COSEWIC
Assessment and Status Report

on the

Northern Riffleshell
Epioblasma torulosa rangiana

in Canada

ENDANGERED
2010

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

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

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COSEWIC
Assessment Summary

Assessment Summary – April 2010

Common name
Northern Riffleshell

Scientific name
Epioblasma torulosa rangiana

Status
Endangered

Reason for designation
This small freshwater mussel is restricted to two rivers in southern Ontario. Since the original COSEWIC assessment (2000), a small, possibly reproducing population was discovered in the Ausable River although only 16 live individuals, including one juvenile, have been found over the last 10 years. Recruitment is occurring at several sites along the Sydenham River and the population appears to be stable, but the perceived recovery could be due to increased sampling effort over the past 12 years. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban and industrial development, subject to siltation and pollution. Only four populations in the world, including the two in Canada, show signs of recruitment.

Occurrence
Ontario

Status history
Designated Endangered in April 1999. Status re-examined and confirmed in May 2000 and April 2010.

COSEWIC
Executive Summary

Northern Riffleshell
Epioblasma torulosa rangiana

Wildlife species description and significance

The Northern Riffleshell is unmistakable among Canadian freshwater mussels because of its small to medium size (45 to 76 mm long) and extreme and unique sexual dimorphism. The brown-yellow to yellow-green shell has diffuse, fine green rays and is irregularly egg-shaped. The posterior end is broader in males. In females, the anterior end is broader and the shell is greatly expanded post-ventrally and swollen. In both sexes, the inner shell surface is pearly white or rarely pink.

The Northern Riffleshell is one of the last remaining members of the near-extinct genus *Epioblasma*. It is one of three subspecies of *E. torulosa*; the other two subspecies are confined to the U.S. and are presumed extinct. The Canadian populations are two of only four remaining populations in North America that show evidence of recruitment, thus they are important for the global survival of the species.

Distribution

Historically, this mussel was found in Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania, West Virginia and Ontario, and it may once have occurred in New York. It has suffered dramatic declines in North America over the past century. Its current distribution represents a range reduction of more than 95% and there are perhaps as few as four populations in the world today. Its range in Ontario once included western Lake Erie, Lake St. Clair, and the Detroit, Thames, Ausable, and Sydenham rivers, but it now appears restricted to the Ausable and Sydenham rivers.

Habitat

This mussel lives mainly in highly oxygenated riffle areas of rivers and streams of various sizes. It also once inhabited shoals in western Lake Erie and Lake St. Clair where wave action was sufficient to produce continuously moving water. The preferred substrate ranges from rocky or sandy bottoms, to firmly packed sand and fine to coarse gravel. It currently occupies a linear distance of 70 km and 72 km along the Ausable and Sydenham rivers, respectively. Because these reaches have a relatively low gradient, riffle habitat would be expected to constitute only a small proportion of the total habitat.

Biology

This mussel can live at least 11 years. It is a long-term brooder (bradytictic) with a gravid period from late summer to the following spring. When the larvae (glochidia) are ready to be released, the female displays a spongy, pure white mantle lining visible for several metres and is known to lure and trap potential host fish. Once expelled into the water, the glochidia must attach to an appropriate host fish to complete development. Potential host fishes in Canada (darters and sculpins) have been identified in the laboratory. Although the exact food preferences and optimum particle sizes for the adults are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria and algae).

Population sizes and trends

Two populations are found in Canada. The Sydenham River population may have had serious declines in the 1970s and 1980s, but recruitment is now occurring at several sites. This perceived recovery could be an artifact of intensive and increased sampling effort over the past 12 years. The Ausable River population was only discovered in 1998 and since then only 16 live animals have been found. This population survives at extremely low densities with a single juvenile being the only evidence of recruitment. Large numbers of weathered, empty shells indicate the population was likely much larger.

Threats and limiting factors

The main factor limiting the occurrence of the Northern Riffleshell is probably the availability of silt-free, riffle habitat. Increased siltation in the Sydenham River has been correlated with the disappearance of this and other riffle-inhabiting species. Because of its narrow habitat requirements, it is extremely vulnerable to impoundments, siltation and pollution globally. All rivers in Canada and the U.S. where it occurs are in areas of either intense agriculture or forestry and are susceptible to siltation and runoff. The distribution in Canada is severely limited by the Zebra Mussel because Lake St. Clair, the Detroit River and the shoals of western Lake Erie are heavily infested with the invasive bivalve, making them uninhabitable to native mussels. However, the remaining populations in the Ausable and Sydenham rivers are not significantly at risk of exposure to Zebra Mussels as they have no major reservoirs that could support a permanent colony of Zebra Mussels.

Protection, status, and ranks

The Northern Riffleshell is currently listed in Schedule 1 (Endangered) of Canada's *Species at Risk Act* and listed as Endangered in Ontario's *Endangered Species Act, 2007*. The federal *Fisheries Act* may also protect the mussel's habitat. Laws that protect mussel habitat in Ontario include the Provincial Policy Statement under Section 3 of *The Planning Act* and the *Ontario Lakes and Rivers Improvement Act*. Stream-side development in Ontario is managed through flood plain regulations enforced by local Conservation Authorities. Land along the Sydenham and Ausable rivers where the species still occurs is mainly privately owned and is used for agriculture. In the U.S., this mussel is listed as Endangered federally and protected under the *Endangered Species Act*. It is also listed under the IUCN as Critically Endangered and is prevented from cross-border trade under CITES.

