COSEWIC
Assessment and Status Report

on the

Wavy-rayed Lampmussel
Lampsilis fasciola

in Canada

SPECIAL CONCERN
2010

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:

COSEWIC. 2010. COSEWIC assessment and status report on the Wavy-rayed Lampmussel *Lampsilis fasciola* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 60 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Previous report(s):

COSEWIC. 1999. COSEWIC assessment and update status report on the Wavy-rayed Lampmussel *Lampsilis fasciola* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 40 pp.

Metcalfe-Smith, J.L., S.K. Staton and E.L. West. 1999. Update COSEWIC status report on the Wavy-rayed Lampmussel *Lampsilis fasciola* in Canada *in* COSEWIC assessment and update status report on the Wavy-rayed Lampmussel *Lampsilis fasciola* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1 - 40 pp.

Metcalfe-Smith, J.L., S.K. Staton and E.L. West . (DRAFT). 1999. Update COSEWIC status report on the Wavy-rayed Lampmussel *Lampsilis fasciola* in Canada *in* COSEWIC assessment and update status report on Wavy-rayed Lampmussel *Lampsilis fasciola* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1 - 30 pp.

Production note:
COSEWIC acknowledges Todd J. Morris and David T. Zanatta for writing the provisional updated status report on Wavy-rayed Lampmussel, *Lampsilis fasciola*, prepared under contract with Environment Canada. Any modifications to the status report during the subsequent preparation of the 6-month interim and 2-month interim updated status reports were overseen by Dwayne Lepitzki, Molluscs Specialist Subcommittee Co-chair, with the continued assistance of the contractors.

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur le lampsile fasciolée (*Lampsilis fasciola*) au Canada.

Cover illustration/photo:
Wavy-rayed Lampmussel — Photo credit: T. Morris, Fisheries and Oceans Canada.

Catalogue CW69-14/209-2010E-PDF
ISBN 978-1-100-16024-5

Recycled paper

COSEWIC
Assessment Summary

Assessment Summary – April 2010

Common name
Wavy-rayed Lampmussel

Scientific name
Lampsilis fasciola

Status
Special Concern

Reason for designation
This medium-sized freshwater mussel is confined to four river systems and the Lake St. Clair delta in southern Ontario. Since the original COSEWIC assessment of Endangered in 1999, surveys have identified a large, previously unknown reproducing population in the Maitland River. The mussels in the Thames River are also now reproducing. The largest population is in the Grand River; smaller but apparently reproducing populations are in the Ausable River and Lake St. Clair delta. Although water and habitat quality have declined throughout most of the species' former range in Canada, there are signs of improvement in some populations but habitats in Great Lakes waters are now heavily infested with invasive mussels and are uninhabitable for native mussels. The main limiting factor is the availability of shallow, silt-free riffle/run habitat. All riverine populations are in areas of intense agriculture and urban and industrial development, subject to degradation, siltation, and pollution. Invasive mussels continue to threaten the Lake St. Clair delta population and could be a threat to populations in the Grand and Thames rivers if they invade upstream reservoirs.

Occurrence
Ontario

Status history
Designated Endangered in April 1999. Status re-examined and confirmed in October 1999. Status re-examined and designated Special Concern in April 2010.

COSEWIC
Executive Summary

Wavy-rayed Lampmussel
Lampsilis fasciola

Wildlife species description and significance

The Wavy-rayed Lampmussel is medium-sized (75-100 mm long) and readily distinguished from other mussels by its yellow or yellowish-green rounded shell with numerous thin, wavy, green rays. Sexual dimorphism is pronounced, with the female having a distended shell, more oval-shaped than the somewhat square shell of males.

Molecular analyses show recent gene flow both within and among Canadian populations. While moderate levels of genetic divergence among river drainages suggest that Canadian populations should be managed separately, there is only one designatable unit.

Distribution

This mussel is found throughout the Ohio and Mississippi river systems as far south as the Tennessee River drainage. In the Great Lakes drainage it is found in the tributaries of lower Lake Huron, Lake St. Clair, and Lake Erie. In Ontario it is found along several branches of the Maitland River; in the Ausable River drainage; in the North, South, and Middle Thames river drainages upstream of the city of London; the upper Grand River drainage; and the shallow nearshore areas of the St. Clair delta within the territory of the Walpole Island First Nation.

Habitat

It inhabits clear rivers and streams of various sizes with steady flows and stable substrates and is typically found in gravel or sand substrates in and around riffle areas. It is most abundant in small to medium-sized streams and invariably occurs at sites that support a great diversity of other mussel species. Occupied habitats in Ontario are generally characterized as clean sand/gravel substrates, often stabilized with cobble or boulders, in steady currents at depths of up to 1 metre. Water and habitat quality have declined throughout a substantial portion of the species' former range in Canada, but signs of improvements are evident in some populations. Habitats in Great Lakes waters are now heavily infested with Zebra Mussels and most can no longer support the Wavy-rayed Lampmussel.

Biology

This mussel lives at least 10 years but rarely more than 20 years. It is a long-term brooder (bradytictic), spawns in August and releases glochidia (larvae) the following July to August. In females of this and closely related species, the edge of the mantle has evolved into a minnow-shaped "lure". When the glochidia are ready to be released, the female waves her lure to attract potential host fishes. Females displaying the typical lure and several other types, including an unusual lure with reddish-orange mantle flaps, have been observed throughout its global range.

Once expelled into the water, the glochidia must attach to an appropriate host fish to complete development. Two host fish, the Smallmouth and Largemouth bass, have been identified; the Smallmouth Bass is known to be a host throughout the species' Canadian range and can be abundant in rivers. Although the exact food preferences and optimum particle sizes are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria and algae).

Population sizes and trends

Extensive quantitative surveys and long-term monitoring have been conducted since the original status assessment in 1999. Many populations are showing signs of improvement. Population estimates have risen, area of occupancy has increased 2-3 fold, and relative abundances have increased from 2-4% to 20-50% in some watersheds. All but one population show signs of reproduction and recruitment.

Population estimates from recent quantitative sampling indicate that the Grand River (approximately 2 million animals) supports the largest remaining population in Canada while the Thames and Maitland river populations (approximately 300,000 animals each) are similar to one another but an order of magnitude smaller than the Grand River. The Ausable River (approximately 30,000 animals) and St. Clair delta (approximately 3,500 animals) still support remnant populations two to three orders of magnitude smaller than the Grand River.

Threats and limiting factors

The main factor limiting the species' occurrence is likely the availability of clean, silt-free, riffle/run habitat. Runoff of sediment, pesticides, fertilizers and livestock manures, the continued loss of riparian vegetation, the physical destruction of streambeds by livestock, and the input of pollutants and pathogens from sewage treatment plants and stormwater runoff are threats. The glochidia of this species are known to be very sensitive to ammonia and copper. Muskrat predation could be a severe threat to small populations. Although Zebra and Quagga mussels have displaced native mussels throughout much of the lower Great Lakes and continue to isolate populations, they do not presently threaten existing river-dwelling populations of this species. However, the extensive system of dams on the Grand and Thames rivers may increase the susceptibility of downstream populations, if Zebra or Quagga mussels ever become established in the reservoirs.

Protection, status, and ranks

The species is currently listed as Endangered on Schedule 1 of the *Species at Risk Act* (SARA) and as such it is illegal to kill, harm, harass, capture or take individuals. SARA also provides protection for the residence and critical habitat of listed species; however, at this time, neither has been described or identified. The mussel is listed as Endangered and protected under the Ontario *Endangered Species Act, 2007*; however, habitat will not be protected under this Act until June 2013, unless a specific habitat regulation is made at an earlier date. The species is considered globally secure (G5) and is ranked as nationally secure (N5) in the United States but nationally imperiled (N2) in Canada. The federal *Fisheries Act* is another piece of legislation currently protecting the species. As shellfish, freshwater mussels are considered 'fish' under the *Fisheries Act* and receive the same protection granted to finfish.

TECHNICAL SUMMARY

Lampsilis fasciola
Wavy-rayed Lampmussel — Lampsile fasciolée
Range of occurrence in Canada (province/territory/ocean): Ontario

Demographic Information

Generation time (estimated from Grand and Thames River populations)	6-10 Yrs
Is there an inferred continuing decline in number of mature individuals?	No
Estimated percent of continuing decline in total number of mature individuals within 2 generations	Not applicable (N/A)
Inferred percent increase in total number of mature individuals over the last 3 generations.	N/A
Suspected percent reduction or increase in total number of mature individuals over the next 3 generations.	N/A
Inferred percent reduction in total number of mature individuals over any 3 generations period, over a time period including both the past and the future.	N/A
Are the causes of the decline clearly reversible and understood and ceased?	N/A
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence Calculated using a minimum convex polygon of sites with live *L. fasciola* from 2000 to 2008	14,153 km²
Index of area of occupancy (IAO, using 2 km x 2 km grid) Biological AO calculated by multiplying the length of the occupied reach in each river by the average river width for the reach and then summing across rivers	764 km² (IAO) 19.4 km² (AO)
Is the total population severely fragmented?	No
Number of "locations*" • Ausable River watershed (1): Ausable River including the Little Ausable record • Grand River watershed (3): main stem Grand including the Speed River record; Conestogo River; Nith River • Maitland River watershed (3): main stem Maitland including the Middle Maitland; South River; Little Maitland River • Thames watershed (4): North Thames River; Fish Creek; Medway Creek; South and Middle Thames rivers • Lake St. Clair (1): lake and St. Clair River	12
Is there an observed continuing decline in extent of occurrence?	No
Is there an observed continuing decline in index of area of occupancy?	No
Is there an observed continuing decline in number of populations?	No
Is there an observed continuing decline in number of locations?	No
Is there an inferred continuing decline in quality of habitat?	Yes
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

* See definition of location.

Number of Mature Individuals (in each population)

Population	**N Mature Individuals**
Ausable River (± SE)	33,600 (±11,200)
Grand River	2,100,000 (±1,200,000)
Maitland River	310,000 (± 86,400)
Thames River	325,000 (±167,500)
Lake St. Clair delta	3,300 (± 1,100)
Total	2,772,000 (±1,466,200)
All values presented above are for total individuals. Numbers of mature individuals are not known but it can be assumed (based on the age distributions presented in Figures 15 and 16) that virtually all individuals collected during the recent surveys were mature. Therefore these estimates likely closely approximate numbers of mature individuals.	

Quantitative Analysis

Probability of extinction in the wild	Not available

Threats (actual or imminent, to populations or habitats)

Riverine populations: loss of habitat/habitat degradation resulting from the combined impacts of urban and agricultural activities (siltation, nutrients, metals). All life stages are susceptible; however, early life stages (glochidia, juvenile) seem particularly at risk.

Introduction of dreissenid mussels to reservoirs upstream of *L. fasciola* habitats (Grand and Thames rivers).

Lake St. Clair population: dreissenid mussels

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? USA: Stable in central and south parts of the range, imperiled in Northern parts of range. Closest populations in U.S.: Michigan – State Threatened, Ohio – Special Concern.	
Is immigration known or possible?	No
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Yes
Is rescue from outside populations likely?	No

Current Status

COSEWIC: Special Concern (designated Endangered in April 1999, status re-examined and confirmed in October 1999, re-examined and designated Special Concern in April 2010)
Canada SARA: Endangered 2003
Ontario ESA: Endangered 2008

Status and Reasons for Designation

Status: Special Concern	**Alpha-numeric code:** not applicable
Reasons for designation: This medium-sized freshwater mussel is confined to four river systems and the Lake St. Clair delta in southern Ontario. Since the original COSEWIC assessment of Endangered in 1999, surveys have identified a large, previously unknown reproducing population in the Maitland River. The mussels in the Thames River are also now reproducing. The largest population is in the Grand River; smaller but apparently reproducing populations are in the Ausable River and Lake St. Clair delta. Although water and habitat quality have declined throughout most of the species' former range in Canada, there are signs of improvement in some populations but habitats in Great Lakes waters are now heavily infested with invasive mussels and are uninhabitable for native mussels. The main limiting factor is the availability of shallow, silt-free riffle/run habitat. All riverine populations are in areas of intense agriculture and urban and industrial development, subject to degradation, siltation and pollution. Invasive mussels continue to threaten the Lake St. Clair delta population and could be a threat to populations in the Grand and Thames rivers if they invade upstream reservoirs.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. The number of mature individuals is not declining.
Criterion B (Small Distribution Range and Decline or Fluctuation): Nearly meets the criterion for Threatened. EO (14,153 km^2) and IAO (764 km^2, 2 km x 2 km grid) are below the thresholds (< 20,000 km^2 and < 2,000 km^2, respectively) and there is a continuing decline inferred in the quality of habitat. However, the species is not severely fragmented, is found at 12 locations, and does not experience extreme fluctuations.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. The total number of mature individuals is estimated to be over 2.7 million, above the thresholds for this criterion (< 10,000 for threatened).
Criterion D (Very Small or Restricted Total Population): Not applicable. Population size and IAO exceed threshold values.
Criterion E (Quantitative Analysis): Not applicable. Probabilities for extinction in the wild have not been calculated.

PREFACE

Since the original COSEWIC status assessment of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in Canada in 1999 a large number of monitoring, research and management projects have occurred. Information collected in the last ten years has been incorporated to update the original COSEWIC report. Some highlights of the new information in this report are outlined below.

Additional qualitative surveys have occurred throughout the range of the species in Canada. These surveys have been done in the Thames River in 2004 and 2005 (Morris and Edwards 2007) and in the Maitland River in 2003 and 2004 (McGoldrick and Metcalfe-Smith 2004). Other smaller timed-search surveys have been conducted in the Ausable River, Grand River and Lake St. Clair delta. These surveys have helped define the Canadian distribution. In addition to these qualitative surveys, more detailed and extensive quantitative surveys were conducted for all populations. Morris (unpubl. data) sampled the Thames (2004-2005), Grand (2007) and Maitland (2008) populations while Baitz *et al*. (2008) sampled the Ausable River population and Metcalfe-Smith *et al*. (2004) surveyed the Lake St Clair delta population. These surveys have confirmed the existence of a large population in the Grand River and a smaller, yet apparently reproducing, population in the Ausable River and St Clair delta. Of particular importance to the reassessment, these studies have identified large reproducing populations in the Maitland and Thames rivers which were previously unknown (Maitland) or believed remnant (Thames). In addition these efforts have provided information on population sizes and demographics (sex ratios, age/size distributions).

Critically important information on host fish usage by the Wavy-rayed Lampmussel in Canada has been studied at the University of Guelph (McNichols *et al.* 2004; McNichols 2007) and has been added to the **BIOLOGY** section and incorporated throughout the report.

New data on the phylogenetic systematics (Zanatta and Murphy 2006) and geno-geographic population structure (Zanatta *et al.* 2007) of the Wavy-rayed Lampmussel have been added to **SPECIES INFORMATION**.

Vital research on the sensitivity of early life stages to waterborne contaminants has been conducted by Gillis *et al*. (2008) and has greatly strengthened the **THREATS and LIMITING FACTORS**.

A species-specific recovery strategy for the Wavy-rayed Lampmussel, one of the first under Canada's *Species at Risk Act*, was completed in 2006 (Morris 2006). This recovery strategy, as well as watershed strategies for the Sydenham, Ausable and Thames rivers, provided direction for much of the recent research allowing this updated report.

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
(2010)

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

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

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

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

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

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

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and classification

Lampsilis fasciola was originally described by Rafinesque in 1820 (Clarke 1981). The type locality is listed as Ohio by Simpson (1914) and as the Kentucky River by LaRoque (1953). According to Simpson (1914), synonyms include: *Unio multiradiatus* Lea 1829, *Margarita (Unio) multiradiatus* Lea 1836, *Margaron (Unio) multiradiatus* Lea 1852, *Lampsilis multiradiatus* Simpson 1900, *Unio fasciolaris* Say 1834, *Unio perradiatus* Lea 1858, *Margaron (Unio) perradiatus* Lea 1870, *Unio altilis* Reeve 1865, and *Unio perovalis* Sowerby 1866. Many of these synonyms resulted from multiple descriptions of the same species by Lea (Watters 1998). Burch (1975) reported that *Unio multiradiatus* Lea 1829 was a synonym of *L. fasciola*.

Phylum Mollusca
- Class Bivalvia (Pelecypoda)
  - Subclass Palaeoheterodonta
    - Order Unionoida
      - Superfamily Unionoidea
        - Family Unionidae
          - Subfamily Lampsilinae
            - Genus *Lampsilis*
              - Species *Lampsilis fasciola*

Morphological description

The distinguishing characteristics of the Wavy-rayed Lampmussel, *Lampsilis fasciola* (Rafinesque, 1820), include a yellow or yellowish-green rounded shell with numerous thin, wavy, green rays (Cummings and Mayer 1992). This species is similar to *Lampsilis ovata* (Pocketbook), but is smaller, relatively thicker and more regularly ovate (Clarke 1981). Also, in *L. fasciola* the rays may be narrow and distinctly separate from one another or several narrow rays may coalesce into apparently wider rays, but they always undulate or are wavy with multiple interruptions, usually at the growth lines. In *L. ovata*, the rays are not wavy and have only a few interruptions. Clarke (1981) describes the shell morphology of *L. fasciola* as follows:

“Shell…with mid-anterior shell wall about 7.5 mm thick; quadrate-ovate (males) or ovate (females), heavy and strong, moderately inflated, and heavily rayed. Surface smooth except for concentric wrinkles and growth rests. Posterior ridge indistinct. Periostracum yellowish, greenish yellow or yellowish brown, and covered with crowded, narrow and wide, interrupted, wavy rays. Many of the wide rays are composed of closely aligned, very narrow rays. Nacre white or bluish white. Beaks elevated, and beak cavities moderately excavated. Beak sculpture rather fine and composed of about 6 concentric broadly curved bars that are sinuous or broken in the centre. Hinge teeth well developed and moderately heavy: pseudocardinal teeth stumpy or subconical, elevated, serrated, 2 in the right valve (the anterior tooth small) and 2 in the left; lateral teeth rather short, strong, slightly curved, 1 in the right valve and 2 in the left.”

Reported shell dimensions vary: Clarke (1981) states that shells may grow to 95 mm in length; Cummings and Mayer (1992) give 89 mm as the maximum length; and Strayer and Jirka (1997) state that the shell is usually less than 75 mm long. Specimens at the Ohio State University Museum of Biological Diversity are up to 100 mm long (Watters pers. comm. 1998). During surveys in Canada, Metcalfe-Smith *et al.* (1998) observed specimens up to 72 mm in length. The female has a distended posterior ventral shell shape, more oval than the somewhat square shell of males (Figure 1).

