter high densities of zebra mussels and suffer considerable mortality.

Natural controls on the size and distribution of mussel populations include the distribution and abundance of their host fishes, predation, parasitism and disease. Unionids can not complete their life cycle without access to the appropriate glochidial host. If host fish populations disappear or decline in abundance to levels below that which can sustain a mussel population, recruitment will no longer occur and the mussel species may become functionally extinct (Bogan 1993). As noted earlier (Life cycle and reproduction), the host fish(es) for *Ligumia nasuta* are currently unknown. Laboratory testing and field confirmation is required to identify the functional host(s) in Ontario waters. Follow-up studies on the health of host fish populations would then be needed to determine if access to glochidial hosts is a limiting factor for this mussel in Ontario. Freshwater mussels are known to be food sources for a variety of mammals and fishes (Fuller 1974). Predation by muskrats in particular may be a limiting factor for the Eastern Pondmussel in the delta area of Lake St Clair, because wetland areas with abundant emergent vegetation are the preferred habitat for muskrats (NatureServe 2005). Tyrrell and Hornbach (1998) and others have shown that muskrats are both size- and species-selective in their foraging, and can therefore significantly affect both the size structure and species composition of mussel communities. There have been several studies of muskrat predation on freshwater mussels (Neves and Odom 1989; Watters 1993-1994; Tyrell and Hornbach 1998), but these studies were not conducted in areas likely to support populations of the Eastern Pondmussel. Thus, the potential impact of muskrat predation on *L. nasuta* in Ontario needs further study. There are currently no data available on the impacts of parasitism or disease on Canadian populations of *L. nasuta*.

SPECIAL SIGNIFICANCE OF THE SPECIES

Freshwater mussels are sensitive indicators of the health of freshwater ecosystems, including water and habitat quality and especially the fish community on which they depend for successful reproduction. The Eastern Pondmussel was historically a significant component of the Great Lakes mussel fauna, being the fourth most common species in the lower Great Lakes and connecting channels prior to 1990. It is reasonable to assume that this species contributed significantly to the function of unionid communities in the Great Lakes ecosystem prior to the dreissenid invasion.

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Ligumia nasuta is listed as secure/apparently secure (G4G5) in North America; its national status is N4N5 in the United States and N2N3 in Canada (NatureServe 2005). It is not currently listed or proposed for listing under the U.S. *Endangered Species Act* (U.S. Fish and Wildlife Service 2005), but it is listed as Lower Risk–Near Threatened (LRnt) in North America on the IUCN Red List of Threatened Species (IUCN 2005). The national general status of freshwater mussels in Canada was completed in 2004, and the Eastern Pondmussel was ranked as 2 (May Be at Risk) nationally and in Ontario (Metcalfe-Smith and Cudmore-Vokey 2004; Wild Species 2005). The species is ranked as S2S3 (imperiled/vulnerable) by Ontario's Natural Heritage Information Centre (NHIC 2005). According to NatureServe (2005), current state ranks for *L. nasuta* are: Connecticut (S1S2), Delaware (S1), District of Columbia (SNR), Maryland (SU), Massachusetts (S3), Michigan (SNR), New Hampshire (S1), New Jersey (S1), New York (S2S3), North Carolina (S1), Ohio (S1S2), Pennsylvania (S1S3), Rhode Island (S1), South Carolina (SNR), Vermont (SNR) and Virginia (S3). Although NatureServe (2005) lists the species as occurring in Vermont and Rhode Island, no county occurrence records are provided. A mussel expert familiar with the unionid fauna of the New England states confirmed that *L. nasuta* does not occur in these states (Nedeau pers. comm. 2005); thus, the state ranks for Rhode Island and Vermont are not shown in Figure 6. The Eastern Pondmussel is listed as Endangered in Ohio (ODNR 2005) and Delaware (DNREC 2005), Threatened in New Jersey (NJDEP 2005) and North Carolina (NCWRC 2005) and Special Concern in Massachusetts (MDFW 2005) and Connecticut (CDEP 2005) and is therefore afforded some protection in these states. New York, Pennsylvania and South Carolina list it as a Species of Conservation Concern but this designation does not provide any protection.

The federal *Fisheries Act* is an important piece of legislation protecting freshwater mussels and their habitats in Canada because fishes are broadly defined under the Act to include shellfishes. The collection of live mussels in Ontario is considered "fishing" and falls under the Ontario Fishery Regulations made under the *Fisheries Act*.

