COSEWIC
Assessment and Status Report

on the

Snuffbox
Epioblasma triquetra

in Canada

ENDANGERED
2011

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. 2011. COSEWIC assessment and status report on the Snuffbox *Epioblasma triquetra* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 50 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

Previous report(s):

COSEWIC. 2001. COSEWIC assessment and status report on the Snuffbox *Epioblasma triquetra* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. viii + 50 pp.

Watson, E.T., J.L. Metcalfe-Smith and J. Di Maio. 2001. COSEWIC status report on the Snuffbox *Epioblasma triquetra* in Canada, *in* COSEWIC assessment and status report on the snuffbox *Epioblasma triquetra* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-50 pp.

Production note:
COSEWIC would like to acknowledge Dr. David Zanatta for writing the status report on the Snuffbox, *Epioblasma triquetra*, in Canada, prepared under contract with Environment Canada. This report was overseen and edited by Dr. Dwayne Lepitzki, Co-chair of the COSEWIC Molluscs Specialist Subcommittee.

For additional copies contact:

COSEWIC Secretariat
c/o Canadian Wildlife Service
Environment Canada
Ottawa, ON
K1A 0H3

Tel.: 819-953-3215
Fax: 819-994-3684
E-mail: COSEWIC/COSEPAC@ec.gc.ca
http://www.cosewic.gc.ca

Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur l'Épioblasme tricorne (*Epioblasma triquetra*) au Canada.

Cover illustration/photo:
Snuffbox — Photo credit: D. Zanatta, CMU.

Catalogue No. CW69-14/205-2012E-PDF
ISBN 978-1-100-20225-9

Recycled paper

COSEWIC
Assessment Summary

Assessment Summary – November 2011

Common name
Snuffbox

Scientific name
Epioblasma triquetra

Status
Endangered

Reason for designation
This small, freshwater mussel is currently found in two rivers in southern Ontario; another population may still survive in the Thames River where one fresh shell was found in 1998. The original COSEWIC assessment (2001) concluded that it had been lost from most of its Canadian range and was confined to the Sydenham River but live mussels from a reproducing population were subsequently found in the Ausable River beginning in 2006. The two remaining populations are in areas of intensive farming and subject to siltation and pollution with siltation being particularly problematic. Invasive Zebra Mussels have rendered much of the historical habitat unsuitable. An invasive fish species, the Round Goby, may pose a new threat by competing with the mussel's two known larval host fishes and by eating juvenile mussels.

Occurrence
Ontario

Status history
Designated Endangered in May 2001. Status re-examined and confirmed in November 2011.

COSEWIC
Executive Summary

Snuffbox
Epioblasma triquetra

Wildlife species description and significance

The Snuffbox, *Epioblasma triquetra*, is a small species of freshwater mussel that is morphologically distinct from any other mussel in Canada: the shell is solid and thick, and is triangular in shape in males and somewhat elongate in females; the ridge on the back part of the shell is high and sharply angled, and the area between the ridge and the top of the shell is wide and covered in strong, wavy ribs; the beak, which is the raised part at the top of the shell, is swollen and sculptured with three or four faint, double-looped ridges; the outside of the shell is yellowish to yellowish green, and is marked with numerous dark green rays that are often broken into triangular spots that look like dripping paint; the shell surface is smooth. Males may reach a shell length of 70 mm, and females are generally 10 mm shorter. If this species were to become extinct, the genus would be at a much higher risk of being lost.

Distribution

The Snuffbox is the most widely distributed member of the genus *Epioblasma*. It was historically known from 18 U.S. states and Ontario. Its distribution has been substantially reduced throughout its range, and remaining populations are small and geographically isolated from one another. The species is thought to be extirpated from Iowa, Kansas, New York and Mississippi. In Canada, there were 31 known historical records from Lake Erie, Lake St. Clair, and the Ausable, Sydenham, Thames, Grand, and Niagara rivers. It is now restricted to several sites in the Sydenham and the Ausable rivers.

Habitat

The Snuffbox is typically found in small- to medium-sized rivers in shallow riffle areas with clean, clear, swift-flowing water and firm rubble/gravel/sand substrates that are free of silt. It was also found in wave-washed shoals in the Great Lakes.

Biology

Snuffbox is a small species with separate sexes and is known to live at least 10 years. It is a long-term brooder: spawning occurs in the summer and the larvae (called glochidia) are released the following May-June. The glochidia are small- to medium-sized, hookless, and attach to the gills of their host fish. The glochidia have a depressed shape that reduces the likelihood of successful initial contact with the host. As a result, the number of young that survive to the juvenile stage may be low. While two of the five known host fishes, as determined by laboratory infections, for this mussel occur in Ontario (Logperch and Blackside Darter), the Logperch is the only probable host in Canada given the mussel's trapping behaviour that can kill host fishes. Transformation to the juvenile stage takes about 3-6 weeks, depending on water temperature. Snuffbox, like all other species of freshwater mussels, eat bacteria and algae.

Population sizes and trends

Snuffbox typically occurs in low numbers in mussel communities where it is found (0.1-0.8% of the assemblage), but it can be locally abundant. In Canada, it is restricted to a 72 km reach of the East Sydenham River and a 60 km reach of the Ausable River. Abundance may have declined since the 1960s, but reproduction is still occurring. While it may appear that the population size has recently increased, since the original COSEWIC report (2001), it is most likely due to increased sampling effort. It has presumably been lost from the lower Great Lakes and their connecting channels due to infestation by dreissenid mussels; 70% of historical records (over a span of more than 3 generations) were from these waters.

Threats and limiting factors

Snuffbox is sensitive to siltation, pollution (including toxic spills), habitat perturbation, inundation of riffle habitat, invasive dreissenid mussels, and loss of glochidial hosts. Sites where it still occurs are high-quality streams with little disturbance to the substrate or riparian zone. The impoundment and diversion of rivers likely destroyed much of the habitat for this species during the last century. Dreissenid mussels have made the habitat unsuitable throughout a large portion of the Snuffbox's former range, i.e., lakes Erie and St. Clair, connecting channels, and the lower Grand River. This species has not been found in the nearshore refuge sites of Lake St. Clair utilized by other mussels. Long-term brooders such as Snuffbox may be more sensitive than short-term brooders to the energy-depleting effects of dreissenid mussels. Agriculture is the main form of land use in the Grand, Thames, Sydenham and Ausable river basins. Thus, water and habitat quality are impaired due to sedimentation and the inputs of pesticides, fertilizers, and livestock manures. The Snuffbox may be more sensitive to sedimentation than most other mussels due to its burrowing habits. The decline in the overall range of this species suggests that it cannot tolerate poor water quality caused by agricultural, municipal, and industrial pollution. In addition, mussels with few host fishes are more sensitive to changes in the fish community than those with many hosts. Only two of the five known hosts for Snuffbox are native to Ontario, and there is some evidence that the most likely host, the Logperch, is declining in some areas.

Protection, status, and ranks

The Snuffbox is listed under Schedule 1 as Endangered under Canada's *Species at Risk Act* and receives protection under this legislation. It is also listed as Endangered under Ontario's *Endangered Species Act*. As such, is it protected from willful destruction and harassment at both the federal and provincial level. The federal *Fisheries Act* may also protect the habitat of Snuffbox in Canada, as fish are broadly defined under the Act to include shellfish. Another mechanism for protecting mussels and their habitat in Ontario is the *Ontario Lakes and Streams Improvement Act*. Stream-side development in Ontario is managed through flood plain regulations enforced by local Conservation Authorities. Land along the reach of the Sydenham River where Snuffbox was recently found alive is privately owned and used in agriculture. Snuffbox is not federally listed in the U.S. at present (although listing is expected in 2011), but it is protected by state legislation in the eight states where it is listed as endangered or threatened. NatureServe has assigned Snuffbox a vulnerable rank globally (G3), and a very rare rank (S1) in 10 U.S. states and Ontario.

TECHNICAL SUMMARY

Epioblasma triquetra
Snuffbox — Épioblasme tricorne
Range of occurrence in Canada (province/territory/ocean): southwestern Ontario

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2008) is being used)	5-10 yrs
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	No decline in last 15 years (~ 3 generations)
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future. -Not in last 15 years (~3 generations)	No decline
Are the causes of the decline clearly reversible and understood and ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	1482 km²
Index of area of occupancy (IAO) (Always report 2x2 grid value; other values may also be listed if they are clearly indicated (e.g., 1x1 grid, biological AO)).	308 km² (2 km x 2 km grid)
Is the total population severely fragmented?	No
Number of locations∗ 1*) Sydenham River* *2) Ausable River* *3?) Thames River (one fresh shell collected in 1998)*	2 (possibly 3)
Is there an [observed, inferred, or projected] continuing decline in extent of occurrence?	No
Is there an [observed, inferred, or projected] continuing decline in index of area of occupancy?	No
Is there an [observed, inferred, or projected] continuing decline in number of populations?	No
Is there an [observed, inferred, or projected] continuing decline in number of locations*?	No
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
Sydenham River (maximum number assuming a continuous distribution along the occupied reach of 72 km and 20 m wide)	21,000 (± 2880 S.E.)
Ausable River (maximum number assuming a continuous distribution along the occupied reach of 59.7 km and 7.5 m wide)	40,745 (± 7164 S.E.)
Total	61,745 (± 10,044 S.E.)

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Not available

Threats (actual or imminent, to populations or habitats)

• Ongoing and possibly increasing siltation from agriculture (Sydenham and Ausable rivers)
• Municipal, industrial and agricultural pollution—including pesticides, herbicides, toxic spills, fertilizers, and metals
• Increasing Round Goby competition with hosts and possible predation on juvenile mussels

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? *U.S.: under review* *Alabama (S1), Arkansas (S1), Illinois (S1), Indiana (S1), Iowa (SX), Kansas (SX), Kentucky (S1), Michigan (S1), Minnesota (S2), Mississippi (S1), Missouri (S1), Nebraska (SNR), New York (SH), Ohio (S1), Pennsylvania (S1), Tennessee (S3), Virginia (S1), West Virginia (S2), Wisconsin (S1)*	
Is immigration known or possible?	No
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	No
Is rescue from outside populations likely?	No

Current Status

COSEWIC: Endangered (Nov 2011)
SARA: Schedule 1 (Endangered, June 2003)
Ontario: Endangered (2008)

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** B1ab(iii) + 2ab(iii)

Reasons for designation:
This small, freshwater mussel is currently found in two rivers in southern Ontario; another population may still survive in the Thames River where one fresh shell was found in 1998. The original COSEWIC assessment (2001) concluded that it had been lost from most of its Canadian range and was confined to the Sydenham River but live mussels from a reproducing population were subsequently found in the Ausable River beginning in 2006. The two remaining populations are in areas of intensive farming and subject to siltation and pollution with siltation being particularly problematic. Invasive Zebra Mussels have rendered much of the historical habitat unsuitable. An invasive fish species, the Round Goby, may pose a new threat by competing with the mussel’s two known host fishes and by eating juvenile mussels.

Applicability of Criteria

Criterion A: Not applicable. The number of mature individuals appears to be stable.
Criterion B: Both B1 and B2 are applicable as EO (1482 km^2) and IAO (308 km^2) are below the thresholds for Endangered (< 5000 km^2 and < 500 km^2, respectively). As the species is found at only 2 locations with one fresh shell being collected at another location in 1998, sub-criterion “a” (no. of locations less than or equal to 5) is applicable. There is a continuing decline inferred in the quality of habitat so sub-criterion “b(iii)” also is applicable.
Criterion C: Not applicable. The total maximum number of mature individuals, estimated to be over 61,000, is above the thresholds for this criterion (< 10,000 for Threatened), and there is no evidence of a recent decline in number of mature individuals.
Criterion D: Nearly meets the criteria for D2 Threatened as the species is found at fewer than 5 locations and while it is prone to the effects of human activities (e.g., degraded water quality and invasive species) these activities are not likely to occur over a very short time frame in an uncertain future.
Criterion E: Not applicable. Probabilities for extinction in the wild have not been calculated.

PREFACE

Since the original status assessment of the Snuffbox, *Epioblasma triquetra,* in Canada (COSEWIC 2001) a large number of monitoring, research and management projects have occurred. The information garnered in the last ten years has been incorporated to update the original COSEWIC report. Some highlights of the new information in this report are as follows:

Extensive quantitative sampling and surveys have been undertaken in the Sydenham (Metcalfe-Smith *et al.* 2007) and Ausable rivers (Ausable Bayfield Conservation Authority unpubl. data) and have aided in the understanding of the stability of the Canadian population and its population dynamics. A major change from the 2001 report is the substantial reproducing population of *E. triquetra* found in the lower reach of the Ausable River, similar to or exceeding the densities and population size in the Sydenham River. The Sydenham River's population is also better understood and appears to be fairly robust and reproducing. Unfortunately, the populations in the Great Lakes and connecting channels have not recovered, with the Detroit River population declared extirpated (Schloesser *et al.* 2006). All this new information has been incorporated. Neither extent of occurrence (EO) nor index of area of occupancy (IAO) was calculated in the original 2001 report.

Vital information on host fish usage by *E. triquetra* in Canada has been studied (Woolnough 2002; McNichols and Mackie 2002, 2003; McNichols *et al.* 2004). It is also now understood how *E. triquetra* attracts and captures its host (Barnhart *et al.* 2008). This information has been added to the **BIOLOGY** section.

New data on the phylogenetic (Zanatta and Murphy 2006) geno-geographic population structure (Zanatta and Murphy 2008) of *E. triquetra* and its Logperch, *Percina caprodes*, host (Zanatta and Wilson 2011) has been added to the **Population spatial structure and variability** section.

Much of the new research described above and throughout this status update is the result of recommendations for research and monitoring (thus allowing for funding) in recently produced recovery strategies for Species at Risk in southern Ontario. Aquatic ecosystem recovery strategies for the Sydenham (Dextrase *et al.* 2003; Staton *et al.* 2003) and Ausable rivers (Ausable River Recovery Team 2005) include *E. triquetra*. A multi-species recovery strategy for five mussel species found in southwestern Ontario (Morris and Burridge 2006), also includes *E. triquetra*.