Figure 1. Female (bottom left) and male (top right) Wavy-rayed Lampmussels (*Lampsilis fasciola*) from the Grand River, Ontario. (Photo credit: T. Morris, Fisheries and Oceans Canada)

Population spatial structure and variability

Lampsilis fasciola belongs to the diverse tribe of North American unionoids called the Lampsilini. Molecular phylogenetics have shown that *L. fasciola* is most closely related to “true” *Lampsilis* (including *L. cardium*, *L. ovata*, and *L. ornata*), forming a well resolved and supported clade (Zanatta and Murphy 2006).

In a population-level molecular analysis, the polymorphic mantle display forms (see **Lifecycle and Reproduction**) of *L. fasciola* were found to be genetically indistinguishable using a suite of microsatellite loci; however, within-population mantle display diversity was correlated with genetic diversity (Zanatta *et al.* 2007). Analysis of molecular variance was used to define populations and population structure (Zanatta *et al.* 2007). Further molecular analysis may be required to determine how and why these polymorphisms occur and if these are heritable traits. In managing populations for propagation, augmentation, and translocation, Zanatta *et al.* (2007) recommended that polymorphic lures be represented in approximate proportions to that observed in wild populations.

Moderate to high gene flow appears to have recently occurred among all of the sampling localities (Figure 2; Zanatta *et al.* 2007) but only six Canadian sites were sampled. Within drainage gene flow was highest and sampling localities within the Ontario drainages displayed panmixia (indiscriminate interbreeding). The relatively recent construction of impoundments on the Grand and Thames rivers and the introduction of dreissenid mussels (*Dreissena polymorpha*, Zebra Mussel and *D*. *rostiformis*, Quagga Mussel) have further isolated remaining populations in Canada. As such, many of the intervening riverine and lacustrine habitats are now inhospitable to *L. fasciola* and thus fragmented. Although not detectable today, this will ultimately lead to ever-increasing genetic divergence and isolation due to drift (Zanatta *et al.* 2007).

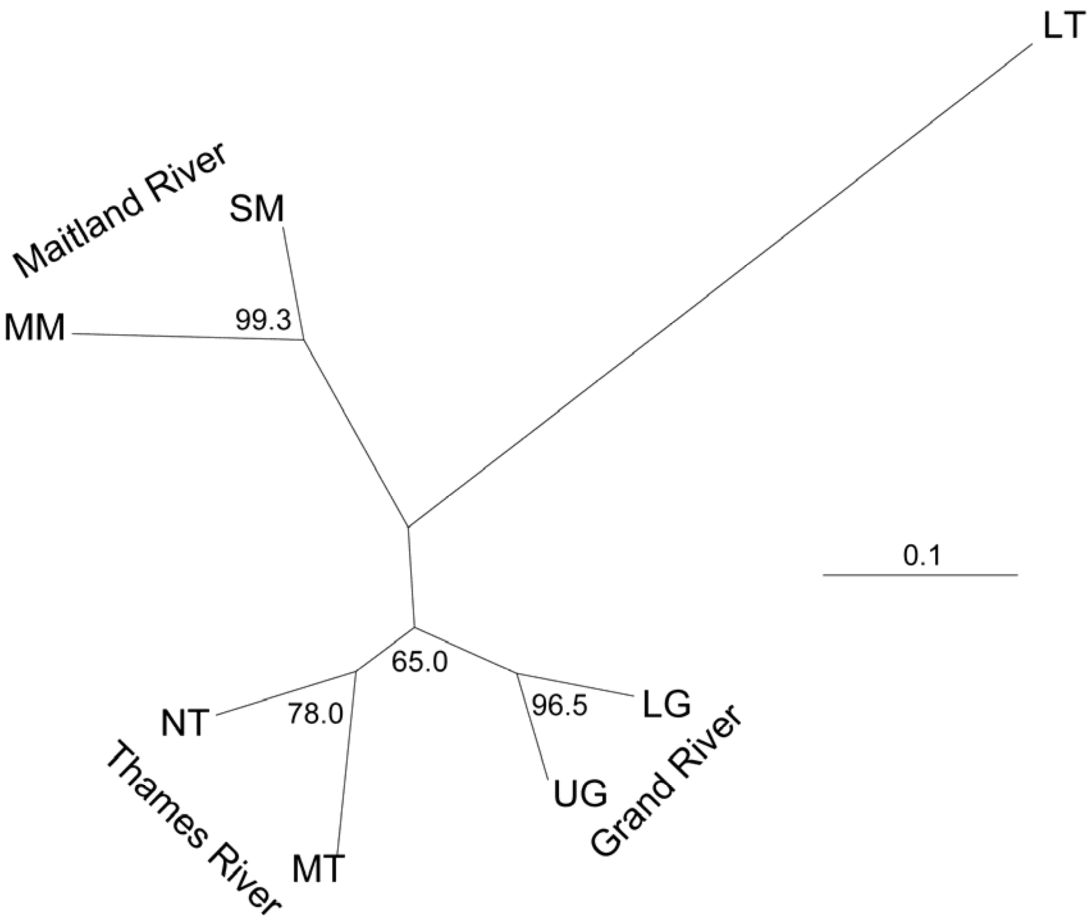

Figure 2. An unrooted neighbour-joining network based on Nei D (genetic distance) for seven populations of Wavy-rayed Lampmussel (*Lampsilis fasciola*). Numbers indicate nodes with bootstrap support of more than 50% for 1000 replications. MM = Middle Maitland River, SM = South Maitland River, NT = North Thames River, MT = Middle Thames River, UG = upper Grand River, and LG = lower Grand River, all in Ontario; LT = Little Tennessee River, North Carolina, U.S.A. (from Zanatta *et al*. 2007).

Populations of *L. fasciola* in the Thames River (North Thames and Middle Thames) showed some evidence (significant under two of four models) of a recent genetic bottleneck (Zanatta *et al.* 2007). This could indicate a rapid decline of *L. fasciola* in the Thames River drainage to very small numbers, followed by an increase in the number of individuals. Although historic data are not available for the Thames River, the mussel populations in the Grand River have shown evidence of recovery in recent decades (Metcalfe-Smith *et al.* 2000). Similar to recovery of unionids in the Grand River, a possible recovery of *L. fasciola* after a genetic bottleneck in the Thames River could be attributed to improvements in water quality in recent decades although water quality trend data for the Thames River are contradictory—some parameters are better, some are worse (see **Habitat Trends**).

Designatable units

Based on moderate F_{ST} values, moderately high genetic distances (Figure 2), and nearly no misclassification among drainages in the assignment test, Zanatta *et al.* (2007) recommended that populations in each Ontario drainage be treated as separate management units (*sensu* Moritz 1994). However, because Canadian populations of *L. fasciola* are in the same COSEWIC Freshwater Biogeographic Zone (Great Lakes – Upper St. Lawrence), they do not currently merit assessment as separate designatable units (DUs) (Green 2005; COSEWIC 2008). In addition, not all Canadian populations have been subjected to genetic analysis. Over time, the continued isolation of the five populations (see below) and fragmentation of the species could lead to further genetic divergence. These isolated mussel populations may satisfy the COSEWIC requirements for "discreteness' and "significance" of DUs in the future.

Special significance

Freshwater mussels in general play an integral role in the functioning of aquatic ecosystems and as indicators of water quality (e.g., ammonia and copper toxicity). Vaughn and Hakenkamp (2001) have summarized much of the literature relating to the role of unionids and identified numerous water column and sediment processes mediated by mussel beds. Water column processes include: size-selective filter-feeding, species-specific phytoplankton selection, nutrient cycling, and control of phosphorus abundance. Sediment processes include: deposit feeding decreasing sediment organic matter, biodeposition of feces and pseudofeces, epizoic invertebrates and epiphytic algae colonize shells, and benthic invertebrate densities positively correlated with mussel density. Welker and Walz (1998) demonstrated that freshwater mussels are capable of limiting plankton in European rivers, while Neves and Odum (1989) reported that mussels also play a role in the transfer of energy to the terrestrial environment through predation by Muskrats (*Ondatra zibethicus*) and Raccoons (*Procyon lotor*). However, given that the Wavy-rayed Lampmussel appears to have always been a minor component of the freshwater mussel community in Canada, its relative contribution to these processes is likely minor.

No Aboriginal Traditional Knowledge was available at the time this report was prepared.

DISTRIBUTION

Global range

Lampsilis fasciola was historically known from New York (Strayer and Jirka 1997), Alabama, Georgia, Illinois, Indiana, Kentucky, Michigan, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and Ontario (Williams *et al*. 1993) (Figure 3). It was found throughout the Ohio and Mississippi river drainages as far south as the Tennessee River system (Clarke 1981) (Figure 3). In the Great Lakes basin, it occurred in tributaries of lower Lake Huron, Lake St. Clair and Lake Erie (Clarke 1981). According to Strayer *et al.* (1991) and Strayer and Jirka (1997), it also inhabited the Niagara River, tributaries of Lake Ontario, and the upper Allegheny drainage in western New York. However, in Ontario, *L. fasciola* has been historically reported from only the Maitland, Sydenham, Thames, Detroit and Grand rivers, the western basin of Lake Erie, and Lake St. Clair (Figure 4).

Figure 3. Global distribution of the Wavy-rayed Lampmussel (*Lampsilis fasciola*).

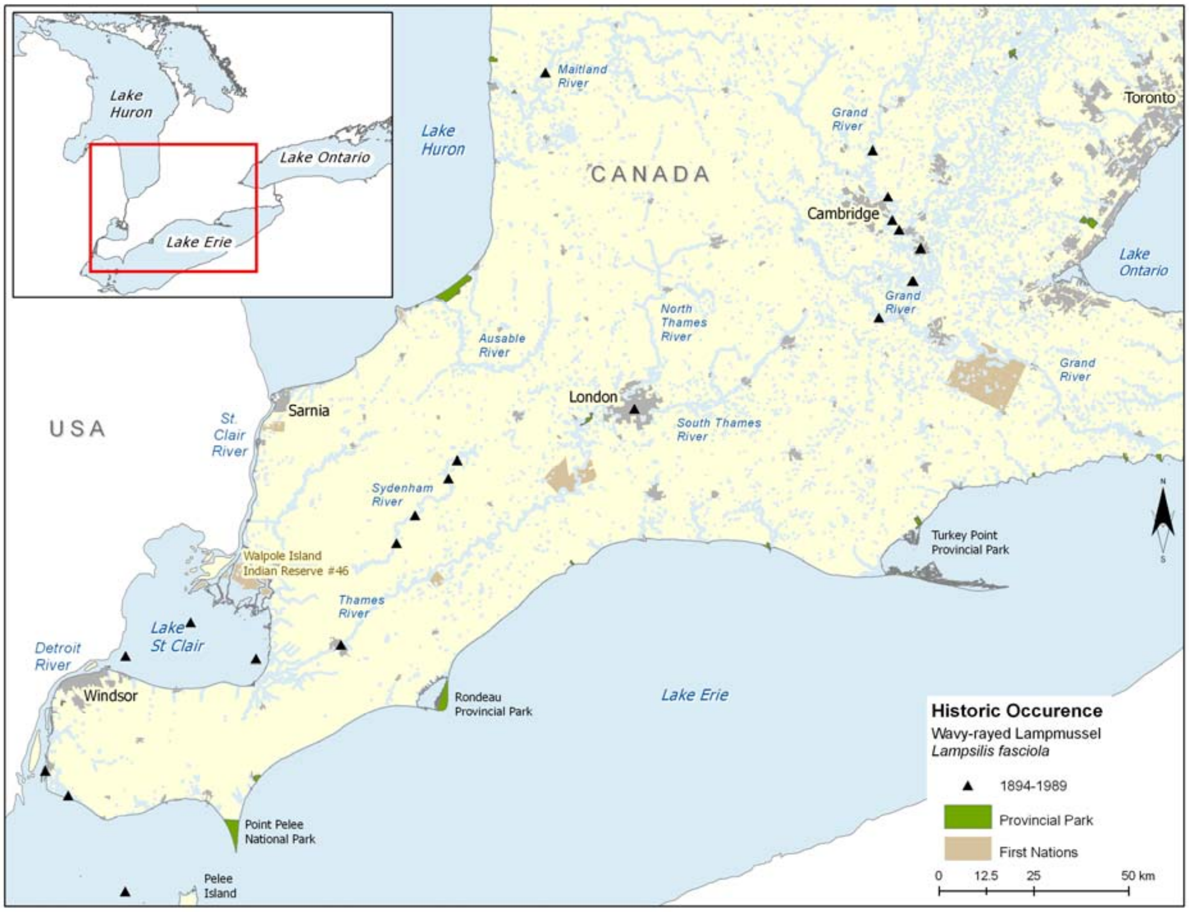

Figure 4. Historic distribution of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in Canada.

Canadian range

In Canada, *L. fasciola* is known only from the Great Lakes drainage of southern Ontario including lower Lake Huron, Lake St. Clair, Lake Erie and the Detroit and St. Clair rivers. There are no records from any other Canadian province or territory (Metcalfe-Smith and Cudmore-Vokey 2004). The first record for *L. fasciola* in Canadian waters was from the Grand River near Galt, Ontario in 1894 by Macoun (CMN-ML002518, accession number of specimen at the Canadian Museum of Nature). It was first recorded from the Thames River in 1902 by Saunders (CMN-ML002542), from the Detroit River in the 1930s by Walker (UM-84186, University of Michigan Museum of Zoology collection), from the Maitland River in 1935 by Oughton (UM-186322), from the Sydenham River in 1965 by Stein (OSUM-19210, Ohio State University Museum of Zoology collection), from western Lake Erie in 1967 by Condit and Forsyth (OSUM-18666), from Lake St. Clair in 1986 (Nalepa *et al.* 1996), and from the Ausable River in 1993 (Morris and Di Maio 1997). The current Extent of Occurrence (EO) for the Wavy-Rayed Lampmussel in Canada, calculated in ArcView GIS v. 3.3 as the area of a convex polygon around the current live distribution, is 14,153 km².

Search effort

Approximately 55% (13/24) of historic Wavy-rayed Lampmussel records (1894-1989) in the Lower Great lakes Unionid Database (see **COLLECTIONS EXAMINED**) are museum specimens for which there is no information on search effort at sites where the species was collected nor from sites where the species was not detected. Historically there is information on sampling effort for Lake St. Clair and the Sydenham, Thames, and Grand rivers (Table 1); the table also provides a summary of historic mussel sampling efforts within the range of the Wavy-rayed Lampmussel.

Table 1. Summary of historic (1934-1989) mussel sampling effort within the range of the Wavy-rayed Lampmussel.

Water body	# of sites	Year	Effort	Notes	Source
Lake St. Clair	29	1986	10 x 0.5 m^2 quadrats per site per year		Nalepa *et al*. (1996)
Detroit River	13	1982-83	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
Lake Erie		1930 1951-52 1973-74			Wright (1955) Wood (1963) Wood and Fink (1984)
	17	1961, 1972, 1982	3 – 5 benthic grabs per site with either a Ponar or Peterson sampler.		Nalepa *et al*. (1991)
Sydenham River	12	1971	0.7 – >4 person-hours		Clarke (1973)
	22	1985	minimum of 1 person-hour	includes 12 sites of Clarke 1973	Mackie and Topping (1988)
Thames River	1	1983	240 0.5 m^2 quadrats		Salmon and Green (1983)
Grand River	115	1970-72	no precise effort reported per site but description of methods reported		Kidd (1973)

Ninety-eight percent of the recent (1990 to present) Wavy-rayed Lampmussel records in the Lower Great Lakes Unionid Database are from surveys designed to assess mussel assemblage composition, abundance and/or density. All of these records have information on survey methodology and effort. Generally these methods involve either semi-quantitative timed-searches or more detailed quantitative methods with substrate excavations (Table 2; see also **Sampling Effort and Methods**).

Table 2. Summary of current (1990-2008) mussel sampling effort within the range of the Wavy-rayed Lampmussel.