The largest known population of *Ligumia nasuta* in Canada occupies the territorial waters of the Walpole Island First Nation in the delta area of Lake St. Clair. As previously noted, these waters are primarily used for hunting and fishing by the Walpole community and are protected from urban development and certain recreational uses. Special user permits are required to access First Nation territory and waters, which limits human disturbance in the area. The Walpole Island First Nation, in partnership with Environment Canada, has developed a Walpole Island Ecosystem Recovery Strategy, which has the following goal: "to conserve and recover the [prairie, savannah, forest, wetland and open water] ecosystems of Walpole Island Territory in a way that is compliant with the Walpole Island First Nation Environmental Policy Statement and provides opportunities for cultural and economic development and protection and recovery for Canada's species at risk" (Bowles 2005).

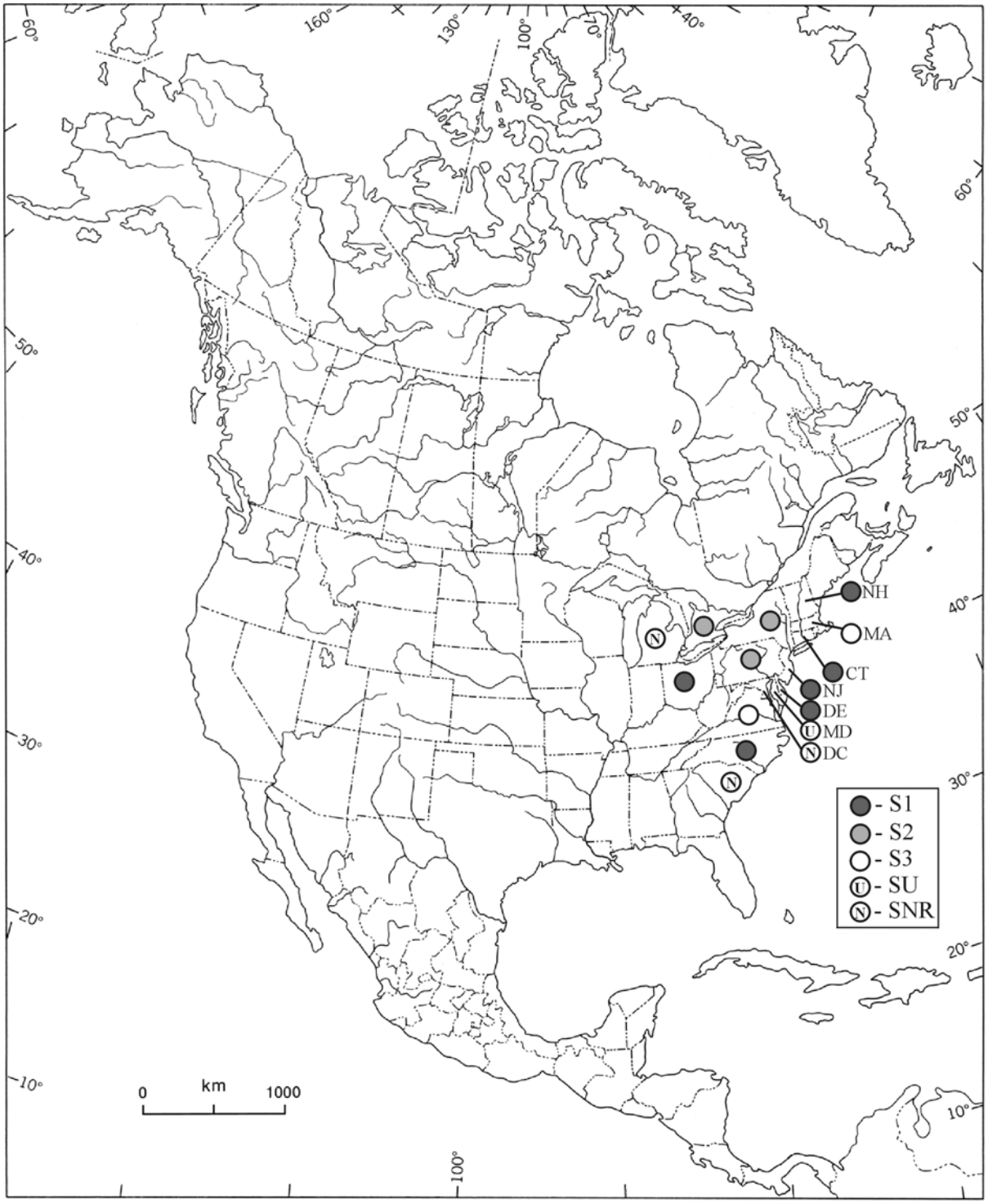

Figure 6. State and provincial conservation priority ranks (S-ranks) for *Ligumia nasuta* (adapted from information provided on www.natureserve.org; SNR = status not ranked; SU = status uncertain; S1 = critically imperiled; S2 = imperiled; S3 = vulnerable). Where rank ranges were assigned (i.e., S2S3) the rank of greater priority is displayed.

TECHNICAL SUMMARY

***Ligumia nasuta* (Say 1817)**
Eastern Pondmussel — Ligumie pointue
Range of Occurrence in Canada: ON

Extent and Area Information	
• *Extent of occurrence (EO)(km²)* **Area within the polygon drawn to contain all occurrences of *Ligumia nasuta* as indicated in the instructions to authors. Historical = 1860 to 1996; Current = 1997 to 2006.**	Historical: ~ 50,500 km² Current: ~ 3,400 km^2
• *Specify trend in EO*	Decline by 93%
• *Are there extreme fluctuations in EO?*	No
• *Area of occupancy (AO) (km²)* **Calculated using scales based on the current IUCN guidelines (see Canadian range)**	Lake St. Clair: 44 km^2 , Lyn Creek: 1 km^2 TOTAL: 45 km²
• *Specify trend in AO*	Decline
• *Are there extreme fluctuations in AO?*	No
• *Number of known or inferred current locations*	2
• *Specify trend in #*	Decline
• *Are there extreme fluctuations in number of locations?*	No
• *Specify trend in area, extent or quality of habitat*	Decline
Population Information	
• *Generation time (average age of parents in the population)*	~ 6-12 years
• *Number of mature individuals*	Unknown
• *Total population trend:*	Declining
• *% decline over the last/next 10 years or 3 generations.*	> 50% inferred over the past 3 generations
• *Are there extreme fluctuations in number of mature individuals?*	Unknown
• *Is the total population severely fragmented?*	Yes
• *Specify trend in number of populations*	Decline