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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
(2011)

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

Epioblasma triquetra was first described by Rafinesque in 1820. The type locality was the Falls of the Ohio River near Louisville, Jefferson County, Kentucky (Ortmann 1919). Early naturalists described virtually every specimen they collected from different geographic areas as new species. Consequently, the same species was described and named many different times, and species designations often reflected only intraspecific or ecophenotypic variation of the shells (Watters 1994; Lydeard and Roe 1998). Although recent systematic and genetic investigations have clarified some relationships, these studies have led to the reinstatement of many earlier names—which has further complicated the nomenclature. Particular confusion has surrounded the use of the generic names *Epioblasma*, *Plagiola* and *Dysnomia* (see Johnson 1978; Bogan 1997). The rediscovery of the original syntype and neotype of *Epioblasma* has now resolved the nomenclature (Bogan 1997). The current classification (Zanatta and Murphy 2006; Graf and Cummings 2007) is as follows:

PHYLUM Mollusca
- CLASS Bivalvia
  - SUBCLASS Palaeoheterodonta
    - ORDER Unionoida
      - SUPERFAMILY Unionoidea
        - FAMILY Unionidae
          - SUBFAMILY Ambleminae
            - TRIBE Lampsilini
              - GENUS *Epioblasma*
                - SPECIES *Epioblasma triquetra.*

In Canada, the French common name for this species is “épioblasme tricorne”, which refers to its current Latin nomenclature (Martel *et al.* 2007).

Morphological description

The Snuffbox, *Epioblasma triquetra* (Rafinesque, 1820), is a small, sexually dimorphic species of freshwater mussel that is not morphologically similar to any other mussel in Canada (Clarke 1981). It bears a superficial resemblance to the Deertoe, *Truncilla truncata*, and the Elktoe, *Alasmidonta marginata*, which also have a triangular shape, and can co-occur with *E. triquetra* in Canada. Figure 1 is a photograph of live male and female specimens collected from the Ausable River, Ontario, in July 2007, and Figure 2 shows the internal and external shell morphology of the two sexes. The following description of the Snuffbox’s shell was adapted from Baker (1928), Simpson (1914), Johnson (1978) and Clarke (1981):

Figure 1. Photograph of a live male (left) and live female *Epioblasma triquetra* found in the Ausable River, Ontario in July 2007 (Photo credit: D. Zanatta, CMU).

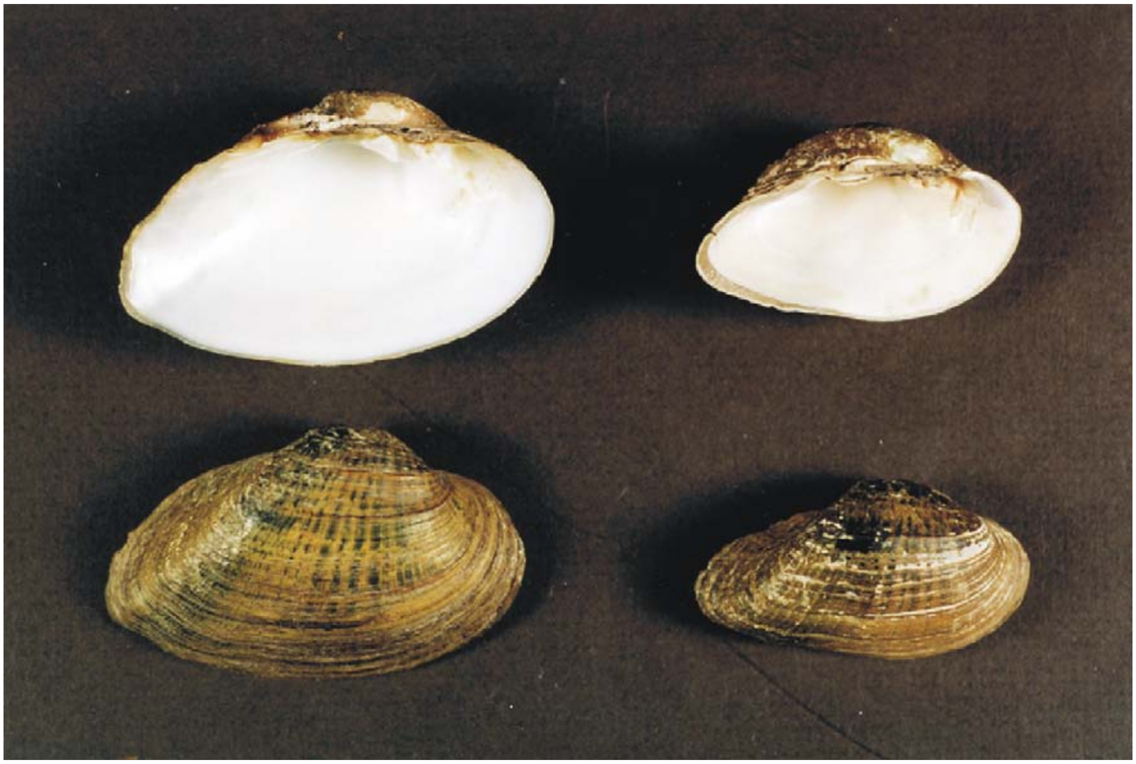

Figure 2. Internal (above) and external (below) shell morphology of a male (left) and female (right) *Epioblasma triquetra* collected from the East Sydenham River, Ontario, in July 1999 (Photo credit: Janice Metcalfe-Smith).

The shell is solid, thick and inflated—triangular in males and somewhat elongate and very inflated in females. The anterior end is rounded; the posterior end is truncated in males and expanded in females. The ventral margin is slightly curved in males and almost straight in females. The dorsal margin is short and straight. The posterior ridge is high and sharply angled, extended posterioventrally in females. The posterior slope is wide, expanded and sculptured with radial, wavy ribs. The umbos are swollen and elevated above the hinge line, and they turn inward and anteriorly. The beaks are located anterior to the middle of the shell and have a sculpture consisting of three or four faint, double-looped ridges. The periostracum is yellowish to yellowish green, and is marked with numerous dark green rays that are often broken so that they appear as triangular or chevron-shaped spots [Note: the status report writer thinks these marks look like “dripping paint”]. The shell surface is smooth (excluding the posterior slope), except for occasional concentric growth rests. The nacre is white, iridescent posteriorly, and has a grey-blue tinge in the deeply excavated beak cavity. Pseudocardinal teeth are ragged, compressed and relatively thin; there are two in each valve. Lateral teeth are very short, straight, elevated and serrated—two in the left valve and one in the right. Anterior muscle scars are deeply impressed. For a description of the soft parts of *E. triquetra* see Baker (1928: 297).

Johnson (1978) states that *E. triquetra* can attain a shell length of up to 80 mm, but Cummings and Mayer (1992) report a maximum length of 64 mm and Parmalee and Bogan (1998) found that it rarely exceeds 50 mm in Tennessee. Males are larger than females: the largest male and female reported by Simpson (1914) were 69 and 52 mm long, respectively, and the largest male and female reported by Ortmann (1919) from Pennsylvania were 68 and 45 mm long, respectively. According to Clarke (1981), a large male is 55 mm long and a mature female is 38 mm long. Recent surveys in the Sydenham and Ausable rivers in Canada have found a few individuals (males) between 60 and 65 mm. Ortmann (1919) said that "both males and females vary greatly in diameter and in the width of the posterior slope" and "there is also great variation in the colour-pattern, and the rays and spots are hardly ever alike in any two specimens." He adds that the shells of males may become quite elongated with age. However, this statement is contradicted by Johnson (1978) who says that the shells of the Snuffbox "exhibit little morphological variation." Surveys in Canada tend to support Johnson's (1978) finding.

Population spatial structure and variability

On a range-wide scale, there is significant genetic variation and population spatial structure in *E. triquetra*. Zanatta and Murphy (2008) sampled seven populations from across the central basin of North America. Samples were genotyped using 15 microsatellite DNA loci and phylogeographic history through the maternal lineage was inferred using mitochondrial DNA (mtDNA) cytochrome c oxidase subunit-I (COI) sequences. Populations in the Clinch (Tennessee) and St. Francis (Missouri) rivers both had unique mtDNA haplotypes indicating population substructuring. The other populations were dominated by a common haplotype, which also occurred in the Clinch River population. Analysis of DNA microsatellites revealed much greater divergences and showed significant genetic structure among populations in the formerly glaciated regions. The population of the St. Francis River may constitute a distinct taxonomic entity (Zanatta and Murphy 2008).

The only Canadian population sampled by Zanatta and Murphy (2008) was that in the Sydenham River. This population grouped with another Great Lakes population in the Huron River, Michigan (Lake Erie drainage).

Sampling and genotyping of both the Sydenham and Ausable river populations was undertaken by Galbraith *et al.* (2010). Using similar microsatellite DNA markers to Zanatta and Murphy (2008), *E. triquetra* showed substantial genetic diversity in each of these rivers, with all populations in Hardy-Weinberg equilibrium. Individual-based population assignment revealed that Snuffbox grouped into two distinct genetic populations from the Sydenham and Ausable rivers, respectively. Correspondingly, isolation by distance analysis of Snuffbox individuals at particular sites indicates that there is no significant genetic structuring within these sites (Galbraith *et al.* 2010).

Assessment of genetic population structuring of the Logperch (*Percina caprodes*), a host fish for *E. triquetra*, has also been completed (Zanatta and Wilson 2011). When the population structures of the mussel and host fish were compared statistically, they were found to be significantly congruent, with the exception of the St. Croix River, Minnesota/Wisconsin (Upper Mississippi River drainage), largely due to the presence of an unnamed cryptic species of Logperch in the St. Croix River. The genetic population structures of *E. triquetra* and Logperch in the Great Lakes and Ohio River drainages were nearly perfectly congruent. Thus, in the Great Lakes and Ohio River drainages, it is likely that Logperch was responsible for the genetic population structure observed in *E. triquetra*.

Designatable units

COSEWIC (2009) guidelines provide three criteria that may be considered to establish whether an entity is discrete: 1) Genetic evidence (e.g., inherited morphological or behavioural traits, and genetic markers), 2) Substantive range disjunctions that limit the possibility of recolonization from one entity to another, and 3) populations occupying different eco-geographic units (e.g., different ecozones or biogeographic zones). While there are documented genetic differences among *E. triquetra* in the Sydenham and Ausable rivers (Galbraith *et al.* 2010), these are differences in allelic frequencies and not sufficient to warrant splitting the two Canadian populations into separate designatable units. Similarly, while these two watersheds are separate, they are both within the Great Lakes–Upper St. Lawrence National Freshwater Biogeographic Zone of COSEWIC (2009).

Special significance

The genus *Epioblasma* is the most imperiled of the 50 genera of freshwater mussels in North America: of the 25 recognized species and subspecies, 10 are in danger of extinction, 14 may already be extinct, and only one, *Epioblasma triquetra*, is listed as threatened (likely to become endangered throughout all or a significant portion of its range) by the American Fisheries Society (Williams *et al*. 1993). It is generally believed that members of this genus are more sensitive to environmental change than members of other genera, as they are usually the first to disappear from the community when the habitat is altered or polluted (Dennis 1987). According to Johnson (1978), the Snuffbox is the most primitive, abundant, and widely distributed of the *Epioblasma*, occupying more of the formerly glaciated region than any other species. The reason why it is not as seriously at risk as other members of the genus may have more to do with its widespread distribution than with any greater tolerance of environmental perturbations. Remaining populations in the United States and Canada are fragmented, many are unhealthy, and some of those in the U.S. may not be reproducing. If efforts are not made soon to preserve and recover the Snuffbox (and remaining members of its genus), it is likely that the entire genus will be lost. If so, it would be the first of the North American unionoid genera to become extinct (Bogan 1998). The Sydenham and Ausable rivers in southwestern Ontario support the only known extant populations of *E. triquetra* in Canada. Another member of the genus, *Epioblasma torulosa rangiana*

(Northern Riffleshell), has a similar range in Canada and was recently re-assessed as endangered (COSEWIC 2010a). There is no Aboriginal Traditional Knowledge currently available on this species; however, Peacock *et al.* (2005) mention *E. triquetra* being collected at numerous ancient Aboriginal shell middens in the United States.

DISTRIBUTION

Global range

The Snuffbox is the most widely distributed member of the genus *Epioblasma* (Figure 3). Historically, it was found in Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Mississippi, Missouri, New York, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, Wisconsin, and Ontario (NatureServe 2010). An account of *E. triquetra* from "eastern Nebraska" by Simpson (1914:6), which was misreported as Oklahoma in Johnson (1978), has not been substantiated. It was known to occur throughout the Ohio–Mississippi River system, and in the Great Lakes system in Lake Erie, Lake St. Clair, and tributaries to lakes Erie, St. Clair, Huron and Michigan (Butler 2007).

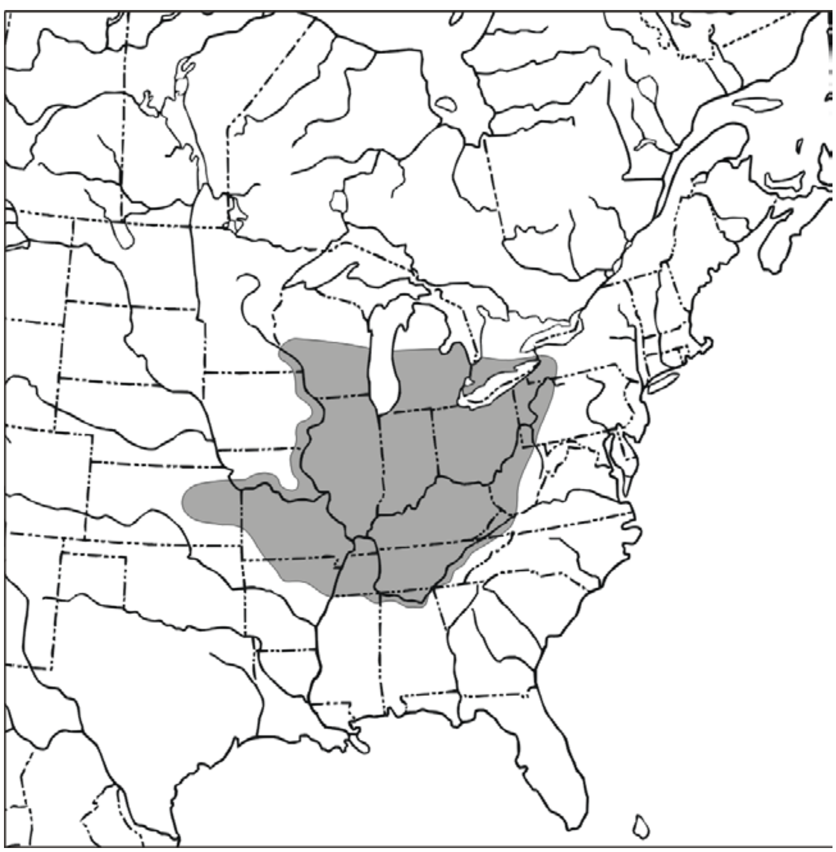

Figure 3. Historical distribution of *Epioblasma triquetra* in North America.