TECHNICAL SUMMARY

Epioblasma torulosa rangiana
Northern Riffleshell épioblasme ventrue
Range of occurrence in Canada: southwestern Ontario

Demographic Information

Generation time (estimated)	3-5 yrs
Is there an inferred continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within 2 generations	Unknown
Inferred percent change in total number of mature individuals over the last 3 generations.	Possibly stable
Suspected percent reduction in total number of mature individuals over the next 3 generations.	Unknown
Inferred percent reduction in total number of mature individuals over any 3 generations period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased?	No
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	983 km²
Index of area of occupancy (IAO) (2 km x 2 km grid: Sydenham River 160 km²; Ausable River 136 km²) Biological AO (length x width of river reach): Sydenham River 1.44 km²; Ausable River 0.53 km²	296 km² Biological AO=1.97 km²
Is the total population severely fragmented?	No
Number of "locations*" Sydenham and Ausable rivers	2
Is there an inferred continuing decline in extent of occurrence?	No
Is there an inferred continuing decline in index of area of occupancy?	No
Is there an observed continuing decline in number of populations?	No
Is there an observed continuing decline in number of locations?	No
Is there an inferred continuing decline in quality of habitat?	Yes
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each population)

Population	**N Mature Individuals**
Sydenham River (± SE) (Metcalfe-Smith *et al.* 2007)	131,000 (±19,000)
Ausable River (± SE) (Staton unpubl. data)	15,400 (±2,700)
Total maximum (± SE)	146,400 (±21,700)

Quantitative Analysis

Probability of extinction in the wild.	Not available

* See definition of location.

Threats (actual or imminent, to populations or habitats)

Siltation from agriculture (Sydenham and Ausable rivers) Municipal, industrial and agricultural pollution – including chlorine, pesticides, herbicides, fertilizers, and metals

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? USA: Endangered IUCN: Critically Endangered	
Is immigration known or possible?	No
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Likely
Is rescue from outside populations likely?	No

Current Status

COSEWIC: Endangered (2010) SARA: Schedule 1 (2005) Ontario ESA: Endangered (2008) IUCN: Critically Endangered CITES: Appendix II

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** B1ab(iii) + 2ab(iii)
Reasons for designation: This small freshwater mussel is restricted to two rivers in southern Ontario. Since the original COSEWIC assessment (2000), a small, possibly reproducing population was discovered in the Ausable River although only 16 live individuals, including one juvenile, have been found over the last 10 years. Recruitment is occurring at several sites along the Sydenham River and the population appears to be stable but the perceived recovery could be due to increased sampling effort over the past 12 years. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban and industrial development, subject to siltation and pollution. Only four populations in the world, including the two in Canada, show signs of recruitment.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. The number of mature individuals appears to be stable. **Criterion B** (Small Distribution Range and Decline or Fluctuation): Both B1 and B2 are applicable as EO (983 km^2) and IAO (296 km^2) are below the thresholds for Endangered (< 5,000 km^2 and < 500 km^2, respectively). As the species is found at only 2 locations, sub-criterion “a” (< or = 5 locations) is applicable. There is a continuing decline inferred in the quality of habitat so sub-criterion “b(iii)” also is applicable. **Criterion C** (Small and Declining Number of Mature Individuals): Not applicable. The total number of mature individuals is estimated to be 146,400, above the thresholds for this criterion (< 10,000 for threatened), although one of the two populations contains 89% of the total estimated population. **Criterion D** (Very Small or Restricted Total Population): Nearly meets the criteria for Threatened D2 as the species is found at fewer than 5 locations but even though it is prone to the effects of human activities (e.g., degraded water quality from agriculture, industrial, and urban activities), these activities are not occurring over a very short time frame in an uncertain future. **Criterion E** (Quantitative Analysis): Not applicable. Probabilities for extinction in the wild have not been calculated.

PREFACE

Since the original status assessment of the Northern Riffleshell, *Epioblasma torulosa rangiana* in Canada (COSEWIC 2000), a large number of monitoring, research and management projects have occurred. The information garnered in the last 10 years has been incorporated to update the original COSEWIC report. Some highlights of the new information in this report are as follows:

Extensive quantitative sampling and surveys in the Sydenham (Metcalfe-Smith *et al.* 2007) and Ausable rivers (Staton *et al.* unpubl. data) have helped understand the stability and dynamics of the Canadian populations (Crabtree and Smith 2009). In a major change from the 2000 report, the Ausable River is now known to have a small, but possibly reproducing population. The population in the Sydenham River is now understood to be one of the three remaining relatively healthy and reproducing populations globally; the others occur in the Upper Ohio River system, Pennsylvania. Unfortunately, the populations in the Great Lakes and connecting channels have not recovered, with the Detroit River population declared extirpated (Schloesser *et al.* 2006). Neither extent of occurrence (EO) or area of occupancy (AO/IAO) were calculated in the original 2000 report.

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

New data on the phylogenetic (Zanatta and Murphy 2006b) geno-geographic population structure (Zanatta and Murphy 2007) have been added to the **WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE** section.

Much of the new research described above and throughout this status update is the result of recommendations for research and monitoring in recently produced recovery strategies for species at risk in southern Ontario. Ecosystem recovery strategies for the Sydenham (Dextrase *et al.* 2003; Staton *et al.* 2003) and Ausable rivers (Ausable River Recovery Team 2004) include *E. t. rangiana*. A multi-species recovery strategy for five mussel species found in southwestern Ontario (Morris and Burridge 2006) also includes *E. t. rangiana*.

COSEWIC HISTORY

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

COSEWIC MANDATE

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

COSEWIC MEMBERSHIP

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

DEFINITIONS
(2010)

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

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

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

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

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Canada

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

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2010

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and classification

Epioblasma torulosa rangiana was originally described by Lea in 1838 and named after the French malacologist Sander Rang (U.S. Fish and Wildlife Service [USFWS] 1994). The type localities for this subspecies are the Ohio River near Cincinnati and Yellow Creek of the Mahoning River near Poland, Ohio (USFWS 1994).