Water body	# of sites	Year	Effort	Notes	Source
Lake St. Clair	29	1990, 1992, 1994	10 x 0.5 m^2 quadrats per site per year		Nalepa *et al*. (1996)
	2	1990, 1992	20 x 1 m^2 quadrats	includes 2 of Nalepa *et al*. (1996) sites	Gillis and Mackie (1994)
Lake St. Clair	3	1998	10 transects at 3 depths (1, 2.5 and 4 m) with 5 x 1 m^2 quadrats and 20 Ekman grabs at each transect		Zanatta *et al*. (2002)
	60	1999	sites < 2.0 m deep employed 0.75 person-hours of snorkelling effort, if mussels present an additional 0.75 person-hours was spent; sites > 2.0 m deep employed 0.5 person-hours of SCUBA effort	includes 10 sites surveyed in 1998	Zanatta *et al*. (2002)
	10	2000	1.5 person-hours of snorkelling	includes 10 sites from previous years	Zanatta *et al*. (2002)
	9	2001	5 – 21 65 m^2 circular plots were surveyed using snorkelers	includes 4 previously sampled	Zanatta *et al*. (2002)
	18	2003	10 x 195 m^2 circular plots surveyed using snorkelers	9 sites in Canadian waters of delta , 9 sites in U.S. waters	Metcalfe-Smith *et al*. (2004)
	10	2003	1 person-hours	2 sites in Canadian waters of delta, 8 sites in U.S. waters	Metcalfe-Smith *et al*. (2004)
	4	2005	3 – 4 person-hours		Metcalfe-Smith *et al*. (2005)
Detroit River	17	1992	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
	9	1994	SCUBA searches over 500 m^2 area over 60-minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
	1	1997	4 x 120 m^2 line transects		Schloesser *et al*. (2006)
	4	1998	500 m^2 area searched for 60 minutes using SCUBA, second 500 m^2 area searched for 25 minutes	sites where live unionids were observed in 1992 and 1994	Schloesser *et al*. (2006)
	1	1998	10 x 1 m^2 quadrats within a 10 m x 10 m grid		Schloesser *et al*. (2006)
Lake Erie	17	1991	3 0.05 m^2 ponar grabs and 5 min tow with epibenthic sled (0.46 x 0.26 m)		Schloesser and Nalepa (1994)
	6	2001	approximately 2 person-hours snorkelling		Zanatta and Woolnough (unpubl. data)

Water body	# of sites	Year	Effort	Notes	Source
	12	2005	1.5 person-hours snorkelling		McGoldrick (unpubl. data)
	5	2005	beach search		McGoldrick (unpubl. data)
Niagara River	22	2001-2002	0.5 person-hours plus 0.5 person-hours if mussels found during first effort	U.S. waters near Grand Island	New York Power Authority (2003)
Saugeen River	6	1993-1994	1 person-hour		Morris and Di Maio (1998-1999)
	8	2006	4.5 person hours		Morris *et al*. (2007)
Maitland River	21	1998, 2003, 2004	4.5 person hours		McGoldrick and Metcalfe-Smith (2004)
	6	2008	60 – 70 x 1 m^2 quadrats	sites included in McGoldrick and Metcalfe-Smith 2004	Morris (unpubl. data)
Bayfield River	18	2007	4.5 person hours		Morris (unpubl. data)
Ausable River	21	1993-94, 1998-02	4.5 person hours by Metcalfe-Smith in 1998-02		Morris and Di Maio (1998-1999); Metcalfe-Smith (unpubl. data)
	7	2006	69 – 75 x 1 m^2 quadrats		Baitz *et al.* (2008)
Sydenham River	16	1991	0.4 – 8.0 person-hours	most productive sites of Clarke 1973	Clarke (1992)
	17	1997-98	4.5 person hours		Metcalfe-Smith *et al*. (2003)
	15	1999-03	60 – 80 x 1 m^2 quadrats	includes 12 sites surveyed in 1997-98	Metcalfe-Smith *et al*. (2007)
Thames River	?	1993	1 person-hour		Bowles (1994)
	16	1994	1 person-hour		Morris and Di Maio (1998-1999)
	16	1995	1 person-hour	includes site of Salmon and Green (1983) and overlap with Bowles 1994	Morris (1996)
	48	1997, 2004	4.5 person hours		Morris and Edwards (2007, unpubl. data)
	5	2004-05	60 – 80 x 1 m^2 quadrats	sites included in Morris and Edwards 2007	Morris (unpubl. data)
	2	2006	2 x 360 m^2	relocation project in Medway Creek	Mackie (unpubl. data)
	1	2008	1 x 444 m^2 plot sampled 14 times between May and October	TM-10 of Morris and Edwards 2007	Morris (unpubl. data)
Grand River	70	1995	1.5 person-hours plus 1.5 person-hours when stream order greater than 4	extra effort directed at surveying deeper areas	Mackie (1996)
	24		4.5 person hours		Metcalfe-Smith *et al*. (2000)
	4	2007	48 – 65 x 1 m^2 quadrats	all sites included in Metcalfe-Smith *et al*. 2000b	Morris (unpubl. data)

Water body	# of sites	Year	Effort	Notes	Source
	1	2007	338 m^2	relocation project at Inverhaugh	Mackie (unpubl. data)
	1	2007	?	relocation project at Bridgeport	Mackie (2008)
	1	2008	1 x 450 m^2 plot sampled 13 times between May and October	GR-03 of Metcalfe-Smith *et al*. 2000	Morris (unpubl. data)

The following descriptions of the distribution of *Lampsilis fasciola* for each waterbody are based on historic surveys and the occurrence of live animals in surveys conducted by the report writers and colleagues since 1990. The upper and lower bounds of the area of occupancy described for each waterbody were determined to be sites where *L. fasciola* was not found alive immediately upstream or downstream of sites where it was found alive. The lengths of the occupied area for each watershed were determined using ArcView GIS v.3.3. The biological Area of Occupancy (AO) was calculated for each population using the length of the occupied reach multiplied by the average width of the reach based on data obtained from field surveys. An Index of Area of Occupancy (IAO) using a 2 km x 2 km and 1 km x 1 km grid systems also was calculated.

Maitland River

The Wavy-rayed Lampmussel was first collected from the Maitland River at Auburn in 1935 by Oughton (Figure 4). There appears to have been no further search for the species in this watershed until 1998 when Metcalfe-Smith revisited the site in preparation for the initial COSEWIC status report (Tables 1 and 2). In 1998, three live animals were collected from the Auburn site although no further searches were done within the watershed. Subsequently, McGoldrick and Metcalfe-Smith (2004) surveyed an additional 20 sites in 2003-2004, using a 4.5 p-h (person-hour) timed search technique, finding live Wavy-rayed Lampmussels at nine sites. Morris (unpubl. data) undertook quantitative surveys at six of these sites in 2008 finding Wavy-rayed Lampmussels at four sites including one site (MR-14 on the Little Maitland River) where McGoldrick and Metcalfe-Smith (2004) did not find them.

Lampsilis fasciola occurs in all four branches of the Maitland River watershed (Figure 5): main stem, Middle, South, and Little. In the Middle Maitland River it is found alive along 23 km of the river from the junction of Morris Rd. (County Rd. 16) and Clyde Line to the confluence with the main stem in Wingham. It also occurs in 15 km of the Little Maitland River from Jamestown to the confluence with the Middle Maitland River just south of Wingham. In the main stem, *L. fasciola* occurs from Wingham downstream to Benmiller (54 km) and in the South Maitland River the species occurs from Londesborough to the confluence with the main stem (10 km). As the average river width at sites supporting live *L. fasciola* is 31 m, the AO is approximately 3.2 km^2 (Table 3). The IAO is 176 km^2 (2 km x 2 km grid) or 101 km^2 (1 km x 1 km grid) (Table 4).

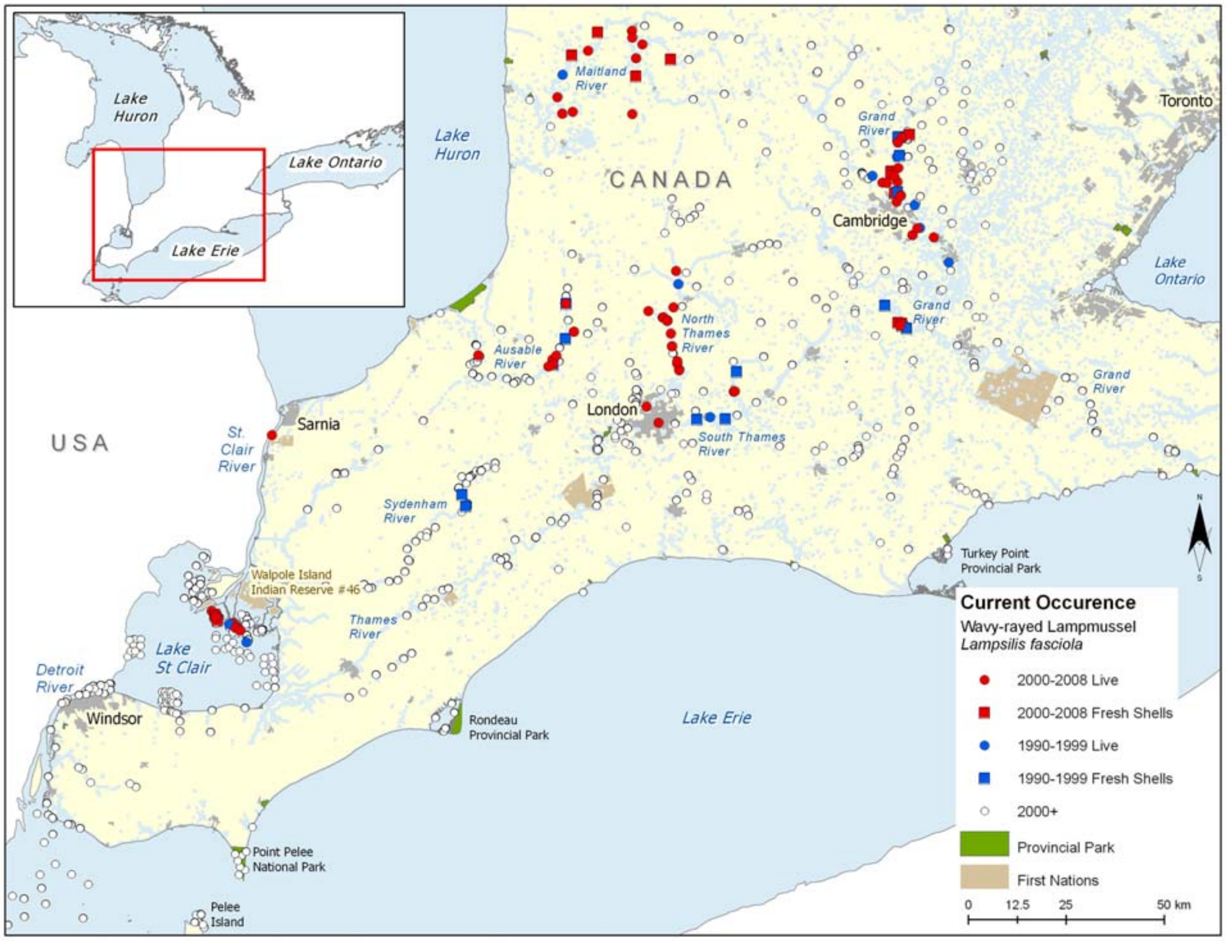

Figure 5. Recent search effort and current distribution of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in Canada. For illustrative purposes the data are presented in two time periods reflective of the data available at the time of the previous COSEWIC assessment (1990-1999) and those collected since then (2000-2008).

Table 3. Population characters determined from semi-quantitative surveys of four southern Ontario watersheds.

Watershed	# of sites surveyed	Effort (person-hours)	# of extant sites	Catch per Unit Effort (animals/person-hour)	Area of Occupancy (km^2)
Ausable River	25	112.5	2	0.017	0.7
Grand River	33	143	12	0.37	7.5
Maitland River	21	94.5	9	0.22	3.2
Thames River	40	180	13	0.30	2.5

Table 4. Estimated population sizes for *Lampsilis fasciola* based on quantitative surveys within the area of occupancy.

Waterbody	# of sites surveyed	Density ($\#/m^2$) (SE)	Area of Occupancy (km^2)	Index of Area of Occupancy (km^2) (2 km x 2 km grid)	IAO (km^2) (1 km x 1 km grid)	Estimated population size (± SE)[1]
Ausable River	4	0.048 (0.016)	0.7	56	33	33,600 (± 11,200)
Grand River	4	0.28 (0.16)	7.5	284	158	2,100,000 (± 1,200,000)
Maitland River	4	0.096 (0.027)	3.2	176	101	310,000 (± 86,400)
Thames River	5	0.13 (0.067)	2.5	224	126	325,000 (± 167,500)
Lake St. Clair[2]	18	0.0006 (0.00021)	5.5	24	8	3,300 (± 1,100)
Total population range			19.4	764	426	1,300,000 – 4,200,000

[1]Estimated population size was calculated by multiplying the Density by the Area of Occupancy.
[2]Calculations of IAO include both the Lake St. Clair delta and St. Clair River.

Ausable River

The Wavy-rayed Lampmussel was first collected from the Ausable River in 1993 by Morris and Di Maio (1998-1999) who found a single specimen. Despite increased sampling effort (Metcalfe-Smith unpubl. data) only two additional animals were found until 2006 when Fisheries and Oceans Canada and Ausable-Bayfield Conservation Authority staff undertook quadrat surveys at seven sites finding 18 animals at five sites (Baitz *et al*. 2008) (Table 2).

The current distribution of *Lampsilis fasciola* in the Ausable River is limited to the bottom 3 km of the Little Ausable River and 84 km of the main stem from Brinsley to Nairn (Figure 5). As the average width of the river along both reaches is 7.5 m the AO for *L. fasciola* in the Ausable River watershed is approximately 0.7 km^2 (Table 3); the IAO is 56 km^2 (2 km x 2 km grid) or 33 km^2 (1 km x 1 km grid) (Table 4).

Sydenham River

Lampsilis fasciola has been reported only sporadically from the Sydenham River over the past 40 years (Figure 4). Athearn surveyed one site on the Sydenham River in 1963 and another in 1967 using a sampling effort of 4 p-h/site and reported *L. fasciola* at the 1967 site but did not note the specimens' condition. Stein surveyed one site in 1965 and another in 1967 using a sampling effort of 6 p-h/site and reported live specimens at the latter site and fresh shells only at the former site. She visited two sites in 1973, one of which was her 1965 site, but did not find any evidence of this species. The first extensive survey of the Sydenham River was conducted in 1971 by Clarke (1973). He visited 12 sites using a sampling effort of 1 p-h/site and observed one live specimen of *L. fasciola* at one site. Mackie and Topping (1988) surveyed 22 sites on the Sydenham and North Sydenham Rivers in 1985 using a sampling effort of 1 p-h/site and reported dead shells only at an undisclosed number of sites on the North Sydenham. In a further investigation of 16 sites in 1991, Clarke (1992) found no trace of this species. Metcalfe-Smith *et al.* (1998) surveyed nine sites on the Sydenham River in 1997, using a sampling effort of 4.5 p-h/site, and reported a small number of fresh whole shells at two sites (Figure 5). Most records for *L. fasciola* from the Sydenham River, including all records for live animals, are from the vicinity of Alvinston. Since the time of the last COSEWIC assessment, Metcalfe-Smith *et al*. (2007) sampled 15 sites using quantitative methods and found no trace of the species.

Lampsilis fasciola has not been found alive in the Sydenham River since 1971, despite more than 600 p-h of search effort by the report writers and associates from 1997 to 2004 (Table 2). It is likely that Wavy-rayed Lampmussels have been extirpated from the Sydenham River. *Lampsilis fasciola* historically occurred in 42 km of the middle reach of the East Sydenham River from Rokeby downstream to Florence.

Thames River

Wavy-rayed Lampmussels were first reported from the Thames River in 1902 (Saunders 1902: CMN28) (Figure 4). Although this collection was recorded as Chatham in the lower river it is likely that the shell had washed out from higher in the watershed as this species has never again been collected from the lower river below London (Figure 5). The first comprehensive surveys of the Thames River were not initiated until 1993 when Morris surveyed Dingman Creek (reported in Bowles 1994) (Table 2). This and subsequent surveys in 1994 (Morris and DiMaio 1998-1999) and 1995 (Morris 1996) did not produce any evidence of Wavy-rayed Lampmussel. Surveys in 1997 and 1998 (Metcalfe-Smith *et al*. 1998) produced the first records of live animals (6 individuals). Morris and Edwards (2007) surveyed 37 sites in the Thames River in 2004-2005 and found *Lampsilis fasciola* at 10 of 25 sites in the upper watershed and none at 10 sites in the lower river.

Lampsilis fasciola occurs in the North (including the Fish and Medway Creek tributaries of the North), South and Middle Thames rivers upstream of the City of London (Figure 5). In the North Thames River *L. fasciola* is found along 34 km of river from near Motherwell downstream to the Fanshawe Lake reservoir. In the Fish Creek tributary, it is found from Regional Road #151 to the confluence with the North Thames River and in the Medway Creek tributary, from Fanshawe Park Rd. downstream to the confluence with the North Thames. In Middle Thames River *L. fasciola* can be found from just upstream of Thamesford through to the confluence then along the South Thames River to Airport Road in the City of London, a reach of river spanning 44 km. The average river width at sites with live *L. fasciola* is 32 m in the Thames River watershed; thus, the AO is approximately 2.5 km^2 (Table 3). The IAO is 224 km^2 (2 km x 2 km grid) or 126 km^2 (1 km x 1 km grid) (Table 4).

<u>Grand River</u>

There have been three major surveys of the Grand River for mussels since 1970 (Tables 1 and 2). Kidd (1973) surveyed 76 sites throughout the system in 1970-72; Mackie (1996) surveyed 70 sites, focusing mainly on tributaries, in 1995; and Metcalfe-Smith *et al.* (1998) investigated 17 sites, primarily on the main stem, in 1997. Kidd (1973) did not specify his sampling effort, but it is believed to have been fairly intensive as the surveys were the focus of his M.Sc. thesis. Mackie (1996) and Metcalfe-Smith *et al.* (1998) used the timed-search method and sampling efforts of 1.5 and 4.5 p-h/site, respectively. Mackie (1996) found 18 live species of mussels at 70 sites, whereas Metcalfe-Smith *et al.* (1998) reported 24 species from only 17 sites. Metcalfe-Smith *et al.* (1998) visited four of Mackie's (1996) sites and consistently found more species. Kidd (1973) reported two live animals from a site in the upper watershed near West Montrose and an additional 22 shells from various sites (Figure 4). The only record of *L. fasciola* from Mackie's (1996) survey is also from West Montrose where two fresh half shells were found. Metcalfe-Smith *et al.* (1998) reported 21 individuals from several sites ranging from West Montrose downstream to, and including, the Nith River. There are no recent surveys for unionids in the Grand River; however, there has been additional work on *Lampsilis fasciola* within this area of known distribution (see Table 2 and **Abundance**).

In the Grand River watershed, *Lampsilis fasciola* occurs along 77 km of the main stem from Inverhaugh (north of Waterloo) downstream to Glen Morris (south of Cambridge) (Figure 5). Live animals were found at every site surveyed within this section of the river. *Lampsilis fasciola* is also found in three tributaries of the Grand River: in the lower 13.5 km of the Conestogo River from approximately St. Jacobs to the confluence with the Grand River; a 10-km stretch of the Speed River and in a 30-km stretch of the Nith River between Drumbo and the confluence with the Grand. The average river width at sites occupied by *L. fasciola* is 63 m; therefore, the AO in the Grand River watershed is approximately 7.5 km^2 (Table 3). The IAO is 284 km^2 (2 km x 2 km grid) or 158 km^2 (1 km x 1 km grid) (Table 4).

Great Lakes and Connecting Channels.

It appears that *Lampsilis fasciola* was never a major component of the unionid fauna of the Great Lakes themselves. The Wavy-rayed Lampmussel was reported from western Lake Erie in 1967 and 1980, but it was not found during a survey of 17 sites in 1991 by Schloesser and Nalepa (1994) (Figure 4). In the Detroit River, Schloesser *et al*. (1998) SCUBA surveyed 13 sites in 1982-83 using transects and quadrats, 17 sites in 1992 and nine sites in 1994 and found no Wavy-rayed Lampmussels. A single live Wavy-rayed Lampmussel was collected in a ponar grab in the St. Clair River near Sarnia in 2001 (Figure 5). This is the only animal ever collected from the St. Clair River and there have been no current or historic surveys for unionids in this river. It is possible that a small remnant population remains; however, given the current state of dreissenid infestations in these major connecting rivers of the lower Great Lakes it is unlikely that a significant and viable population exists.