Canadian range and search effort

In Canada, *E. triquetra* was and is known only from Ontario (Clarke 1981). Fisheries and Oceans Canada Lower Great Lakes Unionid Database (see **COLLECTIONS EXAMINED**) was used to identify historical occurrence records for *E. triquetra* in Ontario. Data sources included natural history museums, the published literature, unpublished reports, and collectors' field notes; for a detailed description of the database and its data sources, see Metcalfe-Smith *et al*. (1998b). This database has been continuously updated since its creation in the late 1990s. A total of 31 records dating from 1885 to 1985 were identified for *E. triquetra* in Ontario (Appendix 1). All records for *E. triquetra* through 2009 are shown in Figure 4. According to this information, the Snuffbox historically occurred in the Ausable, Sydenham, Thames, Grand and Niagara rivers, Lake St. Clair, and Lake Erie.

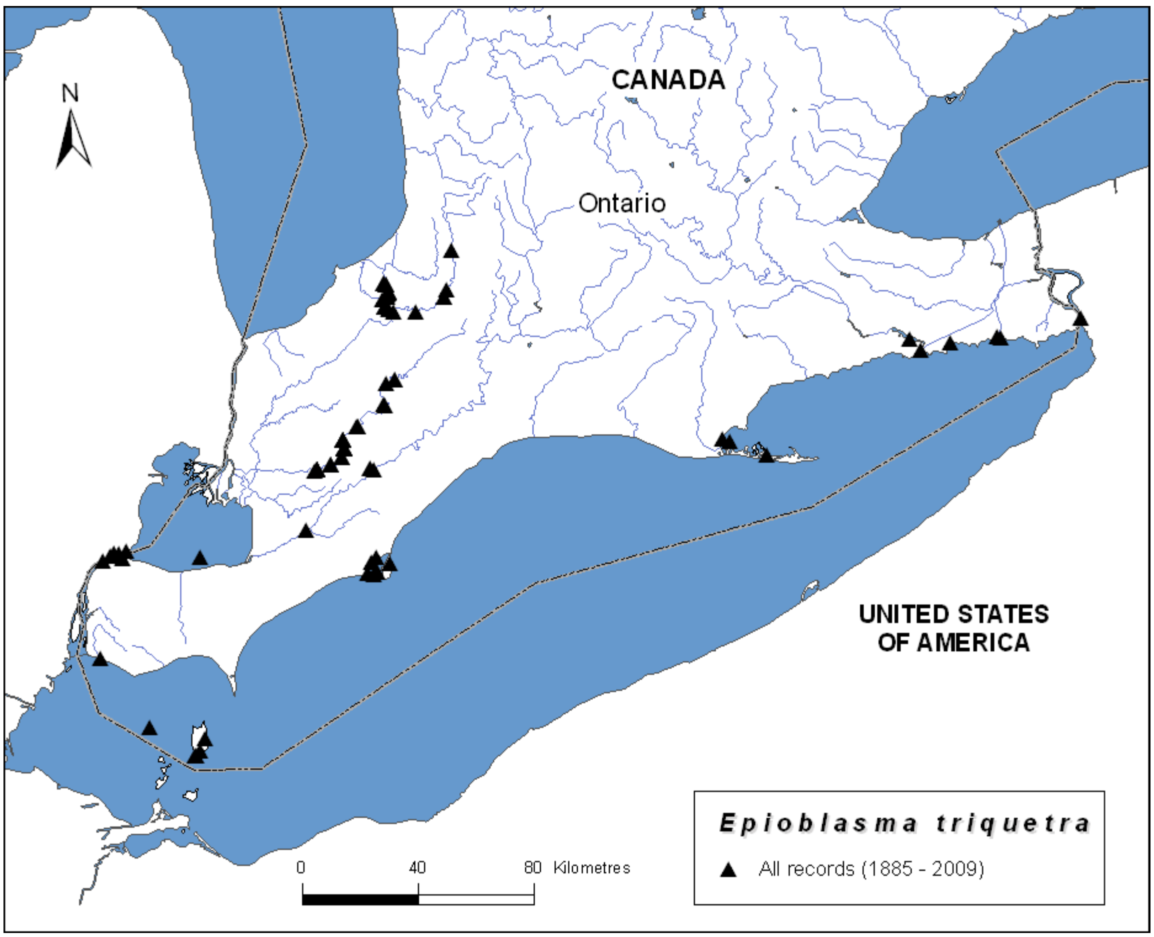

Figure 4. Historical distribution of *Epioblasma triquetra* in Ontario (all records for live animals and shells are included).

Until the mid-1990s, *E. triquetra* was ranked SH (historical; no occurrences verified in the past 20 years) in Ontario by the Ontario Natural Heritage Information Centre. The last report of a live individual involved an unverified specimen from Lake St. Clair in 1983. Prior to that, *E. triquetra* was last confirmed alive in Ontario in 1973 in the Sydenham River. In the period 1990-97, 250 sites within the species' historical range in Ontario were surveyed, but no trace of the species was found (Lower Great Lakes Unionid Database). However, the survey methods used at the 250 sites where records are available were probably not sufficient to detect rare mussel species.

Many of the historical *E. triquetra* records (1885-1985) contained in the Lower Great Lakes Unionid Database are from museum specimens for which there is no information on search effort at sites where *E. triquetra* was collected and no comparable data for sites where *E. triquetra* was not detected. However, there is information on historical sampling effort for the following waterbodies: Lake St. Clair; the Detroit River; the western basin of Lake Erie; and the Sydenham, Thames, and Grand rivers.

All the recent (since 1997) *E. triquetra* records in the Lower Great Lakes Unionid Database (Table 1) are from surveys designed to assess mussel assemblage composition, abundance and/or density. All these records have information on survey methodology and effort. Generally these methods involve either semi-quantitative timed-searches or more detailed true quantitative methods involving substrate excavations (see **Sampling effort and methods** for details on methodology). Extant populations of *E. triquetra* (and other rare mussels) were detected with these specific intensive sampling protocols.

Table 1. Records for *Epioblasma triquetra* collected during mussel surveys of the Sydenham and Ausable rivers, southwestern Ontario, from 1997 to 2009 (Metcalfe-Smith *et al*. 1998c, 1999, 2007; Ausable Bayfield Conservation Authority unpubl. data). Site localities are shown in Figure 5.

Site	Date	Nearest urban centre	Locality description	Latitude	Longitude	Live	Fresh shells (whole)	Fresh shells (valve)	Weathered shells (whole)	Weathered shells (valve)
Ausable River										
AR-05	19980818	Arkona	Rock Glen Cons. Area in Arkona; just upstream of where Rock Glen Cr. enters the Ausable R.	43.085	-81.818	0	1	0	0	1
AR-06	19980819	Arkona	Rock Glen Cons. Area, just upstream of AR-98-5	43.083	-81.817	0	0	0	0	3
AR-07	19980820	Nairn	1st bridge S of Nairn	43.107	-81.565	0	0	0	0	2
AR-04	19980918	Hungry Hollow	Hungry Hollow	43.076	-81.800	0	0	0	0	2
AR-08	19990513	Brinsley	2 concessions upstream of Brinsley, immediately upstream of AR-98-1	43.247	-81.525	0	0	1	0	0
AR-05	19990514	Arkona	Rock Glen Cons. Area in Arkona; just upstream of where Rock Glen Cr. enters the Ausable R.	43.085	-81.818	0	0	0	0	3
AR-16	20030715	Thedford	First bridge crossing downstream of Arkona Gorge (HWY7)	43.151	-81.810	1	0	3	0	0
AR-16	20030715	Sylvan	Observation	43.151	-81.810	1	0	0	0	0

Site	Date	Nearest urban centre	Locality description	Latitude	Longitude	Live	Fresh shells (whole)	Fresh shells (valve)	Weathered shells (whole)	Weathered shells (valve)
AR-21	20040818	Arkona	End of farmer's lane on Laird property - off Arkona Rd.	43.123	-81.796	0	0	0	1	0
AR-16	20040818	Thedford	First bridge crossing downstream of Arkona Gorge (HWY7)	43.151	-81.810	0	0	1	0	0
AR-24	20040819	Ailsa Craig	Sunnyview farms on New Ontario Road at low level crossing	43.128	-81.554	0	0	0	0	1
AR-7	20060719	Nairn	Quadrat	43.107	-81.565	1	0	0	0	0
AR-26	20060809	Laird	Quadrat	43.127	-81.800	17	0	0	0	0
AR-5	20060821	Rock Glen	Quadrat	43.085	-81.816	5	0	0	0	0
AR-12	20060907	Highway 81	Quadrat	43.063	-81.689	3	0	0	0	0
AR-34	20070918	Gorge	Quadrat	43.104	-81.824	2	0	0	0	0
AR-28	20080808	Sadler Tract	Quadrat	43.112	-81.804	44	0	0	0	0
AR-30	20080903	Sadler-Eastman	Timed Search	43.121	-81.801	5	0	0	0	0
AR-33	20080928	Joany's Woods	Timed Search	43.155	-81.816	1	0	0	0	0
AR-33	20090811	Joany's Woods	Observation - Seine netting for mussel SAR host fish and captured a Snuffbox in seine net.	43.155	-81.816	1	0	0	0	0
AR-26	20090814	Laird	Quadrat - Transect 6 located ~50 m upstream of Transect 5 because area directly upstream of 5 too deep for surveying.	43.127	-81.800	19	0	0	0	0
AR-26	20090814	Laird	Observation	43.127	-81.800	1	0	0	0	0
AR-26	20090817	Laird	Observation	43.127	-81.800	1	0	0	0	0
AR-33	20090820	Joany's Woods	Quadrat	43.155	-81.816	1	0	0	0	0
Sydenham River										
SR-01	19970818	Alvinston	7.5 km northeast of Alvinston at bridge crossing	42.860	-81.790	0	0	1	0	0
SR-05	19970820	Florence	Bridge at Florence, just west of town	42.651	-82.010	0	0	0	0	1
SR-12	19980825	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	2	1	0	0	0
SR-17	19980828	Florence	3.4 km N (& slightly W) of bridge at Florence	42.679	-82.017	1	0	0	0	1
SR-12	19990727	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	1	1	0	0	3
SR-03	19990809	Alvinston	5 km downstream of Alvinston at bridge crossing	42.779	-81.835	1	0	0	0	0
SR-06	19991005	Croton	Upstream of Dawn Mills, 2.3 km downstream of bridge at Croton	42.604	-82.072	2	0	0	0	1
SR-05	19991006	Florence	Bridge at Florence	42.651	-82.010	0	0	0	0	1
SR-04	19991006	Shetland	1.8 mi NE of Shetland, near Shetland Conservation Area	42.717	-81.954	0	0	0	0	1
SR-17	20010000	Florence	3.4 km N (& slightly W) of bridge at Florence	42.679	-82.017	8	0	0	0	0
SR-12	20010000	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	5	0	0	0	0
SR-06	20010000	Croton	Upstream of Dawn Mills, 2.3 km downstream of bridge at Croton	42.604	-82.072	2	0	0	0	0
SR-05	20010000	Florence	Bridge at Florence, just west of town	42.651	-82.010	1	0	0	0	0

Site	Date	Nearest urban centre	Locality description	Latitude	Longitude	Live	Fresh shells (whole)	Fresh shells (valve)	Weathered shells (whole)	Weathered shells (valve)
SR-17	20010730	Florence	3.4 km N (& slightly W) of bridge at Florence	42.679	-82.017	3	0	0	0	0
SR-17	20020530	Florence	3.4 km N (& slightly W) of bridge at Florence	42.679	-82.017	2	0	0	0	0
SR-05	20020531	Florence	Bridge at Florence, just west of town	42.651	-82.010	1	0	0	0	0
SR-12	20020619	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	5	0	0	0	0
SR-17	20020704	Florence	3.4 km N (& slightly W) of bridge at Florence	42.679	-82.017	1	0	0	0	0
SR-05	20020705	Florence	Bridge at Florence, just west of town	42.651	-82.010	1	0	0	0	0
SR-10	20020710	Rokeby	4.5 km NE of Alvinston	42.846	-81.825	1	0	0	0	0
SR-05	20020711	Florence	Bridge at Florence, just west of town	42.651	-82.010	2	0	0	0	0
SR-06	20020722	Croton	Upstream of Dawn Mills, 2.3 km downstream of bridge at Croton	42.604	-82.072	1	0	0	0	0
SR-12	20020724	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	2	0	0	0	0
SR-12	20020730	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	3	0	0	0	0
SR-17	20020731	Florence	3.4 km N (& slightly W) of bridge at Florence	42.679	-82.017	3	0	0	0	0
SR-12	20020806	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	7	0	0	0	0
SR-12	20020807	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	2	0	0	0	0
SR-17	20020813	Florence	3.4 km NNW of Florence	42.679	-82.017	1	0	0	0	0
SR-19	20020819	Thames-ville	Quadrat sampling - Behind Babula farm, intersection of Brick Rd. and Dankey Line between Florence and Croton	42.627	-82.023	3	0	0	0	0
SR-01	20020826	Alvinston	7.5 km northeast of Alvinston at bridge crossing	42.860	-81.790	1	0	0	0	0
SR-DM	20020829	Dawn Mills	~1 km downstream of bridge at Dawn Mills	42.588	-82.136	1	0	0	0	0
SR-19	20020830	Thames-ville	Quadrat sampling - Behind Babula farm, intersection of Brick Rd. and Dankey Line between Florence and Croton	42.627	-82.023	3	0	0	0	0
SR-06	20030611	Croton	Upstream of Dawn Mills, 2.3 km downstream of bridge at Croton	42.604	-82.072	2	0	0	0	0
SR-12	20030716	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	18	0	0	0	0
SR-05	20030717	Florence	Bridge at Florence, just west of town	42.651	-82.010	6	0	0	0	0
SR-17	20030724	Florence	3.4 km N (& slightly W) of bridge at Florence	42.679	-82.017	12	0	0	0	0
SR-05	20030813	Florence	Bridge at Florence, just west of town	42.651	-82.010	7	0	0	0	0
SR-19	20030819	Thames-ville	Quadrat sampling - Behind Babula farm, intersection of Brick Rd. and Dankey Line between Florence and Croton	42.627	-82.023	2	0	0	0	0

In the Canadian waters of the lower Great Lakes, *E. triquetra* has been collected only sporadically over the past century. The species was first collected (Appendix I) in Lake Erie near Port Colbourne by J. Macoun (Catalogue # CMNML 000008 [Canadian Museum of Nature]). Numerous other occurrences of the species were recorded from Lake Erie up to the early 1980s but it is not clear if any were collected alive. While several records of *E. triquetra* exist for the Canadian portion of the western basin of Lake Erie (Lower Great Lakes Unionid Database), these were likely wave-deposited empty valves. Schloesser and Nalepa (1994) did not report finding any *E. triquetra* in surveys immediately prior to *Dreissena* invasion. Additional surveys around Pelee Island and Big Creek have not found any living *E. triquetra* (McGoldrick pers. comm. 2009). Historical shell records exist for Rondeau Bay (Lake Erie) and subfossil shells were collected there in 2001, confirming their historical occurrence; however, none were found alive. It was not found during surveys in the U.S. waters of Lake Erie (Schloesser *et al*. 1997; Nichols and Amberg 1999; Schloesser and Masteller 1999). Only one record exists for the Niagara River (E.J. Letson in 1906). R.W. Griffiths collected *E. triquetra* near the mouth of the Ruscom River in Lake St. Clair in 1983. However, it was not found during lakewide surveys of 29 sites in 1986, 1990, 1992 or 1994 (Nalepa *et al*. 1996), nor was it among 22 species—many of them rare—found alive during recent surveys in the St. Clair River delta (Zanatta *et al.* 2002; McGoldrick *et al.* 2009).