Considerable confusion surrounds the taxonomy of this subspecies and closely related taxa (USFWS 1994; Bogan 1997). Bogan (1997) suggested that Isaac Lea described many new species based on only slight differences and consequently described some species many times with different names. Johnson (1978) reviewed this genus (as *Plagiola*) and grouped many variants as one species, *Plagiola torulosa,* apparently attributing differences to ecophenotypic variation. However, Turgeon *et al.* (1998) recognized three distinct subspecies of *Epioblasma torulosa*: *E. t. rangiana, E. t. torulosa,* and *E. t. gubernaculum*. Bogan (1997) synonymized *E. biloba* with *E. t. rangiana* and revealed that the name *biloba* Rafinesque 1831 has taxonomic priority over *rangiana* Lea 1838 but recommended retaining *rangiana* as it is more frequently used. *Epioblasma torulosa rangiana* is considered by many (including the USFWS) to be the headwater form of *E. t. torulosa*; however, others consider it a distinct headwater subspecies (USFWS 1994; Graf 1998). The current naming and classification of this subspecies (Turgeon *et al.* 1998; Graf and Cummings 2007) is:

Phylum Mollusca
- Class Bivalvia (Pelecypoda)
  - Subclass Palaeoheterodonta
    - Order Unionoida
      - Superfamily Unionoidea
        - Family Unionidae
          - Subfamily Ambleminae
            - Tribe Lampsilini
              - Genus *Epioblasma*
                - Species *Epioblasma torulosa*
                  - Subspecies *Epioblasma torulosa rangiana*

Using molecular phylogenetics, *E. t. rangiana* is a lampsiline mussel forming a well-supported monophyletic group with other members of its genus (Zanatta and Murphy 2006b). It also forms a well-supported monophyletic lineage with a clade of *Epioblasma* termed the riffleshells (Jones *et al*. 2006). The riffleshell group was previously defined as the subgenus *Torulosa* by Johnson (1978).

Despite the taxonomic complications, *Epioblasma torulosa rangiana* is the only subspecies of *E. torulosa* that occurs in Canada. As the other two subspecies are considered extinct (Williams *et al.* 1993), *E. t. rangiana* is also the only living subspecies remaining within the species *E. torulosa*. The French common name for *E. t. rangiana* is épioblasme ventrue (Martel *et al.* 2007).

Morphological description

The Northern Riffleshell, *Epioblasma torulosa rangiana* (Lea, 1838), is unmistakable among Canadian freshwater mussels (Figure 1) because of its size, colour, and extreme and unique sexual dimorphism (Clarke 1981). A concise description of the shell characteristics is given in Stansbery *et al*. (1982) as follows:

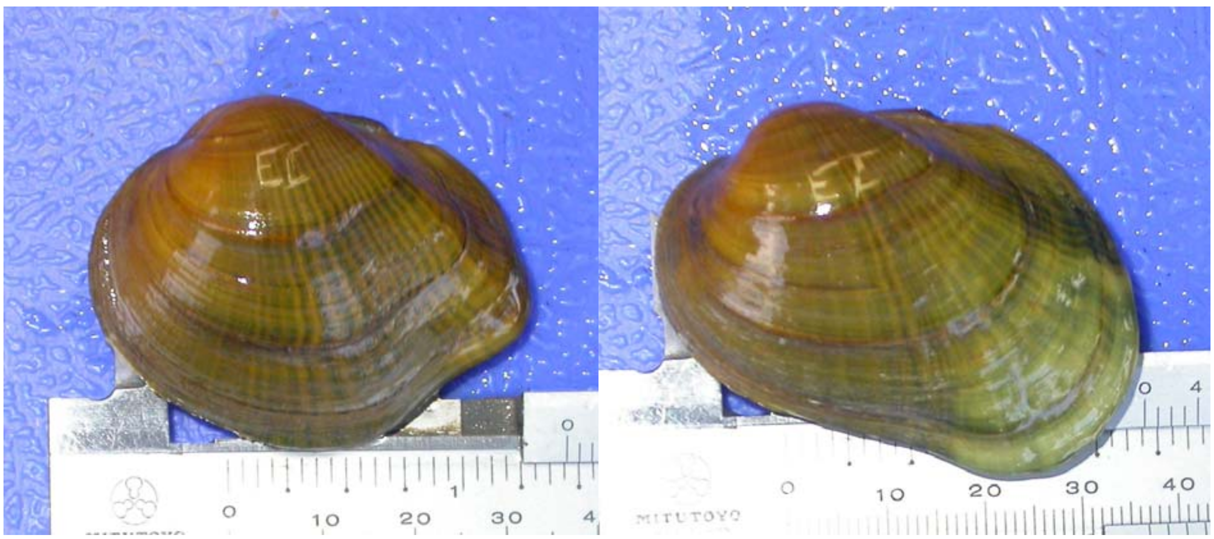

Figure 1. Male (left) and female (right) *Epioblasma torulosa rangiana* from the Sydenham River, Ontario (photo credit: D. Zanatta, Central Michigan University).

"Shell small to medium size, subcompressed to subinflated, solid; male irregularly ovate, with a wide, shallow sulcus just anterior to the posterior ridge; posterior ridge curves down away from hinge line; occasionally a low ridge down the center of the disc, smooth to faintly nodulous; female obovate, greatly expanded post-ventrally, expansion very broadly rounded, transversely swollen, beginning about the third year of growth; umbonal sculpture finely double-looped; periostracum brownish yellow to yellowish green with diffuse, fine green rays; cardinal teeth small, lateral teeth fairly short, moderately thick; nacre white, rarely pink."

A more detailed description of the shell characteristics is found in Clarke (1981). Reported shell dimensions vary: Clarke (1981) states that a mature male is 45 mm long and a mature female is nearly 50 mm; Cummings and Mayer (1992) report lengths up to 51 mm; and the USFWS (1994) reports lengths up to 76 mm but averaging 38 mm. Canadian surveys have produced individuals up to 74 mm long. A detailed description of the animal's soft parts is given by Ortmann (1912, as cited in USFWS 1994).

According to USFWS (1994), mussels that may be confused with *E. t. rangiana* include the other two subspecies of *Epioblasma torulosa*, namely *E. t. torulosa* and *E. t.* g*ubernaculum*, as well as *Epioblasma obliquata perobliqua*. The characteristics that distinguish *rangiana* from the other two subspecies of *E. torulosa* are presented in USFWS (1994); however, both subspecies are presumed extinct (Williams *et al.* 1993) and neither is known to have ever occurred in Canada. In addition, *E. o. perobliqua* does not exist in Canada.

Soft tissues of most unionids are generally not well described, however the morphology and functions of the mantle pad structures of the extant species of *Epioblasma* have been studied (Jones 2004; Barnhart *et al.* 2008). The mantle of female *Epioblasma* exhibits a peculiar ridge with a spongy interior, called the cymapallium by Barnhart *et al*. (2008) (Gr. *kyma* = a wave or swelling; L. *pallium* = a mantle or cover). In *E. t. rangiana*, *E. florentina*, and *E. capsaeformis*, the cymapallium is broadly expanded into mantle pads that line the expanded posterior regions of the female shell (Figure 2). The cymapallium in *E. t. rangiana* is bright white, without pustules or knobs and lacks any microlures (Jones 2004).