• *Are there extreme fluctuations in number of populations?*	No
• *List populations with number of mature individuals in each:* Lake St. Clair: 22,000 – 44,000 total individuals (total *mature* individuals not known) Lyn Creek: unknown	
• Zebra mussels (aquatic invasive species) have destroyed most of the available habitat for *L. nasuta* throughout its range and continue to threaten the remnant population in the delta area of Lake St. Clair. • *Ligumia nasuta* in the St. Clair delta occur at depths of 1.5 m or less. Any changes in water levels in Lake St. Clair due, for example, to climate change could negatively impact the species. • Threats to the population of *L. nasuta* in Lyn Creek have not been assessed**.**	
Rescue Effect (immigration from an outside source)	
• *Status of outside population(s)?* **USA: Endangered – OH, DE** **Threatened – NJ, NC** **Special Concern – MA, CT**	
• *Is immigration known or possible?*	Highly unlikely
• *Would immigrants be adapted to survive in Canada?*	Likely, but genetic testing would be required
• *Is there sufficient habitat for immigrants in Canada?*	No
• *Is rescue from outside populations likely?*	Highly unlikely

Quantitative Analysis	Not available
Current Status	
COSEWIC: ENDANGERED (April 2007)	

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code**: A2ce; B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)

Reasons for Designation:

This was one of the most common species of freshwater mussel in the lower Great Lakes prior to the invasion of the zebra mussel (*Dreissena polymorpha*) in the late 1980s. Zebra mussels attach to the shells of native freshwater mussels in the hundreds or even thousands, causing the native mussels to suffocate or die from lack of food. Over 90% of historical records for the species are in waters that are now infested with zebra mussels and therefore uninhabitable. The species has declined dramatically and now occurs as two small, widely separated populations, one in the delta area of Lake St. Clair and one in a tributary of the upper St. Lawrence River. There is evidence that declines may be continuing at one location. Although zebra mussels appear to be declining in some areas, their impacts on this species may be irreversible if insufficient breeding adults have survived. Climate change is likely to cause a drop in water levels in the delta and further reduce the amount of habitat available to the mussel. Recent surveys in Lake St. Clair, which were conducted as a collaborative effort between Environment Canada and the Walpole Island First Nation, resulted in the identification of a significant refuge for this species within First Nation territory. The refuge is being managed by the First Nation for the protection of this and other aquatic species at risk with which it co-occurs.