Nalepa *et al.* (1996) surveyed 29 sites in Lake St. Clair in 1986, 1990, 1992 and 1994 and found only one live specimen of *L. fasciola* in 1986 and one in 1994. Zanatta *et al.* (2002) surveyed 95 sites in Lake St. Clair between 1998 and 2001. Live unionids were found at 33 of these sites including a total of 19 live Wavy-rayed Lampmussels at five sites. These sites tended to be shallow (< 1 m) with firm sandy substrates in the delta region. Metcalfe-Smith *et al.* (2004) did additional survey work in the delta region and detected five specimens at the five different sites. Based on these data it appears likely that the only significant lake population of the Wavy-rayed Lampmussel historically occurred, and still persists, in the St. Clair delta. The delta region may, in fact, support the most intact freshwater mussel community remaining in the lower Great Lakes and their connecting channels (Zanatta *et al*. 2002; McGoldrick *et al*. 2009).

Lampsilis fasciola continues to persist in 12 km^2 of the shallow nearshore areas of the delta within the territory of the Walpole Island First Nation (Figure 5); however, 12 km^2 is not an appropriate AO for *L. fasciola* because it was only found at a few sites. The AO was therefore calculated as follows using data from Metcalfe-Smith *et al*. (2004): the total area of lake bottom searched at the nine sites surveyed was 14,560 m^2. *Lampsilis fasciola* was found at four sites where the total area searched was 6,760 m^2, or about 46% of the total area searched. Assuming that these sampling sites are representative of the entire area of habitat, *L. fasciola* occupies 46% of the area or 5.5 km^2 (Table 4). The IAO is 24 km^2 (2 km x 2 km grid) or 8 km^2 (1 km x 1 km grid) (Table 4).

Number of locations

In summary, Wavy-Rayed Lampmussel is found in one lake and associated river (Lake St. Clair delta and St. Clair River) and four other watersheds: Ausable, Grand, Maitland, and Thames rivers; each is a separate population (see **Population Spatial Structure and Variability** and **Dispersal and Migration)**. Some of the populations occupy tributaries (subwatersheds) of the main rivers. There are a total of 12 locations (Table 5; Figures 6 through 10), defined on the basis of the predominant threat (see **THREATS AND LIMITING FACTORS**) and the configuration of subwatersheds.

Table 5. Summary of populations, locations, and threats to Wavy-rayed Lampmussel in Canada. Each watershed is a separate population. Locations are defined by the configuration of the subwatershed and presence, severity, and certainty of threats.

Watershed (population)	Tributary or subwatershed (each row is a location)	Cause of inferred, declining water quality		Dreissenid mussels
		Urban	Agriculture	
Lake St. Clair	St. Clair River and delta	x	x	xxx
Ausable River	Ausable River (including Little Ausable record)	x	xxx	
Grand River	main stem (including Speed River record)	xxx	xx	x
	Conestogo River		xxx	x
	Nith River		xxx	
Maitland	main stem (including Middle Maitland River)	x	xxx	
	South Maitland River		xxx	
	Little Maitland River	x	xxx	
Thames	North Thames River	x	xxx	xx
	Fish Creek (North Thames)		xxx	
	Medway Creek (North Thames)	xxx	xx	
	South and Middle Thames rivers	xx	xxx	xx

x – low, possible or impending future threat
xx – medium, current threat but not most significant
xxx – high, current significant threat

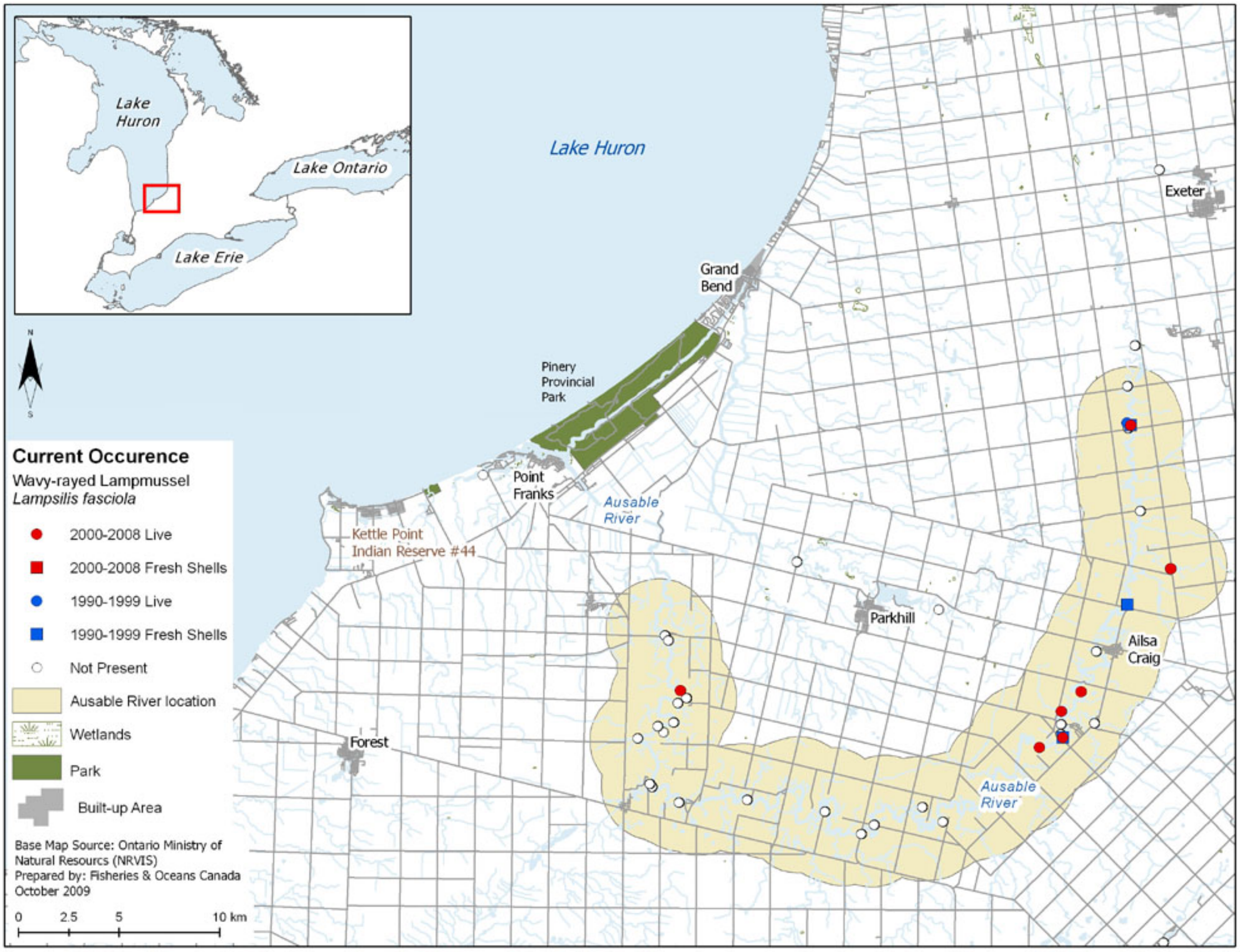

Figure 6. The single location of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in the Ausable River watershed.

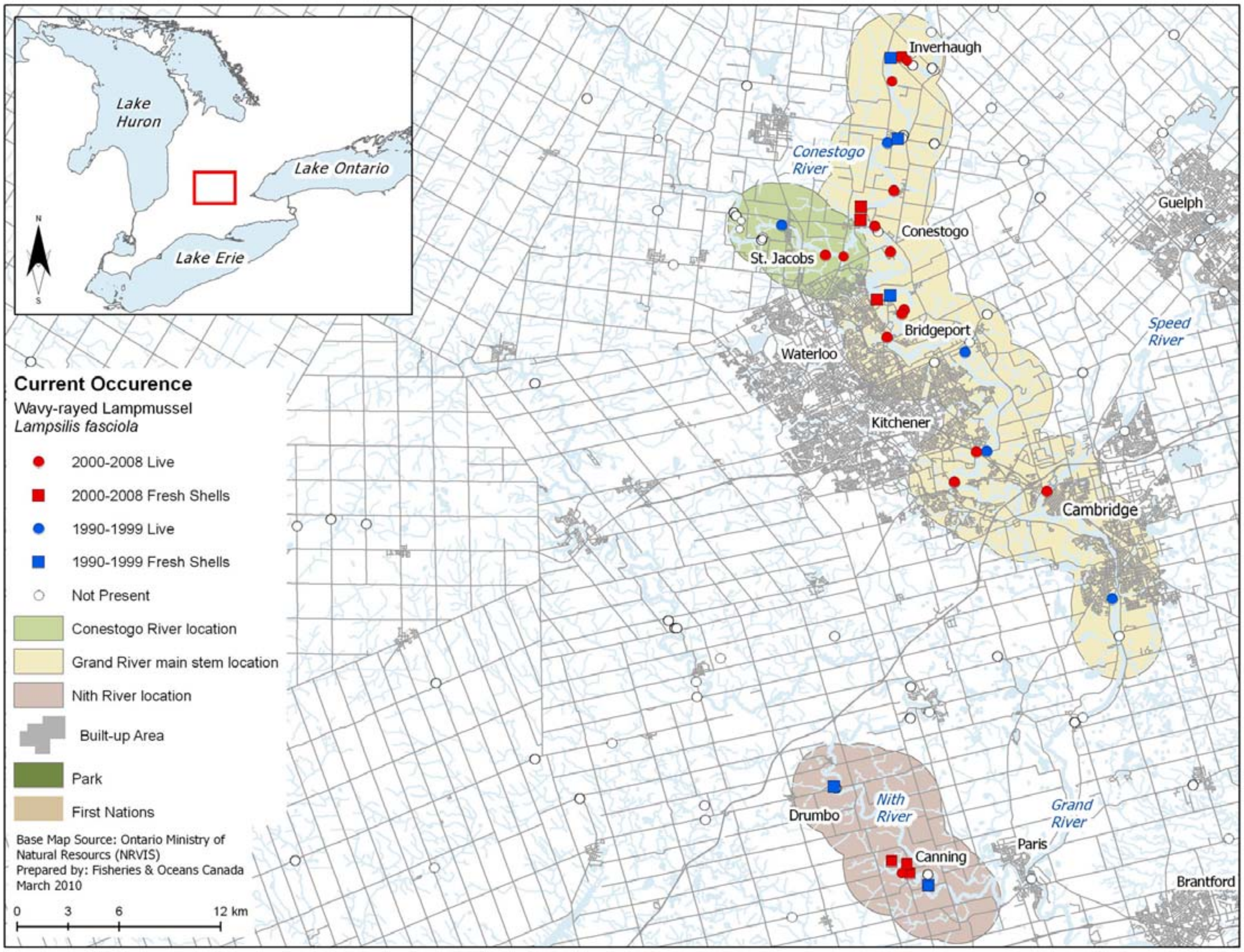

Figure 7. The three locations of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in the Grand River watershed.

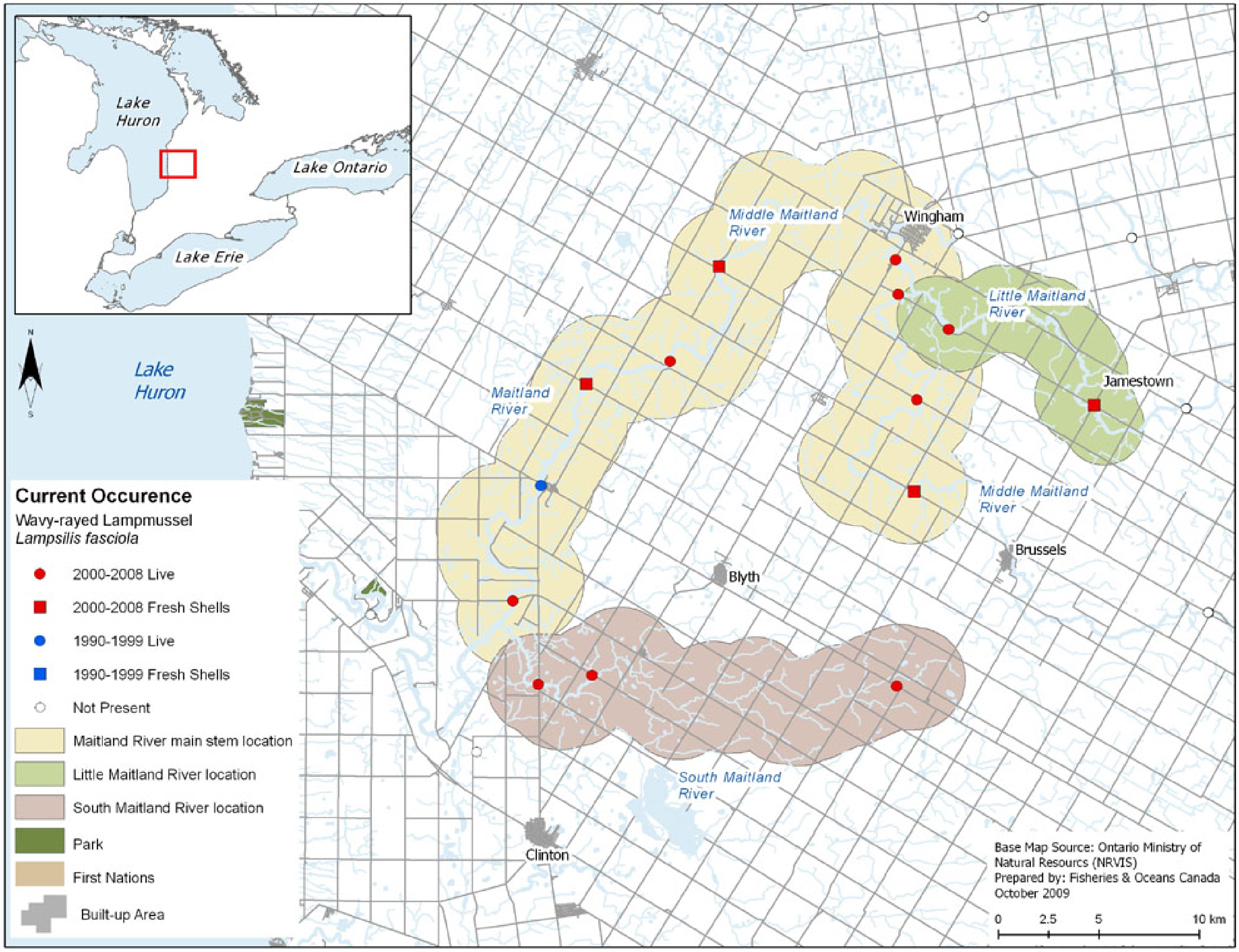

Figure 8. The three locations of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in the Maitland River watershed.

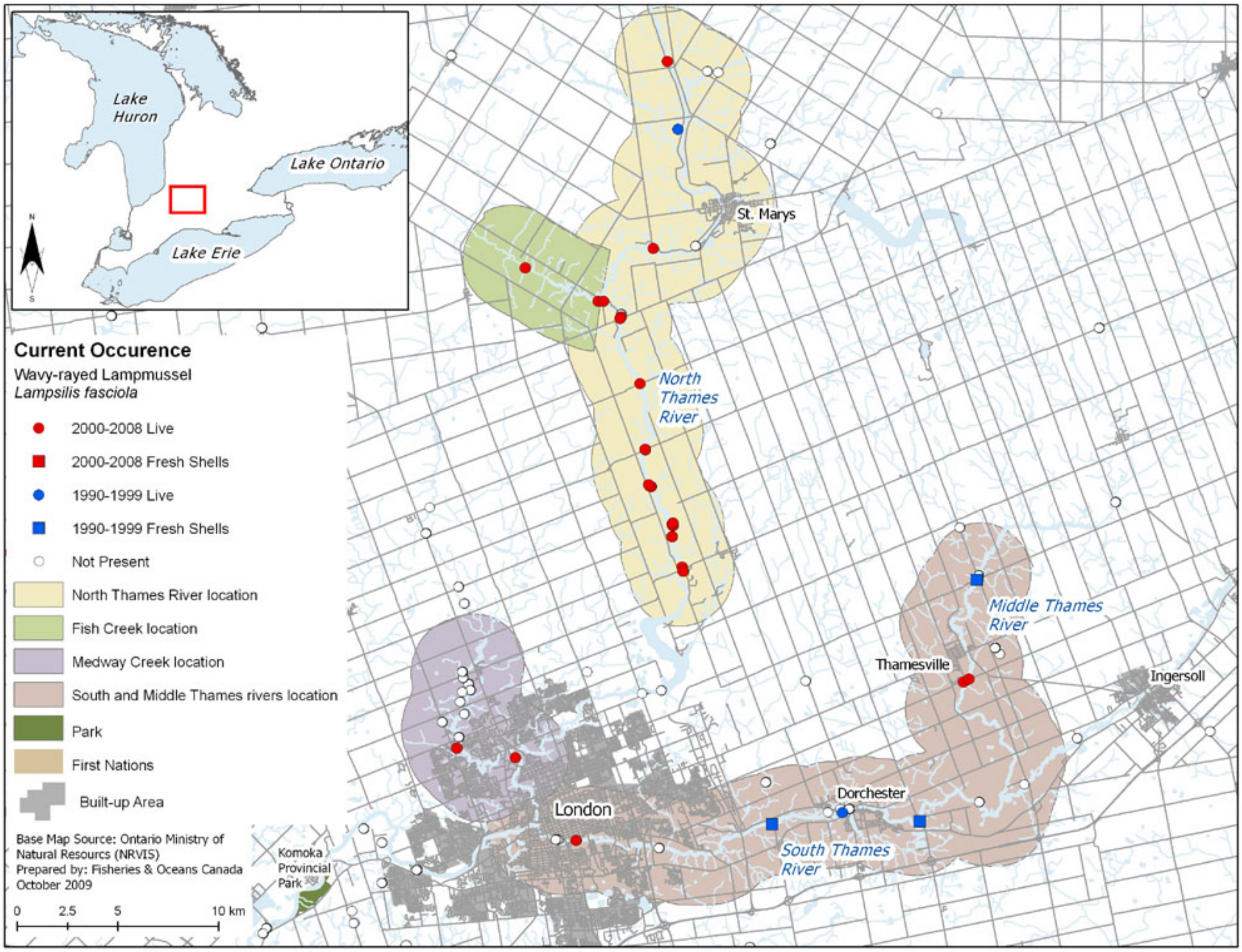

Figure 9. The four locations of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in the Thames River watershed.