Figure 2. Female *Epioblasma torulosa rangiana in situ* showing mantle pad display used for trapping a host (photo credit: J. Jones, Virginia Tech).

Population spatial structure and variability

Microsatellite DNA markers designed specifically for *E. t. rangiana* (Zanatta and Murphy 2006a), another *Epioblasma* (Jones *et al*. 2004), and another lampsiline (Eackles and King 2002) were used in population-level analyses of *E. t. rangiana* and phylogeographic analysis was conducted using mtDNA (Zanatta and Murphy 2007). The analysis was conducted on specimens from the Allegheny River (U.S.), French Creek (U.S.) and Sydenham River (Canada). The mtDNA sequence data did not indicate significant geographic structure among the populations. However, allelic data from the microsatellite DNA loci revealed highly significant population structuring. Also using microsatellite data, individuals of *E. t. rangiana* were assigned to their own river of origin with 98.8% accuracy. Significant isolation-by-distance was also found to occur (Zanatta and Murphy 2007). Within-population levels of heterozygosity were similar among all populations, even the Sydenham River population (population size an order of magnitude smaller than the others). This indicated that the Sydenham River population, while small, contains an equally important amount of genetic diversity when compared with the large populations in the upper Ohio River drainage (Zanatta and Murphy 2007).

Designatable units

All historic and extant populations of *E. t. rangiana* in Canada are in the same COSEWIC Freshwater Biogeographic Zone (Great Lakes – Upper St. Lawrence). While population-level differences between the Ausable and Sydenham river populations have not been assessed, it is unlikely that they would meet the current genetic criterion for designatable units (DU) so there is only one DU. However, in comparison with U.S. populations, microsatellite DNA markers revealed that the Sydenham River population of Northern Riffleshell was distinguishable (e.g., genetic divergence and assignment tests) from the upper Ohio River drainage populations in the Allegheny River and French Creek. Should recovery of the western part (Wabash/Maumee/Great Lakes drainages) of the species' range eventually be feasible, the Sydenham River would be the ideal brood-stock for artificial propagation in the region (Zanatta and Murphy 2007). As such, the Wabash/Maumee/Great Lakes drainages should be deemed a separate management unit (MU) from the Allegheny/French Creek population (*sensu* Moritz 1994).

Special significance

Epioblasma torulosa rangiana is one of the last remaining members of a near-extinct genus (Jones *et al*. 2006). Without intervention, it will undoubtedly follow the same path as other members of the genus. All members of this genus are riffle-dwellers whose habitat was at first gradually eroded (Peacock *et al.* 2005) and more recently has been relentlessly destroyed (Parmalee and Bogan 1998; Williams *et al.* 2008) including the intent to destroy the *E. t. rangiana* population of the Black River (Michigan) by dredging in 1990 prior to the USFWS listing (Badra 2004). The Sydenham and Ausable river populations of *E. t. rangiana* are two of only four remaining populations in North America that show evidence of recruitment. As such, their preservation is important for the global survival of the species. Time is of the essence for recovery of this species: the other *E. torulosa* subspecies, *E. torulosa torulosa* (mainstem of the Ohio, Tennessee and Cumberland rivers) and *E. torulosa gubernaculum* (headwaters of the Tennessee River), are already presumed extinct (Williams *et al*. 2008).

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

DISTRIBUTION

Global range

Historically, *E. t. rangiana* was known from Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania, West Virginia, and Ontario (USFWS 1993; Figure 3). It occurred in the Green River (Kentucky); French Creek, LeBoeuf Creek and the Allegheny River (Pennsylvania); Detroit River (Michigan); Big Darby Creek (Ohio); the Elk River (West Virginia); and Fish Creek (Indiana and Ohio) (USFWS 1994). More recently, a substantial population was rediscovered in the Elk River (West Virginia) (see **Abundance**). Although the species has never been found in New York, it almost certainly occurred there because it has been found in two rivers only a few kilometres from the New York border (Strayer and Jirka 1997). *Epioblasma t. rangiana* occurred throughout the Ohio River drainage in rivers such as the Ohio, Allegheny, Scioto, Kanawha, Little Kanawha, Licking, Kentucky, Wabash, White, Vermilion, Mississinewa, Tippecanoe, Tennessee, Green and Salt (USFWS 1993). In the Great Lakes drainage, it occurred in the Maumee River basin and tributaries of western Lake Erie, such as the Huron River and the River Raisin (USFWS 1993). It also occurred in southern Michigan in the Black River and Elk Creek, tributaries of the St. Clair River (Hoeh and Trdan 1985). In Canada, the species historically inhabited western Lake Erie, Lake St. Clair (La Rocque and Oughton 1937), the Detroit and Sydenham rivers (Clarke 1973), and most likely the Ausable and Thames rivers (see below) in southwestern Ontario (Figures 4 and 5).

Figure 3. North American distribution of the Northern Riffleshell (*Epioblasma torulosa rangiana*).