Epioblasma triquetra was also reported from the U.S. waters of the Detroit River in the early 1990s (Schloesser *et al.* 1998), but is now believed extirpated (Schloesser *et al.* 2006). Prior to the invasion of dreissenid mussels (*Dreissena polymorpha* [Zebra Mussel] and *D. rostriformis bugensis* [Quagga Mussel]), the Detroit River supported a small population of *E. triquetra* that evidently declined rapidly between 1992 and 1994 (Schloesser *et al*. 1998). Live specimens were collected in 1992 but were not found using identical methods in 1994. Further surveys in 1998 failed to find any living unionids leading Schloesser *et al*. (2006) to declare all unionids extirpated from the river. Additional recent surveys on the U.S. side of the Detroit River have failed to find any evidence of living *E. triquetra* (Badra 2006a,b).

Epioblasma triquetra was previously reported from only two sites in the lower reaches of the Grand River: at Byng Park below Dunnville in 1935 and at Port Maitland in 1966 (Appendix 1). Metcalfe-Smith *et al.* (1998c, 1999, 2000) surveyed 24 sites on the Grand River in 1997-1998, including both of these sites, but failed to uncover even weathered shells. It appears that *E. triquetra* no longer persists in this system.

The Sydenham River population of *E. triquetra* was first recorded by H.D. Athearn in 1963 near Shetland (Clarke 1973). Previously, the mussel community of the Sydenham River had been known only from a few records of the more common species. *Epioblasma triquetra* was also collected by C.B. Stein (personal records provided to Zanatta and Staton, September 1997) at Florence in 1965 (four live specimens, OSUM #1963:0105 [Ohio State University Museum]) and during a subsequent visit to Dawn Mills in 1973 (one live specimen). The diverse collections of Stein and Athearn prompted the first survey of the Sydenham River by A.H. Clarke in 1971. Although Clarke (1973) visited 11 sites, he did not record *E. triquetra*. However, Clarke's sampling effort averaged one hour per site, whereas Athearn conducted a four-hour search. Stein returned to her 1965 site near Florence in 1973 and recorded a fresh shell. Mackie and Topping (1988) surveyed 20 sites on the Sydenham River in 1985 using a sampling effort of one hour per site, with the primary objective of determining which species were still alive in the system. Because no live specimens of *E. triquetra* or three other rare species were found, they concluded that these species were no longer living in the Sydenham River or were present in such low densities that they had escaped detection. This alarming information prompted a further survey of 16 sites on the river in 1991 by Clarke (1992). Although Clarke generally spent more time searching than Mackie and Topping (1988) (i.e., an average of 2.3 person-hours per site (p-h/site) (range 0.4-8.0 p-h/site) versus 1 p-h/site), and he did find many more live species, he was unable to find any trace of *E. triquetra*. In the same year, one weathered half shell was found at a site on the Sydenham River by M.J. Oldham near Alvinston. Based on these findings, the species was assigned a subnational conservation status rank of SH (no verified occurrences within the last 20 years) in Ontario by the Natural Heritage Information Centre (COSEWIC 2001).

Many *E. triquetra* have been collected from the Sydenham River since 1997 in a 72 km reach from Dawn Mills to Sexton, with highest abundances in the vicinity of Florence. The average width of the river reach is 20 m; thus, the biological area of occupancy (AO) for *E. triquetra* in the Sydenham River is ~1.44 km^2 while the IAO is 160 km^2 (calculated using a continuous 2 km x 2 km grid) or 85 km^2 (calculated using a continuous 1 km x 1 km grid).

In 1998, a previously unknown population of *E. triquetra* was discovered in the Ausable River (Ausable River Recovery Team 2005). Since the original COSEWIC (2001) report on *E. triquetra*, a total of 99 live *E. triquetra* were found at seven of the 11 sites sampled using systematic quadrat sampling in the Ausable River between 2006 and 2009 (Ausable Bayfield Conservation Authority, unpublished data). Between 1998 and 2009, live *E. triquetra* has been collected in a 59.7 km reach of the Ausable River between the Elgenfield Rd. bridge and Nairn, with the highest concentrations in the lower sections of the Arkona Gorge. The average width of the river reach is 7.5 m; thus, the AO in the Ausable River is ~0.45 km^2 and the IAO is 144 km^2 (calculated using a continuous 2 km x 2 km grid) or 84 km^2 (calculated using a continuous 1 km x 1 km grid).

The Snuffbox was found in the Thames River at Chatham in 1894 (Appendix 1), and the specimen was deposited in the Canadian Museum of Nature (Catalogue CMNML # 0025002). Because the specimen is a fresh whole shell, it is reasonable to assume that it was found alive. Another fresh whole shell was collected near Thamesville in 1935 and deposited in the Royal Ontario Museum. An apparently healthy population was observed at a site on the Middle Thames River north of Thamesford in 1970. Metcalfe-Smith *et al*. (1998c, 1999) surveyed 16 sites on the Thames, Middle Thames and North Thames rivers in 1997-1998, including the sites near Thamesville and Thamesford, and found evidence of this species at only one site. Three weathered valves (half shells) were found at the historical site near Thamesville in 1997 (site TR-7, Figure 5) and another apparently fresh valve in 1998. No Snuffbox (live or dead) were collected in recent intensive quantitative surveys on the Thames River (Morris and Edwards 2007). However, there may be potential for recovery in the lower Thames River, particularly considering its close proximity to the Sydenham River, similar habitat conditions and similarly diverse unionid community. There remains the slight possibility of an extant population in the Thames, given the fresh valve collected in 1998, thus the IAO for this location is 4 km^2 (calculated using a continuous 2 km x 2 km grid) or 1 km^2 (calculated using a continuous 1 km x 1 km grid).

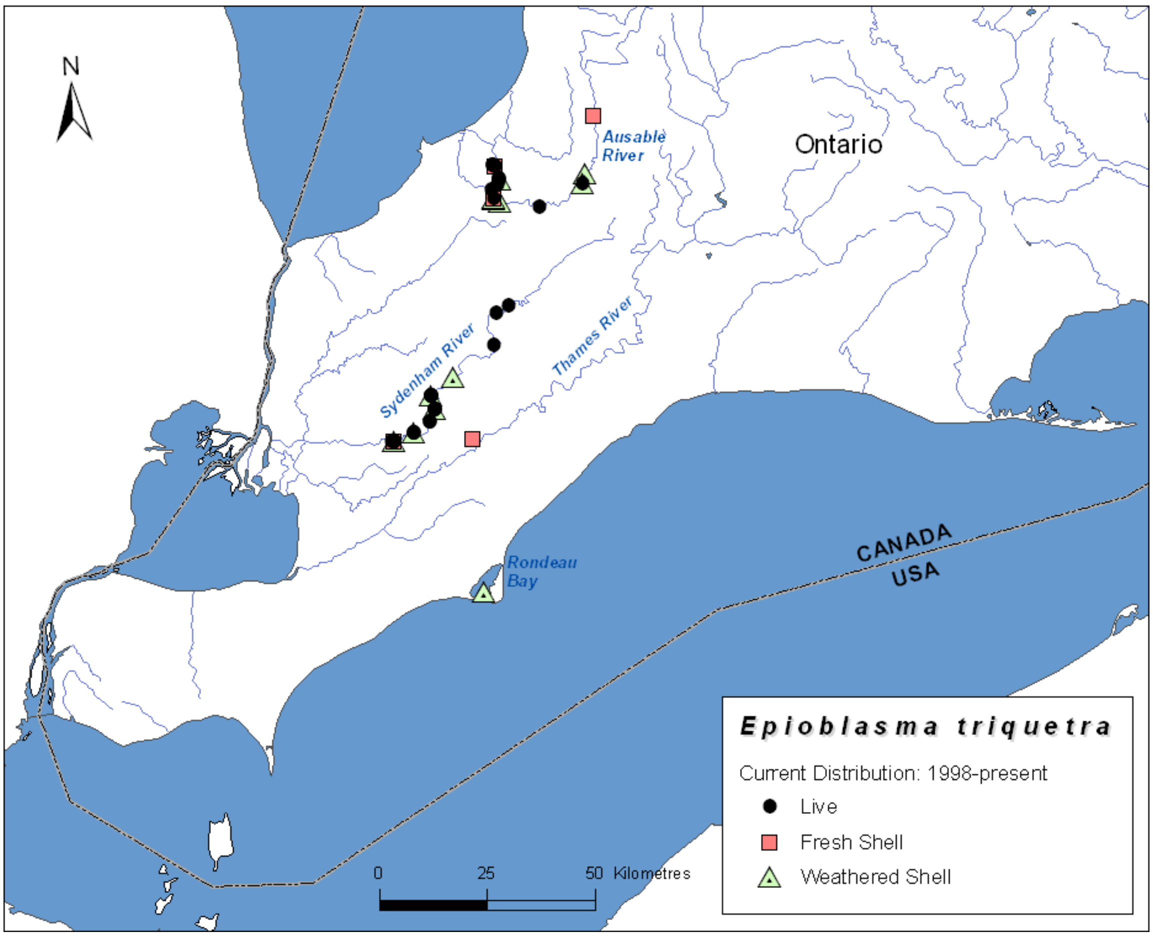

Figure 5. Current distribution of *Epioblasma triquetra* in Ontario, based on records from recent surveys. See Table 1 for details.

The total current extent of occurrence (EO) for *E. triqueta* in Canada, calculated using a minimum convex polygon of live animals and fresh dead shells collected since 1998 (Figure 5), is 1482 km^2. In contrast, the historical EO, using all records from 1885 through 2009 (Figure 4), is 26,173 km^2. The 94% decline between historical and current EO occurred within the past 113 years but records are too few (only 7 records between 1968 and 1985 and only 2 records between 1983 and 1985; Appendix 1) to determine if the decline occurred within the past three generations. If generation time is either 5 or

10 years (see **Development from juvenile to adult**), three generations began either 15 or 30 years before 1998—in 1983 or 1968, respectively. Total index of area of occupancy (IAO), calculated using a 2 km x 2 km grid of live animals and fresh dead shells collected since 1998, is 308 km^2. Extant *E. triquetra* populations in the Sydenham and Ausable rivers meet the IUCN (2001) definition as separate locations as the mussels in the two river drainages cannot be eliminated by any single threatening event (e.g., a chemical spill, see **THREATS AND LIMITING FACTORS**). Recently, COSEWIC also concluded that a 70 km reach of the Ausable River and a 72 km reach of the Sydenham River occupied by Northern Riffleshell were each a location (COSEWIC 2010a). Maps showing the recent search effort for other freshwater mussels in southern Ontario are found in COSEWIC (2010a,b,c).

The total Canadian population of *E. triquetra*, with separate locations in the Sydenham and Ausable rivers, also can be considered isolated and fragmented as (fouling) dreissenid mussels have made the intervening habitats between the Sydenham and Ausable rivers (i.e., St. Clair River and Lake Huron) uninhabitable. Similarly, while there are populations in several Great Lakes tributaries in the U.S. (e.g., Pine, Belle, Clinton, and Huron rivers in Michigan), the probability of natural recolonization from Michigan is extremely low in the event of local extirpations of Canadian populations. While the total Canadian population is fragmented, both the populations in the Sydenham and Ausable rivers appear to be viable as reproduction is occurring at both (see **Fluctuations and trends**); therefore, the population does not meet the definition for severely fragmented (IUCN 2011).

HABITAT

Habitat requirements

Epioblasma triquetra is typically found in riffle areas or shoals (runs) in small- to medium-sized rivers and streams (e.g., van der Schalie 1938; Dennis 1984). Its substrate preference has been variously described as stony and sandy bottoms (Baker 1928; Clarke 1981); gravel, cobble and boulder (Buchanan 1980); sand and cobble (Sherman 1994); coarse sand and gravel (van der Schalie 1938); fine or coarse, closely packed gravel (Ortmann 1919); and medium-sized gravel (Oesch 1984). It has been reported at depths of 5-60 cm (Buchanan 1980), 20-40 cm (Dennis 1984), <1 m (Gordon and Layzer 1989) and 2.5 m (Baker 1928), and is invariably found in areas with swift currents. Buchanan (1980) measured bottom velocities of 0.36-0.51 m/s at collection sites in the Meramac River basin, Missouri. Many of the historical records for this species in Canada come from Lake Erie (Appendix 1), where it probably inhabited the wave-washed shoals that were also occupied by a related species, *E. torulosa rangiana* (USFWS 1994). The Snuffbox is usually found entirely buried in the substrate (Buchanan 1980), or with only the posterior slope exposed to view (Ortmann 1919).