Applicability of Criteria

Criterion A: (Declining Total Population): Meets Endangered A2ce: - population size reduction of > 50% inferred over the past 3 generations (~ 30 years, given that the average age of maturity for unionids is 6-12 years), where the cause (impacts of zebra mussels, which began in 1986) may not have ceased and may not be reversible - 2 - based on a decline in EO of 86% and a decline in the quality of habitat - c - and the effects of introduced taxa (zebra mussels) – e.

Criterion B: (Small Distribution, and Decline or Fluctuation): Meets Endangered B2ab(i,ii,iii,iv,v):- AO < 500 km² (AO ~ 45 km²) - 2. - severely fragmented, i.e., known to exist at only 2 locations separated by more than 800 km - a - continuing decline projected in EO, AO, area, extent and quality of habitat and number of locations (e.g., a decline has been observed at one site in the St. Clair delta since 1999) - b(i,ii,iii,iv,v). Also meets Endangered B1ab(i,ii,iii,iv,v): - EO < 5,000 km² (EO ~ 3,400 km²) - 1- ab(i,ii,iii,iv,v) as documented above for Criterion B2.

Criterion C: (Small Total Population Size and Decline): Does not apply because the number of mature individuals is unknown. The total number of individuals (mature and immature) in the Lake St. Clair population is estimated at 22,000-44,000; thus, the total number of mature individuals likely exceeds the threshold for Threatened (10,000). The size of the Lyn Creek population is unknown, but it is likely 2 orders of magnitude smaller than the Lake St. Clair population based on the relative sizes of the AOs.

Criterion D: (Very Small Population or Restricted Distribution): Meets Threatened D2: - < 5 known locations (2 locations are known), and the species is prone to further declines due to impacts of zebra mussels because: (1) most individuals (~ 90%) are in one population (the St. Clair delta) where losses may be continuing and where 20-30% of individuals are found in one small bay; and (2) it is possible, although unlikely, that zebra mussels could be introduced into the Lyn Creek drainage.

Criterion E: (Quantitative Analysis): Does not apply (no data available).

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Alderman, J.M. North Carolina Resource Commission. 244 Red Gate Road. Pittsboro, NC 27312.

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INFORMATION SOURCES

Barton, D.R., pers. comm. 2005. *Telephone conversation with D.J. McGoldrick*. November 2005. Biology Department. University of Waterloo. Waterloo, Ontario.

BMNHC. 2006. The Bishops Mills Natural History Centre. Press Release 16 August 2006: Rare Mussel found in Lyn Creek: 5 pp.

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

Bogan, A.E. 2002. Workbook and key to the freshwater bivalves of North Carolina. North Carolina Museum of Natural Sciences, Raleigh, NC. 101 pp, 10 colour plates.

Boles, R., pers. comm. 2006. E-mail correspondence with J.L. Metcalfe-Smith. February 2006. Scientific Project Officer, COSEWIC Secretariat, Ottawa, Ontario.

Bowers, R. and F.A. de Szalay. 2004. Effects of hydrology on unionids (Unionidae) and zebra mussels (Dreissenidae) in a Lake Erie Coastal Wetland. American Midland Naturalist 151:286-300.

Bowles, J.M. 2005. Walpole Island Ecosystem Recovery Strategy (Draft 8). Prepared for the Walpole Island Heritage Centre, Environment Canada, and The Walpole Island Recovery Team: 45 pp.

Burch, J.B. 1975. Freshwater Unionacean Clams (Mollusca: Pelecypoda) of North America. Malacological Publications. xviii + 204 pp.

CDEP. 2005. Connecticut Department of Environmental Protection. Web Site: http://dep.state.ct.us/burnatr/wildlife/learn/fwmusl/epm.htm [accessed Dec 2005].

Clarke, A.H. 1981. The Freshwater Molluscs of Canada. National Museums of Canada, Ottawa. 446 pp.