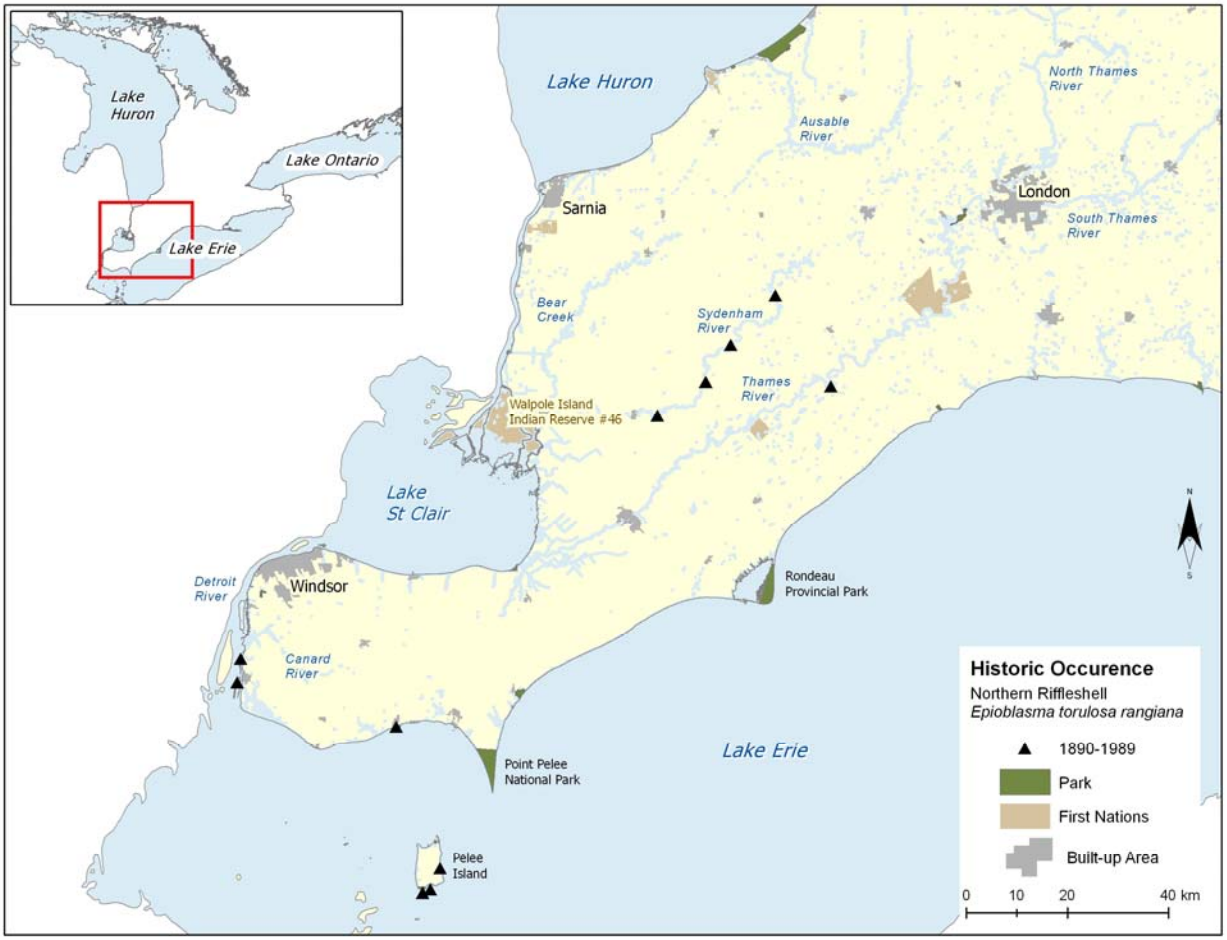

Figure 4. Historic distribution of the Northern Riffleshell (*Epioblasma torulosa rangiana*) in Canada. The triangle on the Thames River is the site where the subfossil valves were found.