Habitats where *E. triquetra* were found alive in recent years in the Sydenham and Ausable rivers (Figure 5) were consistent with those described above, i.e., shallow riffle/run areas with coarse substrates in a medium-sized river (Metcalfe-Smith *et al.* 2007; Staton, Veliz, and Woolnough unpubl. data). The habitat where each live specimen was found in the Sydenham River is described in detail in Metcalfe-Smith *et al.* (2007). Water levels in the Sydenham River were lower than normal throughout this period, particularly in 1999. Water depths and current velocities where *E. triquetra* were found may therefore represent tolerance limits, rather than optimal conditions.

Habitat trends

According to Neves (1993), the "decline, extirpation and extinction of mussel species is almost totally driven by habitat loss and degradation." Williams *et al*. (1993) identified habitat destruction from dams, dredging, channelization, siltation and pollution, and the introduction of non-indigenous molluscs, as the primary reasons for the decline of mussels across North America. Richter *et al*. (1997) evaluated the impacts of a wide range of anthropogenic stressors and their sources on a variety of freshwater fish, amphibian and invertebrate species at risk, and concluded that suspended sediment and nutrient loadings from agricultural activities, exotic species, and altered hydrology due to impoundments were the dominant problems for mussels. Freshwater mussel communities in the Great Lakes region are exposed to many of these threats.

The introduction of the Zebra Mussel to the Great Lakes in the late 1980s (Hebert *et al*. 1989) led to dramatic declines of native mussels in Lake St. Clair (Nalepa *et al*. 1996) and western Lake Erie (Schloesser and Nalepa 1994). It was originally thought that unionids would be completely extirpated from Great Lakes waters by the Zebra Mussel. However, healthy and diverse communities were discovered in Lake Erie in nearshore areas with firm substrates (Schloesser *et al*. 1997) and coastal marshes (Nichols and Amberg 1999), and in similar habitats around the St. Clair River delta in Lake St. Clair (Mackie *et al*. 2000). *Epioblasma triquetra* was not among the species recorded during any of these investigations, although small numbers of a related species, *E. torulosa rangiana*, were found in Lake St. Clair. Trdan and Hoeh (1993) observed Zebra Mussels had eliminated a population of *E. triquetra*, which had been temporarily relocated to the Detroit River to protect it from a dredging operation, within one year. Because two-thirds of the historical records for *E. triquetra* in Ontario are from the Great Lakes and their connecting channels, it may be assumed that the Zebra Mussel invasion has caused a substantial loss of habitat for this unionid throughout a large portion of its former range. Zebra Mussels also infest the lower reaches of the Grand River (below the Dunnville Dam), which is the only area in this river where *E. triquetra* was found in the past.

Southwestern Ontario is the most heavily populated and intensively farmed region of Canada; thus, agricultural, urban and industrial impacts have likely resulted in a loss of habitat for *E. triquetra* in the Grand, Thames, Sydenham and Ausable rivers. The proportion of the Grand River basin in agricultural use has increased steadily and is currently at 75% (GRCA 1998, 2010). Consequently, runoff of sediment, pesticides, fertilizers and livestock manures is increasing. The human population increased from 375,000 in 1971 to 787,000 in 1996 and 925,000 in 2010 (GRCA 1997, 2010). Poor water quality is believed to be responsible for a dramatic decline in mussel species from a historical total of 31 to only 17 by the early 1970s (Kidd 1973). Although many species have since rebounded, probably due to improvements in sewage treatment (Metcalfe-Smith *et al*. 2000), it is possible that some rare species such as *E. triquetra* were unable to recover. The human population of the basin is projected to grow by another 300,000 people by the year 2031 (GRCA 2010), and there is concern that the river will not have the capacity to dilute the additional wastewaters produced.

The Thames River has lost a significant proportion of its mussel community; 30% of species known from historical records were not found alive during the surveys of 1997-2005 (Metcalfe-Smith *et al*. 1999; Thames River Recovery Team 2004; Morris and Edwards 2007). This decline in mussel diversity likely reflects degradation of habitat throughout the system. Livestock farming is the main form of agriculture in the upper portion of the Thames River, whereas row crop farming predominates in the lower Thames. By 1989, only 8% of the basin was still forested. The upper Thames supports a large urban population, with 22 sewage treatment plants and two industries discharging their wastes into this part of the system (WQB 1989; Thames River Recovery Team 2004). Tile drainage systems, wastewater drains, manure storage and spreading, and insufficient soil conservation practices all contribute to the impairment of water and habitat quality in the Thames River. Soil and streambank erosion is severe, causing high suspended sediment loads in the lower reaches where *E. triquetra* historically occurred. There has been a steady increase in phosphorus and nitrogen inputs to the Thames River, and some of the highest livestock phosphorus loadings for the entire Great Lakes basin are attributable to the Upper Thames watershed (WQB 1989; Thames River Recovery Team 2004). Despite recent efforts to improve water quality throughout the basin, poor water quality still exists in some areas. For example, mean ammonia concentrations exceed the federal freshwater aquatic life guideline in all sub-basins, and mean copper concentrations exceed the guideline in several sub-basins (WQB 1989; Thames River Recovery Team 2004).

The Sydenham River supports the most diverse and intact mussel fauna of any river in Canada; 30 of the 34 species historically known from the river were found alive in 1997-2009 (Staton *et al.* 2003). This river lacks the urban impacts of the Grand and Thames rivers, which may explain why its mussel communities have remained healthier. Population growth in the basin has been modest. For example, the population of the major municipalities in the Sydenham basin increased by about 40% from about 26,000 in 1967 (Osmond 1969) to 37,000 in 1996 (Dextrase *et al.* 2003), while the population of the Grand River basin is more than an order of magnitude larger and growing at a faster rate (GRCA 2010). There have also been major improvements in sewage treatment. In 1965, only Strathroy, Petrolia and Wallaceburg treated their sewage (DERM 1965; Dextrase *et al.* 2003), whereas all towns and villages now have some form of sewage treatment. Land use in the watershed is predominantly agricultural, i.e., row crops, pasture and woodlot, and 96% of the land is privately owned. Flooding is a problem in some areas, so there is an extensive land drainage system (DERM 1965; Dextrase *et al.* 2003). Tile drains cause fine-grained suspended solids to infiltrate the river and clog gill structure of unionids. With over 60% of watershed being tile drained and a general lack of riparian vegetation, there remains great concern for chronic effects on unionid health (Dextrase *et al.* 2003). Mackie and Topping (1988) observed diminishing dissolved oxygen concentrations with distance downstream in both branches of the Sydenham River in 1985, and suggested that this was an indication of deteriorating water quality. Arthur H. Clarke surveyed the river for mussels in 1971 (Clarke 1973) and again in 1991 (Clarke 1992), and reported that most of the riffle areas had become covered in silt over that 20-year period. The East Sydenham River supports a greater diversity of mussel species (28) than Bear Creek (19), and most rare species, including *E. triquetra*, are found only in the East Sydenham River (Metcalfe-Smith *et al.* 2003). Thus, it will be very important for the preservation of these species to determine if water and/or substrate quality are continuing to deteriorate in this branch. An examination of 30 years' of water quality data collected by the Ontario Ministry of the Environment between 1965 and 1996 showed that chloride and conductivity levels have been increasing steadily over time in the East Sydenham River. These findings could indicate that runoff of contaminants from roads and/or agricultural activities is increasing (Dextrase *et al.* 2003).

The Ausable River supports a remarkably diverse and abundant mussel community (24 species) for such a small river (Ausable River Recovery Team 2005). Because of a lack of historical data for this system, it cannot be determined if there have been significant changes in the mussel community over time. However, there have been dramatic alterations in habitat. Agriculture is the primary land use in the Ausable River watershed, with over 70% of the area being used for row crops (corn and beans) and only 13% remaining forested (ABCA 1995; Ausable River Recovery Team 2005). Livestock farming is also intensive, particularly in the upper reaches. Water quality is generally poor because of runoff from agricultural lands, septic system seepage, and pollution from manure. About 70% of the land is artificially drained with headwaters becoming increasingly enclosed (i.e., tiles), which decreases base flows in the river and contributes to 'flashiness' and flooding during storm events (Ausable River Recovery Team 2005; Veliz and Sadler Richards 2005). Sediment loadings are high. 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. Detweiler (1918) remarked that the lower river was once "paved with shells", and that prior to the construction of the artificial channels, the river had been "…admirably suited to the support of mussel life".

BIOLOGY

Reproduction and early development

Freshwater mussels are generally dioecious. A few species reproduce primarily as hermaphrodites, and hermaphroditic individuals have been encountered in low frequencies in populations of many predominantly dioecious species (Kat 1983). However, hermaphroditism has not been reported for *E. triquetra* (van der Schalie 1970). The basic life cycle of the freshwater mussel is applicable to the Snuffbox. During spawning, males release sperm into the water and females living downstream take in the sperm through their incurrent siphons. Ova are fertilized and the developing embryos are held in modified portions of the gills, called marsupia, until they reach an intermediate larval stage called the glochidium. The marsupia become progressively more swollen and pad-like as the glochidia develop. The length of time required for larvae to reach this stage varies from species to species and is also dependent on water temperature. Release of glochidia is usually triggered by changes in water temperature. The female mussel expels the mature glochidia into the water column through the incurrent siphon, by forcefully closing her valves (Kat 1984). The glochidia must then attach to an appropriate host and encyst in the host's tissues in order to complete their metamorphosis to the juvenile stage. After transformation, the juvenile detaches from the host and falls to the substrate where it completes its development into a free-living adult.

Epioblasma triquetra is a long-term brooder (bradytictic), which means that fertilization occurs in the late summer and glochidia are held over winter for release the following spring or summer. In Pennsylvania, Ortmann (1919) found that females were gravid from September to May, and glochidia were discharged in late May.
Van der Schalie (1938) reported gravid females in all months except July and August in the Huron River drainage of southeastern Michigan. In the Powell River of the upper Tennessee River drainage, gravid females were seen from May 1 to June 5 at water temperatures of 15.0-17.8°C (Yeager and Saylor 1995). Sherman (1994) states that spawning of *E. triquetra* in the Clinton River, Michigan, probably occurs from mid-July to August when water temperatures are 21-27°C. She found that glochidia were released from early May to mid-July when water temperatures were 16-29°C. Sherman (1994) also observed that females release their glochidia over several weeks, rather than all at once, and she suggested that temperatures above 16°C may trigger release in this species.

The glochidia of *E. triquetra* are small- to medium-sized, nearly semicircular, hookless, and measure 210 μm in both length and height (Clarke 1981; Oesch 1984). The glochidia of many rare species of unionids, including all members of the genus *Epioblasma*, are morphologically depressed (i.e., valve height is equal to or less than valve length). According to Hoggarth (1993), morphologically depressed glochidia are less likely to make initial contact with a host than elongate glochidia due to a smaller valve gape, but are better adapted to holding on tightly once contact has been made. Hoggarth (1993) suggested that species with morphologically depressed glochidia have a lower rate of recruitment, and may therefore be more at risk of extinction once numbers of breeding adults drop below a critical threshold level.

After they have attached to a host, the glochidia cause "epithelial proliferation" of host tissue and become completely encysted within two to 36 hours (Lefevre and Curtis 1910). Glochidia are not host-specific in attachment, and when encystment occurs on an unsuitable host, the fish will slough them off within 4-7 days (Kat 1984). Once encystment on a suitable host occurs, it may take from 6 days to over 6 months to complete the transformation from glochidium to juvenile mussel (Kat 1984). During this period, the glochidium is parasitic in that it absorbs organic molecules from the host's tissues and requires plasma for development (Ellis and Ellis 1926; Isom and Hudson 1982). Once metamorphosis is complete, the juvenile mussel ruptures the cyst by extending its foot (Lefevre and Curtis 1910). According to Watters (1994), the odds that a glochidium will reach this stage in its life cycle are 4 in 100,000.

Five species of fish have been shown to serve as hosts for *E. triquetra*: the Banded Sculpin (*Cottus carolinae*), Blackspotted Topminnow (*Fundulus olivaceous*), Ozark Sculpin (*Cottus hypselurus*), Logperch, and Blackside Darter (*Percina maculata*) (Sherman 1994; Yeager and Saylor 1995; Hillegass and Hove 1997; Barnhart 1998). The Snuffbox did not transform on any of 44 other fishes from many different families that were tested in these laboratory exposures. Barnhart (1998) reported a transformation time of 21-27 days at 20ºC on Logperch, and Yeager and Saylor (1995) observed a transformation time of 24-44 days at 17°C on Logperch and Banded Sculpin. Sherman (1994) examined 17 species of wild fish from the Clinton River, Michigan, for possible *E. triquetra* infections and found that Logperch had the highest rate of infection, coinciding with the timing of glochidial release. Two of the five known host fishes for *E. triquetra* are native to Ontario: the Logperch and Blackside Darter. Logperch and Blackside Darter have been confirmed as hosts for *E. triquetra* in Canada in laboratory testing (Woolnough 2002; McNichols and Mackie 2002, 2003; McNichols *et al.* 2004).

Female *E. triquetra* use a fascinating behaviour to infest a potential host fish (Barnhart *et al.* 2008). A female Snuffbox will gape, waiting for a Logperch to insert its rostrum into the valve gap. When the fish touches the mussel, it snaps shut trapping the fish. Upon capture, the mussel forms a "gasket" with its mantle flesh around the mouth of the fish. The mussel pumps glochidia into the mouth of the fish; the glochidia then attach to and infest the gills as described above. The conical snout and unique foraging behaviour of Logperch renders them particularly susceptible to parasitism by *E. triquetra*. Also of note, the Logperch has a strong skull and survives the closing of the mussel shell, while other darter species (*Etheostoma* sp.) that were used by Barnhart *et al.* (2008) had their skulls crushed, died, and thus were not infested with glochidia. Blackside Darters were not included in these experiments. This evidence is consistent with co-evolution between mussel and host fish. See Barnhart (2008) for video and Barnhart *et al.* (2008) for further descriptions of this fascinating behaviour.