Corey, C. and D.L. Strayer. 1999. Videotape display behavior of the eastern pondmussel *Ligumia nasuta*, (Bivalvia: Unionidae). Page 74 in Program Guide & Abstract of the First Symposium of the Freshwater Conservation Society, 17-19 March 1999, Chattanooga, Tennessee. 92 pp.

Corey, C.A., R. Dowling, and D.L. Strayer. 2006. Display behavior of *Ligumia* (Bivalvia: Unionidae). Northeastern Naturalist 13(3):319-332.

Cudmore-Vokey, B. and E.J. Crossman. 2000. Checklists of the fish fauna of the Laurentian Great Lakes and their connecting channels. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2550: v + 39 p.

Di Sabatino, A., R. Gerecke and P. Martin. 2000. The biology and ecology of lotic water mites (Hydrachnidia). Freshwater Biology 44: 47-62.

DNREC. 2005. Delaware Department of Natural Resources and Environmental Control. Web Site: www.dnrec.state.de.us/fw/telist.htm [accessed Dec 2005].

Ecological Specialists. 1999. Final report: Unionid survey in the Western basin of Lake Erie near the Bass Islands and southwest shore. Prepared by Ecological Specialists, Inc., St. Peters, Missouri, for the Ohio Division of Wildlife - Department of Natural Resources, Columbus, Ohio and the U.S. Fish and Wildlife Service, Reynoldsburg, Ohio. 22 pp.

Edsall, T.A., B.A. Manny, and C.N. Raphael. 1988. The St. Clair River and Lake St. Clair, Michigan: an ecological profile. U.S. Fish and Wildlife Service Biological Report BR-85(7.3). 130 pp.

Environment Canada. 2004. Threats to Water Availability in Canada. National Water Research Institute, Burlington, Ontario. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. 128 pp.

Esch, G.W. and J.C. Fernandez. 1993. A Functional Biology of Parasitism. Ecological and Evolutionary Implications.Chapman and Hall, London, U.K. xiii + 337 pp.

Fuller, S.L.H. 1974. Clams and Mussels (Mollusca: Bivalvia). Pp. 215-273. *In* C.W. Hart, Jr., and S.L.H. Fuller (eds.). Pollution Ecology of Freshwater Invertebrates. Academic Press, New York, New York, U.S.A. xiv. + 389 pp.

Gagnon, J.-M., pers. comm. 2005. E-mail correspondence with D.J. McGoldrick. November 2005. Chief Collection Manager, Invertebrate Collections, Canadian Museum of Nature, P.O. Box 3443, Station D, Ottawa, Ontario, K1P 6P4.

Gatenby, C.M., B.C. Parker and R.J. Neves. 1997. Growth and survival of juvenile rainbow mussels, *Villosa iris* (Lea, 1829) (Bivalvia: Unionidae), reared on algal diets and sediment. American Malacological Bulletin. 14(1):57-66.

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

Hanlon, S.D. and R.J. Neves. 2000. A comparison of reintroduction techniques for the recovery of freshwater mussels. Report to the Virginia Department of Game and Inland Fisheries, Richmond, Virginia. April, 2000. 118 pp.

Hebert, P.D.N., B.W. Muncaster and G.L. Mackie. 1989. Ecological and genetic studies on *Dreissena polymorpha* (Pallas): a new mollusc in the Great Lakes. Canadian Journal of Fisheries and Aquatic Science 46:1587-1591.

Hoggarth, M.A. 1993. Glochidial functional morphology and rarity in the Unionidae. Pp. 76-80 *in* K.S. Cummings, A.C. Buchanan, and L.M. Koch (eds.) Conservation and Management of Freshwater Mussels. Proceedings of the Upper Mississippi River Conservation Committee Symposium, St. Louis, Missouri, October 1992. Illinois Natural History Survey, Champaign, Illinois.

Hunter, R.D., pers. comm. 2004. *E-mail correspondence to D.J. McGoldrick*. December 2004. Department of Biological Sciences, Oakland University, Rochester, MI, 48309-4401.

Hunter, R.D. and K.A. Simons. 2004. Dreissenids in Lake St. Clair in 2001: evidence for population regulation. Journal of Great Lakes Research 30: 528-537.

IUCN. 2005. The IUCN red list of threatened species. Web Site: www.redlist.org [accessed April 2005].

Kat, P.W. 1984. Parasitism and the Unionacea (Bivalvia). Biological Reviews 59:189-207.