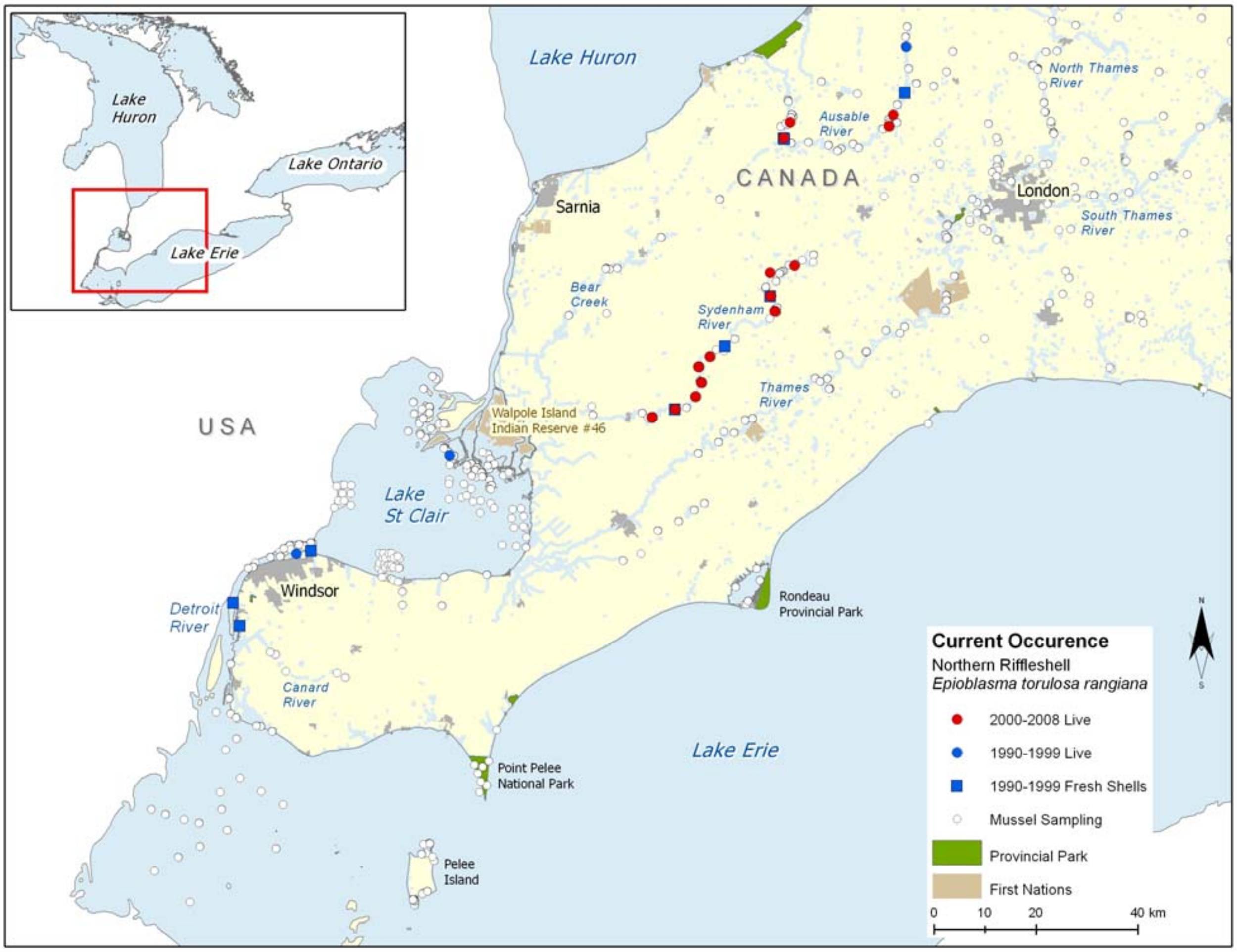

Figure 5. Recent search effort and current distribution of the Northern Riffleshell (*Epioblasma torulosa rangiana*) in Canada. For illustrative purposes the data presented here are divided into two time periods reflective of the data available at the time of the previous COSEWIC assessment (1990-1999) and the data collected since the last assessment (2000-2008).

This mussel has suffered dramatic declines in North America over the past century, with the current distribution representing a range reduction of more than 95% (USFWS 1993). Detailed information on the current and historic distributions of this subspecies in the U.S. are in USFWS (1994).

Since the USFWS (1994) listing of *E. t. rangiana*, the only remaining reproducing populations appear to be in French Creek and Allegheny River (Pennsylvania) and the Sydenham and Ausable rivers (Ontario). All other populations described above appear to be either extirpated or in rapid decline (Zanatta and Murphy 2007; Crabtree and Smith 2009). In the summer of 2008 approximately 1700 adult *E. t. rangiana* were translocated from the Allegheny River to Big Darby Creek (Ohio) in order to reintroduce the subspecies to a part of its former range (Watters pers. comm. 2009). The translocated individuals appear to be thriving in Big Darby Creek, with no mortalities encountered as of April 2009 (Watters pers. comm. 2009; D.T. Zanatta pers. obs.).

Canadian range

The historic (pre-1990) distribution of *E. t. rangiana* in Ontario, based on records from the National Water Research Institute's Lower Great Lakes Unionid Database (see **COLLECTIONS EXAMINED**), included Lake Erie and the Detroit and Sydenham rivers (Figure 4). Until the mid-1990s, *E. t. rangiana* was presumed extirpated from Canada. Although it was not found alive in the Sydenham River during surveys by Mackie and Topping (1988) and Clarke (1992) in 1985 and 1991, respectively, a remnant population was discovered in 1997 by Metcalfe-Smith *et al*. (1998). Although not sampled historically, a small population was discovered in the Ausable River in 1998 (see below).

The current Ontario distribution (Figure 5) also shows all the sites in the Lake Erie and Lake St. Clair drainage basins that were surveyed for live mussels between 1990 and 2008. It may be reasonably assumed that *E. t. rangiana*, like so many other mussel species, has been eradicated from Lake Erie and the Huron-Erie corridor by the Zebra Mussel, *Dreissena polymorpha* (see **THREATS AND LIMITING FACTORS**). A single live male *E. t. rangiana* was collected in the St. Clair delta in 1999 (Zanatta *et al*. 2002), but this mussel has not been collected in any survey of the area since then. The current extent of occurrence (EO) in Canada, calculated using a minimum convex polygon, is 983 km^2; the index of area of occupancy (IAO, 2 km x 2 km grid) is 296 km^2 or 165 km^2 (1 km x 1 km grid)

Search effort

Many of the historic *E. t. rangiana* records (1930-1989) contained in the Lower Great Lakes Unionid Database are museum specimens for which there is no information available on search effort at sites where *E. t. rangiana* was collected nor from sites where *E. t. rangiana* was not detected. During the historic period there is information on sampling effort for Lake St. Clair; the Detroit River; the western basin of Lake Erie; and the Sydenham, Thames, and Grand rivers (Table 1).

Table 1. Summary of historic (1934-1989) mussel sampling effort within the range of the Northern Riffleshell (*E. t. rangiana*).

Water body	# of sites	Year	Effort	Notes	Source
Lake St. Clair	29	1986	10 x 0.5 m^2 quadrats per site		Nalepa *et al*. (1996)
Detroit River	13	1982-83	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
Lake Erie		1930			Ohio State Uni. Museum
		1951-52			Ohio State Uni. Museum
		1973-74			Ohio State Uni. Museum
	17	1961, 1972, 1982	3 – 5 benthic grabs per site with either a Ponar or Peterson sampler.		Nalepa *et al*. (1991)
Sydenham River	12	1971	0.7 – >4 person-hours		Clarke (1973)
	22	1985	minimum of 1 person-hour	includes 12 sites of Clarke 1973	Mackie and Topping (1988)

All recent *E. t. rangiana* records in the Lower Great Lakes Unionid Database (Table 2) are from surveys designed to assess mussel assemblage composition, abundance and/or density. These records have information on survey methodology and effort. Generally the methods are either semi-quantitative timed-searches or more detailed true quantitative methods with substrate excavations (see **Sampling Effort and Methods** for details on methodology).

Table 2. Summary of current (1990-2008) mussel sampling effort within the range of the Northern Riffleshell (*E. t. rangiana*).

