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Environment Canada
Water Science and Technology Directorate

Direction générale des sciences et de la technologie, eau
Environnement Canada

Status of the Snuffbox, *Epioblasma triquetra*, in Canada

Ernest T. Watson, Janice L. Metcalfe-Smith and Joanne Di Maio

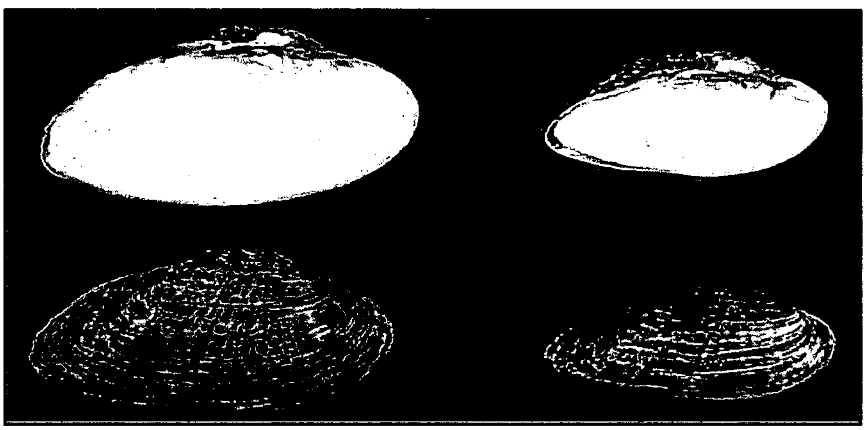
NWRI Contribution No. 00-141

COSEWIC
Assessment and Status Report

on the

Snuffbox
Epioblasma triquetra

in Canada



THREATENED
2001

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

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COMITÉ SUR LA SITUATION DES
ESPÈCES EN PÉRIL
AU CANADA

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For additional copies contact:

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

Tel.: (819) 997-4991 / (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 Rapport du COSEPAC sur la situation de l'*Epioblasme tricorne* (*Epioblasma triquetra*) au Canada.

Cover illustration:
Snuffbox — photo of internal (above) and external (below) shell morphology of a male (lef) and female (right) *Epioblasma triquetra* collected from the East Sydenham River, Ontario, in July 1999.

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COSEWIC Assessment Summary

Assessment Summary – May 2001

Common name
Snbuffbox

Scientific name
Epioblasma triquetra

Status
Endangered

Reason for designation
Declines in extent of occurrence, area of occupancy and number of extant locations; total population extremely fragmented, all four extant sites in one river (Sydenham River); entire population could be eliminated by a single upstream catastrophic event. Habitats already exposed to high silt loading from agricultural practices and pollution from point and non-point sources.

Occurrence
Ontario

Status history
Designated Endangered in May 2001.

COSEWIC
Executive Summary

Snuffbox
Epioblasma triquetra

Description

The Snuffbox, *Epioblasma triquetra* (Rafinesque, 1820), is a small species of freshwater mussel that is not closely similar to 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 in between 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. The inside of the shell is white, iridescent along the back edge, and has a grey-blue tinge in the depression on the inside of the beak. As in all mussels, the two halves of the shell are joined together by a hinge. The triangular teeth at the front edge of the hinge are ragged and sharp, and there are two in each half of the shell. The elongated teeth along the inside of the hinge are short, straight, raised and notched, and there are two on the left side of the shell and one on the right. There are deep scars on the inside of the shell at the place where the muscles attach that hold the two halves of the shell together. Males may reach a shell length of 70 mm, and females are generally 10 mm smaller.

Distribution

The Snuffbox is the most widely distributed member of the genus *Epioblasma*. It was historically known from 18 states and the Province of Ontario. Its distribution has been significantly reduced throughout its range, and remaining populations are small and geographically isolated from one another. It is no longer found in 60% of formerly occupied streams in the United States. In Canada, there are 31 known historical records for *E. triquetra* from Lake Erie, Lake St. Clair, and the Ausable, Sydenham, Thames, Grand, and Niagara rivers. It is now restricted to several small populations in the Sydenham River, and possibly the Ausable River. The species is thought to be extirpated from Iowa, Kansas, New York and Mississippi. Although it is not federally listed in the United States at the present time, is listed as endangered or threatened in many states. The Nature Conservancy has assigned it a Global Rank of G3 (rare and uncommon globally), and it has an SRANK of S1 (very rare) in 10 states and Ontario.

Population Size and Trend

Epioblasma triquetra 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. The Clinton River, Michigan, supports the largest remaining populations. There are believed to be fewer than 50 reproducing, extant occurrences of the Snuffbox in North America. Although the species' distribution remains relatively widespread, the long-term viability of such fragmented populations is in question. In Canada, *E. triquetra* appears to be restricted to a 50 km reach of the East Sydenham River, where only 7 live animals were found during extensive surveys in 1997-1999. Abundance may have declined since the 1960s, but reproduction is still occurring. It has presumably been lost from the lower Great Lakes and their connecting channels due to zebra mussels; 70% of historical records were from these waters.

Habitat

The habitat requirements of *Epioblasma triquetra* are highly specialized. It 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. As it usually burrows into the substrate, it may be particularly sensitive to siltation. Zebra mussels have destroyed the habitat throughout a large portion of *E. triquetra*'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 utilized by other 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 inputs of pesticides, fertilizers, livestock manures and sediment.

Biology

Epioblasma triquetra is a small species with separate sexes that is known to live at least 10 years. It is a long-term brooder; spawning occurs in the summer, and the larvae (which are 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 is poorly adapted to making a successful contact with the host. As a result, the number of young that survive to the juvenile stage may be relatively low for this species. Two of the five known fish hosts for this mussel occur in Ontario, namely, the Logperch (*Percina caprodes*) and Blackside Darter (*P. maculata*). Transformation to the juvenile stage takes about 3-6 weeks, depending on water temperature. This and all species of freshwater mussels utilize bacteria and algae as their primary food sources.

Limiting Factors

Epioblasma triquetra is sensitive to pollution, siltation, habitat perturbation, inundation, 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 of large rivers destroyed much of the habitat for this species during the last century. Limiting factors at present include zebra mussels, siltation and pollution due to agricultural activities, and access to fish hosts. Long-term brooders such as *E. triquetra* may be more sensitive than short-terms brooders to the energy-depleting effects of zebra mussels. The Snuffbox may also 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. As remaining populations in Ontario are located in areas of intensive farming, exposure to agricultural runoff may be an important limiting factor. Mussels with few fish hosts are more sensitive to changes in the fish community than those with many hosts. Only two of the five known hosts for *E triquetra* are native to Ontario, and there is some evidence that the most likely host, the Logperch, is declining in some areas.

Protection

Canada does not have federal endangered species legislation at present, although a proposed Species At Risk Act was introduced on 11 April 2000. Should *E. triquetra* be listed as endangered in Ontario, it would be protected from willful destruction under the Ontario Endangered Species Act. The federal Fisheries Act may also protect the habitat of *E. triquetra* in Canada, as fish are broadly defined under the Act to include shellfish. Other mechanisms for protecting mussels and their habitat in Ontario include the Ontario Lakes and Streams Improvement Act and the voluntary Land Stewardship II program. 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 *E. triquetra* was recently found alive is privately owned and in agricultural use. In the United States, freshwater mussels have been protected under the Endangered Species Act since 1973. The Act requires recovery plans to be implemented for every endangered and threatened species. *Epioblasma triquetra* is not federally listed at present, but it is protected by state legislation in the eight states where it is listed as endangered or threatened. However, only two states require the implementation of a recovery plan.

Evaluation and Status Recommendation

Epioblasma triquetra has been lost from 60% of its former range in North America. Remaining populations are small and fragmented, and most are in decline. It may be the only member of the genus *Epioblasma* that could still be saved from extinction with adequate recovery efforts. In Canada, it was historically found in Lake Erie, Lake St. Clair, and the Grand, Thames, Sydenham, Ausable and Niagara rivers. It is now believed to be restricted to perhaps 200 animals in a 50 km reach of the Sydenham River. This populations represents one of only about 50 extant occurrences in North America. The species is extremely vulnerable to loss due to its highly specialized habitat requirements, few fish hosts, and low densities and rates of reproduction. A single adverse ecological event in the Sydenham River could result in its extirpation from Canada. There is currently no immigration of individuals from populations in the

United States. Based on the above considerations, the authors recommend a status designation of Endangered for the Snuffbox, *Epioblasma triquetra*, in Ontario and Canada.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) determines the national status of wild species, subspecies, varieties, and nationally significant populations that are considered to be at risk in Canada. Designations are made on all native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fish, lepidopterans, molluscs, vascular plants, lichens, and mosses.

COSEWIC MEMBERSHIP

COSEWIC comprises representatives from each provincial and territorial government wildlife agency, four federal agencies (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biosystematic Partnership), three nonjurisdictional members and the co-chairs of the species specialist groups. The committee meets to consider status reports on candidate species.

DEFINITIONS

Species	Any indigenous species, subspecies, variety, or geographically defined population of wild fauna and flora.
Extinct (X)	A species that no longer exists.
Extirpated (XT)	A species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A species facing imminent extirpation or extinction.
Threatened (T)	A species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Not at Risk (NAR)**	A species that has been evaluated and found to be not at risk.
Data Deficient (DD)***	A species for which there is insufficient scientific information to support status designation.

* 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.

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.

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.

COSEWIC Status Report

on the

Snuffbox
Epioblasma triquetra

in Canada

Ernest T. Watson[1]
Janice L. Metcalfe-Smith[2]
Joanne Di Maio[2]

2001

[1]111-53 Southpark Drive
Winnipeg, MB
R3T 2L9
[2]Aquatic Ecosystem Branch
National Water Research Institute
Environment Canada
P.O.Box 5050
867 Lakeshore Road
Burlington, ON
L7R 4A6

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DESCRIPTION

The Snuffbox, *Epioblasma triquetra* (Rafinesque, 1820), is a small, sexually dimorphic species of freshwater mussel that is not closely 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. Figure 1 is a photograph of a live male and live female specimen collected from the Sydenham River, Ontario, in October 1999, and Fig. 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.

The shell is solid, thick and inflated - triangular in males and somewhat elongate 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 authors think these marks look like "dripping paint"].

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.

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*, the reader is referred to Baker (1928:297-298).

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 grow to be larger than females. For example, 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. Of 34 live specimens and shells collected from Ontario rivers between 1997 and 1999, the largest male was 68 mm and the largest female 49 mm (Table 1). Johnson (1978) said that the shells of the Snuffbox "exhibit little morphological variation." However, this statement is contradicted by Ortmann (1919) who 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 goes on to say that the shells of males may become quite elongated with age.

Table 1. Records for *Epioblasma triquetra* collected during mussel surveys of 66 sites on five southwestern Ontario rivers from 1997 to 1999 (Metcalfe-Smith *et al.* 1998c, 1999, unpublished data). Shell length in mm is given for each specimen. Site locations are shown in Fig. 6.