Masteller, E.C., pers. comm. 2002. *E-mail correspondence to J.L. Metcalfe-Smith*. May 2002. Pennsylvania State University, Station Road, Erie, PA, 16563.

McMahon, R.F. 1991. Mollusca: Bivalvia. Pp. 315-399 *in* J.H. Thorpe and A.P. Covich (eds.). Ecology and Classification of North American Freshwater Invertebrates, Academic Press, San Diego.

Metcalfe-Smith, J.L, and B. Cudmore-Vokey. 2004. National General Status assessment of freshwater mussels (Unionacea). Environment Canada, National Water Research Institute, Burlington, Ontario. NWRI Contribution No. 04-027. 27 pp. + appendices.

Metcalfe-Smith, J.L., J. Di Maio, G.L. Mackie and S.K. Staton. 2000a. Effects of sampling effort on the efficiency of the timed search method for sampling freshwater mussels. Journal of the North American Benthological Society 19(4):725-732.

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

Metcalfe-Smith, J.L., D.J. McGoldrick, C.R. Jacobs, J. Biberhofer, M.T. Arts, G.L. Mackie, V.S. Jackson, D.W. Schloesser, T.J. Newton, E.M. Monroe and M.D. Drebenstedt. 2005a. Creation of managed refuge sites for native freshwater mussels to mitigate impacts of the exotic zebra mussel in the delta area of Lake St. Clair. Final report to the Endangered Species Recovery Fund and Environment Canada – Ontario Region: 48 pp.

Metcalfe-Smith, J.L., D.J. McGoldrick, C.R. Jacobs and B.L. Upsdell. 2005b. Monitoring and assessment of managed refuge sites for native freshwater mussels on

Walpole Island First Nation. Report to the Endangered Species Recovery Fund and Environment Canada – Ontario Region: 35 pp.
Metcalfe-Smith, J.L., D.J. McGoldrick, M. Williams, D.W. Schloesser, J. Biberhofer, G.L. Mackie, M.T. Arts, D.T. Zanatta, K. Johnson, P. Marangelo and T.D. Spencer. 2004. Status of a refuge for native freshwater mussels (Unionidae) from the impacts of the exotic zebra mussel (*Dreissena polymorpha*) in the delta area of Lake St. Clair. Environment Canada, National Water Research Institute, Burlington, Ontario. Technical Note No. AEI-TN-04-001. 47 pp. + appendices.
MDFW. 2005. Massachusetts Division of Fisheries & Wildlife. Natural Heritage & Endangered Species Program. Web Site: www.mass.gov/dfwele/dfw/nhesp/nhspecies.htm [accessed Dec 2005.
Nalepa, T.F. 1994. Decline of native unionid bivalves in Lake St. Clair after infestation by the zebra mussel, *Dreissena polymorpha*. Canadian Journal of Fisheries and Aquatic Sciences 51:2227-2233.
Nalepa, T.F., D.J. Hartson, D.L. Fanslow and G.A. Lang. 2001. Recent population changes in freshwater mussels (Bivalvia: Unionidae) and zebra mussels (*Dreissena polymorpha*) in Lake St. Clair, U.S.A. American Malacological Bulletin 16: 141-145.
Nalepa, T.F., D.J. Hartson, G.W. Gostenik, D.L. Fanslow, and G.A. Lang. 1996. Changes in the freshwater mussel community of Lake St. Clair: from Unionidae to *Dreissena polymorpha* in eight years. Journal of Great Lakes Research 22(2):354-369.
Nalepa, T.F., D.J. Hartson, G.W. Gostenik, D.L. Fanslow and G.A. Lang. 2001. Recent population changes in freshwater mussels (Bivalvia: Unionidae) and zebra mussels (*Dreissena polymorpha*) in Lake St. Clair, U. S. A. American Malacological Bulletin 16:141-146.
Nalepa, T.F., B.A. Manny, J.C. Roth, S.C. Mozley, and D.W. Schloesser. 1991. Long-term decline in freshwater mussels (Bivalvia: Unionidae) of the western basin of Lake Erie. Journal of Great Lakes Research 17(2):214-219.
NatureServe. 2005. Natureserve Homepage: A Network Connecting Science with Conservation. Web site: www.natureserve.org [accessed August 2005].
NCWRC. 2005. North Carolina Wildlife Resources Commission. Web Site: www.ncwildlife.org [accessed Dec 2005].
Nedeau, E.J., pers. comm. 2005. *E-mail correspondence with D.J. McGoldrick*. April 2005. Consultant. Biodrawversity. 36 Longmeadow Rd. Amherst, MA 01002.
Nedeau, E.J., M.A. McCollough, and B.I. Swartz. 2000. The Freshwater Mussels of Maine. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 118 pp.
Neves, R.J., and M.C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. Journal of Wildlife Management 53:934-941.
New York Power Authority. 2003. Occurrences of rare, threatened, and endangered mussel species in the vicinity of the Niagara Power Project. Niagara Power Project (FERC No. 2216). iii + 11 pp.
NHIC. 2005. Natural Heritage Information Centre. Ontario Ministry of Natural Resources. Web Site: http://nhic.mnr.gov.on.ca/nhic.cfm [accessed April 2005].
Nichols, S.J. and J. Amberg. 1999. Co-existence of zebra mussels and freshwater unionids: population dynamics of Leptodea fragilis in a coastal wetland infested with zebra mussels. Canadian Journal of Zoology 77:423-432.