Water body	# of sites	Year	Effort	Notes	Source
Lake St. Clair	29	1990, 1992, 1994	10 x 0.5 m^2 quadrats per site per year		Nalepa *et al*. (1996)
	2	1990, 1992	20 x 1 m^2 quadrats	includes 2 of Nalepa *et al*. (1996) sites	Gillis and Mackie (1994)
	3	1998	10 transects at 3 depths (1, 2.5 and 4 m) with 5 x 1 m^2 quadrats and 20 Ekman grabs at each transect		Zanatta *et al*. (2002)
	60	1999	sites < 2.0 m deep employed 0.75 person-hours of snorkelling effort, if mussels present an additional 0.75 person-hours was spent; sites > 2.0 m deep employed 0.5 person-hours of SCUBA effort	includes 10 sites surveyed in 1998	Zanatta *et al*. (2002)
	10	2000	1.5 person-hours of snorkelling	includes 10 sites from previous years	Zanatta *et al*. (2002)
	9	2001	5 – 21 65 m^2 circular plots were surveyed using snorkelers	includes 4 previously sampled	Zanatta *et al*. (2002)
	18	2003	10 x 195 m^2 circular plots surveyed using snorkelers	9 sites in Canadian waters of delta, 9 sites in U.S. waters	Metcalfe-Smith *et al*. (2004)
	10	2003	1 person-hour	2 sites in Canadian waters of delta, 8 sites in U.S. waters	Metcalfe-Smith *et al*. (2004)
	4	2005	3 – 4 person-hours		McGoldrick *et al.* (2009)
Detroit River	17	1992	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
	9	1994	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
	1	1997	4 x 120 m^2 line transects		Schloesser *et al*. (2006)
	4	1998	500 m^2 area searched for 60 minutes using SCUBA, second 500 m^2 area searched for 25 minutes	sites where live unionids were observed in 1992 and 1994	Schloesser *et al*. (2006)
	1	1998	10 x 1m^2 quadrats within a 10 m x 10 m grid		Schloesser *et al*. (2006)
Lake Erie	17	1991	3 0.05 m^2 ponar grabs and 5 min tow with epibenthic sled (0.46 x 0.26 m)		Schloesser and Nalepa (1994)

Water body	# of sites	Year	Effort	Notes	Source
	2	1997	4.5 person-hours		Metcalfe-Smith *et al*. (2000)
	6	2001	approximately 2 person-hours snorkelling		D. Zanatta and D. Woolnough (unpubl. data)
	12	2005	1.5 person-hours snorkelling		D. McGoldrick (unpubl. data)
	5	2005	beach search		D. McGoldrick (unpubl. data)
Ausable River	?	1993-94	1 person-hour		Morris and Di Maio (1998-1999)
	25	1998-04	4.5 person-hours		Metcalfe-Smith (unpubl. data)
	10	2006-08	69 – 75 x 1 m^2 quadrats	6 sites in 2006 (Ausable Bayfield Cons. Auth. - ABCA) 1 site in 2007 (Woolnough); 3 sites in 2008 (ABCA)	Staton and Woolnough (unpubl. data)
Sydenham River	16	1991	0.4 – 8.0 person-hours	most productive sites of Clarke 1973	Clarke (1992)
	17	1997-98	4.5 person-hours		Metcalfe-Smith *et al*. (2003)
	15	1999-03	60 – 80 x 1 m^2 quadrats	includes 12 sites surveyed in 1997-98	Metcalfe-Smith *et al*. (2007)
Thames River	?	1993	1 person-hour		Bowles (unpubl. data)
	16	1994	1 person-hour		Morris and Di Maio (1998-1999)
	16	1995	1 person-hour	includes site of Salmon and Green (1983) and overlap with Bowles 1994	Morris (1996)
	48	1997, 2004	4.5 person-hours		Morris and Edwards (2007; unpubl. data)
	5	2004-05	60 – 80 x 1 m^2 quadrats	sites included in Morris and Edwards (2007)	Morris (unpubl. data)
	2	2006	2 x 360 m^2	relocation project in Medway Creek	Mackie (unpubl. data)
	1	2008	1 x 444 m^2 plot sampled 14 times between May and October	TM-10 of Morris and Edwards (2007)	Morris (unpubl. data)

In the Canadian waters of the lower Great Lakes, *E. t. rangiana* has been collected only sporadically over the past century. The mussel was first collected in Lake Erie at Kingsville in 1890 by J.T. McQueen (CMNML #002450 [Accession Number, Canadian Museum of Nature]). Three other occurrences were recorded from Pelee Island in Lake Erie between 1934 and 1960, but there have been no records since. *Epioblasma t. rangiana* was also reported from the Canadian waters of the Detroit River at Bois Blanc Island by Bryant Walker in 1934 (UMMZ #906617 [University of Michigan Museum of Zoology]) but has not been reported since.

Prior to the invasion of dreissenids (Zebra [*Dreissena polymorpha*] and Quagga [*Dreissena rostiformis*] mussels), the Detroit River supported a very large population that declined rapidly from 1992 to 1994 (Schloesser *et al*. 1998). Schloesser *et al*. (1998) collected *E. t. rangiana* alive in 1992 but found none alive using identical methods in 1994. Further surveys in 1998 failed to find any living unionids leading Schloesser *et al*. (2006) to declare unionids extirpated from the river. Additional recent surveys on the U.S. side of the Detroit River have failed to find any living *E. t. rangiana* (Badra 2006a,b).

While several records exist of *E. t. rangiana* from the western basin of Lake Erie (Lower Great Lakes Unionid Database), most of these were likely shells washed up on beaches. Schloesser and Nalepa (1994) did not report any *E. t. rangiana* in surveys immediately prior to Zebra Mussel invasion. Additional surveys around Pelee Island and Big Creek have not found any living *E. t. rangiana* on the Canadian side of Lake Erie (McGoldrick pers. comm. 2009).

The Sydenham River population of *E. t. rangiana* was first recorded by H.D. Athearn in 1963 (Clarke 1973). Previously, the mussel community of the Sydenham River had been known only from a few records of the more common species. *Epioblasma t. rangiana* was also collected by C.B. Stein (personal records provided to Zanatta and Staton, September 1997) in 1965 (numerous live and dead specimens, OSUM #19212 [Ohio State University Museum]) and during a subsequent visit to a different site on the river in 1967 (one fresh shell, OSUM #19745). On both occasions, Stein visited only one site. The diverse collections of Stein and Athearn prompted the first extensive survey of the Sydenham River by A.H. Clarke in 1971. Although Clarke (1973) visited 11 sites, he did not record *E. t. rangiana*. However, it should be noted that Clarke's sampling effort averaged 1 hour per site, whereas Athearn conducted a 4 hour search. Stein returned to her 1965 site in 1973 and found large numbers of fresh shells in a Muskrat (*Ondatra zibethicus*) midden while searching the shoreline. She also visited a new site and found one live specimen during 3 hours of sampling by feel. Mackie and Topping (1988) surveyed 20 sites on the Sydenham River in 1985 using a sampling effort of 1 hour per site, with the primary objective of determining which species were still present in the system. Because no live specimens of *E. t. rangiana* or three other rare species were found, they concluded that these species were no longer living in the Sydenham River or were present in such low densities that they had escaped detection. This alarming information prompted a further survey of 16 sites on the river in 1991 by Clarke (1992). Although Clarke generally spent more time searching than Mackie and Topping (1988) (i.e., an average of 2.3 person-hours per site [p-h/site] [range 0.4-8.0 p-h/site] versus 1 p-h/site), and he found many more live species, he was unable to find any trace of *E. t. rangiana*. In the same year, one weathered half shell was found at a site on the Sydenham River by M.J. Oldham (pers. comm. 1997). Based on these findings, the species was assigned a subnational conservation status rank of SH (no verified occurrences within the last 20 years) in Ontario by the Natural Heritage Information Centre (Natural Heritage Information Centre 1997).