Site	Date	Nearest urban centre	Locality description	Lat.	Long.	Collectors[1]	Sampling effort (p-h)	Live specimens		Fresh shells		Weathered shells	
								Female	Male	Female	Male	Female	Male
Ausable River:													
AR-4	18/08/98	Hungry Hollow	Hungry Hollow	43.076	-81.800	1	4.5						47 & 50 H[4]
AR-5	18/08/98	Arkona	just upstream of the Rock Glen Conservation Area	43.084	-81.818	1	4.5				55 W[4]		56 H
AR-6	19/08/98	Arkona	just upstream of site AR-5	43.083	-81.816	1	4.5						45, 50 & 65 W
AR-7	20/08/98	Nairn	first bridge south of Nairn	43.106	-81.565	1	4.5					43 H	42 H
AR-8	13/05/99	Brinsley	2 concessions upstream of Brinsley	43.247	-81.525	2	?[2]			43 H			
AR-5	14/05/99	Arkona	just upstream of the Rock Glen Conservation Area	43.084	-81.818	2	?[2]					45 H	48 & 53 W
Sydenham River:													
SR-1	18/08/97	Alvinston	7.5 km northeast of Alvinston at bridge crossing	42.859	-81.790	3	4.5				45 H		
SR-5	20/08/97	Florence	bridge at Florence, just west of town	42.650	-82.009	3	4.5					28 H	
SR-12	25/08/98	Dawn Mills	bridge at Dawn Mills	42.589	-82.126	4	12.0		40 & 48	32 W			
SR-17	28/08/98	Florence	3.4 km north and slightly west of bridge at Florence	42.679	-82.016	5	4.5		68				61 H
SR-12	27-29/07/99	Dawn Mills	bridge at Dawn Mills	42.589	-82.126	6	11.0[3]		63	49 W		34 H	42 H
SR-3	09-11/08/99	Alvinston	5 km downstream of Alvinston at bridge crossing	42.779	-81.835	6	9.4[3]		54				
SR-6	05/10/99	Croton	2.3 km downstream of bridge at Croton	42.604	-82.072	7	7.5	25	57			36 H	
SR-4	06/10/99	Shetland	3 km northeast of Shetland, near the Shetland Conservation Area	42.716	-81.954	7	3.0					35 H	
SR-5	06/10/99	Florence	bridge at Florence, just west of town	42.650	-82.009	7	4.5						44 H
Thames River:													
TR-7	14/08/97	Thamesville	8 km northeast of Thamesville, behind a small museum	42.580	-81.900	3	4.5					34 H	30 & 33 H
TR-7	22/06/98	Thamesville	8 km northeast of Thamesville, behind a small museum	42.580	-81.900	8	-			49 H			
TOTALS								1	6	4	2	7	14

[1] 1 = S. Staton, E. Walker & I. Scott; 2 = J. Smith, S. Staton and J. Di Maio; 3 = J. Smith, S. Staton & E. Walker; 4 = S. Staton, E. Walker, B. Hess, D. Zanatta, J. Archbold & S. Reynolds; 5 = S. Staton, E. Walker & B. Hess; 6 = J. Smith, J. Di Maio & J. Kraft; 7 = J. Smith, J. Di Maio & D. Zanatta; 8 = J. Smith, S. Staton & I. Scott.
[2] search time unknown; found incidentally while collecting specimens of another species for a related study.
[3] collected during quadrat surveys.
[4] H = half shell (valve); W = whole shell.

TAXONOMIC STATUS OF THE SPECIES

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). Synonyms that have been used for the species, as cited by Parmalee and Bogan (1998), include:

Truncilla triqueter Rafinesque, 1820; Rafinesque, 1820:300
Unio triqueter (Rafinesque, 1820); Short and Eaton, 1831:79
Truncilla (*Truncilla*) *triquetra* (Rafinesque, 1820); Simpson, 1900a:517
Truncilla triquetra (Rafinesque, 1820); Scammon, 1906:283
Dysnomia triquetra (Rafinesque, 1820); Danglade, 1922:5
Dysnomia (*Truncillopsis*) *triquetra* (Rafinesque, 1820); Ortmann and Walker, 1922:65
Plagiola (*Truncillopsis*) *triquetra* (Rafinesque, 1820); Johnson, 1978:248
Plagiola triquetra (Rafinesque, 1820); Oesch, 1984:232
Unio triangularis Barnes, 1823; Barnes, 1823:272
Mya triangularis (Barnes, 1823); Eaton, 1826:221
Margarita (*Unio*) *triangularis* (Barnes, 1823); Lea, 1836:18
Margaron (*Unio*) *triangularis* (Barnes, 1823); Lea, 1852c:23
Unio cuneatus Swainson, 1823; Swainson, 1823b:112
Unio formosus Lea, 1831; Lea, 1831:111
Unio triangularis var. longisculus de Gregorio, 1914; de Gregorio, 1914:40
Unio triangularis var. pergibosus de Gregorio, 1914; de Gregorio, 1914:40

The taxonomy and nomenclature of the entire Family Unionidae (Pearly Mussels) has been in a state of confusion since the late 1600s. Early collectors 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 American Fisheries Society recently published a revised compilation of the generally accepted common and scientific names for molluscs in the United States and Canada (Turgeon *et al.* 1998), which we consider to be the authority for the current classification of *E. triquetra*: PHYLUM Mollusca, CLASS Bivalvia, SUBCLASS Palaeoheterodonta, ORDER Unionoida, SUPERFAMILY Unionoidea, FAMILY Unionidae, SUBFAMILY Lampsilinae, GENUS *Epioblasma*, SPECIES *Epioblasma triquetra*.

DISTRIBUTION

Historical Distribution in North America

The Snuffbox is the most widely distributed member of the genus *Epioblasma*. 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 (TNC 2000a). 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. Appendix 1 presents the known occurrences of this species in the United States.

In Canada, *E. triquetra* was known only from the Province of Ontario (Clarke 1981). The National Water Research Institute's Lower Great Lakes Unionid Database was used to identify historical species occurrence records for *E. triquetra* in Ontario. At the time of writing, the database consisted of 5902 records (defined as the occurrence of given species at a given location on a given date) for 40 species collected from 2056 sites in the lower Great Lakes drainage basin since 1860. 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). A total of 31 records dating from 1885 to 1985 were identified for *E. triquetra* in Ontario (Appendix 2; Fig. 3). According to this information, the Snuffbox once occurred in the Ausable, Sydenham, Thames, Grand and Niagara rivers, Lake St. Clair, and Lake Erie. A range map for *E. triquetra*, which is based on known occurrences in the United States and Canada, is presented in Fig. 4.

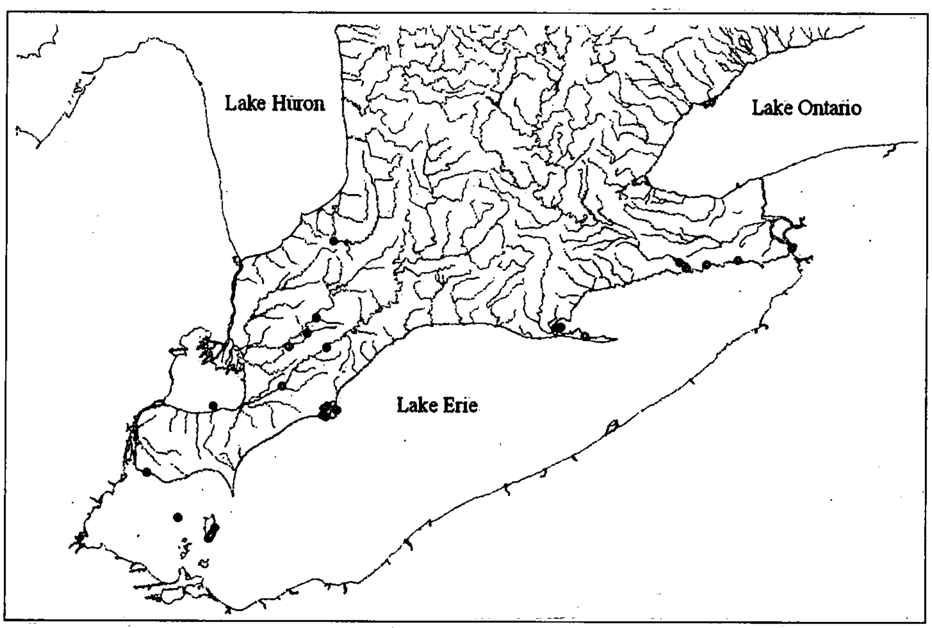

Figure 3. Historical distribution of *Epioblasma triquetra* in Ontario (all records for live animals and shells are included).

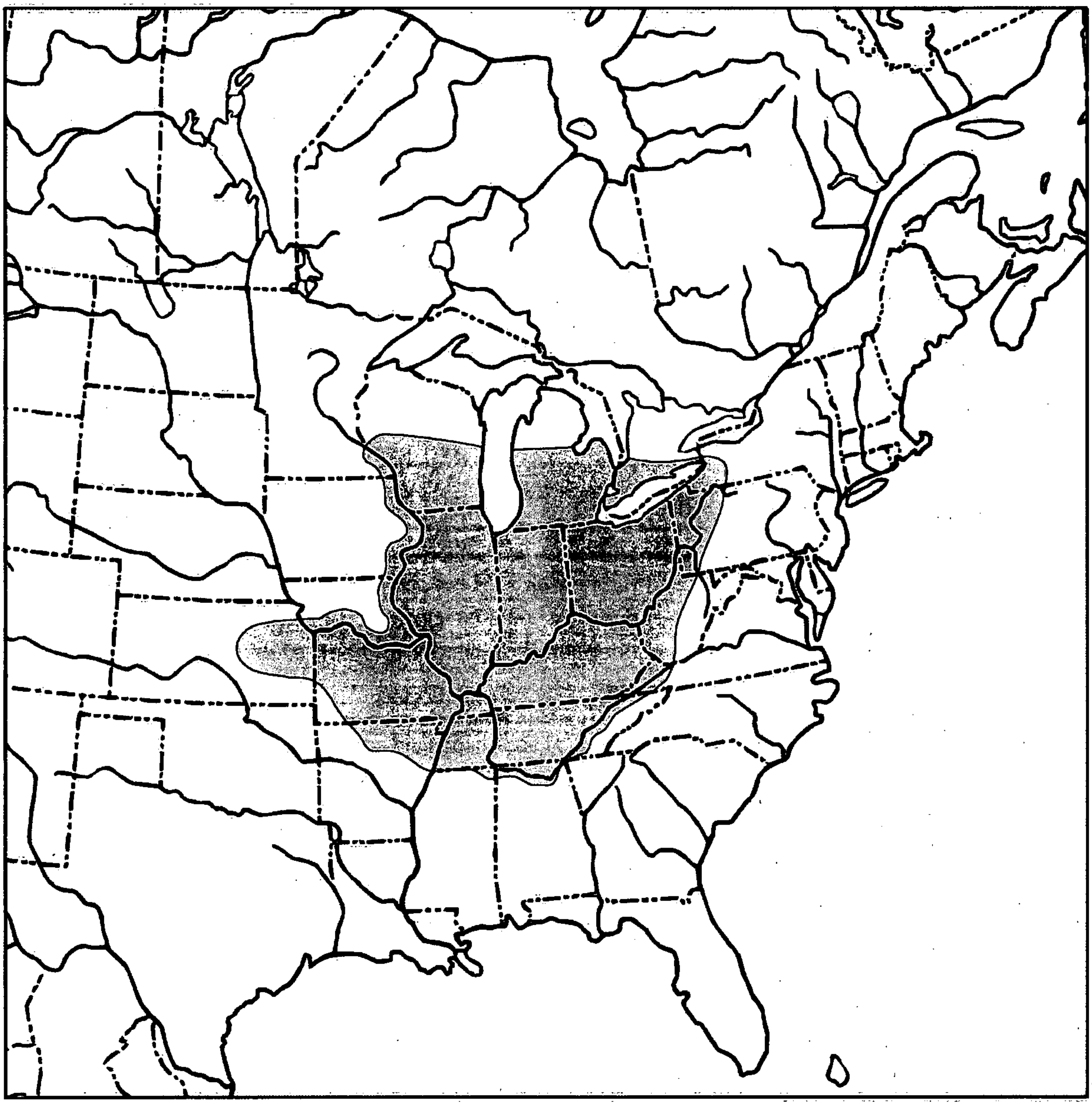

Figure 4. Historical distribution of *Epioblasma triquetra* in North America.