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

NJDEP. 2005. New Jersey Department of Environmental Protection. Web Site: www.state.nj.us/dep/fgw/tandespp.htm [accessed Dec 2005].

ODNR. 2005. Ohio Department of Natural Resources. Web Site: www.ohiodnr.com/endangered/endangered4.htm [accessed Dec 2005].

OSUM. 2005. Ohio State University Mussel/Host Database. Web Site: http://128.146.250.63/Musselhost [accessed Dec 2005]

Schloesser, D.W., W.P. Kovalak, G.D. Longton, K.L. Ohnesorg, and R.D. Smithee. 1998. Impact of zebra and quagga mussels (*Dreissena* spp.) on freshwater mussels in the Detroit River of the Great Lakes. American Midland Naturalist 140:299-313.

Schloesser, D.W., W.P. Kovalak, R. Smithee and G.D. Longton. 1997. Zebra mussel induced mortality of unionids in firm substrata of western Lake Erie and a habitat for survival. American Malacological Bulletin 14:67-74.

Schloesser, D.W., J.L. Metcalfe-Smith, W.P. Kovalak, G.D. Longton, and R.D. Smithee. 2006. Extirpation of freshwater mussels (Bivalvia: Unionidae) following the invasion of dreissenid mussels in an interconnecting river of the Laurentian Great Lakes. The American Midland Naturalist 155:295-308.

Schloesser, D.W. and T.F. Nalepa. 1994. Dramatic decline of unionid bivalves in offshore waters of western Lake Erie after infestation by the zebra mussel, *Dreissena polymorpha*. Canadian Journal of Fisheries and Aquatic Sciences 51:2234-2242.

Schneider, K., pers. comm. 2002. *Telephone conversation with J.L. Metcalfe-Smith*. November 2002. Stuyvesant Environmental Consulting, LLC, P.O. Box 169, 16 Frisbee Lane, Stuyvesant Falls, NY 12174.

Schueler, F.W. pers. comm. 2005. *E-mail correspondence to D.J. McGoldrick*. October 2005. Bishops Mills Natural History Centre, RR#2 Bishops Mills, ON K0G 1T0.

Schueler, F.W. pers. comm. 2006. *E-mail correspondence to D.J. McGoldrick*. August 2006. Bishops Mills Natural History Centre, RR#2 Bishops Mills, ON K0G 1T0.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184 of the Fisheries Research Board of Canada, Ottawa, Canada: 966 pp.

Stansbery D.H. 1961. The naiads (Mollusca, Pelecypoda, Unionacea) of Fishery Bay, South Bass Island, Lake Erie. Sterkiana. no.5 37pp.+plates1-5.

Standards and Petitions Working Group. 2006. Guidelines for Using the IUCN Red List Categories and Criteria: Version 6.1. Prepared by the Standards and Petitions Working Group for the IUCN SSC Biodiversity Assessments Sub-Committee in July 2006. 60 pp.

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

Strayer, D.L., and K.J. Jirka. 1997. The pearly mussels of New York State. Memoirs of the New York State Museum 26:1-113 + plates 1-27.

Strayer, D.L. and H.M. Malcom. 2007. Effects of zebra mussels (*Dreissena polymorpha*) on native bivalves: the beginning of the end or the end of the beginning? Journal of the North American Benthological Society 26: 111-122.