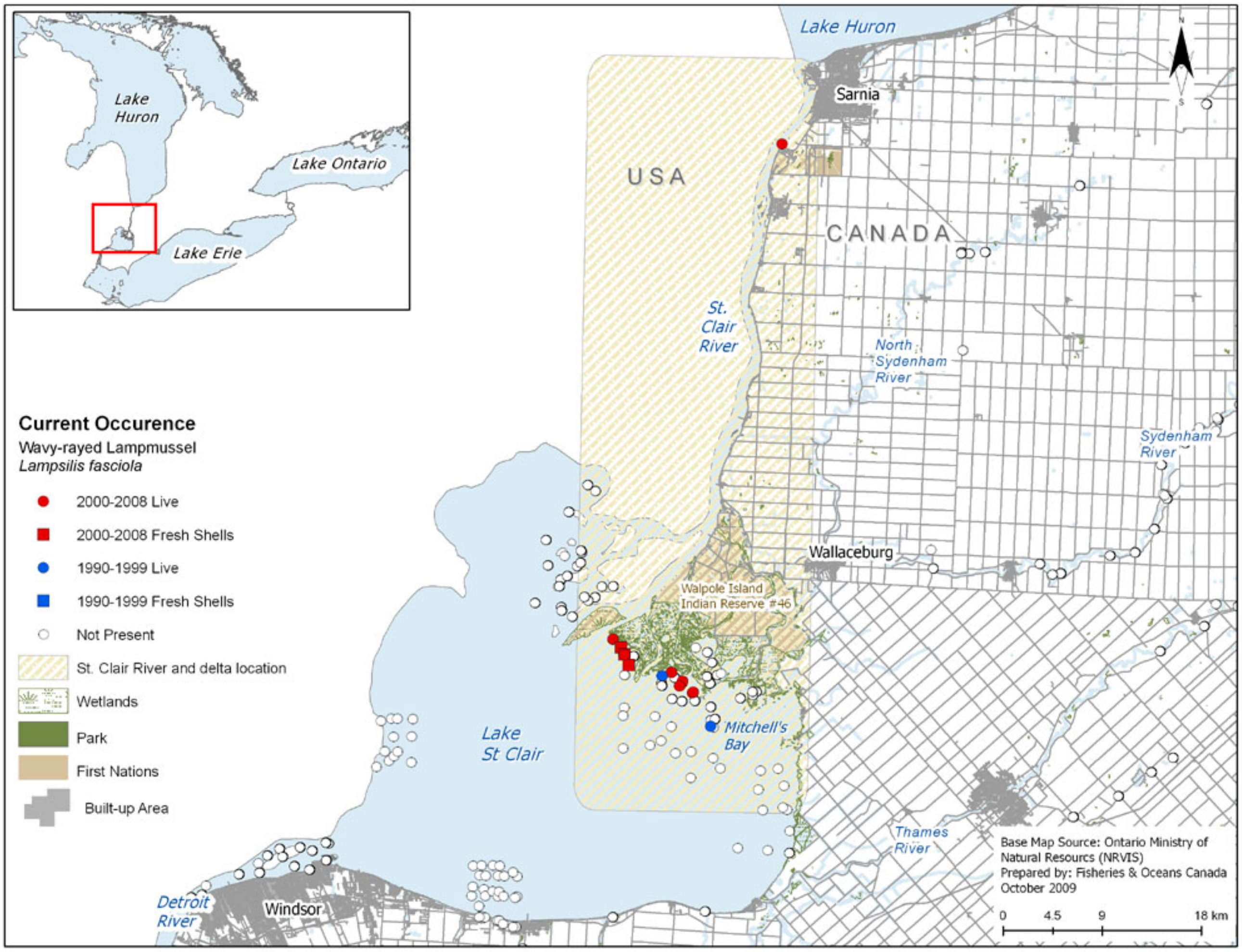

Figure 10. The single location of the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in the St. Clair River and Lake St. Clair watershed.

Dreissenid mussels are a dominant threat only for the St. Clair River and delta location. For the other 11 locations, threats are related to habitat degradation and loss through a combination of agricultural and urban activities as described below and in Table 5. Given that these animals occur in flowing systems, threats are likely to act in a linear and downstream manner. Therefore the extent of a location is based on the flow patterns of the occupied stream reach and the threats. A threat within a given reach has the potential to affect animals downstream of the threat but not upstream. Thus, the maximum extent of each location is the subwatershed boundary (mostly quaternary watersheds) with break points at confluences with other subwatersheds or the main branch. As the major threats relating to habitat degradation and loss are diffuse it is somewhat difficult to define the minimum extent of a location as a threat could in theory act at an extremely small scale (i.e., a reach or site). Because it is possible to detect water quality differences at the subwatershed scale, the subwatershed is the minimum extent of a location. This approach assumes that the threat acts equally throughout the subwatershed.

HABITAT

Habitat requirements

According to Clarke (1981) and Cummings and Mayer (1992), *Lampsilis fasciola* live mainly in gravel or sand bottoms of riffle areas in medium-sized streams. Strayer and Jirka (1997) reported that *L. fasciola* typically lives in and around riffles in clear, hydrologically stable (i.e., having steady flows and stable substrates) rivers and large creeks. In southeastern Michigan, Strayer (1983) found this species in medium-sized and large streams on the outwash plains. Such streams are characterized by low gradients, clear water, steady flows, and substrates of sand and gravel. Dennis (1984) examined recent and historic mussel records for the Tennessee River basin, including her own data from comprehensive surveys conducted between 1973 and 1981, and determined the stream size and habitat associated with each of the 72 species. *Lampsilis fasciola* was typical of small to medium-sized streams, defined as 2^{nd} to 7^{th} order. In both environments, the most productive areas for mussels of all species were shoals with stable substrates consisting of mixtures of fine particles, gravel and rocks. *Lampsilis fasciola* and two species with which it frequently co-occurred (*Elliptio dilatata* [Spike] and *Lasmigona costata* [Flutedshell]) were found to "…commonly inhabit muddy gravel substrates in areas of moderate to slow current, and will tolerate some silt deposition during periods of low flow" (Dennis 1984).

The recovery strategy for the Wavy-rayed Lampmussel in Canada (Morris 2006) agrees with this habitat description and identifies the functional habitat requirements as:

- permanently wetted and
- of a stream order greater than two (riverine populations only) and
- having clean sand/gravel substrates sometimes stabilized by larger material (rubble, boulder or bedrock) and
- riffle/run habitat (riverine populations only) or
- shallow sand flats (Great Lakes populations).

Habitat Trends

The habitat for the Wavy-rayed Lampmussel has undergone a variety of changes over the last several decades. The most significant habitat change is associated with the invasion of the dreissenid mussels (*Dreissena polymorpha*, Zebra Mussel and *D. rostiformis*, Quagga Mussel) in the mid-1980s. Dreissenid mussels compete with native unionids for space and food and, by attaching directly to native mussel shells, impair the ability of the native mussels to feed, respire and move normally (see **THREATS AND LIMITING FACTORS**). Within about a decade of the first invasion, native unionids had been almost completely eradicated from Lake St. Clair, Lake Erie and the Detroit and Niagara rivers (Schloesser and Nalepa 1994; Nalepa *et al*. 1996; Schloesser *et al*. 2006). Approximately 15% of historic Wavy-rayed Lampmussel records in the Lower Great Lakes Unionid Database were from areas that have been negatively impacted by dreissenid mussels, areas where unionids are considered essentially extirpated. Despite these catastrophic effects, there are still areas where dreissenid mussels occur in sufficiently low densities to allow coexistence with unionids, such as the St. Clair delta (Zanatta *et al*. 2002). Strayer and Malcom (2007) suggested the potential for continued coexistence in areas where the impacts of dreissenids are more related to competition for food (e.g., the Hudson River in New York) than to biofouling.

Habitat trends for riverine populations are difficult to assess as there are few historic records. The general conditions for unionids in these watersheds are summarized below.

The habitat trends in the Maitland and Ausable rivers, based on descriptions in COSEWIC (2006a), are as follows. Although there have been some minor impacts from urban and industrial expansion, these are greatly overshadowed by technological changes in the agricultural industry. Typical farming in the 1960s and 1970s focused on pasture and hay crops. Small grains were rotated through the grass fields and corn was grown on the better lands. An extensive tile drainage system was installed during the 1970s. Better outlets were required to accommodate the improved drainage, which necessitated the installation or improvement of open drains, especially in wetlands. There was also a move towards larger farm implements in the 1970s and this required the expansion of field size through the clearing of fence lines/hedgerows and the straightening of field edges. It is now possible to grow corn and beans on lands that had only been suitable for grazing and hay in the past. The amount of row cropping greatly expanded through the 1980s as improved seed varieties were developed. The overall impact of these technological changes would have resulted in more nutrients, pesticides and sediment entering watercourses through run-off. As land prices increased due to improved crop values, there was also a move towards cattle feedlots. Factory farming for hogs expanded significantly in the 1990s. These two changes resulted in fewer livestock having access to watercourses, but there were now new impacts in the form of liquid manure applications on tiled crop lands. Environmental programs introduced to keep pace with these changes have had some success through efforts in conservation tillage, watercourse rehabilitation (fencing livestock and reforestation) and most recently with nutrient management.

Habitat trends for the Ausable River watershed are summarized from Nelson *et al*. (2003). Mussel habitat in the Ausable River has been dramatically altered over time. Prior to European settlement, 80% of the basin was covered in forest, 19% was in lowland vegetation and 1% was marsh. By 1983, 85% of the land area was agricultural (70% in row crops), and only 13% remained in small unconnected woodlots. Over 70% of the basin is now in tile drainage. The natural course of the lower portion of the river was destroyed in the late 1800s, when it was diverted in two places to alleviate flooding. The Ausable River has been described as “event responsive”, which means that there are large increases in flow during runoff events following storms. In contrast, the nearby Sydenham, Thames and Maitland rivers are more stable (Richards 1990). There are 21 dams in the watershed that cause sediment retention upstream and scouring downstream. Water quality data collected since 1965 show that total phosphorus levels are consistently above the Provincial Water Quality Objective and have decreased only marginally over the past 35 years. Nitrate levels currently exceed federal guidelines for the prevention of eutrophication and the protection of aquatic life and are slowly rising. Mean total suspended solid concentrations in the lower Ausable River exceed levels required for healthy aquatic life.

The Sydenham River flows through an area of prime agricultural land in southwestern Ontario. Over 85% of the land in the watershed is agricultural, with 60% of land in tile drainage (Dextrase *et al.* 2003). Large areas of the river have little to no riparian vegetation as only 12% of the original forest cover remains. Strayer and Fetterman (1999) identified high sediment and nutrient loads and toxic chemicals from non-point sources, especially agriculture, as the primary threat to riverine mussels. Agricultural lands, particularly those with little riparian vegetation and large amounts of tile drain, allow large inputs of sediments into the watercourse. In tile drained land, the sediment is often very fine grained that can clog the gills of mussels and result in decreased feeding and respiration rates and reductions in growth efficiency. The Sydenham River has had high nutrient levels with total phosphorus consistently exceeding provincial water quality standards over the last 30 years while chloride levels have shown recent increases due to increased use of road salt (Dextrase *et al.* 2003). Human population pressure within the watershed is low as the total population is less than 90,000 with roughly half occurring in urban settings. Although the watershed is not highly populated, the lower portion of the river is subject to commercial shipping activities that tend to fluctuate in response to economic conditions.

Habitat trends for the Thames River watershed are summarized from Taylor *et al*. (2004). Agriculture is the dominant form of land use in the Thames River watershed, with 78% of the land area in the upper Thames and 88% in the lower Thames in agriculture. Forested areas have been reduced to 12% of the land area in the upper Thames and 5% in the lower Thames. Eight percent of the watershed is classified as urban, with concentrations in the cities of London (population 350,000), Stratford and Woodstock in the upper watershed and Chatham in the lower watershed. As the land was cleared, flooding became a serious problem. Three large dams and reservoirs were constructed in the upper watershed between 1952 and 1965. Numerous private dams and weirs have been installed since the 1980s and there are now 173 structures in the upper watershed and 65 in the lower watershed. Zebra Mussels were discovered in Fanshawe and Springbank reservoirs in 2003 and have since spread downstream where they were found attached to native mussels in 2004 (Morris and Edwards 2007). Fortunately, these two reservoirs are located downstream of the existing populations of the Wavy-rayed Lampmussel. Should Zebra or Quagga mussels become established in either Pittock or Wildwood reservoirs, located above the occupied reach, they could pose a significant threat to the Thames River population. The extent of tile drainage in the watershed is not known. Water quality data collected since the 1960s show that concentrations of phosphorus and heavy metals are declining while nitrate and chloride levels are on the rise. The upper Thames River where the Wavy-rayed Lampmussel occurs is moderately turbid, while the lower Thames is highly turbid. Soil conservation remains a serious issue in the watershed.

Mussel communities in the Grand River are among the most well studied in Canada and there is abundant evidence indicating that these communities have undergone a significant decline and subsequent recovery over the last 35 years (Kidd 1973; Mackie 1996; Metcalfe-Smith *et al*. 2000). When Kidd (1973) sampled the river (115 sites between 1970-72) he reported only 17 of the 31 species historically known from the river. He attributed much of this loss to impaired water quality related to agricultural activity and habitat fragmentation from dam construction. Mackie (1996) indicated that anthropogenic stressors, particularly below urban centres, were likely driving the species declines. Metcalfe-Smith *et al*. (2000) surveyed 94 sites over a four-year period and found 25 species, representing a 50% increase in species richness compared with Kidd's (1973) results from 25 years earlier. Much of the improvement in mussel communities of the Grand River was related to improved water quality and the addition of fish ladders, which allows dispersal through host fish movement and reconnection of formerly fragmented habitat (Metcalfe-Smith *et al*. 2000).

In summary, there is an inferred continuing decline in the habitat quality in all five watersheds occupied by Wavy-rayed Lampmussel: Lake St. Clair and the Maitland, Ausable, Thames, and Grand rivers although there has been some recent improvement, especially in the Grand River (see also **THREATS AND LIMITING FACTORS**). Runoff from agriculture and urban development contribute to habitat degradation and loss. Some changes in agricultural practices and sewage treatment have improved some water quality parameters but other parameters are consistently above water quality objectives.

BIOLOGY

Freshwater mussels like the Wavy-rayed Lampmussel are long-lived, relatively sedentary filter-feeders. Heller (1991) reports lifespans for the Lampsilini of approximately 20 years while Morris *et al.* (2009) report a maximum age of 32 years for *Lampsilis fasciola* in Canada with the median age of the Grand and Thames river populations being seven and 11 years respectively (see also <u>Size and Age Class Distribution)</u>.

Freshwater mussels have a complex reproductive cycle involving a period of obligate parasitism on a vertebrate host. Juvenile mussels are believed to burrow completely below the substrate surface where they will spend the first 3-5 years of life (Balfour and Smock 1995; Schwalb and Pusch 2007). During this time they are likely feeding on a combination of detritus, algae and bacteria obtained from the interstitial pore water or through pedal feeding (Wächtler *et al.* 2000) (pedal feeding occurs when juveniles drop off the host fish and scoop food particles into their mouth using the foot before the filters are fully developed). Adult mussels are found at the substrate surface during the summer, but are known to burrow below the surface during the winter likely in response to dropping water temperatures or changing flow regimes (Schwalb and Pusch 2007). Adults feed by filtering material from the water column but may also engage in some pedal feeding (Nichols *et al*. 2005). The following is based on published reports and personal observations of the status report writers.

Life cycle and reproduction

The life cycle of the Wavy-rayed Lampmussel is similar to that of all freshwater mussels. The following is adapted from Kat (1984), Watters (1999) and Nedeau *et al*. (2000). 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 (marsupial), where they are held until they reach a larval stage (glochidium). The female mussel releases the glochidia, which must attach to an appropriate host, usually a fish. The glochidia become encysted on the host and feed on the host's body fluids until the larvae metamorphose into juveniles—a process that can last from a few weeks to several months. 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 per female. 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). Sexual maturity of Wavy-rayed Lampmussel in the Grand and Thames rivers occurs at 3–4 years (Morris *et al*. 2009) (see also Size and Age Class Distribution).

Wavy-rayed Lampmussels are reportedly bradytictic (long-term brooders); that is, they spawn in mid- to late summer, brood glochidia over winter, and release them the following summer (Clarke 1981). In a study of the Thames and Grand river Wavy-rayed Lampmussel populations in 2008, Morris (unpubl. data) found gravid, displaying females at the substrate surface continually from May 15th through September 24th although abundance showed two distinct peaks. These peaks occurred in late May to early June (peak one) and early to late July (peak two) although both peaks occurred earlier in the Grand River. Females typically appeared in one peak or the other but not both—only 18% of Grand River females and 27% of Thames River females were common to both peaks. Male abundance at the surface peaked during late June just prior to the second female peak. At this time male abundance was approximately 3–4 times higher than at other points during the sampling period. It is likely that males are coming to the surface to release sperm during this time period.

The glochidia are small (mean height = 302 µm, mean length = 246 µm; mean hinge length = 112 µm) and lack hooks indicating they are likely acting as gill parasites (Figure 11) (Morris *et al*. 2009). McNichols (2007) reported a mean number of glochidia per female of 34,192 with a range of 6075–76,667. Glochidial hosts for the Wavy-rayed Lampmussel in Canada, as identified through laboratory infestations (McNichols *et al*. 2004), include: Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*M. salmoides*), Mottled Sculpin (*Cottus bairdii*) and Brook Stickleback (*Culaea inconstans*).