Current Distribution in North America

According to The Nature Conservancy (TNC 2000b), the distribution of *E. triquetra* has been significantly reduced throughout its range, and most populations have become small and geographically isolated from one another. This decline is reflected in the current State or Subnational Rank (SRANK) and Status for the species in each jurisdiction (Table 2). Figure 5 illustrates the current range and SRANKs for the Snuffbox in North America.

Table 2. State Rank (TNC 2000a) and State Status of *Epioblasma triquetra* in each jurisdiction.

State/Province	SRANK[1]	State Rank	State Status Reference[2]
Alabama	S1	State Listed	D.N. Shelton, 2000 (pers. comm.)
Arkansas	S1	none	C. Osborne, 1999 (pers. comm.)
Illinois	S1	**Endangered**	K.S. Cummings, 1999 (pers. comm.)
Indiana	S1	**Endangered**	R. Hellmich, 1999 (pers. comm.)
Iowa	SX	none	D. Howell, 1999 (pers. comm.)
Kansas	SX	Extirpated	B. Obermeyer, 1999 (pers. comm.)
Kentucky	S3	none	R. Cicerello, 1999 (pers. comm.)
Michigan	S1	Endangered	R.R. Goforth, 2000 (pers. comm.)
Minnesota	S2	Threatened	M. Davis, 1999 (pers. comm.)
Mississippi	S1	Endangered	T.M. Mann, 1999 (pers. comm.)
Missouri	S1	not available	
New York	SH	none	K. Schneider, 1999 (pers. comm.)
Ohio	S?	Endangered	G.T. Watters, 1999 (pers. comm.)
Pennsylvania	S1	none	C.W. Beir, 1999 (pers. comm.)
Tennesssee	S3	none	TDEC (1997)
Virginia	S1	Endangered	Terwilliger (1991)
West Virginia	S3	none	J. Clayton, 1999 (pers. comm.)
Wisconsin	S1	Endangered	J.M. Burnham, 2000 (pers. comm.)
Ontario	S1	none	

[1]State Ranks are assigned by state Natural Heritage Programs using methodology developed by The Nature Conservancy. State Ranks are assigned based upon the best available information, and are defined as follows:

- SX: Extirpated (believed to be extirpated from the state).
- SH: Historical (occurred historically, but suspected to still be extant).
- S1: Critically imperiled because of extreme rarity, or because some factor(s) make it especially vulnerable to extirpation from the state (typically 5 or fewer occurrences, or very few remaining individuals).
- S2: Imperiled because of rarity, or because some factor(s) make it very vulnerable to extirpation (6 to 20 occurrences or few remaining individuals).
- S3: Rare and uncommon (21 to 100 occurrences).
- S?: Unranked (the species is not yet ranked in the state).

[2]see Acknowledgements for affiliations.

In the United States, *E. triquetra* is thought to be extant in only 37 of the 99 streams for which historical records are available (See Appendix 1). 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 (R.R. Goforth, Michigan Natural Features Inventory, pers. comm., January 2000). Nevertheless, the Snuffbox is believed to be extirpated from Iowa and Kansas (TNC 2000a), 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, Virginia and Wisconsin, threatened in Minnesota, and "state-listed" (no specific status) in Alabama. The Nature Conservancy has assigned it a Global Rank of G3 (rare and uncommon globally), and an SRANK of S1 in ten states (TNC 2000a, Fig. 5). The American Fisheries Society lists it as threatened in North America (Williams *et al.* 1993).

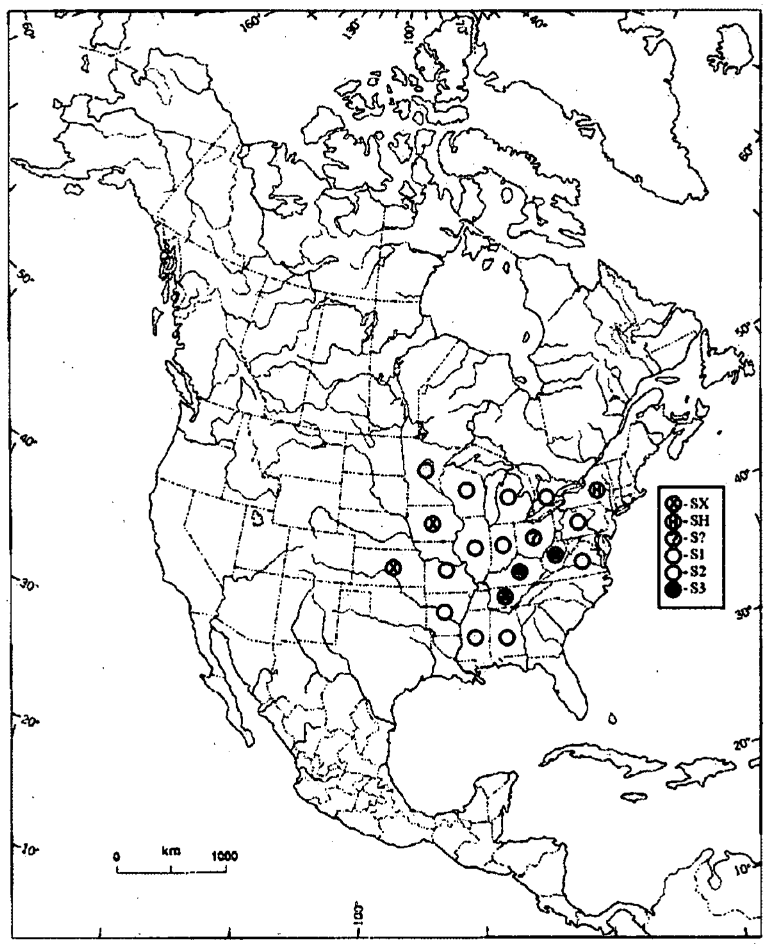

Figure 5. Current range and SRANKs of *Epioblasma triquetra* in North America.

Until recently, *E. triquetra* was ranked SH (historical; no occurrences verified in the past 20 years) in Ontario by the Ontario Natural Heritage Information Centre (D.A. Sutherland, NHIC, pers. comm., December 1996). The last live record for the species was from Lake St. Clair in 1983, but the specimen was not verified. Prior to that, *E. triquetra* was last seen alive at a site on the Sydenham River in 1973. According to the Lower Great Lakes Unionid Database, approximately 250 sites within *E. triquetra*'s former range were surveyed by various researchers between 1990 and 1997, and no trace of this species was found. In 1999, Mackie *et al.* (2000) searched for mussels at various depths on 22 transects along the Canadian shoreline of Lake St. Clair, and 4 transects along the Michigan shoreline. They found 21 species alive, but *E. triquetra* was not among them.

Intensive surveys conducted at 66 sites on tributaries to Lake Erie, Lake St. Clair and lower Lake Huron in 1997-1998 (Metcalfe-Smith *et al.* 1998c, 1999), and additional collections at some of these sites in 1998 and 1999, yielded a total of 34 specimens from 13 different sites on the Ausable, Sydenham and Thames rivers (Table 1). Only 7 of these specimens were found alive, and all were taken from 4 sites on the Sydenham River (Fig. 6). Weathered shells[1] accounted for most of the remaining specimens (21), but fresh shells[1] were found at several sites on the Sydenham, 1 site on the Thames, and 2 sites on the Ausable River (Fig. 6). Based on these findings, the Snuffbox is currently restricted to several small isolated populations on the Sydenham and possibly the Ausable and Thames rivers. Its SRANK in Ontario has been revised to S1 (TNC 2000a; D.A. Sutherland, NHIC, pers. comm., September 1999).

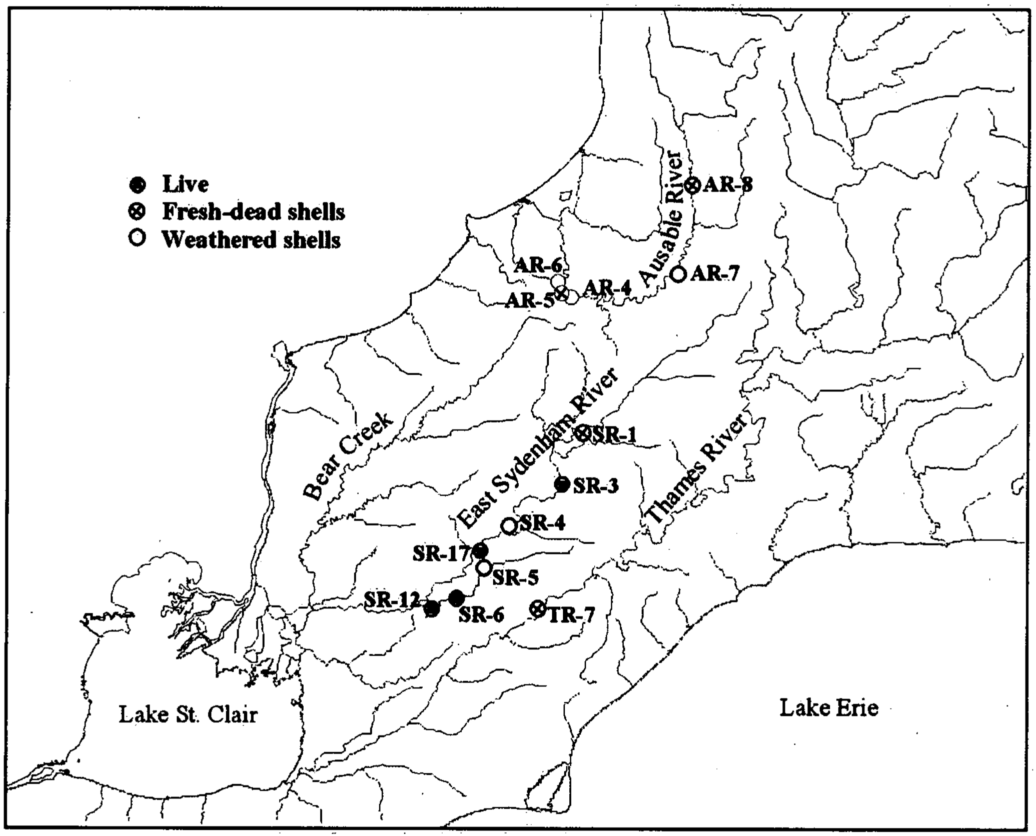

Figure 6. Current distribution of *Epioblasma triquetra* in Ontario, based on records from recent surveys (Metcalfe-Smith *et al* 1998, 1999, unpublished data). See Table 1 for details.

[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 (D.L. Strayer, Institute of Ecosystem Studies, Millbrook, NY, pers. comm., July 1996).