Development from juvenile to adult

A newly metamorphosed juvenile mussel has only rudimentary gills that do not fully develop until the second month of life (Howard 1922). Once it has detached from its host, and if it has been deposited into suitable habitat, the juvenile begins to feed and grow immediately. Juveniles are very active, and may be capable of migrating short distances to find suitable substrate (Howard 1922). At three weeks of age, a gland on the posterior median edge of the foot secretes a sticky thread called a byssus (Fuller 1974). The byssus, which persists until the end of the second growing season, allows purchase on solid objects and prevents the juvenile from being swept away by water currents (Howard 1922). In addition to Snuffbox, the report writer has observed buried juveniles of two species, the Rayed Bean (*Villosa fabalis*) and Fragile Papershell (*Leptodea fragilis*), in the field with byssal threads attached to one or more small (<0.5 cm diameter) pebbles.

Growth is most rapid during the first few years of life. Growth rates decline significantly upon maturation, reflecting the allocation of energy to reproduction. Age at sexual maturity is variable among species. Members of the Ambleminae are generally slow growing and long-lived, and tend to mature later in life (generally at 6-8 years of age). Lifespan and age at sexual maturity is not known for *E. triquetra*. However, Dennis (1984) collected 8- to 10-year-olds from the Clinch River, Virginia, and Yeager and Saylor (1995) reported that gravid females collected from the Powell River, Tennessee, in 1984 were 5-10 years of age. Based on these observations, the generation time for *E. triquetra* is estimated to be 5-10 years.

Food and feeding

Freshwater mussels feed by passing water (which is propelled by beating cilia on the gills) between the gill filaments to filter out suspended particles (Burky 1983). The filtered particles are passed to two pairs of labial palps that sort food from non-food items (McMahon 1991). Filtered particles that are not consumed are bound in mucus, passed off the edges of the palps, and carried posteriorly by cilia along the edges of the mantle. This "pseudofeces" is then ejected by forceful contractions of the valves (McMahon 1991). Food items are passed to the mouth, which is a simple opening between the two pairs of palps, where they are ingested. Freshwater mussels consume a variety of materials, including algae, plankton, rotifers, diatoms, protozoans, detritus, and sand (Coker *et al*. 1921; Churchill and Lewis 1924). Unionids (including *E. triquetra*) have been successfully raised on algae and yeast cultures in the laboratory (USFWS 1994). Nichols and Garling (1999) used a combination of techniques, including identification of gut contents, carbon and nitrogen stable isotope ratios, and tissue biochemical analyses to determine the dietary habits of various species of unionids in a Michigan stream. Results showed that all species were using algae and bacteria as food sources. The specific food habits of *E. triquetra* are unknown.

POPULATION SIZES AND TRENDS

Sampling effort and methods

Timed searches

Timed-search methods produce data on species presence/absence and 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 person-hours. Searches may be conducted using only the naked eye when conditions are favourable or may be assisted using polarized sunglasses. When turbidity is high, searching the substrate by feel is the more effective search method (also called "grubbing" or "raccooning"). 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 river alive. Since 1997 these methods have been employed at 104 riverine sites within the historical Canadian range of *E. triquetra*.

Quadrat excavations

Additional surveys were conducted starting in 1999 in the rivers of southern Ontario using a quadrat excavation method developed by Metcalfe-Smith *et al*. (2007) in an effort to establish long-term monitoring stations for unionids in southwestern Ontario. In this method, an area of approximately 400 m^2 encompassing the most productive portion of the reach (as defined by previous sampling) is selected as the study area. Sampling is conducted using a systematic sampling design whereby the study area is divided into 3 m x 5 m blocks and the same three 1 m^2 quadrats, chosen randomly, within each block are sampled (= 20% of the entire 400 m^2 study area). Each quadrat is excavated to a depth of approximately 10 cm and all mussels are removed. As with the timed-search method, individuals are identified, sexed if possible, females checked for gravidity, 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 approach of Metcalfe-Smith *et al*. (2007) and Mackie *et al.* (2008) has been employed at 31 riverine sites within the historical Canadian range of *E. triquetra*.

Abundance

Intensive surveys were conducted at 66 sites on tributaries to Lake Erie, Lake St. Clair and lower Lake Huron in 1997-1999 (Metcalfe-Smith *et al*. 1998c, 1999) and yielded a total of 34 specimens from 13 different sites on the Ausable and Sydenham rivers (Table 1). Only seven of these specimens were found alive, and all were taken from four sites on the Sydenham River (Figure 5). Weathered shells[1] accounted for most of the remaining specimens (21), but fresh shells[1] were found at several sites on the Sydenham, one site on the Thames, and two sites on the Ausable River (Figure 5). Based on these findings, the Snuffbox is currently restricted to several small isolated populations on the Sydenham and Ausable rivers and possibly the Thames River.

Metcalfe-Smith *et al*. (1998c, 1999) surveyed 17 sites on the Sydenham River in 1997-1998, and made supplementary collections at several of these sites in 1998 and 1999. The sites at Shetland, Florence and Dawn Mills where *E. triquetra* had been found historically were visited, as were three other sites within this reach (bounded by sites SR-4 and SR-12 in Figure 5). A total of seven live specimens, two fresh whole shells, one fresh valve and seven weathered valves were found at seven different sites on the East Sydenham River. Most specimens were found in the historically occupied reach, but one live animal and one fresh shell were found further upstream (Figure 5). No specimens were found at the five sites surveyed on the north branch of the Sydenham River (Bear Creek), nor had the Snuffbox been previously reported from this drainage. These findings suggest that the distribution of *E. triquetra* in the Sydenham River has not changed appreciably over time.

[1]Shells that exhibited dull nacre and wear to the periostracum and hinge teeth were defined as “weathered”; shells in this condition could be decades old. Shells having an intact periostracum, shiny nacre, and little or no wear of the hinge teeth were defined as “fresh”. Shells in this condition were estimated to be one to three years old (Strayer pers. comm. 1996).

A total of 17 live *E. triquetra* were found at seven of the 15 sites quantitatively sampled in the Sydenham River between 1999 and 2003 (Metcalfe-Smith *et al*. 2007). Mean density over the seven sites was 0.015/m^2 (S.E. = 0.002), while total unionid density at the seven sites ranged from 3.01 to 14.1/m^2. Assuming that the distribution of *E. triquetra* is continuous within the reach bounded by those seven sites on the East Branch (72 km, Dawn Mills to Sexton) and that the average width of the river in this stretch is approximately 20 m yields a potential of 1.44×10^6 m^2 of habitat and a maximum population estimate of 21,000 (± 2880 S.E.) individuals. A size-frequency distribution for the Sydenham River (Figure 6) indicates recruitment and representation from multiple size classes. However, these results should be viewed cautiously. Evidence of recent recruitment was noted for only three of seven sites (Dawn Mills, Florence, and SR-17) and the total number of juveniles (<25 mm) was relatively small (Metcalfe-Smith *et al.* 2007; Zanatta pers. obs.). Metcalfe-Smith *et al*. (2007) also noted sex ratios of Snuffbox skewed toward males (77% M: 23% F) and suggested that the paucity of female specimens in the Sydenham River "may have serious consequences for the continued survival" of this species in the system.

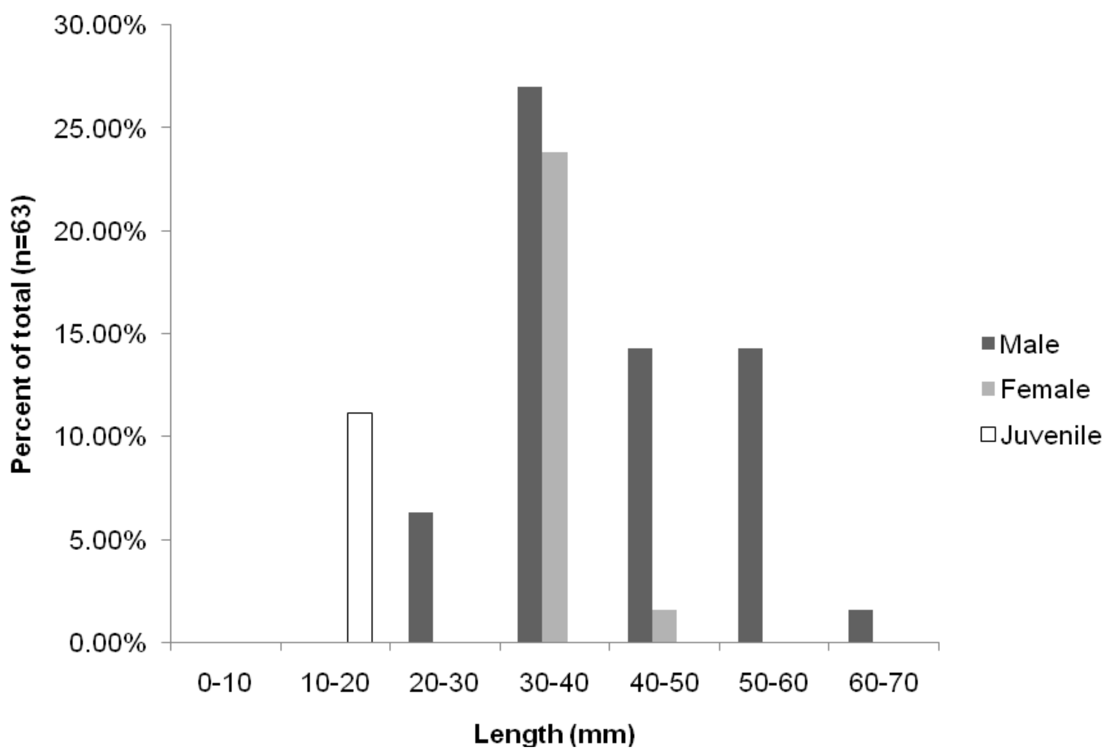

Figure 6. Size classes of *Epioblasma triquetra* collected from the Sydenham River in 2009 (K. McNichols, University of Guelph unpubl. data).

In the Ausable River, mean density of *E. triquetra* at the 11 sites where the mussel was found was 0.091/m^2 (S.E. = 0.016). Assuming that the distribution of *E. triquetra* is continuous within the reach bounded by the 11 sites (59.7 km, Elginfield Rd. to Nairn Rd.) and with the average width of the river in this stretch being approximately 7.5 m yields a potential of 4.5×10^5 m^2 of habitat and a maximum population estimate of 40,745 (± 7164 S.E.) individuals. The size-frequency distribution for *E. triquetra* in the Ausable River (Figure 7) indicates recent recruitment (numerous juveniles) with representation from multiple size classes (19 – 62 mm). This new information (collected since the 2001 status report) shows that the reach length, densities (at some sites), and overall population sizes of *E. triquetra* in the Ausable and Sydenham rivers may be similar.

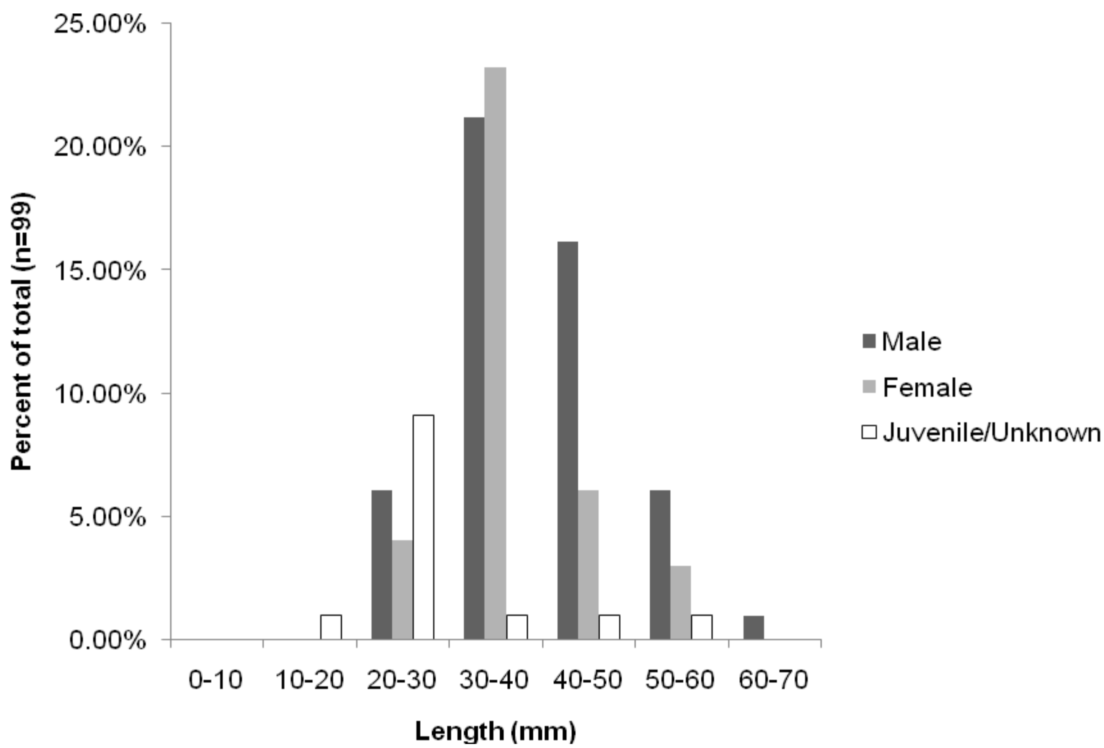

Figure 7. Size classes of *Epioblasma triquetra* collected from the Ausable River between 2006 and 2009 (Ausable Bayfield Conservation Authority unpubl. data).

Fluctuations and trends

It is difficult to determine if there have been changes in the abundance of *E. triquetra* in the Sydenham River over time, because few live animals had been observed before the intensive sampling in the late 1990s and 2000s. Capture rates at sites SR-4, SR-5 and SR-12 appeared to decline between 1963-1973 and 1997-1999. Current catch rates at three other sites for which no previous data exist also tended to be lower than historical rates at the above sites. This evidence, although weak, suggests that the Snuffbox has suffered a decline in abundance over the long-term in the Sydenham River. However, anecdotally, numbers of *E. triquetra* collected in the 2000s for genetic analysis (Zanatta and Murphy 2008; Galbraith *et al.* 2010) and host fish testing (K. McNichols, University of Guelph unpubl. data) appear to show increased numbers when compared to sampling in the mid-1990s. Many *E. triquetra* have been found in yearly visits to sites at Dawn Mills and Florence (2001 through 2010; Zanatta pers. obs.; Galbraith *et al.* 2010; McNichols pers. comm. 2010). It is difficult to determine if this is an artifact of increased sampling or an actual increase in Snuffbox abundance. A repeat of the 1999-2003 quadrat sampling on the Sydenham River is needed to determine population trajectories for *E. triquetra* and other unionid Species at Risk.