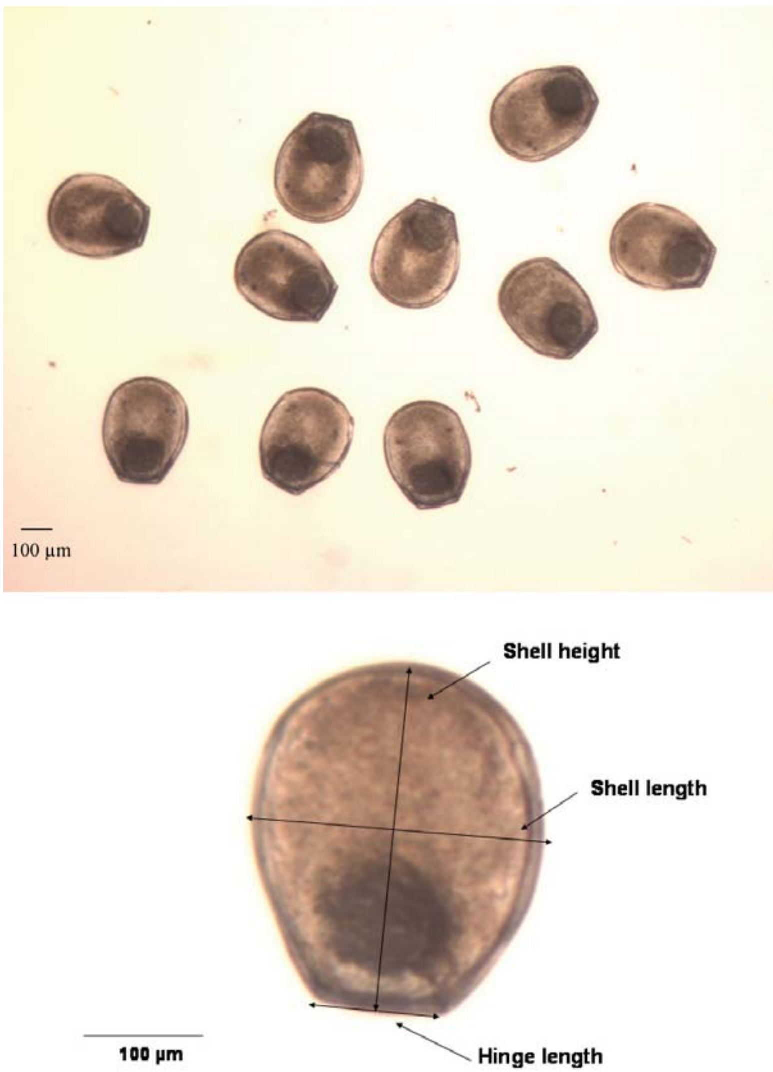

Figure 11. Glochidia of *Lampsilis fasciola*. (Photo credit: T. Morris, Fisheries and Oceans Canada)

The functional host(s) of *Lampsilis fasciola* in the wild are most likely visual predators (i.e., bass), as female *L. fasciola* have developed a specialized “lure” to attract suitable hosts and facilitate the infestation of the fish with glochidia. The report writers have observed at least four distinct lure morphs in female *L. fasciola* in Ontario (Figure 12). One lure morph is completely black; one is completely orange or red; another effectively mimics a small fish—complete with eyespots, lateral line and tail; and the fourth, termed a flamboyant attractor, is similar to the fish lure but lacks much of the complex pigmentation. All four lure morphs occurred within single beds in the Grand and Thames rivers (Morris unpubl. data). When a fish strikes at the lure the suction caused by the striking fish causes the water tubes of the female mussel’s gills to rupture thus releasing a pulse of glochidia, some of which attach themselves and encyst within the gills of the fish (Barnhart *et al.* 2008).

Figure 12. Typical examples of mantle diversity in the Wavy-rayed Lampmussel (*Lampsilis fasciola*): (A) orange, no appendages, no eyespot; (B) hellgrammite-like, dark, generally patternless dorsum contrasting with lighter sides (sublateral), dark pigment extends lobe-like into lighter area, lacks eyespot, simple appendages; (C) darter-like variants, midlateral spots, often with dorsal spots, simple appendages, distinct eyespot; (D) other variable fish-like or crayfish-like display, “flamboyant attractor”, gaudy colors and patterns, some compound (branched) appendages, eyespot present but not well-defined (Morris *et al.* 2009).

Predation

Predation by Muskrats is a potential limiting factor for some mussel species. For example, in the Tippecanoe River, Indiana, Muskrat predation appeared to be a major cause of death for the endangered Clubshell (*Pleurobema clava*) at many sites, based on numerous shells in middens (USFWS 1994). Similarly, in the Tennessee River drainage, Muskrat predation seems to be inhibiting the recovery of endangered mussel species and likely contributing to further population declines (Neves and Odum 1989). Historically, Muskrat predation probably had little, if any, effect on healthy mussel populations; however, similar levels of predation today pose a serious threat to endangered species already reduced to low densities and isolated by anthropogenic impacts (Neves and Odum 1989). Consequently, the removal of Muskrats has been undertaken at some U.S. sites identified as important refugia for endangered mussels (Tolin pers. comm. 1998). Muskrat predation could potentially be a severe threat to small populations of *L. fasciola* because Muskrats tend to prey on mussels with shell lengths of about 45-65 mm (Convey *et al.* 1989; Neves and Odum 1989) or up to 70-120 mm (Watters 1993-1994). Muskrats even preferred *L. fasciola* over other mussels (Neves and Odum 1989): during an 8-year period, they consumed 47% of adult *L. fasciola* from a site on the North Fork Holston River, Virginia, in contrast to only 9-24% of adults of other species.

Physiology

No specific studies on the physiology of the Wavy-rayed Lampmussel have occurred. In general, freshwater mussels of the family Unionidae are good indicators of overall ecosystem health and are particularly sensitive to heavy metals (see **THREATS AND LIMITING FACTORS**).

Dispersal and migration

There are no specific studies on movement of adult Wavy-rayed Lampmussels. In general, adult mussels have limited dispersal abilities and, although adult movement can be directed upstream or downstream, studies have found a net downstream movement (Balfour and Smock 1995; Villella *et al*. 2004). Small-scale movements on the order of centimetres per week have been reported by Amyot and Downing (1998) for *Elliptio complanata* (Eastern Elliptio); however, the primary means for large-scale dispersal, upstream movement, and the movement into novel habitats is limited to the encysted glochidial stage on the host fish. Infected host fishes can transport larval unionids into new habitats and replenish depleted populations with new individuals. Dispersal is particularly important for genetic exchange among populations (Nedeau *et al*. 2000).

In a study of the relationship between the Wavy-rayed Lampmussel and its glochidial host in the upper Grand River, Morris and Granados (2007) determined that *L. fasciola* glochidia (identified using a microscope and a multivariate analysis of shell morphology) occurred at relatively low densities in the drift (mean of < 0.08 animals per m^3) but abundance showed a seasonal trend peaking at all three stations between mid-July and late August. This low glochidial abundance in the drift is consistent with the expectations from a species that uses a mantle lure. Glochidia of luring species are generally released in close proximity to the host and would not require an extended period of buoyancy in the water column to permit host attachment. Simulated releases of Wavy-rayed Lampmussel glochidia in southern Ontario resulted in downstream drift of only 20–30 m on average with less than 1% travelling distances greater than 64 m (Schwalb pers. comm. 2009). These results indicate that little dispersal occurs during the process of encystment.

Morris and Granados (2007) also examined glochidial infestation rates on Smallmouth Bass (which can be abundant in river reaches), captured over beds containing Wavy-rayed Lampmussels and reported relatively high infestation levels. Thirty-four percent of all Smallmouth Bass showed signs of glochidial infestation with intensity ranging from 1 to 196 glochidia per fish. They also sampled larger Smallmouth Bass targeted by anglers during a bass derby and found an infestation rate of 47%. The distance fish move while carrying encysted glochidia is unknown; however, this period offers the greatest chance for active dispersal. Bunt *et al*. (2002) report a tagged Smallmouth Bass from the reach of the Grand River where Wavy-rayed Lampmussels occur moved from the area near Doon Heritage Crossroads downstream to Paris and then up the Nith River as far as Ayr: a total distance of nearly 100 km. Typical movements are smaller (2-10 km; Scott and Crossman 1998).

The total population of Wavy-rayed Lampmussels in Canada is fragmented. Dreissenid mussels have made intervening habitats between watersheds occupied by Wavy-rayed Lampmussels largely uninhabitable and host fish movement between watersheds is unlikely. Thus the probability of natural recolonization from one watershed to another, should Wavy-rayed Lampmussels be extirpated from a watershed, is extremely low. This means each watershed is a separate population (also see **Population Spatial Structure and Variability, Number of Locations,** and **Rescue Effect**).

Interspecific interactions

Larval (glochidia) Wavy-rayed Lampmussels are obligate parasites on vertebrate hosts. These hosts are believed to be Smallmouth and Largemouth bass. Freshwater mussels of the Great Lakes region have been severely and negatively impacted by the invasive dreissenid mussels *D. polymorpha* and *D. rostiformis* (see **Habitat Trends** and **THREATS AND LIMITING FACTORS**).

Adaptability

The Wavy-rayed Lampmussel is reported to have fairly broad habitat tolerances (see **Habitat Requirements**) both in terms of flow and substrate preferences, suggesting they may be able to tolerate some environmental change. However, the sedentary nature of adult freshwater mussels, general sensitivity to water quality (see

THREATS AND LIMITING FACTORS) and host dependency may offset these broader habitat tolerances. Wavy-rayed Lampmussels have been successfully reared in captivity and may be artificially propagated for future recovery activities (Hanlon and Neves 2000). Results of mussel relocations from development activities on the Grand and Thames rivers (Mackie 2008) are not yet available.

POPULATION SIZES AND TRENDS

Sampling effort and methods

Timed-Searches

Timed-searches produce data on species presence/absence and provide relative measures of abundance. Metcalfe-Smith *et al*. (2000) describe the methods in detail but they can be summarized as follows. The riverbed is searched by a team (usually 3-5 individuals) for a period equal to 4.5 p-h (person-hours). Searches may be made by the naked eye when conditions are favourable or through polarized sunglasses, view boxes or even manually by searching the substrate when turbidity is high. Individual mussels are collected, held in mesh diver's bags until the end of the sampling period and then identified to species, sexed if possible, counted, measured, and finally returned to the same collection spot alive. Since 1997 these methods have been employed at 147 riverine sites within the Canadian range of the Wavy-rayed Lampmussel (Table 2).

Quadrat Excavations

Additional surveys have been conducted in the rivers of southwestern Ontario using a quadrat excavation method developed by Metcalfe-Smith *et al*. (2007) in an effort to establish long-term monitoring stations for unionids. With this method, an area of approximately 400 m^2 encompassing the most productive portion of the reach (as defined by previous sampling) is selected. Using a systematic sampling design with three random starts, the area is divided into 3 m x 5 m blocks and sampled using a 1 m^2 quadrat. Each quadrat is excavated to a depth of approximately 10 cm and all mussels removed. As with the timed-searches, individuals are identified, sexed if possible, counted and measured before being returned to the quadrat alive. This excavation approach allows for the determination of assemblage composition, total and species-specific density estimates, sex ratios, size frequencies and estimates of recruitment. To date, the quadrat methodology of Metcalfe-Smith *et al*. (2007) has been used at 31 riverine sites within the Canadian range of the Wavy-rayed Lampmussel (Table 2).

Other methods

The Wavy-rayed Lampmussel has been listed and protected under the *Species at Risk Act* since the *Act* came into force in June 2003. Occasionally development activities (e.g., bridge crossings, sewer/sanitary main crossings) have been allowed to proceed within the range of this species with a stipulation that all individual mussels be relocated prior to any in-stream activities. In these situations, the responsible jurisdiction —Fisheries and Oceans Canada—has employed a standardized protocol (Mackie *et al*. 2008), a combination of the quadrat and timed-search methods outlined above. To date there have been three such relocations involving the Wavy-rayed Lampmussel (Table 2).

Abundance

Quantitative surveys for freshwater mussels have now been conducted in all localities where *Lampsilis fasciola* currently occurs or was historically known to occur in Ontario. These quantitative surveys include targeted efforts designed to monitor recovery in the Sydenham (2001-2004) (Metcalfe-Smith *et al*. 2007), Thames (2004) (Morris unpubl. data), Ausable (2006-2008) (Baitz *et al*. 2008), Grand (2007) and Maitland rivers (2008) (Morris unpubl. data), and mussel relocations (e.g., Grand River [Mackie 2008]). All quantitative efforts involved complete survey of the mussel community, and population estimates should be considered free of the size and sex bias commonly associated with timed-searches. Population estimates from quantitative sampling (Table 4) indicate the Grand River supports the largest population in Canada while the Thames and Maitland river populations are similar to one another but an order of magnitude smaller than the Grand River. The Ausable River and St. Clair delta still support remnant populations two to three orders of magnitude smaller than the Grand River. These population estimates should be interpreted with caution as, in all cases except the St. Clair delta, they assume a continuous, homogenous distribution throughout the occupied reach, and sampling was usually done in the most productive areas of the reach. As such they likely represent a maximum population estimate.

Since 1997, semi-quantitative surveys have been conducted in the Ausable, Grand, Maitland and Thames rivers using the same timed-search method described previously. As method and effort were consistent in these surveys, the relative abundance based on the Catch per Unit Effort (CPUE) of *L. fasciola* in these four watersheds can be compared (Table 3). The largest population density occurs in the Grand River (CPUE = 0.37) followed by the Thames (CPUE = 0.30) and Maitland rivers (CPUE = 0.22). Only two live animals were found in these surveys of the Ausable River (CPU = 0.017) and the Lake St. Clair delta supports a small and sparse population (density = 0.0006 animals/m^2). It is unclear whether the populations in the Ausable River and Lake St. Clair are viable although they appear to be reproducing (see next section).

<u>Size and Age Class Distribution</u>

Length frequency distributions, based on maximum shell length, are provided by sex for *L. fasciola* from the Grand (Figure 13) and Thames (Figure 14) rivers. For each population, animals from a wide range of size classes are represented and the shell lengths appear to be approximately normally distributed. Length frequency distributions have not been presented for the remaining populations due to small sample sizes. However, even for these smaller populations, samples have produced individuals of multiple size classes indicating recent reproduction (Table 6). The reproductive status of the Lake St. Clair population is less certain. Even though the Lake St. Clair samples do not include excavation which would typically produce representatives of the smaller size classes, the length frequency distribution for *L. fasciola* from Lake St. Clair is smaller in comparison to the other riverine populations (Table 6). This is likely because freshwater mussels tend to grow rounder and shorter in sheltered areas such as lakes and reservoirs than in moving water (Green 1972; Bailey and Green 1988).

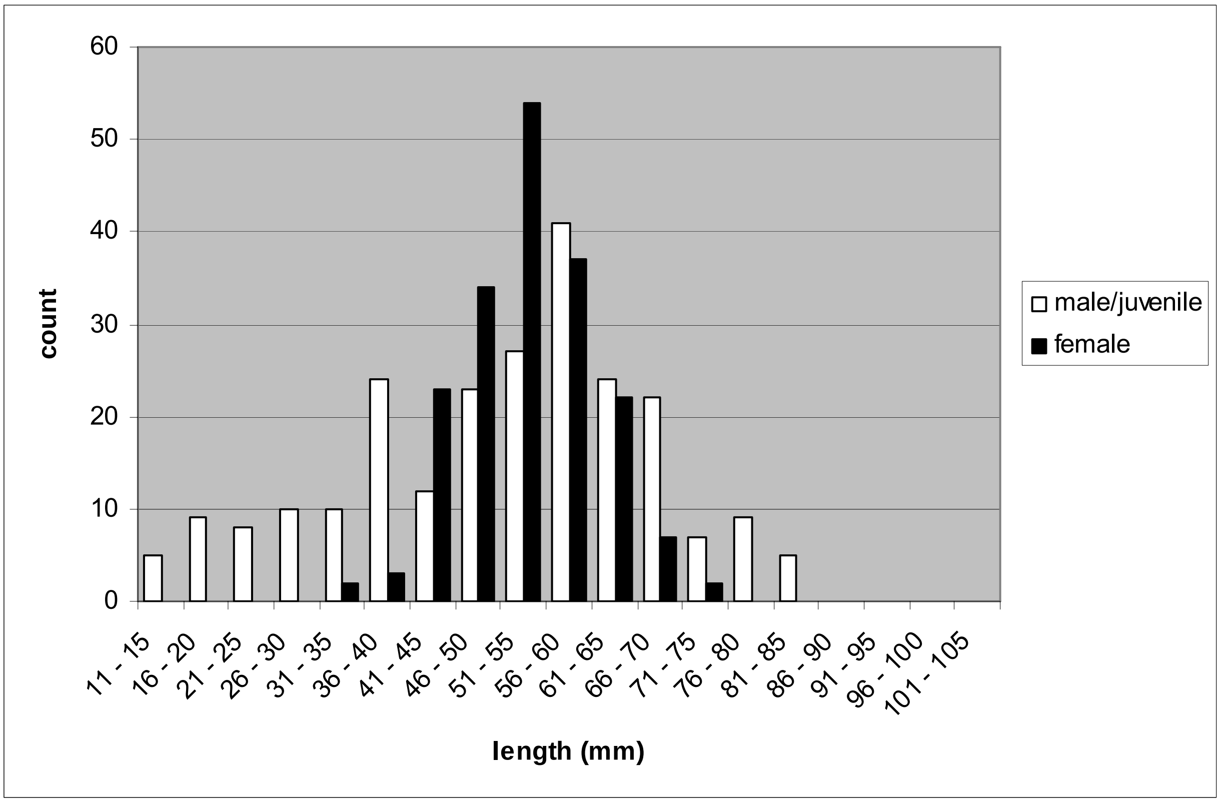

Figure 13. Size class distribution of *Lampsilis fasciola* collected from the Grand River between 1997 and 2008. Male category includes juveniles (Morris *et al*. 2009).

Table 6. Shell length for *Lampsilis fasciola* populations from the Ausable and Maitland rivers and Lake St. Clair delta. Ausable and Maitland river samples include excavation studies while Lake St. Clair samples do not.