PROTECTION CURRENTLY PROVIDED

Canada

Canada does not have federal endangered species legislation at present, although the proposed Species at Risk Act (SARA) was introduced into the House of Commons on 11 April 2000 (Environment Canada 2000a). The proposed legislation follows the signing of the Accord for the Protection of Species at Risk by the federal, provincial, and territorial ministers responsible for wildlife in 1996, which committed all of Canada's jurisdictions to "establish complementary legislation and programs that provide for effective protection of species at risk throughout Canada" (Environment Canada 2000a).

Ontario is one of five provinces that have stand-alone Endangered Species Acts (B.T. Fowler, Chair, Lepidoptera and Mollusca Subcommittee, COSEWIC, pers. comm., October 1999). Ontario's Endangered Species Act, which came into effect in 1971, prohibits willful destruction of, or interference with, a regulated endangered species or its habitat. The maximum penalty for violating Ontario's Endangered Species Act is a fine of $50,000, imprisonment for two years, or both (Rishikof 1997). Should *E. triquetra* be listed as endangered in Ontario, it would be afforded protection.

The Federal Fisheries Act may also protect the habitat of *E. triquetra* in Canada. Fish are broadly defined under the Act to include shellfish, although the intent was to protect marine shellfish harvested for human consumption. The Fisheries Act prohibits fishing without a license and makes it illegal to harm fish habitat, which is defined as "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes." The maximum penalty for fishing without a license is a fine of up to $500,000 and/or imprisonment for up to two years, and the maximum penalty for destroying fish habitat is a fine of up to $1,000,000 per day and/or imprisonment for up to three years. The protection of fish and their habitat may indirectly protect the habitat of *E. triquetra*.

As mussels are considered fish under the Federal Fisheries Act, however, the collection of live mussels is theoretically "fishing" and would fall under the Ontario Fishery Regulations that are made under the Federal Fisheries Act. The Provincial Policy Statement under Section 3 of the Planning Act provides for protection from development and site alteration in significant portions of the habitats of threatened and endangered species. Other mechanisms for protecting mussels and their habitat in Ontario include the Ontario Lakes and Streams Improvement Act, which prohibits the impoundment or diversion of a watercourse if it would lead to siltation; and the voluntary Land Stewardship II program of the Ontario Ministry of Agriculture, Food, and Rural Affairs, which is designed to reduce erosion on agricultural lands. Stream-side development in Ontario is managed through flood plain regulations enforced by local Conservation Authorities. Most of the land along the reach of the Sydenham River where *E. triquetra* was found alive in recent years is privately owned and in agricultural use (M. Andreae, St. Clair Region Conservation Authority, pers. comm., March 1998).

United States

The United States Endangered Species Act (USESA), originally passed in 1973, is the primary federal statute for protecting species at risk in that country. The U.S. Fish and Wildlife Service is required to adopt a recovery plan for every species listed as endangered or threatened under the Act. The USESA also provides for possible land acquisition, in cooperation with state agencies. Listing under the USESA prohibits the "taking" of a listed species, which includes conducting any habitat modification that would harm the species. Violation of the Act can result in fines of up to $100,000, up to a year in jail, and forfeiture of any property used in breaking the law. There are currently 69 species of freshwater mussels listed as endangered (61) or threatened (8) in the United States (USFWS 2000). *Epioblasma triquetra* is not federally listed at the present time; however, it would be indirectly protected where it co-occurs with any listed species. It was previously listed as a Category 2 Federal Candidate, which was defined as a species for which there was some evidence for vulnerability but not enough data for listing as endangered or threatened (Cummings and Mayer 1992). This designation was discontinued in 1996, and state and local governments are no longer asked to take Category 2 candidates into account in their environmental planning (Roth 1997).

Most states have their own Endangered Species Acts, but rely heavily on the USESA for enforcement and funding. Of the 18 states in which *E. triquetra* historically occurred, only Alabama, Arkansas and West Virginia do *not* have legislation to protect endangered species (Defenders of Wildlife 1996). As previously noted, *E. triquetra* is listed as Endangered in Illinois, Indiana, Michigan, Mississippi, Ohio, Virginia and Wisconsin, and Threatened in Minnesota. All of these states prohibit the taking of listed species, and also provide for the possible acquisition of land or aquatic habitat. Only Michigan and Mississippi require a recovery plan to be implemented for listed species. Penalties for violating the Endangered Species Act in these states range from $25 to $10,000 in fines, and/or up to a year in prison (Defenders of Wildlife 1996).

Most states have also enacted legislation making it illegal to possess more than a certain number mussels, if any. For example, Missouri allows the possession of only five live or dead mussels per day without a Commercial Musseling Permit (Missouri Department of Conservation 2000); Pennsylvania allows possession of up to 50 mussels per day (C.W. Beir, Pennsylvania Natural Diversity Inventory, pers. comm., November 1999); and Wisconsin allows the taking of up to 50 pounds of mussels a day without a Commercial Clamming Permit (Wisconsin Department of Natural Resources 1998). The collection of freshwater mussels is prohibited in Alabama, Indiana, Michigan, Mississippi, New York, Ohio, Virginia and West Virginia (personal communications with state agency representatives).

POPULATION NUMBERS, SIZES AND TRENDS

United States

Epioblasma triquetra typically occurs in low numbers in mussel communities where it is found, but it can be locally abundant. For example, Ortmann (1919) described the species as "widely distributed" but "not found anywhere in great numbers" throughout the Ohio River drainage of Pennsylvania, but he found it to be "rather abundant" in the headwaters of the Monongahela River drainage in West Virginia. It is very uncommon in Missouri, comprising only 0.1% of 20,589 mussels collected from 198 sites in the Meramec River Basin in eastern Missouri in the late 1970s (Buchanan 1980). Dennis (1984) found small numbers of *E. triquetra* at several sites in Tennessee and Virginia during quadrat surveys in 1973-1975. Of 955 mussels representing 35 species collected from Kyles Ford on the Clinch River, only 3 (0.3%) were of this species. It was similarly sparse (0.8% of the total catch) at two sites on the Powell River. A density of $<0.01/m^2$ was reported for the Snuffbox at a site on French Creek in the Allegheny River drainage of Pennsylvania in 1998 (G.F. Zimmerman, EnviroScience, Inc., Ohio, pers. comm., March 1999). This creek supports the largest remaining population of a related species, the federally endangered Northern Riffleshell (USFWS 1994), which was present at a density of $0.1/m^2$. A portion of the Clinton River in Oakland County, Michigan, is thought to sustain the largest remaining population of *E. triquetra* in that state. Trdan and Hoeh (1993) found it to be the dominant species at a site in this portion of the river in 1992, representing 38% of 2113 mussels collected. Sherman (1994) observed a "density" of 15 female *E. triquetra* per hour of searching at a site in this reach in the same year.

It has been estimated that there are fewer than 50 reproducing, extant occurrences of the Snuffbox in North America (TNC 2000b). Although the species' distribution remains relatively widespread (it is believed to survive in all states in which it formerly occurred, with the exceptions of Iowa, Kansas, Mississippi and New York; Appendix 1), the long-term viability of such fragmented populations is in question. For example, *E. triquetra* was historically recorded from 13 streams in Pennsylvania, but is presently known from only 4 streams - only one of which has a "healthy population" (C.W. Beir, Pennsylvania Natural Diversity Inventory, pers. comm., November 1999). Although it historically inhabited 12 streams in Illinois, it is now thought to occupy only one, the Embarras River (K.S. Cummings, Illinois Natural History Survey, pers. comm., November 1999). In Indiana, it is currently restricted to 4 of 13 previously inhabited streams (R. Hellmich, Indiana Natural Heritage Data Center, pers. comm., December 1999). Similarly, it is presently known from 3 streams in Ohio, down considerably from the 22 it used to occupy (G.T. Watters, Ohio State University, pers. comm., December 1999). And in Michigan, *E. triquetra* is now found in only 4 of 17 historically occupied streams (R.R. Goforth, Michigan Natural Features Inventory, pers. comm., January 2000). According to Magers (1999), populations in the Meramac River of Missouri are probably not reproducing. West Virginia appears to be the only state in which the range of *E. triquetra* has not decreased: it is believed to occur in all 11 streams where it was historically recorded (J. Clayton, West Virginia Department of Natural Resources, pers.

comm., December 1999). Overall, *E. triquetra* is now found in just over a third of the streams that supported it historically.

Canada

In Canada, the Snuffbox was historically known from the Ausable, Sydenham, Thames, Grand and Niagara rivers, Lake St. Clair, and Lake Erie (Fig. 3; Appendix 2). J. Macoun was first to collect *E. triquetra* in Canada, finding 2 fresh whole shells in Lake Erie at Port Colborne in 1885. There are 17 additional records from Lake Erie between 1894 and 1982, but to our knowledge there have been no recent collections. It was not found during recent mussel surveys in the American waters of Lake Erie (Schloesser *et al.* 1997, Schloesser and Masteller 1999, Nichols and Amberg 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 21 species - many of them rare - found alive during surveys in the St. Clair River delta in 1999 (Mackie *et al.* 2000).

Metcalfe-Smith *et al.* (1998c, 1999) surveyed 66 sites on the Grand River (Lake Erie drainage), Thames and Sydenham Rivers (Lake St. Clair drainage), and Ausable and Maitland Rivers (lower Lake Huron drainage) in 1997 and 1998 to assess the conservation status of rare species of freshwater mussels in southwestern Ontario. They used the timed-search method, which is the most effective method for detecting rare species (Strayer *et al.* 1997), and an intensive sampling effort of 4.5 person-hours (p-h)/site. Sites that were known to support rare species and/or diverse mussel communities in the past were targeted. Several sites were revisited in 1998 or 1999 for additional searches. All live mussels collected during these searches were returned to the river unharmed at the end of the survey. When handling rare species, particular care was taken to replace them in the same location and orientation in which they were found. One male *E. triquetra* was sacrificed as a voucher specimen. Since a fresh whole female shell was found, there was no need to sacrifice any female animals.

Results of these surveys are compared with the historical data to determine population trends for the Snuffbox in these rivers. The Maitland River will not be discussed, because there are no historical records available for *E. triquetra*, and it was not found at the single site surveyed.

Grand River: *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 2). Metcalfe-Smith *et al.* (1998c, 1999) surveyed 24 sites on the Grand River in 1997-1998, including both of these locations, but failed to uncover even weathered shells. It appears that *E. triquetra* no longer persists in this system.

Thames River: The Snuffbox was found in the Thames River at Chatham in 1894, and the specimen was deposited in the Canadian Museum of Nature (Catalogue # 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 (F.W. Grimm, consultant, pers. comm., September 1997). 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, Fig. 6), and one fresh valve was found during additional collections in 1998. These results suggest that a small population of the Snuffbox may still persist in the lower reaches of the Thames River.

Ausable River: We are aware of only one record for *E. triquetra* from the Ausable River: specimens of unknown condition were taken from a site at Hungry Hollow near Arkona in 1950 (Appendix 2). As the search area for the Lower Great Lakes Unionid Database did not originally include rivers in the lower Lake Huron drainage basin, it is possible that there are additional historical records that we are unaware of. We do know that Morris and Di Maio (1998) surveyed 6 sites on the river in 1993-1994 and did not find any trace of this species. Metcalfe-Smith *et al.* (1998c, 1999) surveyed 8 sites on the Ausable River in 1998, including the Hungry Hollow site (AR-4) and two other nearby sites (AR-5, AR-6; see Fig. 6). No live specimens were found, but 11 weathered valves, one fresh valve and one fresh whole shell were collected from 5 different sites (Table 1). As the fresh shells were found in two different reaches of the river, this suggests that several small, isolated populations of *E. triquetra* may still occur in the Ausable River.