Due to the paucity of data in the Ausable River, it is impossible to determine if *E. triquetra* populations have changed over time.

Information on sex ratios and size class structure can be used to indicate population health and reproductive success. The sex ratio of males to females was 66% M: 34% F in the Sydenham in 2009 and 57% M: 43% F in the Ausable from 2006-2009. Sex ratios in healthy populations of *E. triquetra* are nearly 1:1 (Trdan and Hoeh 1993). As such there appears to be a slightly disproportionate number of males in both rivers; however, this could be a result of sampling bias toward larger males. If these ratios are valid, the Ausable population appears to have a healthier sex ratio than the Sydenham population. The broad range of sizes for specimens of both sexes (Figure 6 and 7) indicates that several year classes are represented in both the Sydenham and Ausable rivers, suggesting there is ongoing recruitment in both populations.

Rescue effect

All Canadian populations of *E. triquetra* are isolated from one another and from U.S. populations by large areas of unsuitable habitat (or dry land), making the likelihood of re-establishing extirpated populations by immigration negligible. The Logperch and Blackside Darter hosts of *E. triquetra* are not capable of the large-scale movements required to connect populations (Woolnough *et al.* 2009; Schwalb *et al.* 2011). Furthermore, *E. triquetra* populations in adjacent U.S. states are all endangered or extirpated (Figure 8). The nearest U.S. populations are in Michigan (Belle, Pine, Clinton, and Huron rivers), only a few kilometres of river distance across the U.S. border. However, even relatively nearby populations of *E. triquetra* in the tributaries of the St. Clair River, Lake St. Clair and Lake Erie in Michigan (Badra and Goforth 2003) are separated by habitats that are heavily infested with dreissenid mussels and Round Gobies (*Neogobius melanostomus*) (Poos *et al.* 2010), a competitor with hosts.

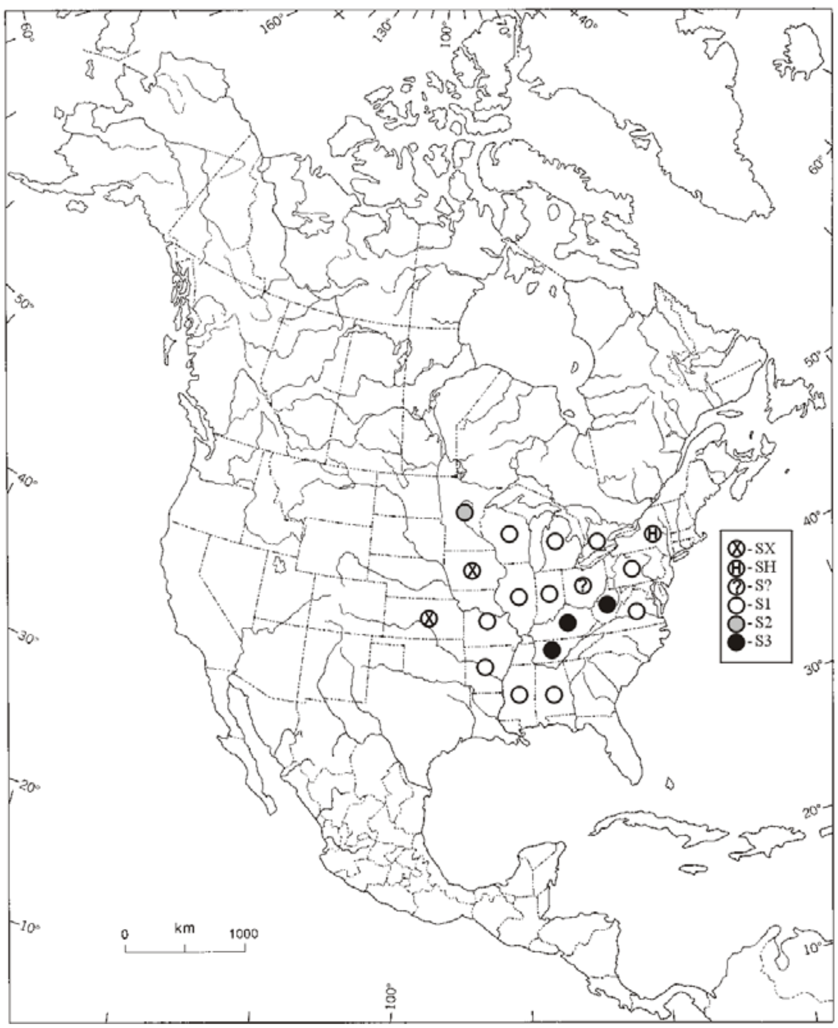

Figure 8. Current range and SRANKs of *Epioblasma triquetra* in North America (NatureServe 2010).

THREATS AND LIMITING FACTORS

Approximately 67% of the nearly 300 species of freshwater mussels in North America are either extinct or vulnerable to extinction (NNMCC 1998). The decline of mussel populations during the 20th century may be largely attributed to impoundments, siltation, channel modification, pollution and, more recently, the introduction of the non-indigenous dreissenid mussels into North American waterways (Williams *et al*. 1993). Metcalfe-Smith *et al*. (1998a) showed that mussels are also declining in the lower Great Lakes drainage basin of central Canada, where three-quarters of Canada's freshwater mussel species were historically found. According to Metcalfe-Smith *et al*. (1998b), as many as 15 of the 40 species native to this region may be at risk.

According to NatureServe (2010), *E. triquetra* is sensitive to pollution, siltation, habitat perturbation, inundation, and loss of glochidial hosts. Sites where it still occurs are described as "…high quality streams with little disturbance to the substrate or riparian zone". In Virginia, the impoundment of large rivers has destroyed much of the habitat for *E. triquetra*, and the greatest threats to remaining populations are the deterioration of water quality and habitat alteration (Virginia DCR 2000). Specific threats and limiting factors for this species, and their relevance to Canadian populations, are described below.

Siltation

There is a general perception that high sediment loads due to poor land-use practices are one of the major causes of unionid declines across the continent (Richter *et al*. 1997; Brim-Box and Mossa 1999). Fine sediments adversely affect mussels in many ways, e.g., they can clog the gills, thereby reducing respiration rates, feeding efficiency, and growth; they can affect the food source by reducing the amount of light available for photosynthesis; and they can affect mussels indirectly by impacting on their host fishes (see Brim-Box and Mossa 1999 for a review). Heavy deposits of silt, such as in riverine impoundments, can bury and smother mussels. Dennis (1984) found that mussels transplanted to heavily silted areas in the Tennessee River system exhibited poor survival and reduced fertilization success after a 1 year exposure. Investigations have shown that the negative relationships between sediment and mussels may be weaker than originally thought, and that increased sedimentation may not be detrimental to all species under all circumstances (Brim-Box and Mossa 1999; Strayer and Fetterman 1999). Species that inhabit normally turbid waters apparently are not as affected by siltation as species that inhabit riffle areas with stable substrates. Strayer and Fetterman (1999) suggest that fine sediments may be more harmful to mussels in streams with low gradients than high gradients, as the sediments will settle rather than being flushed out.

Epioblasma triquetra is probably extremely sensitive to siltation because of its specialized habitat requirements and burrowing habits. As stated by the Virginia Department of Game and Inland Fisheries (1999), “This species is usually found in fast-flowing, clean water in substrates that contain relatively firm rubble, gravel, and sand substrates swept free from siltation. They are buried in the substrate in shallow riffle and shoals areas.” The Snuffbox is one of only two species of mussels in Ontario that burrow completely, or almost completely, in the substrate (the other is the endangered *Villosa fabalis*; West *et al*. 2000; COSEWIC 2010b). These species may be more sensitive to sedimentation than most other unionids, because an accumulation of silt on the streambed would reduce flow rates and dissolved oxygen concentrations below the surface. Siltation has undoubtedly increased in most southwestern Ontario rivers concurrently with increased agricultural activity (see **Habitat trends**), and is likely a major factor limiting the occurrence of *E. triquetra* in these systems. Concentrations of suspended solids at two sites in the stretch of the East Sydenham River where *E. triquetra* was found alive in recent years have averaged 50 and 64 mg/L, respectively, over the past several decades, although there is no indication that levels are increasing (Ontario Ministry of the Environment unpubl. data). Even higher mean levels of suspended solids have been recorded for the Ausable River (117 mg/L; Ausable River Recovery Team 2005).

Pollution

During the early part of the 20th century, chemical pollution from acid mine drainage, agricultural runoff, and untreated domestic and industrial effluents, were responsible for the mass destruction of mussel communities in North American rivers (Baker 1928; Havlik and Marking 1987; Bogan 1993). Mussel populations living immediately downstream of major U.S. cities were extirpated as a result of degraded water quality (Miller and Payne 1998). According to Neves *et al*. (1997), eutrophication was the primary water problem in the 1980s. Sewage treatment has greatly improved over the years, such that the major threats to mussels today are believed to be high loads of sediment (see above), nutrients, and toxic chemicals from non-point sources, especially agriculture (Strayer and Fetterman 1999). Neves *et al*. (1997) reported that levels of nitrates, chloride and metals in North American rivers have increased due to the increased use of fertilizers and road salt. Havlik and Marking (1987) showed that heavy metals, pesticides, ammonia, crude oil, and many other environmental contaminants are toxic to mussels, especially during their early life stage. However, the specific effects of these substances and the levels at which they are detrimental are still not well understood (NNMCC 1998).

According to the Virginia DCR (2000), the greatest threats to the continued existence of *E. triquetra* are the deterioration of water quality and habitat alteration. NatureServe (2010) states that “pollution through point and non-point sources is perhaps the greatest on-going threat to this species and most freshwater mussels.” The decline in the overall distribution of the Snuffbox suggests that it is not tolerant of poor water quality. As the remaining range of *E. triquetra* in Ontario is in an area of intensive agricultural activity, exposure to agricultural chemicals may be an important factor limiting its occurrence in Canada.

During the glochidial stage, mussels are particularly sensitive to heavy metals (Keller and Zam 1990; Gillis *et al.* 2008), ammonia from wastewater treatment plants (Goudreau *et al*. 1993), acidic water from mine runoff and sandy soils (Huebner and Pynnönen 1992), salinity (Liquori and Insler 1985, as cited in USFWS 1994; Gillis pers. comm. 2008), and chlorine (Valenti *et al.* 2006). Particularly concerning is that the glochidia of *E. triquetra* and other at-risk unionid species are extremely sensitive to waterborne copper. They are significantly more sensitive than common species and the current Canadian Water Quality Guidelines for copper are well above the threshold EC50 for the glochidia of *E. triquetra* (Gillis *et al.* 2008). Fortunately, the complex chemistry (e.g., high turbidity and dissolved concentration of dissolved solutes) of most natural waters in southern Ontario where *E. triquetra* are found will provide protection from acute copper exposure (Gillis *et al.* 2008).

Access to hosts

Due to the parasitic stage in their life cycle, unionids are sensitive not only to environmental factors that limit them directly, but also to factors that affect their hosts (Burky 1983; Bogan 1993). Any factor that changes the species composition or decreases the abundance of host fauna may have detrimental effects on mussel populations.

Two of the five known host fishes for *E. triquetra* are native to Ontario, namely, the Logperch and Blackside Darter. Because these fishes are known to exist in abundance throughout the Canadian range of *E. triquetra*, it is unlikely that access to hosts is limiting for *E. triquetra* in Canada (Poos *et al.* 2007; Schwalb *et al.* 2011). However, should either of these species decline in their distribution and/or abundance, their presence is crucial to the survival of this mussel and should be investigated.

A potential threat to hosts (and juvenile unionids) is the Round Goby. Round Gobies have recently invaded the Sydenham and Ausable rivers and now overlap the range of the Snuffbox. Goby densities are currently low in these rivers, but may increase as the invasion progresses. Should Round Gobies severely infest the Sydenham and Ausable rivers, they have the potential to negatively impact Snuffbox in the future by competing with its hosts, Logperch and Blackside Darter (both bethic fishes), as well as preying on juvenile and even young adult Snuffbox (Poos *et al.* 2010).

Dreissenid mussels

The introduction and spread of the dreissenid mussels throughout the Great Lakes in the late 1980s has decimated native mussel populations in the Lower Great Lakes region of Ontario (Schloesser *et al*. 1996). Dreissenids attach to a unionid's shell, interfering with activities such as feeding, respiration, excretion and locomotion—effectively starving it to death (Haag *et al*. 1993; Baker and Hornbach 1997). Ricciardi *et al*. (1998) estimated that the invasion of the Mississippi River basin by dreissenids has increased freshwater mussel extinction rates in that system by 10-fold, from about 1.2% of species per decade to 12% per decade.

Unionid mussel species differ in their sensitivities to dreissenids. Long-term brooders are generally more sensitive than short-term brooders, possibly because they tend to have greater energy requirements for growth and reproduction than short-term brooders and may therefore be more vulnerable to further depletion of their energy reserves by dreissenids (Strayer 1999). *Epioblasma triquetra* has several traits that suggest it may be very sensitive to dreissenid infestation; i.e., it is small, a long-term brooder, and uses few host fish. However, it may escape serious infestation due to its burrowing habits. The importance of dreissenids as a limiting factor for this and other unionids in Great Lakes waters will depend on the extent and quality of the nearshore refuge areas that have recently been discovered (McGoldrick *et al.* 2009; Crail *et al.* 2011). The dreissenids do not threaten existing populations of *E. triquetra* in the Sydenham or Ausable rivers, because they are not navigable by boats and have no significant impoundments that could support a permanent colony. The Fanshawe Lake in the Thames River watershed is now infested with Zebra Mussels and is acting as a seed population for the downstream reach. Zebra Mussels have been found as far downstream as Thamesville (Upper Thames River Conservation Authority 2004). In Michigan, dreissenids (primarily Zebra Mussels) are known to infest *E. triquetra* populations in the Clinton and Huron rivers (Zanatta pers. obs.).