Population	sample size	mean (SE)	minimum	maximum
Ausable (male/juvenile)	13	53.7 (4.89)	22	80
Ausable (female)	5	59.4 (7.35)	45	83
Maitland (male/juvenile)	11	52.3 (5.34)	29	79
Maitland (female)	13	57.8 (3.19)	39	77
Lake St Clair delta (male/juvenile)	5	51.0 (2.66)	46	61
Lake St Clair delta (female)	10	48.0 (2.64)	35	59

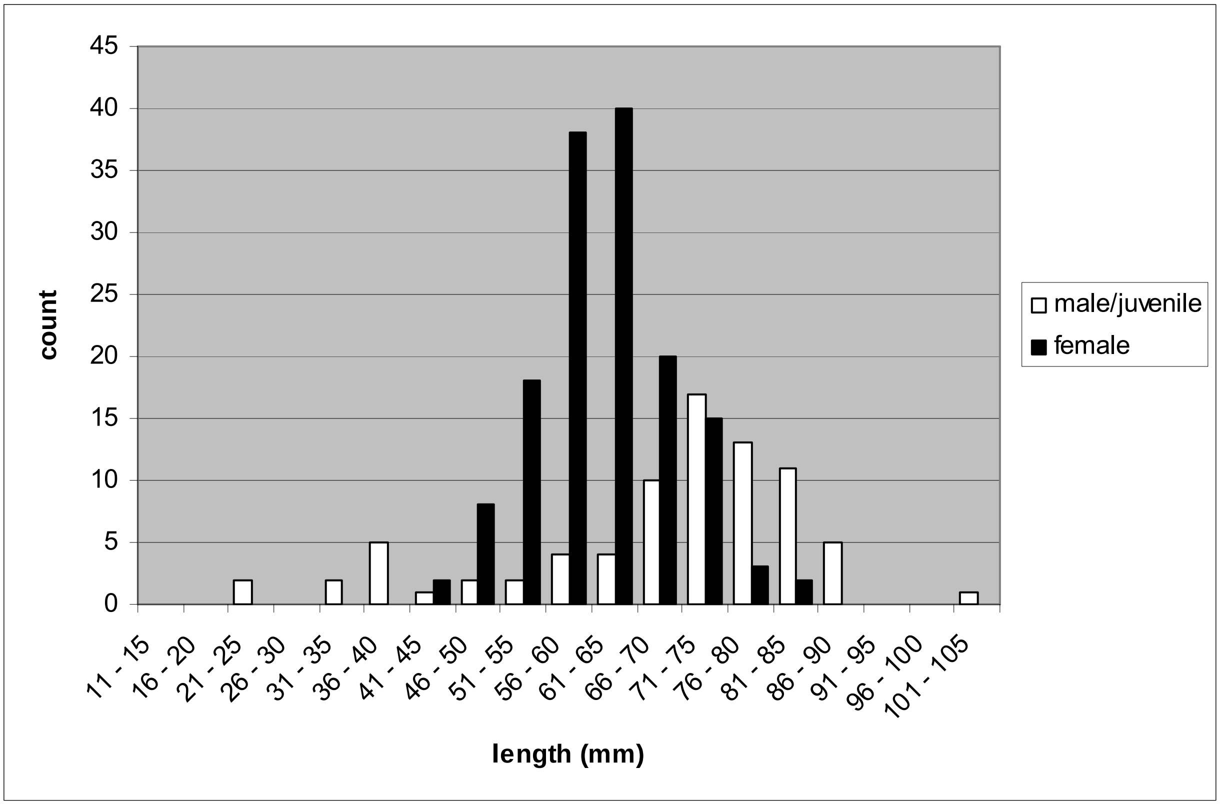

Figure 14 Size class distribution of *Lampsilis fasciola* collected from the Thames River between 1997 and 2008 (Morris *et al*. 2009).

Morris (unpubl. data) has developed length-at-age curves for *L. fasciola* males and females from the Grand and Thames rivers following the methods of Neves and Moyer (1988). Age structure differs between the two populations (Figures 15 and 16). Although both populations have a skewed normal distribution, the median age of Thames River animals (11 years) is approximately 4 years older than the Grand River population (7 years). In general there is a wider age distribution in the Thames River; however, the maximum ages are similar in both watersheds. In both rivers it appears that females can be readily discerned from males by about 3-4 years old. Shell morphology, a result of the brooding behaviour and luring of host fishes with the mantle flaps, allows sexual differentiation and suggests that females are reproductively active by this time (Morris *et al*. 2009).

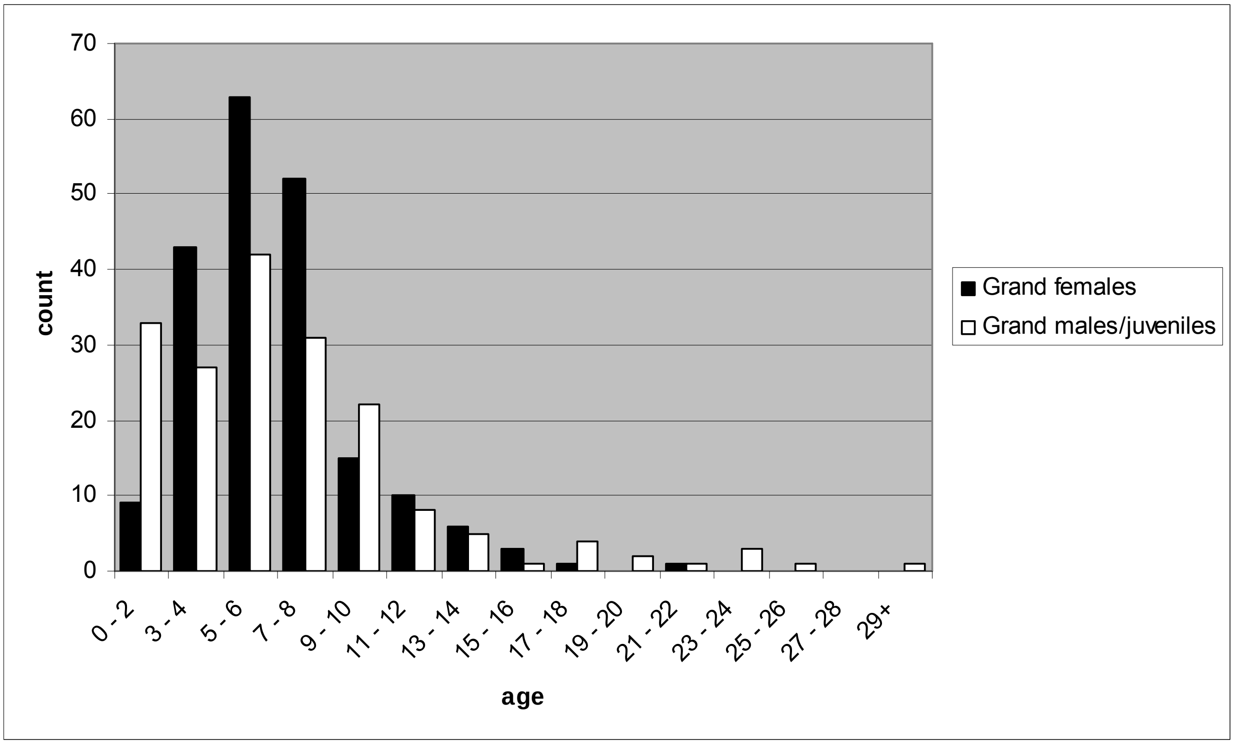

Figure 15. Age distribution of *Lampsilis fasciola* collected from the Grand River between 1997 and 2008. Male category includes juvenile animals (Morris *et al*. 2009).

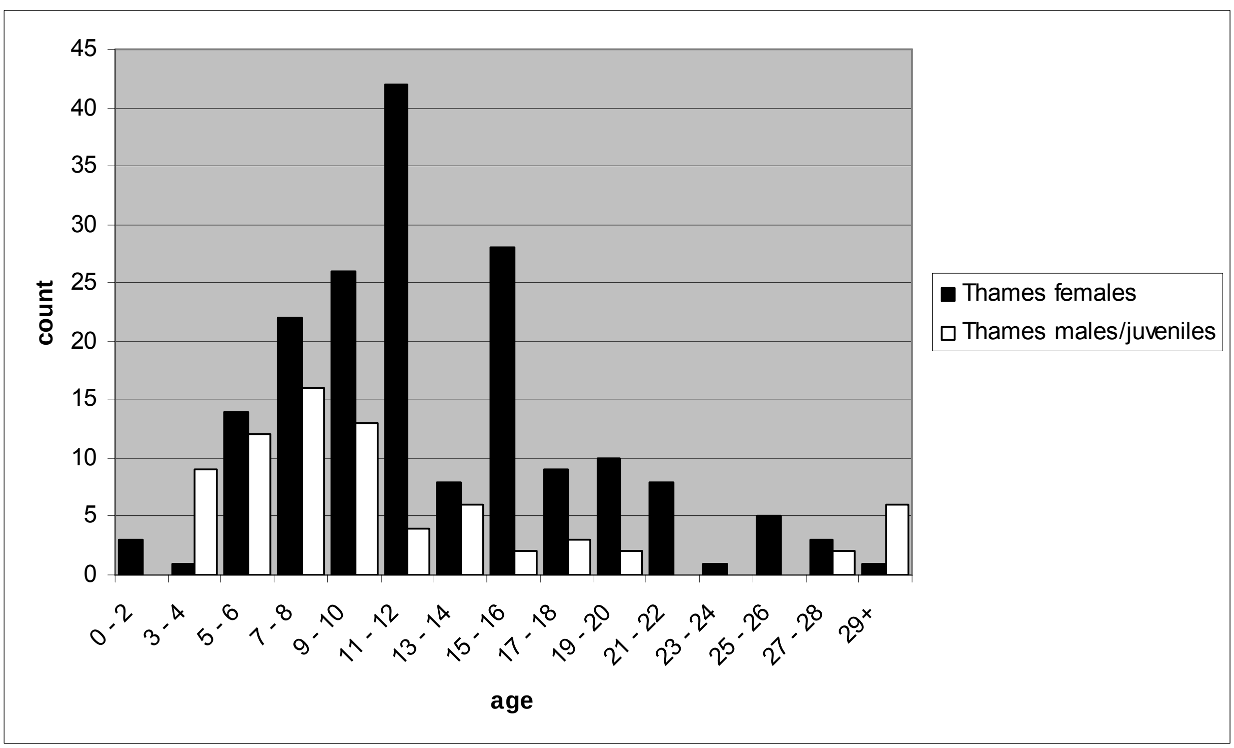

Figure 16. Age distribution of *Lampsilis fasciola* collected from the Thames River between 1997 and 2008. Male category includes juvenile animals (Morris *et al*. 2009).

The Thames and Grand river populations have distinctive generation times, with generation time defined as the average age of parents in the population (COSEWIC 2006b). The Grand River population has a generation time of 6.3 years whereas the Thames population has a generation time of 10.4 years. This yields an estimated generation time of between 6 and 10 years for the species.

Sex Ratios

Sex ratios from timed-searches (Table 7) and quantitative quadrat excavations (Table 8) are different. Ratios from timed-searches should be interpreted with caution as these collections are known to be biased by animal size (juveniles are rarely detected), vertical position in the substrate (burrowed versus unburrowed), and other features which might make one sex more obvious to the observer (i.e., the lure attractants of females). During quantitative surveys of the Grand and Maitland rivers in 2007-2008 (Morris unpubl. data), the vertical position of each Wavy-rayed Lampmussel (surface versus burrowed) was determined; 18% of animals in the Grand River and 17% of animals in the Maitland River were at the surface during the sampling period (August). This indicates that timed-searches are likely missing 4-5 times as many animals as they are detecting and, given the differences in vertical distributions of the sexes (see **Lifecycle and Reproduction**), likely missing more males than females.

Table 7. Sex ratios for *Lampsilis fasciola* found in semi-quantitative surveys of Ontario waters 1997-2008.

Population	Live animals			Shells + Live animals		
	male	female	ratio	male	female	ratio
Ausable River	0	2	0.00	12	5	2.40
Maitland River	13	11	1.18	46	32	1.44
Thames River	70	155	0.45	79	168	0.47
Grand River	42	94	0.45	108	147	0.73
Lake St. Clair	13	17	0.76	17	20	0.85
Sydenham River	0	0	-	3	9	0.33

Table 8. Sex ratios for *Lampsilis fasciola* found during quantitative sampling of watersheds where the species occurs between 2004 and 2008.

Population	male	female	ratio
Ausable River	7	5	1.40
Maitland River	11	13	0.85
Thames River	17	16	1.06
Grand River	128	93	1.38

Data from timed-searches (Table 7) are nonetheless included because there are more data for timed-searches than quadrat excavations and no excavation data exist for the Lake St. Clair delta population. In an attempt to minimize the potential biases of timed-searches, the sex ratios of shells that were collected while conducting the surveys are included because there would not be a detection bias based on behavioural differences between sexes.

Sex ratios from quantitative quadrat excavations are believed to be highly representative of the true ratio at the site as capture rates are unbiased. For all populations with quantitative data, sex ratios appear nearly balanced, indicating a healthy population, even though the total sample sizes are relatively small for some watersheds (Table 8). For the Lake St. Clair delta population, where excavation data are lacking, the sex ratio still remains relatively close to balanced (0.85 M:F; Table 7).

Fluctuations and trends

Most populations lack repeated quantitative sampling necessary for abundance trends. However, there are two sites along the North Thames River for which comparisons can be made (Table 9). Morris (unpubl. data) also quantitatively sampled the site in 2004 and estimated a density, including burrowed and unburrowed mussels, of 0.12 animals/m^2. In 2004, Wavy-rayed Lampmussels represented 24-28% of all mussels detected in the North Thames. In 2008, Morris again visited this site, to study gravid female Wavy-rayed Lampmussels, examined an area of 444 m^2 adjacent to the site sampled in 2004 and detected 136 animals for a density estimate of 0.31 animals/m^2, not including burrowed animals.

Table 9. Trends in *Lampsilis fasciola* abundance in the Thames River.

Site	Year surveyed	Abundance (#)	Effort (hours)	CPUE
Elginfield Road[1]	1995	0	1	0
Elginfield Road[2]	2004	15	4.5	3.33
Plover Mills[3]	1998	1	4.5	0.22
Plover Mills[4]	2008	14	5	2.8

[1]Morris (1996).
[2]Morris and Edwards (2007).
[3]Metcalfe-Smith, Environment Canada, (unpubl. data).
[4]Morris and Woolnough, Fisheries and Oceans Canada/Central Michigan University (publ. data).

Multiple years of data also exist for a site on the North Thames at Plover Mills (Table 9).

Although no directly comparable surveys have been conducted in other watersheds, it is possible to assess trends within the Grand River where additional work has been recently conducted. Metcalfe-Smith *et al.* (2000) surveyed a site on the Grand River in Kitchener near Doon in 1998 and found eight live Wavy-rayed Lampmussels (CPUE = 1.77). Morris (unpubl. data) quantitatively sampled the same site in 2007 and found 46 animals in an area of 63 m^2 (density = 0.73/m^2) making it the most abundant species at the site (52% of all mussels detected). In 2008 Morris sampled a patch adjacent to this site as part of his study on gravid females and found 87 animals in an area of 450 m^2 (density = 0.19/m^2). Given that the 2008 estimate represents only animals detected at the surface, it is likely comparable to the overall estimate reported for 2007. The locations of both the 2007 and 2008 work were contained within the survey area of Metcalfe-Smith *et al*. (2000).

Another estimate of trends in abundance can be obtained by examining changes in the size of the occupied reaches for each population (Table 10). For all riverine populations except the Sydenham River, the lengths of occupied reaches have increased substantially since the last assessment. Of particular importance are the increases in the Thames and Grand rivers (3–9 times larger), as these rivers were both extensively surveyed prior to the last assessment, reducing the possibility that the changes are artifacts of sampling effort. The decline in the Sydenham River should be interpreted cautiously as the inclusion of a 5 km reach in the previous assessment was based on fresh shells indicating a population. Live animals have not been found in the Sydenham River for over 35 years (approximately 3 generations) despite over 600 p-h of sampling effort.

Table 10. Trends in the length of occupied reach since the 1999 assessment for riverine populations of *Lampsilis fasciola*. Note that the length of occupied reach for the Sydenham River in 1999 was based only on the presence of fresh shells as no live animals have been found since 1971.

Watershed	Length of Occupied Reach 1999 (km)	Length of Occupied Reach 2008 (km)	Change
Ausable River	single site	90	-
Grand River	40	118	295%
Maitland River	single site	102	-
Sydenham River	5	0	-
Thames River	8	78	975%

Rescue effect

All Canadian populations of the Wavy-rayed lampmussel are isolated from one another and from U.S. populations by large areas of unsuitable habitat (including land), making the likelihood of re-establishing extirpated populations by natural immigration unlikely. The two hosts, Largemouth and Smallmouth bass, although capable of long-distance movements (~100 km), are not capable of movements large enough to connect these populations. Furthermore, Wavy-rayed Lampmussel populations in adjacent U.S. states that could be sources are not stable (Table 11). The Wavy-rayed Lampmussel occurs in six Great Lakes states; however, it is considered Critically Imperiled in New York (S1), Imperiled in Illinois, Indiana and Michigan (S2) and Vulnerable in Ohio. Only Pennsylvania considers the species to be not at risk with a rank of Apparently Secure (S4). With the exception of populations in the Lake Erie and Lake St. Clair drainages of Michigan, it is extremely unlikely that mussels in any of these states could support a natural recovery of Canadian populations.

Table 11. Subnational conservation rankings for the Wavy-rayed Lampmussel in the U.S.. Tied rankings have been assigned the higher conservation rank. All information from NatureServe (2009). Great Lakes States are in bold.

Conservation rank	Description	Jurisdiction
SH	Possibly extirpated	Mississippi
S1	Critically imperiled	Alabama, Georgia, New York, North Carolina
S2	Imperiled	Illinois, Indiana, Michigan, West Virginia,
S3	Vulnerable	Ohio
S4	Apparently secure	Kentucky, Pennsylvania, Tennessee, Virginia
S5	Secure	N/A
SNR	Not ranked	N/A

THREATS AND LIMITING FACTORS

Water quality

Certain life-history characteristics of freshwater mussels make them particularly sensitive to water and sediment pollution in rivers: they live in close association with sediments and they obtain food principally by filter-feeding. Juvenile mussels spend their early years completely buried in the substrate where they feed on particles associated with sediments and pore water (Yeager *et al*. 1994; Gatenby *et al*. 1997; Wächtler *et al.* 2000). Consequently, all life stages of *Lampsilis fasciola* are exposed to contaminants that are dissolved in the water, associated with suspended particles, and deposited in sediments.