Sydenham River: *Epioblasma triquetra* was first reported from the Sydenham River by Athearn in 1963; one live animal was taken from a site near Shetland (Appendix 2). He revisited this site in 1967 and reported another occurrence, but did not indicate if the specimen(s) were found alive or dead. Stein surveyed a site near Florence in 1965 and found 4 live specimens; she revisited the site in 1973 and found only one fresh whole shell. Mackie and Topping (1988) surveyed the same site in 1985, and found only a few weathered shells (J.L. Metcalfe-Smith, personal observation of the specimens deposited in the Canadian Museum of Nature). Stein also surveyed a site at Dawn Mills in 1973, where she found one live animal. Arthur H. Clarke surveyed 11 sites on the Sydenham River in 1971 and 16 sites in 1991, but did not find any trace of *E. triquetra* (Clarke, 1973, 1992).

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 3 other sites within this reach (bounded by sites SR-4 and SR-12 in Fig. 6). A total of 7 live specimens, 2 fresh whole shells, 1 fresh valve and 7 weathered valves were found at 7 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 (Fig. 6). No specimens were found at the 5 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.

It is difficult to determine if there have been changes over time in the abundance of *E. triquetra* in the Sydenham River, because so few live animals have ever been collected. However, current and/or historical catch rates for 6 sites are presented for comparison in Table 3. Capture rates at sites SR-4, SR-5 and SR-12 appeared to decline between 1963-1973 and 1997-1999. Current catch rates at 3 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 time in the Sydenham River.

Table 3. Comparison of current and historical capture rates (CPUE) for *Epioblasma triquetra* from sites on the Sydenham River. Site locations are shown in Fig. 6.

Site	Current CPUE (1997-1999)[1]	Historical CPUE
SR-4	no live animals found	0.25 animals/p-h[2]
SR-5	no live animals found	0.67 animals/p-h[3]
SR-12	0.17 animals/p-h (1998)	0.33 animals/p-h[4]
SR-12	0.09 animals/p-h (1999)	0.33 animals/p-h[4]
SR-3	0.11 animals/p-h	no data
SR-17	0.22 animals/p-h	no data
SR-6	0.27 animals/p-h	no data

[1]Metcalfe-Smith et al. 1998c, 1999, unpublished data; [2]Athearn 1963; [3]Stein and Stillwell 1965; [4]Stein 1973.

In order to rank the quality of populations of *E. triquetra*, The Nature Conservancy has developed "element (species) occurrence specifications" based on capture rates and reproductive potential as well as habitat suitability and size (TNC 2000b). An A-ranked occurrence is defined (in-part) by a capture rate of 2-3+ live animals per survey hour, while B-, C-, and D-ranked occurrences are defined as 1 live animal/h, 1 live animal/2-4 h, and 1-2 live animals/1-2 days, respectively. Current capture rates for this species at the four sites where it was found alive in 1997-1999 (Table 3) would qualify the Sydenham River population(s) for a D-ranked occurrence at best. Density estimates for *E. triquetra* are available for two sites (SR-3 and SR-12) that were sampled quantitatively in 1999 (Mackie *et al.* 2000). At site SR-3, 230 mussels of 20 species were collected from 69-1m^2 quadrats in a sampling area of 345 m^2, for an overall density of 3.3 mussels/m^2. Only 1 live *E. triquetra* was found, for a density of 0.014/m^2. At site SR-12, 235 mussels of 19 species were collected from 78-1m^2 quadrats in a sampling area of 390 m^2, for a density of 3.0 mussels/m^2. Again, only 1 live *E. triquetra* was found, for a density of 0.013/m^2. The only other density estimate available for comparison is <0.01/m^2 from a site on French Creek in Pennsylvania (see under "United States" in this section).

Information on sex ratios and size class structure can be used to indicate population health and reproductive success. Combining the data for fresh-dead shells and live animals, we found 3 females and 7 males in the Sydenham River in 1997-1999. We know that sex ratios in healthy populations of *E. triquetra* are nearly 1:1 (Trdan and Hoeh 1993), but there are too few specimens available from the Sydenham River to determine the sex ratio. The broad range of sizes for specimens of both sexes (25-49 mm for females and 40-68 mm for males) indicates that several year classes are represented, and suggests there is ongoing recruitment.

HABITAT

Habitat and Microhabitat 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 2), where it probably inhabited the wave-washed shoals that were also occupied by a related species, *E. t. 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* was found alive in the Sydenham River in 1998-1999 were consistent with those described above, i.e., shallow riffle/run areas with coarse substrates in a medium-sized river. The habitat where each live specimen was found is described in detail as follows (site locations are shown in Fig. 6):

- A large male was taken from site SR-17 in August, 1998. The river was 20 m wide at this location, and the average depth was 15-20 cm. Water clarity (maximum depth at which the streambed was clearly visible) was 28 cm, water temperature was 23.5°C, and the habitat was 80% riffle and 20% run. Current velocity was 0.48 m/s. The substrate was composed of 25% boulder, 60% rubble (cobble), 10% gravel and 5% sand. There was little silt present, and no aquatic vegetation. The specimen was taken from a bar of fine gravel and sand created by a fallen tree on an inside bend. The same gravel bar also yielded 6 specimens of the Northern Riffleshell.
- Two *E. triquetra* were also found at site SR-12 in August, 1998. The river here was 30 m wide, and average depth was 30 cm. Water clarity was only 10 cm, water temperature was 28°C, and velocity was 0.23 m/s. The

habitat was 100% run, and the substrate was composed of 20% boulder, 40% gravel, 30% sand and 10% silt. There was about 10% coverage with emergent vegetation. The specimens were found while sifting through sand in a weedy sand bar at a depth of about 30 cm.

- An additional specimen was collected at site SR-12 during quantitative sampling in July, 1999. The specific quadrat in which it was found was 13 cm deep and completely covered in emergent aquatic vegetation. Current speed was 0.14 m/sec, and the substrate consisted of 10% boulder, 5% rubble, 40% gravel, 35% sand and 10% silt. Water temperature was 25°C.
- A single specimen was taken from site SR-3 during quantitative sampling in August, 1999. The quadrat in which this animal was found was 39 cm deep, with no macrophyte growth. Current speed was 0.20 m/sec, and the substrate consisted of 25% boulder, 25% rubble, 40% gravel and 10% sand. Water temperature was 20°C.
- Two live animals were collected at site SR-6 in October, 1999. The first, a large male, was found in very shallow water in "pea" gravel between two islands. The other, a small female, was found in a back channel in swift-flowing water, among rocks. She was found while sieving scoops of sediment through a coarse sieve.

It should be noted that 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, for this species.

Habitat Trend

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 nonindigenous 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 recently 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. t. rangiana*, were found in Lake St. Clair. Trdan and Hoeh (1993) observed Zebra Mussels destroy a population of *E. t. rangiana*, which had been temporarily relocated to the Detroit River to protect it from a dredging operation, within one year. Since 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 significant 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 location 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). 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 (GRCA 1997). 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 population of the basin is projected to grow by another 300,000 people over the next 25 years, and there is concern that the river will not have the capacity to assimilate 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 1997-1999 (Metcalfe-Smith *et al.* 1999). This decline in mussel diversity likely reflects a significant loss of mussel habitat throughout the system. Livestock farming is the main form of agriculture in the upper portion of the Thames River, whereas cash 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). 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). 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).

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 1997-1999. 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 (based on the Statistics Canada census of 1996), while the population of the Grand River basin more than doubled during the same period. There have also been major improvements in sewage treatment. In 1965, only Strathroy, Petrolia and Wallaceburg treated their sewage (DERM 1965), whereas all towns and villages now have some form of sewage treatment (current information provided by the Ontario Ministry of the Environment). Land use in the watershed is predominantly agricultural, i.e., cash crops, pasture and woodlot, and 96% of the land is privately owned (M. Andreae, St. Clair Region Conservation Authority, pers. comm., March 1998). Flooding is a problem in some areas, so there is an extensive land drainage system (DERM 1965). 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.*, in preparation). Thus, it will be very important for the preservation of these species to determine if water and/or substrate quality are deteriorating 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 have 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.

The Ausable River supports a remarkably diverse and abundant mussel community for such a small river; Metcalfe-Smith *et al.* (1999) collected over 1800 live specimens of 18 species from only 8 sites in 1998. Because of a lack of historical data for this system, we cannot determine 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 50% of the area being used for row crops (corn and beans) and only 13% remaining forested (ABCA 1995). 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 60% of the soils are artificially drained, which decreases base flows in the river and contributes to flooding during storm events. 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".

GENERAL 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, and is illustrated in Fig. 7. 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 termed 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.

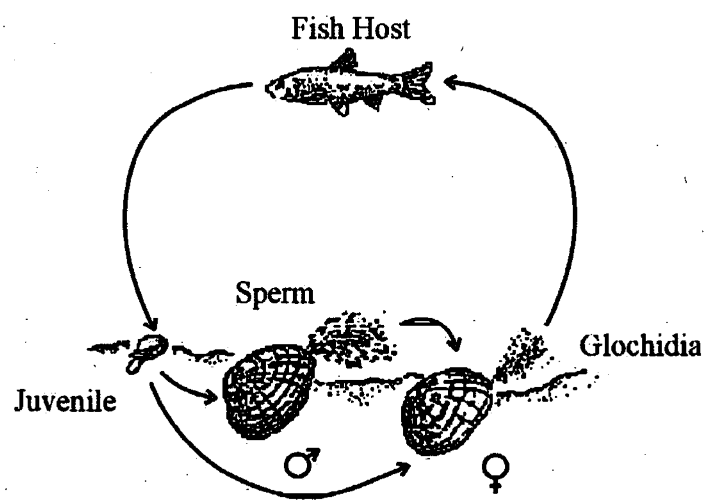

Figure 7. The life cycle of a freshwater mussel. Sperm are taken in by the female and fertilize the eggs in modified portions of the gills. Parasites larvae (glochidia) attach to the gills or fins of an appropriate host and encyst. After a few weeks, the glochidia transform into juvenile mussels and detach from the host. (After Martin 1997).

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 mm in both length and height (Clarke 1981, Oesch 1984). The glochidia of many rare species of unionids, including all members of the genus *Epioblasma*, have glochidia that 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. He 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. Most species with morphologically depressed glochidia attach to the fins of their hosts. Members of the subfamily Anodontinae are fin parasites, and their glochidia have large micro-spined hooks on the edges of their valves that penetrate the host's tissues to ensure a secure attachment (McMahon 1991). Allmembers of the Lampsilinae, including *Epioblasma* species, have hookless glochidia and are gillparasites. The more successful members of this subfamily have elongate glochidia, which are more likely to make a successful contact with their host.

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 is 4 in 100,000.