Turgeon, D.D., J.F. Quinn, Jr., A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P.M. Mikkelsen, R.J. Neves, C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F.G. Thompson, M. Vecchione, and J.D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks. 2nd Edition. American Fisheries Society Special Publication 26: ix-526.

Tyrrell, M., and D.J. Hornbach. 1998. Selective predation by muskrats on freshwater mussels in 2 Minnesota rivers. Journal of the North American Benthological Society 17:301-310.

U.S. Fish and Wildlife Service. 2005. United States Fish and Wildlife Service. Web Site: http://endangered.fws.gov/wildlife.html [accessed April 2005].

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

Watters, G.T. 1993-1994. Sampling freshwater mussel populations: The bias of muskrat middens. Walkerana. 7(17/18):63-69.

Watters, G.T. 1999. Morphology of the conglutinate of the kidneyshell freshwater mussel, *Ptychobranchus fasciolaris*. Invertebrate Biology 118(3):289-295.

Watters, G.T., S.H. O'Dee and S. Chordas III. 2001. Patterns of vertical migration in freshwater mussels (Bivalvia: Unionidae). Journal of Freshwater Ecology 16(4):541-549.

Wild Species. 2005. Wild Species – General Status of Species in Canada. Web Site: www.wildspecies.ca/home.cfm?lang=e [accessed Dec 2005].

Yeager, M.M., D.S. Cherry and R.J. Neves. 1994. Feeding and burrowing behavior of juvenile rainbow mussels, *Villosa iris* (Bivalvia: Unionidae). Journal of the North American Benthological Society 13(2):217-222.

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

Zanatta, D.T. and R.W. Murphy. 2006. Evolution of active host-attraction strategies in the freshwater mussel tribe Lampsilini (Bivalvia: Unionidae). Molecular Phylogenetics and Evolution: in press.

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Janice L. Metcalfe-Smith is an Aquatic Research Biologist with the Water Science and Technology Directorate of Environment Canada in Burlington, Ontario. She has a B.Sc. (Hons.) in Zoology from the University of Manitoba (1973), and 33 years of experience as a technologist (1973-1978) and biologist (1978-present) with Fisheries and Oceans Canada (Winnipeg, Manitoba and St. Andrews, New Brunswick) and Environment Canada (Burlington, Ontario). She has conducted research in several areas, including the effects of forestry practices and acid rain on Atlantic salmon, the use of benthic macroinvertebrate communities in water quality assessment, the development of biological monitoring techniques for measuring contaminant trends in freshwater ecosystems, and aquatic toxicology. Since 1995, her research has focused

on the assessment and conservation of freshwater mussels in Ontario. She has authored or co-authored over 80 scientific papers and reports, including 30 on freshwater mussels. She is a member of the North American Benthological Society and the Freshwater Mollusk Conservation Society, and co-chairs the Molluscs Specialist Subcommittee of COSEWIC. She co-authored ten previous status reports on mussel species at risk for COSEWIC.

Daryl J. McGoldrick is an Aquatic Ecologist with the Water Science and Technology Directorate of Environment Canada in Burlington, Ontario. He has a B.Sc. (Hons.) in Environmental Science from the University of Waterloo (1999) and a M.Sc. (Biology) from the University of Waterloo (2003). Mr. McGoldrick's M.Sc. thesis was entitled "An Investigation of the Littoral Food Web of Little Rice Bay on Long Point, Lake Erie." He has worked in the field of aquatic ecology since 1999. In addition to his thesis research, he has been involved in benthic biomonitoring studies and conducted research on planktonic trophic dynamics of Canadian Shield lakes. Since 2002, he has focused on the assessment and conservation of freshwater mussels in Ontario. Daryl is a member of the North American Benthological Society and the Freshwater Mollusk Conservation Society. He co-authored the status report on the Rainbow (*Villosa iris*) for COSEWIC.

COLLECTIONS EXAMINED

In 1996, all available historical and recent data on the occurrences of freshwater mussel species throughout the lower Great Lakes drainage basin were compiled into a computerized, GIS-linked database referred to as the Lower Great Lakes Unionid Database. The database is housed at the National Water Research Institute in Burlington, Ontario. 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 data acquired. Janice Metcalfe-Smith 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 and now contains approximately 8700 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.