Chemical contaminants

The majority of what follows is from controlled laboratory studies. These studies typically focus on the sensitivity of an organism to one contaminant at a time. Although these studies are critical to the derivation of water quality criteria for an individual chemical or stressor, they do not necessarily indicate how an organism responds to the simultaneous exposure of multiple stressors as is often the situation in the wild. Further field-based studies are required to fully understand the threat that complex mixtures of environmental contaminants pose to *L. fasciola*

<u>i) Ammonia and Copper</u>

While freshwater mussels, as a group, appear to be sensitive to poor water quality, two contaminants are particularly concerning for the sensitive early life stages (glochidia and juveniles). *Lampsilis fasciola,* and most freshwater mussels, are very sensitive to ammonia and copper (Jacobsen *et al*. 1997; Mummert *et al*. 2003; Wang *et al*. 2007; Gillis *et al*. 2008). Gillis *et al.* (2008) reported that glochidia from the six endangered species tested (including *L. fasciola*) were significantly more sensitive to copper than the three common species tested. Furthermore, Augspurger *et al.* (2007) suggested that ammonia should be considered among the factors that may be limiting the survival and recovery of freshwater mussels. Glochidia and newly transformed juveniles (including *L. fasciola*) are more sensitive to copper and ammonia than routinely tested aquatic organisms such as *Daphnia magna* (cladoceran) and *Pimephales promelas* (Fathead Minnow) (Wang *et al.* 2007). This is important because toxicity data from the routinely tested organisms were used to derive water quality regulations before the majority of data on early life stages were available. A number of studies have questioned whether current North American water quality guidelines for copper (March *et al.* 2007; Wang *et al*. 2007; Gillis *et al.* 2008) and ammonia (Augspurger *et al.* 2007) will adequately protect freshwater mussels. Augspurger *et al.* (2007) and March *et al*. (2007) both concluded that the current U.S. Environmental Protection Agency (USEPA) criteria for these contaminants would be lower if the recently published data had been included in their derivation. Now that standardized test methods (ASTM 2006) are available to assess sensitivity of the early life stages of freshwater mussels to waterborne contaminants, any future revisions of the water quality guidelines for copper and ammonia would include these data and thus should result in guidelines and criteria which will better protect freshwater mussels.

Water chemistry also has a significant effect on metal sensitivity of aquatic organisms. Gillis *et al*. (2008) found that *L. fasciola* glochidia were significantly more sensitive to copper (suffered mortality at a lower concentration) when they were exposed to copper in soft water compared to hard water. Also, *L. fasciola* glochidia survived higher concentrations of copper in water with elevated levels of dissolved organic carbon. These results indicate that the risk of toxic copper exposure will vary significantly with the water composition of a mussel's habitat. For instance, *L. fasciola* that inhabit soft water with low dissolved organic carbon would be the most vulnerable to acute copper toxicity. Of the five remaining populations of *L. fasciola*, only the one in Lake St. Clair is found in soft water (Gillis pers. comm. 2010).

<u>ii) Pesticides</u>

A number of studies have investigated the sensitivity of freshwater mussels to pesticides. Bringhoff *et al*. (2007) examined the toxicity of technical grade atrazine, pendimethalin, fipronil, and permethrin on five species of glochidia, including *L. fasciola*. Although they found that the relative risk associated with acute exposure of early life stages to these pesticides is likely low, the decreased growth and survival observed during chronic (21 days) exposures with juvenile *L. siliquoidea* (Fatmucket) indicate that long-term exposure to high concentrations (3.8 mg/L) of atrazine may have the potential to impact mussel populations. Milam *et al*. (2005) also investigated the toxicity of pesticides to the glochidia of six species and although they did not specifically test *L. fasciola*, they concluded that the risk of acutely toxic exposures of carbaryl, 4-nonylphenol, permethrin, 2,4-D, and pentachlorophenol to freshwater mussels in the natural environment is relatively low. Bringhoff *et al*. (2007) also examined the toxicity of fungicides (chlorothalonil, propiconazole, and pyraclostrobin) to glochidia of *L. siliquoidea* and found that while glochidia were extremely sensitive to these chemicals, they experienced acute toxicity at concentrations similar to other commonly tested aquatic organisms. Because the early life stages of unionids are not uniform in their sensitivity to pesticides and sensitivity is species- and chemical- (or possibly chemical class) specific (Bringhoff *et al*. 2007), caution should be used when extrapolating the results of sensitivity tests among species of mussels.

<u>iii) Fluoride</u>

Keller and Augspuger (2005) tested the sensitivity of glochidia and juvenile mussels to fluoride. They found *L. fasciola* juveniles had an LC_{50} (172 mg/L) which was comparable to the other two species tested, but based on measured fluoride concentrations in a fluoride-impacted stream (1.5-8 mg/L), they concluded that acute fluoride toxicity in the natural environment was unlikely.

iv) Emerging Contaminants (Nanoparticles, Municipal Effluents, Road Salt)

Gagné *et al*. (2008) reported that cadmium nanoparticles (cadmium–telluride) were immunotoxic to adult *Elliptio complanata* and led to oxidative stress in gills and DNA damage. The effect of nanoparticles on other life stages or species of mussels is unknown.

Exposure to municipal effluents also negatively affects the health of freshwater mussels. Gagné *et al*. (2004) demonstrated that *Elliptio complanata* caged downstream of a municipal outflow for one year displayed a complex but characteristic pattern of responses that could lead to harmful health effects including neuroendocrine disruption of reproduction. They suggested that mussels were likely exposed to estrogenic chemicals in the effluent plume. Similarly, Gagnon *et al*. (2006) reported that *Elliptio complanata* caged downstream of a municipal effluent for 90 days accumulated metals from both waterborne and dietary sources. Both these studies found that the exposed mussels exhibited numerous biomarkers of toxic stress. Because many of the Canadian endangered freshwater mussels inhabit urbanized rivers that receive input from municipal treatment plants, further investigation is required to fully understand the effect of this exposure. Of particular concern for *L. fasciola* is the Grand River, which receives effluent from more than 20 municipal treatment plants.

Gillis (pers. comm. 2009) found that glochidia, including those of *L. fasciola* are very sensitive to chloride (Cl) salts (*L. fasciola* LC_{50}, 100 mg Cl/L). Although Canada does not currently have a water quality guideline for chloride, neither the USEPA criteria (230 mg/L) nor the British Columbia Environment guideline (BCMOE 2008) (600 mg/L) would protect *L. fasciola* glochidia from acute chloride toxicity. Ontario has no water quality guideline for chloride. The concentration of chloride in North American rivers has been shown to be correlated with the percentage of impermeable surfaces in the watershed (Kaushal *et al.* 2005). Therefore the increased salinization of freshwater due to road salt may be of particular concern for Canada's endangered freshwater mussels whose ranges are limited to streams and rivers in road dense southern Ontario. Morris *et al.* (2009) reported that chloride was the one parameter measured that had consistently increased in rivers occupied by the Wavy-rayed Lampmussel over the last 10 years.

Water quality and composition

i) Dissolved Oxygen

Low dissolved oxygen (DO) events usually result from spills of organic material (e.g., agricultural wastes and untreated sewage) and can kill fish and mussels for several kilometres downstream. A spill of agricultural waste into Big Darby Creek, Ohio in 2000 resulted in levels of DO approaching zero and remaining low for one week (Tetzloff 2001). Thousands of fish and mussels were killed. Most species of mussels were affected by the event, but the survival rates among species varied considerably. Almost all individuals of some species, such as *Amblema plicata* (Threeridge) and *Fusconaia flava* (Wabash Pigtoe) survived the event but *Lampsilis fasciola* was among the most sensitive of the 18 species present and only 5% of the *Lampsilis fasciola* survived the spill.

ii) Phosphorus, Nitrates/Nitrites, Turbidity

While the toxicological effects of most contaminants on freshwater mussels have not been published, many of these contaminants may have deleterious effects on *Lampsilis fasciola*. Morris *et al*. (2009) sampled water quality at 66 sites in the Ausable, Grand, Maitland, Sydenham and Thames rivers over a two-week period in mid-September 1998. Each of these sites had been surveyed for mussels in 1997 or 1998. In 2004, the sampling was repeated at 16 of these sites and an additional 20 sites in the same rivers that were found to support live *L. fasciola* during mussel surveys conducted between 1998 and 2004. A principal component analysis using several water quality parameters along with Wavy-rayed Lampmussel abundance as variables was conducted for both sampling events. The results of each analysis were similar; abundance of *L. fasciola* at a site was negatively correlated with the concentration of total phosphorus (TP), nitrates/nitrites, total Kjeldahl nitrogen (TKN), and turbidity. *Lampsilis fasciola* were not found alive at sites with TP concentrations greater than 0.10 mg/L and were most abundant at sites with concentrations less than 0.05 mg/L. Wavy-rayed Lampmussels were also more abundant at sites with nitrate/nitrite concentrations less than 3 mg/L, and live animals were not found at sites with turbidity levels greater than 8 JTU (Jackson Turbidity Unit). Increased concentrations of nutrients in the form of phosphorus and nitrogen compounds contribute to higher levels of turbidity in aquatic systems and it is likely that the impacts of these contaminants on *L. fasciola* are linked. In an assessment of trends in Provincial Water Quality Monitoring Network data over two periods (1988-98 and 1999-2008) Morris *et al*. (2009) showed that nitrates had only increased slightly in the Grand and Thames rivers but remained unchanged in the Ausable and Maitland rivers. Over the same period, TP had declined in all four watersheds.

iii) Potassium

Another naturally occurring but potentially toxic metal in Ontario rivers that receives little attention, in terms of the protection of aquatic life, is potassium (K). Imlay (1973) observed that only two of ten rivers in the U.S. with baseline K concentrations of greater than 4 mg/L supported freshwater mussels whereas 28 of 39 rivers with levels less than 4 mg/L supported mussels. He confirmed this relationship through laboratory exposures and found that concentrations of 11 mg/L were lethal to 90% of the adult mussels after exposures of 36-52 days. Preliminary studies indicate the early life stages of freshwater mussels are also very sensitive to K: the 24 h LC_{50} for *L. fasciola* glochidia was 10 mg K/L (Gillis *et al.* unpubl. data). Morris *et al*. (2009) observed that *L. fasciola* are not abundant at sites with K concentrations greater than 6 mg/L which is consistent with these findings. These laboratory studies and field observations suggest that levels of K in Ontario waters (1-55 mg/L; Ontario Ministry of the Environment 2008) may indeed be a threat to the recovery of freshwater mussels including *L. fasciola*. There are currently no water quality guidelines for potassium concentrations in rivers or lakes in Ontario.

Dreissenid Mussels

Although dreissenid mussels have had a dramatic impact on some unionids, *L. fasciola* is primarily a riverine species that is unlikely to encounter Zebra Mussels throughout most of its range. Only 15% of historic records for *L. fasciola* in Ontario are from areas now infested by Zebra Mussels. Dreissenid mussels make most of the offshore habitats in the Great Lakes and connecting channels uninhabitable for *L. fasciola* and other unionids—and they remain an ongoing threat to coastal wetland refuges where a small population of *L. fasciola* continues to persist (McGoldrick *et al.* 2009). However, "…recent discoveries of Zebra Mussel populations in small North American rivers suggest that given an upstream source of veligers competent to settle, some small rivers can provide suitable habitat for Zebra Mussels" (Hunter *et al.* 1997). Thus, the presence of dams may greatly increase the likelihood of Zebra Mussels successfully colonizing a river system. According to Mackie (1996), reservoirs with retention times greater than 20-30 days will give veligers enough time to develop and settle, after which the impounded populations will seed downstream reaches on an annual basis. Zebra Mussels have been recently detected in two reservoirs of the Thames River system (Fanshawe and Springbank) and have since spread throughout much of the lower Thames River although at extremely low densities (Morris and Edwards 2007). At present these reservoirs and the infected river stretches, are downstream of the area occupied by the Wavy-rayed Lampmussel. However, should either Wildwood or Pittock reservoirs, above the occupied reaches in the Thames River, become infested by Zebra Mussels the outcome might be different. Likewise the reservoirs in the Grand River watershed (Guelph Lake, Belwood Lake, and Conestogo Reservoir) could act as source populations for Zebra Mussels downstream. In contrast, a specimen of *L. fasciola* was one of only six mussels still found alive in Lake St. Clair in 1994 (Nalepa *et al.* 1996), and this species did not suffer a decline in abundance in the Clinton River, southeastern Michigan, after the invasion of the Zebra Mussel (Hunter *et al.* 1997), and continued to co-exist with Zebra Mussels in the Clinton River in 2009 (Zanatta and Woolnough unpubl. data).

PROTECTION, STATUS, AND RANKS

Legal protection and status

The Wavy-rayed Lampmussel is currently listed as Endangered on Schedule 1 of the *Species at Risk Act* (SARA) and as such it is illegal to kill, harm, harass, capture or take individuals. The collection of freshwater mussels requires a collection permit issued under authority of the federal *Fisheries Act*. In Ontario, this permit is issued by the Ontario Ministry of Natural Resources.

Effective June 2008, the Wavy-rayed Lampmussel was listed as Endangered and protected under the *Ontario Endangered Species Act, 2007*. Habitat will not be protected under this Act until June 2013, unless a specific habitat regulation is made at an earlier date.

Non-legal status and ranks

The Wavy-rayed Lampmussel is considered globally secure (G5) and is ranked as nationally secure (N5) in the U.S. but nationally imperiled (N2) in Canada (NatureServe 2009). It is not on the IUCN's Red List. The national general status assessment of freshwater mussels in Canada (Metcalfe-Smith and Cudmore-Vokey 2004), assigned a national rank of 1 (At Risk) to the Wavy-rayed Lampmussel that corresponds with a sub-national rank in Ontario of Imperiled (S2) (National Heritage Information Centre 2009). The Wavy-rayed Lampmussel is considered vulnerable to possibly extirpated in ten U.S. jurisdictions and apparently secure in four (Table 11). The species is state-listed as Endangered in Illinois, Threatened in Michigan and New York and Special Concern in Indiana, North Carolina and Ohio (NatureServe 2009).

Habitat protection and ownership

The Canadian *Species at Risk Act* (SARA) offers some protection of habitat for Wavy-rayed Lampmussel including protection of individuals and their residences and critical habitat, once defined and delineated. However, at this time, neither residence nor critical habitat have been described or identified for this species (Morris 2006). As shellfish, freshwater mussels are considered 'fish' under the federal *Fisheries Act* and therefore their habitat is protected from harmful alteration, disruption or destruction unless authorized by the Minister of Fisheries and Oceans, or his/her delegate. The Ontario *Lakes and Rivers Improvement Act* prohibits the impoundment or diversion of a watercourse if siltation will result. Stream-side development in Ontario is managed through floodplain regulations enforced by local conservation authorities. A majority of the land adjacent to the rivers where the Wavy-rayed Lampmussel is found is privately owned; however, the river bottom is generally owned by the federal Crown.

The last remaining lake population of this mussel is located in the territorial waters of the Walpole Island First Nation (WIFN). These waters are relatively low-impact areas used primarily for hunting and fishing. Access to these areas is regulated through user permits issued by WIFN.

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

The report writers wish to acknowledge the efforts of the original status report writers: Janice Metcalfe-Smith, Shawn Staton, and Emma West. Their thorough report made the preparation of this update easier. We also acknowledge Environment Canada for providing the funding necessary to produce this document. Many other funding agencies provided support for the data reported in this status update. The following authorities were contacted and consulted regarding the preparation of this report:

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BIOGRAPHICAL SUMMARY OF REPORT WRITERS

Dr. Todd J. Morris is a Research Scientist with the Great Lakes Laboratory for Fisheries and Aquatic Sciences with Fisheries and Oceans Canada in Burlington, Ontario, Canada. He has a B.Sc. (Hons.) in Zoology from the University of Western Ontario (1993), a Diploma in Honors Standing in Ecology and Evolution from the University of Western Ontario (1994), an M.Sc. in Aquatic Ecology from the University of Windsor (1996) and a Ph.D. in Zoology from the University of Toronto (2002). Dr. Morris's research interests focus on the biotic and abiotic factors structuring aquatic ecosystems and he has worked with a wide variety of aquatic taxa ranging from zooplankton to predatory fishes. He has been studying Ontario's freshwater mussel fauna since 1993, has authored three recovery strategies addressing eight COSEWIC-listed freshwater mussel species, chairs the Ontario Freshwater Mussel Recovery Team and is a member of the Molluscs Specialist Subcommittee of COSEWIC.

Dr. David Zanatta is an Assistant Professor in the Biology Department at Central Michigan University. Dr. Zanatta has ten years of experience working on unionid mussels. He has a B.Sc. (Hons.) in Biology from Laurentian University (1998); an M.Sc. in Zoology from the University of Guelph (2000); a Ph.D. from the University of Toronto (2007) where he researched the evolution and population genetics of lampsiline mussels; and held an NSERC post-doctoral fellowship at Trent University in 2008 prior to starting a tenure-track professorship at Central Michigan University. Dr. Zanatta has authored seven peer-reviewed papers on freshwater mussel biology, including a paper on the conservation genetics of the Wavy-rayed Lampmussel and has ongoing research on the species. He has also co-authored three COSEWIC status reports on Ontario freshwater mussel species and is a member of the Molluscs Specialist Subcommittee of

COSEWIC. Dr. Zanatta is a member of the recovery teams for Thames, Sydenham and Ausable Rivers as well as the Ontario Freshwater Mussel Recovery Team.

COLLECTIONS EXAMINED

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

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 Fisheries and Oceans Canada's Great Lakes Laboratory for Fisheries and Aquatic Sciences in Burlington, Ontario. Original data sources included the primary literature, natural history museums, federal, provincial, and municipal government agencies (and some American agencies), conservation authorities, Remedial Action Plans for the Great Lakes Areas of Concern, university theses and environmental consulting firms. Mussel collections held by six natural history museums in the Great Lakes region (Canadian Museum of Nature, Ohio State University Museum of Zoology, Royal Ontario Museum, University of Michigan Museum of Zoology, Rochester Museum and Science Center, and Buffalo Museum of Science) were the primary sources of information, accounting for over two-thirds of the initial data acquired. Janice Metcalfe-Smith personally examined the collections held by the Royal Ontario Museum, University of Michigan Museum of Zoology and Buffalo Museum of Science, as well as smaller collections held by the Ontario Ministry of Natural Resources. The database continues to be updated with new field data and now contains approximately 8200 records of unionids from Lake Ontario, Lake Erie, Lake St. Clair and their drainage basins as well as several of the major tributaries to lower Lake Huron. The majority of records in the database are now from recent (post-1990) field collections made by Fisheries and Oceans Canada, Environment Canada, provincial agencies, universities and conservation authorities. This database is the source for all information on Canadian populations of the Wavy-rayed Lampmussel discussed in this report.

The report writers have personally verified live specimens from all populations described in this report.