Five species of fish have been shown to serve as hosts for *E. triquetra*, namely, the Banded Sculpin (*Cottus carolinae*), Blackspotted Topminnow (*Fundulus olivaceous*), Ozark Sculpin (*Cottus hypselurus*), Logperch (*Percina caprodes*), 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 laboratory exposures by these researchers. Barnhart (1998) reported a transformation time of 21-27 days at 20°C 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 fish hosts for *E. triquetra* are native to Ontario, namely, the Logperch and Blackside Darter.

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). We have 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 mm 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), while the Anodontinae are fast growing, short-lived, and usually mature within 2 to 5 years (Kat 1984). The Lampsilinae are intermediate in growth rate, longevity and age at maturity. Lifespan and age at sexual maturity is not known for *E. triquetra*. However, Dennis (1984) collected 8-10 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.

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 have been reported to consume all sorts of materials, including algae, plankton, rotifers, diatoms, protozoans, detritus, and sand (Coker *et al.* 1921, Churchill and Lewis 1924). They have been successfully raised on algae and yeast cultures in the laboratory (USFWS 1994). Recently, 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 utilizing algae and bacteria as food sources. The specific food habits of *E. triquetra* are unknown.

LIMITING FACTORS

Approximately 67% of the nearly 300 species of freshwater mussels in North America are either extinct or vulnerable to extinction (National Native Mussel Conservation Committee 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 nonindigenous Zebra Mussel 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 The Nature Conservancy (2000b), *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" (TNC 2000b). 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 limiting factors for this species, and their relevance for Canadian populations, are described below.

Zebra Mussels

The introduction and spread of the Zebra Mussel throughout the Great Lakes in the late 1980's has decimated native mussel populations in the Lower Great Lakes region of Ontario (Schloesser *et al.* 1996). Zebra Mussels 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 Zebra Mussels has increased freshwater mussel extinction rates in that system by 10-fold, from about 1.2% of species per decade to 12% per decade.

Mussel species differ in their sensitivities to Zebra Mussels. 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

Zebra Mussels (Strayer 1999). According to Mackie *et al.* (2000), species that are more obese in shape, sexually dioecious, and have more glochidial hosts remained relatively stable after Zebra Mussels invaded Lake St. Clair, while species that became more rare were smaller and had specific substrate requirements and fewer known fish hosts. *Epioblasma triquetra* has several traits that suggest it may be very sensitive to Zebra Mussels, i.e., it is small, a long-term brooder, and has few fish hosts. However, it may escape serious infestation due to its burrowing habits. The importance of Zebra Mussels 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. The Zebra Mussel does not threaten existing populations of *E. triquetra* in the Sydenham River, since the river is not navigable by boats and has no significant impoundments that could support a permanent colony.

Siltation

There is a general perception that high loadings of sediment due to poor land-use practices is 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 one-year exposure. Recent investigations have shown that the 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 (Strayer and Fetterman 1999; Brim-Box and Mossa 1999). 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 Rayed Bean; West et al. 2000). 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 Trend), and is likely a major factor limiting the occurrence of *E. triquetra* in these systems. For example, the stretch of the lower Ausable River where *E. triquetra* was found alive in the past, and where most shells were found during recent surveys, is rated high for suspended sediment loading stress (ABCA 1995). Concentrations of suspended solids at two sites in the stretch of the East Sydenham River where *E. triquetra* was found alive in recent surveys have averaged 50 and 64 mg/L, respectively, over the past several decades, although there is no indication that levels are increasing (data courtesy of the Ontario Ministry of the Environment).

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 American 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. The Nature Conservancy (2000b) 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.

Dams/Impoundments

The stable riffles that *E. triquetra* inhabits are seriously affected by dams (Layzer *et al.* 1993). Dams separate mussels from their fish hosts, 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 Populations Numbers, Sizes and Trends), but there are no dams on this branch. All occurrences of *E. triquetra* in the Grand River were below the overflow weir at Dunnville.

Access to Fish 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 abundance or species composition of host fauna may have detrimental effects on mussel populations.

Two of the five known fish hosts for *E. triquetra* are native to Ontario, namely, the Logperch and Blackside Darter. To determine if either or both of these fishes are probable hosts for this mussel in Ontario waters, their distribution patterns were compared with that of the Snuffbox. Data on the distributions of fishes in the Grand, Thames, Sydenham and Ausable rivers were obtained from the Royal Ontario Museum, Toronto, and the Ontario Fisheries Information Centre, Peterborough: a total 7500 records for 129 fish species dating from 1884 to 1997 were provided.

The Blackside Darter was historically found in the middle to upper reaches of the Grand and Thames rivers and throughout the Sydenham River (Fig. 8a), whereas the Logperch was more often found in the middle to lower reaches of these rivers (Fig. 9a). As the historical distribution of the Logperch is more similar to that of the Snuffbox (Fig. 3), it is more likely to be the primary host. Furthermore, all studies to determine the host fish(es) for *E. triquetra* identified the Logperch as the main host, i.e., the host that transformed the largest number of juveniles (see General Biology). The range of the Logperch appears to have contracted over time in most systems, although this may be partly a function of sampling effort. Since 1990, it has been found at only one location on the Grand River and two on the Thames River. As noted earlier (see Population Numbers, Sizes and Trends), the Snuffbox has not been found alive in these rivers in recent years. In the Sydenham system, the Logperch is now found only in the lower reaches of the East Sydenham River and Bear Creek, where it is known to co-occur with the Snuffbox at only one location (compare Figs. 9b and 6). Recent records for the Blackside Darter show that it presently occupies the same reach of the Sydenham River as *E. triquetra*. However, it is a lesslikely host since it was never found in the reaches of the Grand and Thames rivers where the Snuffbox historically occurred (compare Figs. 8a and 4). If the Logperch is the main, or only, host for *E. triquetra* in these rivers, any decline in its distribution and/or abundance is crucial to the survival of this mussel and should be investigated.

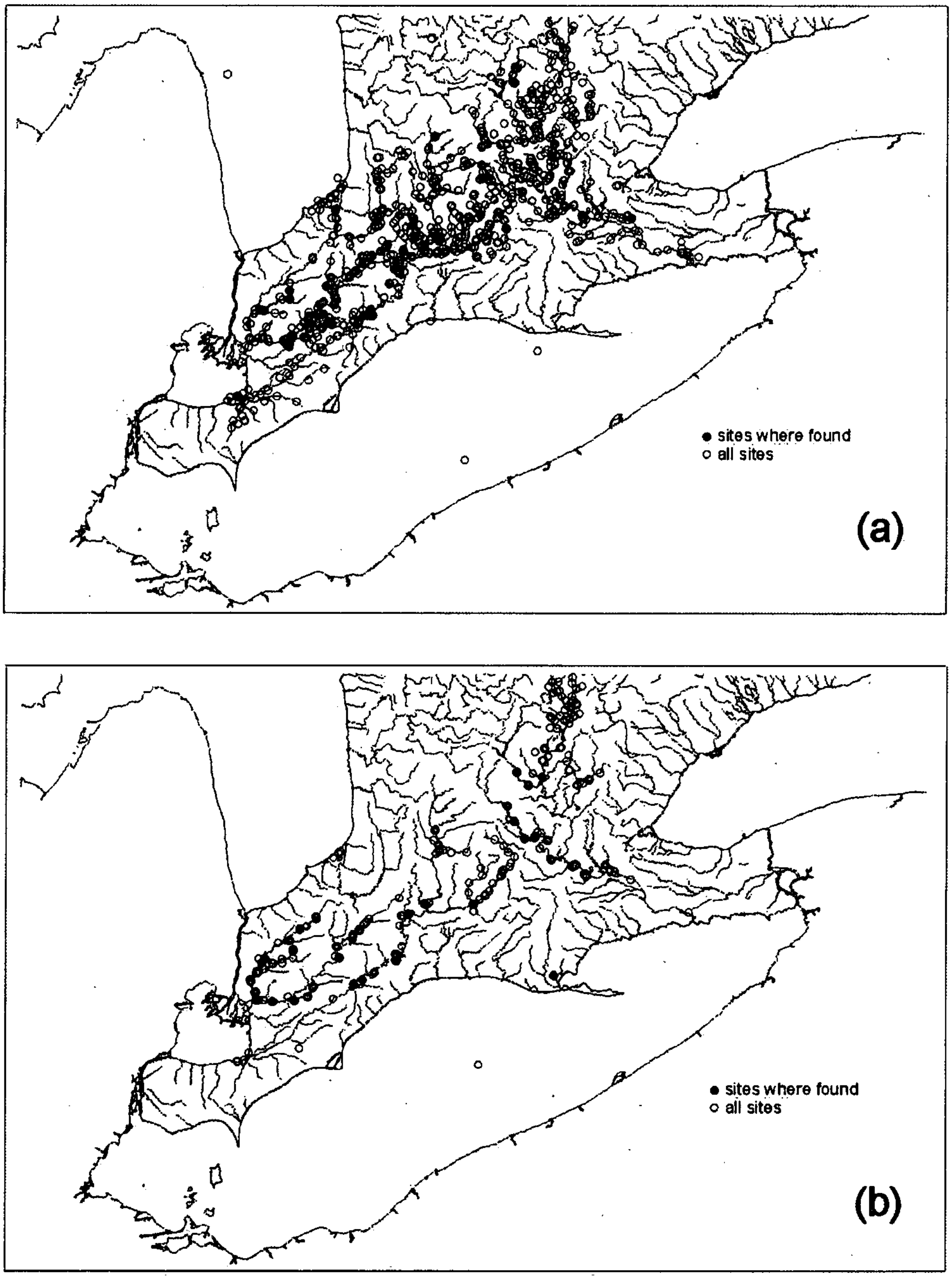

Figure 8. Distribution of Blackside Darter (a) before 1990 and (b) after 1990.

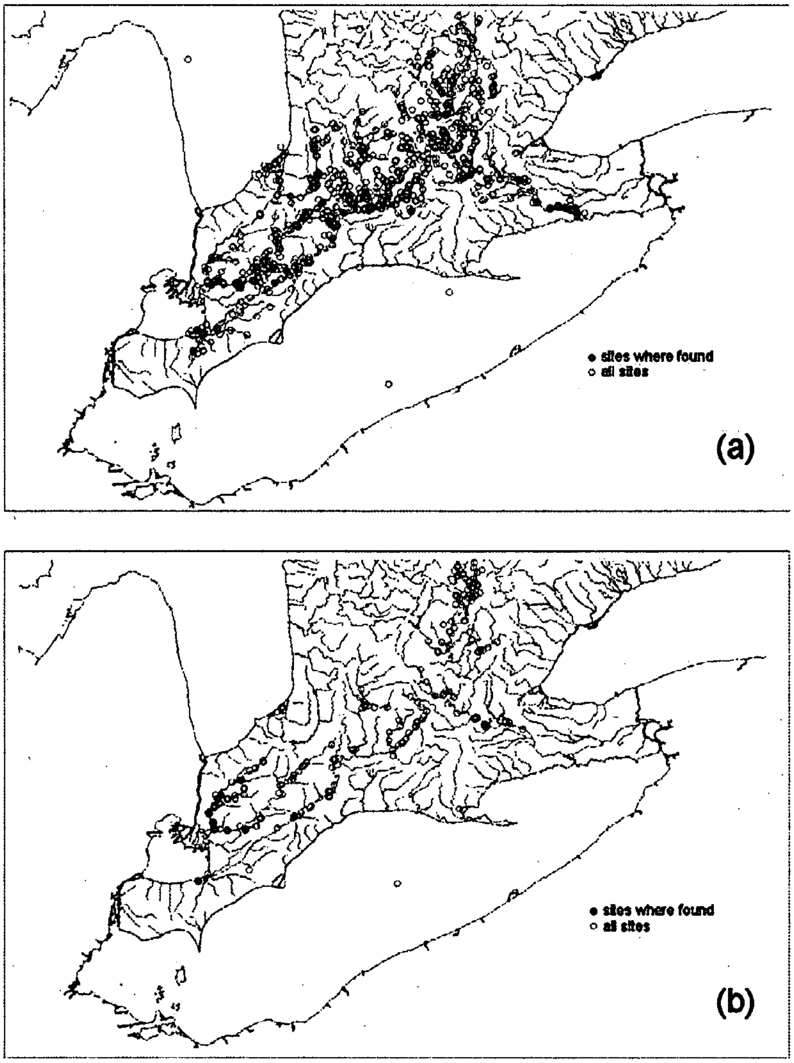

Figure 9. Distribution of Logperch (a) before 1990 and (b) after 1990.