Predation

Freshwater mussels are known to be food sources for a variety of mammals and fish (Fuller 1974). In particular, foraging by Muskrats (*Ondatra zibethicus*) may be a limiting factor for *E. triquetra*. Muskrat predation has been shown to significantly alter the population structure of mussels in both lakes and rivers (Convey *et al*. 1989; Hanson *et al*. 1989; Jokela and Mutikainen 1995). Neves and Odum (1989) suggested that Muskrat predation may be causing further declines in endangered mussel species in the North Fork Holston River, Virginia. Although there is no direct evidence that predation by Muskrats is threatening *E. triquetra* in the Sydenham River, Dr. C.B. Stein (Ohio State University, retired, personal records) reported recovering 32 fresh shells of a related species, *E. torulosa rangiana*, from a midden heap in the lower river in 1973. As populations of *E. triquetra* in the Sydenham and Ausable rivers are small, any level of predation limits population sizes and could jeopardize their continued existence. Also see discussion on Round Goby predation in **Access to hosts**.

Dams/Impoundments

The stable riffles that *E. triquetra* inhabits are seriously affected by dams (Layzer *et al*. 1993). Dams separate mussels from their host fishes, alter substrate composition, temperature regimes, water chemistry, and dissolved oxygen concentrations in downstream areas, and cause an accumulation of silt, which smothers mussels, in the impoundments (Bogan 1993). Changes in normal water temperature cycles can suppress reproduction or induce it at the wrong time, cause the abortion of glochidia, and delay mussel maturation and/or development (Fuller 1974; Layzer *et al*. 1993). Although dams are an important limiting factor for *E. triquetra* in other portions of its range, they do not threaten Canadian populations. The Sydenham and Ausable rivers have only a few small dams in their headwaters, and these are well upstream of the historical range of the species. Similarly, there are several reservoirs in the Thames River drainage, but all are 100 km or more upstream of known occurrences of the Snuffbox in the main stem of the river. One population was identified in the Middle Thames River in the 1970s (see **POPULATION SIZES AND TRENDS**), but there are no dams on this branch. All historical occurrences of *E. triquetra* in the Grand River were below the overflow weir at Dunnville.

PROTECTION, STATUS, AND RANKS

Legal protection and status

Because the Snuffbox mussel is listed as Endangered on Schedule 1 of Canada's *Species at Risk Act* (SARA), it is currently illegal to kill, harm, harass, capture or take individuals. SARA also provides protection for the residence and critical habitat of listed species, once identified. In addition, the species is listed as Endangered under Ontario's *Endangered Species Act, 2007*, which came into force on June 30, 2008. However, the habitat of the Snuffbox will not be protected under this new provincial Act until June 30, 2013 unless the provincial government develops a specific habitat regulation at an earlier date. Until the habitat provisions of these statutes come into effect, the federal *Fisheries Act* may represent the most important legislation currently protecting the habitat of the Snuffbox. Under this Act, freshwater mussels are considered to be shellfish, which are included in the definition of "fish" and therefore their habitat is protected from harmful alteration, disruption or destruction unless authorized by the Minister of Fisheries and Oceans. The *Fisheries Act* also contains provisions that can be applied to regulate flow needs for fish and fish passage. In Ontario, the Provincial Policy Statement under Section 3 of *The Planning Act* prohibits development and site alteration in the habitats of threatened and endangered species.

Non-legal status and ranks

COSEWIC previously assessed this species in May 2001 as Endangered (COSEWIC 2001) and re-examined and confirmed the status as Endangered in Nov. 2011. The distribution of *E. triquetra* has been significantly reduced throughout its range, and most populations have become small and geographically isolated from one another (NatureServe 2010). This decline is reflected in the current state or subnational rank (SRANK) and status for the species in each jurisdiction (Figure 8).

In the United States, *E. triquetra* is thought to be extant in only 37 of the 99 streams for which historical records are available (Butler 2007). The situation may not be quite this grim, as in some cases the absence of current records may reflect insufficient sampling effort or a lack of recent surveys (Butler 2007). The Snuffbox is believed to be extirpated from Iowa and Kansas (NatureServe 2010), and has not been recorded from New York since 1950 (Strayer and Jirka 1997). It is listed as endangered in Illinois, Indiana, Michigan, Mississippi, Ohio, Pennsylvania, Virginia and Wisconsin, threatened in Minnesota, and “state-listed” (no specific status) in Alabama. NatureServe has assigned it a Global Rank of G3 (vulnerable), and an SRANK of S1 (critically imperiled) in ten states and Ontario (NatureServe 2010, Figure 8). The American Fisheries Society lists it as threatened in North America (Williams *et al*. 1993). Federal listing of *E. triquetra* is now imminent in the U.S. (Williams pers. comm. 2010).

Habitat protection and ownership

Stream-side development in Ontario is managed through flood plain regulations enforced by local Conservation Authorities. The land along the currently occupied reaches of the Sydenham and Ausable rivers where *E. triquetra* occurs is mainly privately owned. Along the Sydenham River, there are only two publicly owned properties: Mosa Township Forest (20.2 ha) and Shetland Conservation Area (6.9 ha) (Dextrase *et al.* 2003). Along the Ausable River, there are substantial public land holdings managed by the Ausable Bayfield Conservation Authority within the Arkona Gorge (362 ha) where the Snuffbox is present in its highest densities (Nelson *et al.* 2003); smaller tracts of public lands along the upper reaches of the Ausable River include Crediton Conservation Area (1.8 acres), the Dixon Tract (40.5 ha) and Lion’s Park near Ailsa Craig (~4 ha).

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

Funding for this status report came from Environment Canada through the Committee on the Status of Endangered Wildlife in Canada. E.T. Watson, J. Di Maio, and J.L. Metcalfe-Smith are acknowledged for preparing the original status report on the Snuffbox mussel (COSEWIC 2001). COSEWIC status reports are considered “living documents” with COSEWIC as the author. As such, the original report preparers have waived their moral right to the report and the update report has used much of the original text with updated formatting, knowledge, and data incorporated throughout. Thanks to Ms. Jenny Wu from the COSEWIC Secretariat for constructing distribution maps and making the EO and IAO calculations. Many other funding agencies provided support for the data reported in this status report. The following authorities were contacted and consulted regarding the preparation of this report:

Jean, Kari. Aquatic Biologist, Ausable Bayfield Conservation Authority, 71108 Morrison Line, RR#3 Exeter, ON N0M 1S5, Telephone: (519) 235-2610 x244, Fax: (519) 235-1963. Email: kjean@abca.on.ca

McNichols, Kelly. Research Technician, University of Guelph, Department of Integrative Biology, Guelph, ON N1G 2W1, Telephone: (519) 824-4120 ext. 56008, Fax: (519) 767-1656. Email: kmcnicho@uoguelph.ca

McConnell, Angela. Canadian Wildlife Service, Environment Canada, 4905 Dufferin Street, Downsview ON M3H 5T4, Telephone: (416) 739-5715, Fax: (416) 739-4560. E-mail: angela.mcconnell@ec.gc.ca

Morris, Todd. Department of Fisheries and Oceans, Great Lakes Laboratory for Fisheries & Aquatic Sciences, 867 Lakeshore Road, Burlington, ON L7R 4A6 L7R 4A6. Telephone: (905) 336-4734, Fax: (905) 336-6437, Email: Todd.Morris@dfo-mpo.gc.ca

Nantel, Patrick. Species Assessment Specialist, Ecological Integrity Branch Parks Canada. (819) 953-4781.

Oldham, Mike. Ontario Natural Heritage Information Centre, Ministry of Natural Resources, 300 Water Street, 2nd Floor, North Tower, Peterborough, Ontario K9J 8M5, Phone: (705) 755-2159, Fax: (705) 755-2168, E-mail: michael.oldham@ontario.ca

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BIOGRAPHICAL SUMMARY OF REPORT WRITER

Dr. David Zanatta is an Assistant Professor in the Biology Department at Central Michigan University. Dr. Zanatta has over 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 professorship at Central Michigan University. Dr. Zanatta has authored or co-authored numerous peer-reviewed papers on freshwater mussel biology, including papers on the phylogeography of Snuffbox and its host fishes. He has also co-authored several COSEWIC status reports on Canadian freshwater mussel species and is a member of the Molluscs Specialist Subcommittee of COSEWIC. Dr. Zanatta is a member of the recovery teams for the 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 (2001).

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 most information on Canadian populations of Snuffbox mussel discussed in this report.

The current and original status report writers have personally verified live specimens from all populations described in this report.

Appendix 1. Historical distribution (1885-1985) of *Epioblasma triquetra* in Canada, based on occurrence records from the Lower Great Lakes Unionid Database. F shells = fresh shells, W shells = weathered shells (see text for definitions). For records with no accompanying information on the numbers of specimens collected and whether they were found alive or dead, the last five columns are left blank.

Date[a]	Waterbody	Nearest urban centre	Locality description	Latitude	Longitude	Collector(s)	Data source[b]	Database reference number	Museum catalogue number	Live	F shells (whole)	F shells (half)	W shells (whole)	W shells (half)
18850000	Lake Erie	Port Colborne		42.879	-79.254	Macoun, J.	CMN	8	002411		2			
18940000	Lake Erie	Rondeau		42.292	-81.840	Macoun, J.	MZUM	MZUM105	UM67157					
18940000	Lake Erie	Rondeau		42.300	-81.917	Macoun, J.	CMN	24	002504		5			
18940000	Thames River	Chatham		42.407	-82.183	Macoun, J.	CMN	25	002502		1			
19060000	Niagara River	Buffalo		42.917	-78.900	Letson, E.J.	BMS	BMS41	M365A-1					
19260500	Ausable River	Arkona	Below bridge on Ausable Riv. at Hungry Hollow, 2.5 mi. E of Arkona	43.067	-81.783	Kurina, J.F.	CMN		031093					1
19340000?	Lake Erie	Pelee Island	ditch @ Pelee Island	41.774	-82.631	Walker, B.	MZUM	MZUM42	UM91331					
19340624	Lake Erie	Rondeau P.P.	enclosed bay	42.313	-81.896	Oughton, J.P. & E.M. Walker	ROM	ROM35	UM186264					
19350000?	Lake Erie	Rondeau Bay	mouth of harbour	42.261	-81.908	Goodrich, C.	MZUM	MZUM92	UM91349					
19350000?	Lake Erie	Port Rowan		42.622	-80.432	Goodrich, C.	MZUM	MZUM91	UM91344					
19350000?	Lake Erie	Port Colbourne		42.875	-70.242	Goodrich, C.	MZUM	MZUM101	UM91338					
19350628	Thames River	Thamesville	5 mi NE of Thamesville	42.583	-81.889	Oughton, J.P.	ROM	ROM116	M3477		1			
19351103	Grand River	Byng		42.894	-79.621	Blakeslee, C.L. coll.	RMSC	RMSC6	50/N.1.					
19500819	Ausable River	Arkona	Hungry Hollow	43.085	-81.815	Reimann, I.G.	MZUM	MZUM100	UM178600					
19560827	Lake Erie	Long Point	Point off Sawlog Creek	42.567	-80.250	Bousfield, E.L.	CMN	499	093054					1
19600706	Lake Erie	Pelee Island	South Bay	41.736	-82.653	David H. Stansbery, OSU Field Zoo. class	OSUM	1960:0074	9483		1			
19610812	Lake Erie	Rondeau Harbour	Erieau Beach, near shore	42.267	-81.933	Herrington, H.B.	CMN	83	015129					1
19630619	Lake Erie	Low Banks Beach		42.874	-79.453	David H. Stansbery, Carol B. Stein	OSUM	1963:0063	10986					
19630802	Lake Erie	St. Williams	1.1 mi. S.E. of St. Williams, Sta. HDA 544	42.617	-80.400	Athearn, H.D.	CMN	246	048172				3	1

Date[a]	Waterbody	Nearest urban centre	Locality description	Latitude	Longitude	Collector(s)	Data source[b]	Database reference number	Museum catalogue number	Live	F shells (whole)	F shells (half)	W shells (whole)	W shells (half)
19630804	Sydenham River	Shetland	1.8 mi NE of Shetland	42.717	-81.951	Athearn, H.D.	ATH-2	c52		1				
19650815	Sydenham River	Florence	S edge of town, at Co.Rt. 1 bridge	42.650	-82.010	Stein, C.B., Joanne E. Stillwell	OSUM	1965:0105	19211	4				
19661029	Grand River	Port Maitland	Outlet of Grand River, Station G-55	42.857	-79.578	Oughton, J.G.	CMN	373	070996					1
19670711	Lake Erie	East Sister Island		41.815	-82.857	John M. Condit, Jane L. Forsyth	OSUM	1967:0056	18668			1		
19670813	Sydenham River	Shetland	2.9 km NE of Shetland	42.717	-81.951	Athearn, H.D. & M.A. Athearn	ATH-92	ATH1						
19670816	Lake Erie	Pelee Island	beach at S point of island	41.721	-82.670	Jane L. Forsyth	OSUM	1967:0090	20617					
19730825	Sydenham River	Florence	above Co. Rt. 1 at Florence, 9.7 mi NE of Dresden	42.650	-82.010	Stein, C.B.	CBS	1973:57			1			
19730826	Sydenham River	Dawn Mills	Bridge at Dawn Mills	42.589	-82.126	Stein, C.B.	CBS	1973:66		1				
19780703	Lake Erie	Pelee Island	S end (Fish Point), [19 mi. N of Sandusky]	41.721	-82.671	Barry D. Valentine	OSUM	1978:0444	46026					
19780713	Lake Erie	Pelee Island	S end (Fish Point), [19 mi. N of Sandusky]	41.722	-82.671	Barry D. Valentine	OSUM	1978:0445	46111					
19820710	Lake Erie	mouth of Big Creek	2.1 mi. SW of Malden Centre, [19.6 mi. S of Windsor]	42.033	-83.053	Thomas M. Freitag	OSUM	1982:0347	53192					
19830502	Lake St. Clair		by outlet of Ruscom River	42.333	-82.625	Griffiths, R. W.	GRIF-87	G157		1				
19850800	Sydenham River	Florence	Just W. of Florence, Station K#K-36	42.650	-82.011	Mackie, G.	CMN	K36	092765					1

[a]where actual month or day unknown, “00” is used.

[b]CMN = Canadian Museum of Nature; MZUM = Museum of Zoology, University of Michigan; BMS = Buffalo Museum of Science; ROM = Royal Ontario Museum; RMSC = Rochester Museum and Science Center; OSUM = Ohio State University Museum of Biological Diversity; ATH = H.D. Athearn, Museum of Fluviatile Mollusks, Cleveland, Tennessee (Emeritus, Tennessee Academy of Science), personal records; CBS = Dr. Carol B. Stein, Johnstown, Ohio (retired from the OSUM), personal records; GRIF = R.W. Griffiths, Ontario Ministry of the Environment, personal records.