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 Odom (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. t. rangiana*, from a midden heap in the lower river in 1973. As populations of *E. triquetra* in the Sydenham River are very small, any level of predation could jeopardize its continued existence.

SPECIAL SIGNIFICANCE OF THE SPECIES

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 *Epioblasmas*, 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, and many are unhealthy and may not be reproducing. If efforts are not taken soon to preserve and recover the Snuffbox, 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 River in southwestern Ontario supports the only known population of *E. triquetra* in Canada.

RECOMMENDED MANAGEMENT OPTIONS

The conservation of native freshwater mussels has been an ongoing effort in the United States since the Clean Water Act and Endangered Species Act were passed in 1972 and 1973, respectively. According to Bogan (1998), these efforts have so far had only a localized or limited effect. As of 1998, 12% of the 300 mussel species in North America were presumed extinct, 43% were listed or proposed for listing as endangered or threatened, and an additional 25% were in decline. Thus, less than 25% of mussel taxa are maintaining stable populations. Extinction rates for mussels over the past century were about 1.4% per decade (35 species lost since 1900); however, Ricciardi *et al.* (1998) have shown that the Zebra Mussel invasion has increased this rate of loss by 10-fold.

In 1998, the National Native Mussel Conservation Committee (an ad hoc committee with representatives from US state, tribal, and federal agencies, the mussel industry, conservation groups, and academia) released its "National Strategy for the Conservation of Native Freshwater Mussels" (NNMCC 1998). The National Strategy identifies research, management, and conservation actions necessary to maintain and recover mussel populations, and many of the recommendations can be applied in Canada.

There are two accepted ways to manage declining mussel populations, i.e., to maintain and protect the existing populations, and to expand the current range to historical proportions (TNC 1986). The latter may be accomplished by stocking with laboratory-reared specimens; augmenting marginal populations with specimens from large, stable populations; and translocating mussels from healthy populations into areas from which they were extirpated. Captive breeding programs are in their infancy, and the success of reintroductions has not yet been confirmed (Neves 1997). Before translocations can be considered, it must be determined that the source populations can withstand the reduction in their numbers, and that the animals being moved can survive the stress. Trdan and Hoeh (1993) showed that some specimens of a related species, *E. t. rangiana*, survived for over 3 years after a move from the Black River, Michigan, to a corral on the bottom of the Detroit River. However, translocation is clearly not an option for *E. triquetra* in Ontario, since populations are extremely small (only 7 live animals have been found during hundreds of hours of survey effort in recent years).

The best course of action at present would be to protect existing populations of the Snuffbox in the Sydenham River from further habitat deterioration. The 50 km reach of the East Sydenham River between Alvinston and Dawn Mills supports a great diversity of mussels, including this and several other rare and endangered species. We need to know why these species are persisting in this reach, and whether populations are declining or stable. According to the NNMCC (1998), further degradation of mussel habitat can be halted and reversed by: (1) enforcing existing government regulations that protect mussels and their habitat; (2) encouraging government agencies to create programs, or modify existing ones, to protect and recover mussel habitat; (3) encouraging local industries and landowners to modify their activities such that mussel habitat can be protected and recovered; and (4) encouraging conservation organizations and agencies to acquire key habitats. Education of the general public, land owners and government agencies about the need for protecting and enhancing natural stream ecosystems for the benefit of mussels and other freshwater organisms is crucial to the success of any rehabilitation program (Bogan 1998, NNMCC 1998).

In order to effectively manage *E. triquetra*, much more must be known about its life history and environmental requirements (TNC 2000b; NNMCC 1998). Its host fish(es) in Ontario must be identified; it is possible that the Snuffbox is using different hosts here than in other parts of its range. Life history studies must be conducted to determine its age and size at sexual maturity, recruitment success, age class structure, habitat requirements, and viable population size. Specific effects of various perturbations (e.g., siltation, agricultural chemicals, domestic and industrial effluents, fluctuations in temperature, DO, pH and flow) and the levels at which they are limiting must be determined. The locations and densities of all existing populations must be known, and these populations must be monitored for evidence of change. Nearshore areas in Lake Erie and Lake St. Clair that have been shown to be refuges from the Zebra Mussel for other native mussel species, should be surveyed for the presence of *E. triquetra*. Under the Great Lakes Wetlands Conservation Action Plan, over 4000 hectares of wetlands have been secured, and the rehabilitation of more than 14,000 hectares is underway (Environment Canada 2000b). These wetlands may represent a significant portion of the available habitat for native mussels in Ontario waters. As such, they should be managed with the needs of mussels, in addition to those of other wetland species, in mind.

The recovery plan for the Clubshell (*Pleurobema clava*) and Northern Riffleshell (*E. t. rangiana*) in the United States recommends the development of comprehensive watershed plans for the "...maintenance of the ecosystems on which these mussels and their hosts depend" (USFWS 1994). The U. S. Fish and Wildlife Service is now recommending a basin-wide approach to the conservation of mussels, rather than species-specific recovery plans (Bogan 1998). In keeping with these recommendations, an aquatic ecosystem recovery plan is currently being developed for the Sydenham River.

EVALUATION

The Snuffbox is the most widely distributed member of the genus *Epioblasma*. It was historically known from 18 states and the Province of Ontario. The distribution of *E. triquetra* has become significantly reduced throughout its range. In the United States, it is no longer found in 60% of formerly occupied streams. Remaining populations are small and geographically isolated from one another, and not all of them are healthy and reproducing. The species has probably been extirpated from Iowa, Kansas, New York and Mississippi. Although it is not federally listed in the United States at the present time, is listed as endangered or threatened in many states. The Nature Conservancy has assigned it a Global Rank of G3 (rare and uncommon globally), and it has an SRANK of S1 (very rare) in 10 states and Ontario.

In Canada, there are 31 known historical records for *E. triquetra* from Lake Erie, Lake St. Clair, and the Ausable, Sydenham, Thames, Grand, and Niagara rivers. No trace of the species was found at approximately 250 sites surveyed within the species' range by various researchers between 1990 and 1997, and it was assigned an SRANK of SH (no verified occurrences in the past 20 years) by the Ontario Natural Heritage Information Centre in the mid-1990s. Until recently, the last verified occurrence of *E. triquetra* was a single live animal taken from a site on the Sydenham River in 1973.

Intensive surveys (4.5 person-hours of sampling effort) were conducted at 66 sites on tributaries to Lake Erie, Lake St. Clair and lower Lake Huron in 1997-1998 to determine the occurrence of this and other rare species of mussels. All sites where *E. triquetra* had previously been recorded were surveyed. Several sites were revisited for additional searches in 1998 and 1999. Only 7 live animals were found (1 female and 6 males) at a total of 4 sites within a 50 km reach of the East Sydenham River between Alvinston and Dawn Mills. The average width of this reach is 25 m (Metcalfe-Smith *et al.* 1998c, unpublished data); thus, the extent of occurrence for this species in Canada is 1.25 km^2. Based on the results of a recent survey to determine the amount of mussel habitat in the

East Sydenham River (Staton *et al.* 2000), the preferred habitat of the Snuffbox (riffle areas with gravel/cobble/boulder substrate) accounts for approximately 13.5% of the occupied reach. An optimistic estimate of the total number of individuals in the East Sydenham River can be derived by multiplying the extent of occurrence (1.25 km^2) by the proportion of this area that has suitable habitat for the Snuffbox (13.5%) by the maximum known density in an area of optimal habitat (0.014animals/m^2 in a riffle area near Alvinston), and assuming that the population is continuous at that density. The estimate would be about 2350 individuals. As not all areas of apparently suitable habitat are likely to support maximum densities, we suspect that the actual number of live individuals would be an order of magnitude lower, i.e., less than 250.

The reach of the Sydenham River between Alvinston and Dawn Mills also harbours the endangered Northern Riffleshell (*Epioblasma torulosa rangiana*). Although the Northern Riffleshell is more rare globally than the Snuffbox (global ranks are G1G2 and G3, respectively), it is much more abundant in Ontario. As shown in Table 4, 6× as many *E. t. rangiana* were found at 2× as many sites as *E. triquetra* using the same sampling effort.

Table 4. Comparison of the distribution and abundance of the Northern Riffleshell (*Epioblasma torulosa rangiana*) and Snuffbox (*Epioblasma triquetra*) in southwestern Ontario rivers in 1997-1999.

Site[1]	Year	Sampling effort (p-h)	Live specimens found: Northern Riffleshell	Live specimens found: Snuffbox
Sydenham River:				
SR-3	1997	4.5	2	0
	1999	9.4	17	1
SR-7	1997	4.5	5	0
	1999	not determined	1	0
SR-17	1998	4.5	11	1
SR-5	1997	4.5	2	0
	1999	4.5	2	0
SR-6	1997	4.5	2	0
	1999	7.5	0	2
SR-12	1998	12.0	2	2
	1999	11.0	0	1
Ausable River:				
AR-8	1998	4.5	1	0
AR-7	1999	4.5	1	0
Totals			46 at 8 sites	7 at 4 sites

[1]sites arranged in an upstream to downstream direction in both rivers. Locations of all sites except SR-7 are shown in Fig 6; site SR-7 is located midway between sites SR-4 and SR-17.

Epioblasma triquetra is typically found at very low densities, representing <1% of the mussel assemblage. The largest remaining population in North America is found in the Clinton River, Michigan, where it is the dominant species (804 of 2113 specimens collected from a site in 1992 were *E. triquetra*). Capture rates for the Snuffbox in the Sydenham River would qualify the population for a D-ranked occurrence (the lowest rank) according to criteria developed for this species by The Nature Conservancy.

Comparisons of current catch rates in the Sydenham River with those from the 1960s and 1970s suggest that abundance has declined. As several year classes were represented among the live specimens and fresh shells collected in 1997-1999, recruitment may still be occurring at some locations.

Approximately 70% of historical occurrences of *E. triquetra* in Ontario were from the Great Lakes and their connecting channels, which are now infested with Zebra Mussels. The specific sensitivity of the Snuffbox to Zebra Mussels is not known. Although it was recently discovered that nearshore areas in Lake Erie and Lake St. Clair may serve as refuges for native mussels from the Zebra Mussel, *E. triquetra* has not been found in these refuges. The probability of re-establishing the Snuffbox in this portion of its former range (including the mouth of the Grand River) is remote.

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. There is little likelihood of re-establishing the species in the Thames and Grand rivers due to poor water quality and Zebra Mussels, respectively. The status of the species in the Ausable and other lower Lake Huron rivers is unclear at present due to insufficient sampling effort. The Sydenham River probably supports the last remaining population(s) of the Snuffbox in Ontario and Canada. Urban impacts on this river are minor, and water quality may have improved in recent years due to a significant improvement in sewage treatment coupled with only modest population growth. Agricultural activities continue to increase, however, and run-off of silt and agricultural chemicals (and possibly road run-off) may be limiting the distribution of *E. triquetra* in this system. It is not known at present if water and/or habitat quality are declining, and this is currently under investigation by the Sydenham River Recovery Plan Team.

Epioblasma triquetra is the only member of the genus *Epioblasma* that is not listed as either extinct or endangered by the American Fisheries Society, and this may simply be because it is more widely distributed and hence has more extant occurrences than other *Epioblasmas*. All members of the genus are believed to be extremely sensitive to environmental perturbations. The Snuffbox has a number of traits that may increase its vulnerability and affect its ability to recover from adverse impacts. These include:

- highly specialized habitat requirements (shallow riffle and shoal areas with clean, clear, swift-flowing water and firm rubble/gravel/sand substrates that are free from siltation).
- few fish hosts (only two of the five known fish hosts for this species are found in Ontario and one, the Logperch, may be declining. If there are other hosts, they have not yet been identified. Mussels with few hosts are more sensitive to changes in the fish community than those with many hosts).
- long-term brooder (more sensitive to the energy-depleting effects of the Zebra Mussel, because they require more energy for reproduction than short-term brooders).

- morphologically depressed glochidia (species with depressed glochidia have a lower rate of recruitment than species with elongate glochida, and may not be able to recover once their populations are in decline).
- burrowing habits (usually found entirely buried in the substrate, or with only the posterior slope exposed. As such, it may be more sensitive to the effects of siltation than the majority of species, which do not burrow).
- population(s) believed to occupy only a short reach of one river in Ontario (a single adverse ecological event in the Sydenham River could result in the extirpation of this species).

There is no natural immigration of individuals from the United States at the present time, although global warming could result in this and other mussel species extending their ranges further north. Artificial translocations from healthy populations are theoretically possible provided the populations are genetically similar.

Based on the above considerations, the authors recommend a status designation of **Endangered** for the Snuffbox in Canada.

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THE AUTHORS

Ernest T. Watson has a B.Sc. in Zoology (1995), and a M.Sc. in Zoology (2000) from the University of Manitoba. The topic of his M.Sc. research was the relationships between the distributions of freshwater mussels and environmental factors within the Assiniboine River drainage in Manitoba, and the breeding cycle, population age structure, and seasonal benthic distributions of *Anodontoides ferussacianus* in a small prairie stream. He has prepared one publication and two conference presentations on this work. Through contract work as an aquatic biologist with the Department of Fisheries and Oceans, Freshwater Institute, Winnipeg (1995 to 1999), and TetrES Consultants Inc., Winnipeg (1999), he has become experienced in the collection and taxonomic identification of mussels, fish and invertebrates, habitat assessment techniques, data analysis, and writing scientific reports. He has been a member of the American Fisheries Society and the North American Benthological Society since 1995, a member of the American Malacological Society since 1996, and a member of the Freshwater Mollusk Conservation Society since 1999.

Janice L. Metcalfe-Smith is an Aquatic Research Biologist with the National Water Research Institute of Environment Canada in Burlington, Ontario. She has a B.Sc. (Hons.) in Zoology from the University of Manitoba (1973), and 28 years of experience as a technologist (1973-1978) and biologist (1978-present) with the departments of Fisheries & Oceans (Winnipeg, MB and St. Andrews, NB) and Environment (Burlington, ON). She has conducted research in several areas, including the effects of forestry practices and acid rain on Atlantic salmon, the use of benthic macroinvertebrate communities in water quality assessment, and the development of biological monitoring techniques for measuring contaminant trends in freshwater ecosystems. Over the past five years, her research has focused on the assessment and conservation of freshwater mussels in Ontario. She has authored or co-authored approximately 55 scientific papers and reports, and 40 conference presentations. She is a member of the North American Benthological Society, the Freshwater Mollusk Conservation Society, and the Mollusc Working Group of the Lepidoptera and Mollusca Subcommittee of COSEWIC. She is also an Associate Editor of the Water Quality Research Journal of Canada. She co-authored three previous status reports on mussel species at risk.

Joanne Di Maio received a B.Sc. (Honours Biology) from the University of Toronto in 1993 and a M.Sc. (Biological Science) from the University of Windsor in 1995. The focus of her Master's research was the influence of hydrological variability on the distribution of freshwater mussels in rivers. Part of her thesis research was published in the Canadian Journal of Zoology and the Journal of Molluscan Studies. Joanne studied the macroinvertebrate communities from headwater streams of the Oak Ridges Moraine for the Ontario Ministry of the Environment, and aquatic oligochaetes from Ontario rivers and lakes for the Royal Ontario Museum. Results of these studies were published in the Canadian Field-Naturalist. She is a member of the North American Benthological Society. At the time of writing, Joanne was a research technologist with the National Water Research Institute of Environment Canada.

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Appendix 1. Distribution of *Epioblasma triquetra* in the United States.

State	River/Stream	Occurrence[a]	Reference
Alabama	Bear Creek	H	T. Manasco (pers. comm.)[b]
	Flint River	na	Johnson 1979
	Paint Rock River	P	T. Manasco (pers. comm.)
	Tennessee River	na	Johnson 1979
Arkansas	Black River	na	C. Osborne (pers. comm.)
	Spring River	na	"
	Strawberry River	na	"
	White River	na	"
Illinois	Embarras River	P	K.S. Cummings (pers. comm.)
	Fox River	H	"
	Illinois River	H	"
	Kankakee River	H	"
	Kaskaskia River	H	"
	Little Wabash River	H	"
	Mississippi River	H	"
	Ohio River River	H	"
	Rock River	H	"
	Sangamon River	H	"
	Vermillion River	H	"
	Wabash River	H	"
Indiana	Blue River	H	R. Hellmich (pers. comm.)
	Buck Creek	P	"
	Clifty Creek	P	"
	Fall Creek	H	"
	Flatrock River	H	"
	Graham Creek	H	"
	Muscatatuck River	H	"
	Sand Creek	H	"
	Sugar Creek	P	"
	Tippencaonoe River	P	"
	Wabash River	H	"
	White River	H	"
	Youngs Creek	H	"
Iowa	Mississippi River	na	Johnson 1978
Kansas	Wakarusa River	H	Murray and Leonard 1962
	Marais des Cygnes River	H	"
Kentucky	Beaver Creek	na	Johnson 1978
	Kentucky River	P	R. Cicerello (pers. comm.)
	Kinniconick Creek	P	"
	Licking River	P	"
	Lower Cumberland River	H	"
	Lower Green River	H	"
	Ohio River	H	"
	Salt River	P	"
	Tyarts Creek	P	"
	Upper Cumberland River	P	"
	Upper Green River	P	"
Michigan	Belle River	P	R.R. Goforth (pers. comm.)
	Big Salt River	H	"

State	River/Stream	Occurrence[a]	Reference
Michigan	Cass River	H	R.R. Goforth (pers. comm.)
	Chippewa River	H	"
	Clinton River	P	"
	Detroit River	H	"
	Grand River	P	"
	Huron River	P	"
	Lake St. Claire	H	"
	Muskegon River	na	"
	Otter Creek	H	"
	Pine River	H	"
	Saginaw River	H	"
	Sebewaing River	H	"
	St, Joseph River	H	"
	St. Clair River	H	"
	Tittabawasee River	H	"
Minnesota	Mississippi	H	M. Davis (pers. comm.)
	St. Croix River	P	"
Mississippi	Bear Creek	H	T.M. Mann (pers. comm.)
Missouri	Black River	na	Johnson 1978
	Bourbeuse River	na	"
	Meramec River	na	"
	Big River	na	"
	Big River	na	"
	St. Francis River	na	Oesch 1984
New York	Lake Erie	H	Strayer and Jirka 1997
	Buffalo Creek	H	"
	Niagra River	H	"
	Tonawanda Creek	H	"
Ohio	Alum Creek	H	G.T. Watters (pers. comm.)
	Big Darby Creek	P	"
	Big Walnut Creek	H	"
	Caesar Creek	H	"
	Deer Creek	H	"
	Grand River	P	"
	Hocking River	H	"
	Killbuck Creek	P	"
	Little Darby Creek	H	"
	Little Miami River	P	"
	Little Salt Creek	H	"
	Middle Fork Salt Creek	H	"
	Olentangy River	H	"
	Salt Creek	H	"
	Sandusky River	H	"
	Scioto Bush Creek	H	"
	Scioto River	H	"
	South Fork of Scioto Brush Creek	H	"
	Stillwater River	H	"
	Swan Creek	H	"
	Walhonding River	P	"
	Whetstone Creek	H	"
Pennsylvania	Shenango River	na	Johnson 1978
	Leboeuf Creek	na	"
	French Creek	na	"

State	River/Stream	Occurrence[a]	Reference
	Allegheny River	na	"
	Dunkards Creek	na	"
Tennesssee	Clinch River	na	Parmalee and Bogan 1998
	Cumberland River	na	"
	Duck River	na	"
	Elk River	na	"
	Little River	na	"
	Nolichuchy River	na	"
	North Fork Holsten River	na	"
	Obey River	na	"
	Powell River	na	"
	South Fork Holsten River	na	"
	Tennessee River	na	"
Virginia	Holsten River	H	Terwilliger 1991
	Clinch River	P	"
	Powell River	P	"
West Virginia	Cedar Creek	P	J. Clayton (pers. comm.)
	Dunkard Creek	P	"
	Elk River	P	"
	Henrys Fork	P	"
	Hughes River	P	"
	North Fork Hughes River	P	"
	South Fork Hughes River	P	"
	Leading Ck. of the Little Kanawaha	P	"
	Little Kanawha River	P	"
	Middle Island Creek	P	"
	West Fork River	P	"
Wisconsin	Embarrass River	P	J.M. Burnham (pers. comm)
	Fox River	H	"
	Little Wolf River	P	"
	St. Croix River	P	"
	Wisconsin River	H	"
	Wolf River	P	"

[a]H = believed to be of historical occurrence only, based on a lack of recent records; P = believed to be present, based on recent collections; na = no information available.
[b]see Acknowledgements for affiliations.

Appendix 2. 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	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					
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					
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					
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	Inner Bay, 1.1 mi. S.E. of St. Williams, Station HDA 544	42.617	-80.400	Athearn, H.D.	CMN	246	048172					
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					
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				

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)
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	436	092765					

[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.

Environment Canada Environnement Canada

Canadä

Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington (Ontario)
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon (Saskatchewan)
S7N 3H5 Canada

St. Lawrence Centre
105 McGill Street
Montreal, Quebec
H2Y 2E7 Canada

Centre Saint-Laurent
105, rue McGill
Montréal (Québec)
H2Y 2E7 Canada

Place Vincent Massey
351 St. Joseph Boulevard
Gatineau, Quebec
K1A 0H3 Canada

Place Vincent-Massey
351 boul. St-Joseph
Gatineau (Québec)
K1A 0H3 Canada