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

In 1998, a previously unknown population of *E. t. rangiana* was discovered in the Ausable River (Ausable River Recovery Team 2004). This population, occurring in the lower Lake Huron drainage, is the most northerly extent of the species. While no historical information exists and analyses of quadrat data are ongoing, anecdotal evidence (i.e., large numbers of dead shells) suggests that the Ausable River population was once much larger, perhaps rivalling the Sydenham River in total abundance and exceeding the Sydenham in density (Staton and Woolnough unpubl. data). A total of 16 live *E. t. rangiana* have been collected in a 70 km reach from the Arkona Gorge (downstream of the Rock Glen Conservation Area) to Brinsley (Middlesex County Rd 24 bridge), with the highest abundances in the reach between Nairn and Ailsa Craig. The average width of the river reach is 7.5 m; thus, the AO in the Ausable River is approximately 0.53 km^2 and the IAO is 136 km^2 (2 km x 2 km grid) or 80 km^2 (1 km x 1 km grid).

Mussel research on the lower Thames River in 2008 near Big Bend recovered several sub-fossil valves of *E. t. rangiana,* which could be from decades to centuries old (Zanatta unpubl. data; Figure 6), representing the first record of the species in that river. There are few historical data (pre-1990s) on unionids in the Thames River (see Figure 4) and it is likely that *E. t. rangiana* was overlooked. It also is likely that the species was extirpated from the watershed several decades ago. However, there may be potential for recovery in the lower Thames River in the future, particularly considering its close proximity to the Sydenham, similar habitat conditions and similarly diverse unionid community.

Figure 6. Subfossil *Epioblasma torulosa rangiana* valves from lower the Thames River at Big Bend (four specimens on left) in comparison with fresh female shell valves (two on right) from the Sydenham River (photo credit: J. Jones, Virginia Tech).

Epioblasma t. rangiana in the Sydenham and Ausable rivers meet the IUCN (2001) definition as separate locations as the remaining mussels in the two river drainages cannot be eliminated by any single threatening event (e.g., a chemical spill). The total Canadian population of *E. t. rangiana*, with separate populations in the Sydenham and Ausable rivers, also can be considered isolated and fragmented as fouling dreissenid mussels have made the intervening habitats between the Sydenham and Ausable rivers (i.e., St. Clair River and Lake Huron) uninhabitable. The probability of natural recolonization of one population or location by the other, should one become extirpated, is close to zero.

HABITAT

Habitat requirements

It is widely accepted that *E. t. rangiana* lives mainly in highly oxygenated riffle areas of rivers (Ortmann 1919, as cited in USFWS 1993; Clarke 1981; Cummings and Mayer 1992). The preferred substrate ranges from rocky, sandy bottoms (Clarke 1981) to firmly packed sand and fine to coarse gravel (Cummings and Mayer 1992). Recent observations have confirmed this in the Sydenham River. *Epioblasma t. rangiana* occurs in streams of various sizes and its existence in the western basin of Lake Erie was apparently due to sufficient wave action producing continuously moving water (USFWS 1994). There is no information on thermal tolerance of *E. t. rangiana*; however, water temperatures at sites where live specimens were found in the Sydenham and Ausable rivers in 1997-1998 ranged from 18-27°C. The reach of occupied habitat in the east branch of the Sydenham River where this species still occurs has a relatively diverse substrate and associated habitat with well-defined riffles and pools, which create exceptional habitat for native mussels (Dextrase *et al*. 2003).

The extent of preferred habitat (Figure 7) in the Ausable and Sydenham rivers where *E. t. rangiana* still occurs is largely unknown. Because the occupied reach of the Sydenham River has a relatively low gradient of about 0.4 m/km (Department of Energy and Resources Management 1965), riffle habitat would be expected to constitute only a small proportion of the total habitat. Similar habitat conditions would be expected in the Ausable River, although gradients are somewhat steeper in the lower reaches within the Arkona Gorge. The ability of *E. t. rangiana* to tolerate reduced current velocities has not been reported. However, Metcalfe-Smith *et al.* (unpubl. data) observed at least one individual in an area of preferred substrate with almost no current. Further investigation of the identified stretches of both the Sydenham and Ausable rivers is required to quantify the amount of preferred habitat available and to determine the extent to which sub-optimal habitat may be occupied.

Figure 7. Habitat of the Northern Riffleshell, Sydenham River near Florence (photo credit: J. Jones, Virginia Tech).

Habitat trends

According to Williams *et al.* (1993), the most significant cause of the decline of freshwater mussels across North America during the past century is the destruction of their habitat by siltation, dredging, channelization, the creation of impoundments, and pollution. Reservoir construction in particular has eliminated the long reach of flowing water that is necessary for their survival (Biggins *et al*. 1995); reservoirs alter water velocity and temperature downstream and isolate upstream populations from their host fishes. Erosion due to deforestation, poor agricultural practices and the destruction of riparian buffer zones, leads to an increase in siltation and shifting substrates that can smother mussels. As noted by Bogan (1993), domestic sewage; effluents from paper mills, tanneries, chemical industries and steel mills; acid mine runoff; heavy metals; and pesticides have all been implicated in the destruction of mussel communities.

The Sydenham River flows through an area of prime agricultural land in southwestern Ontario. Over 85% of the land in the watershed is agricultural, with 60% of land in tile drainage (Dextrase *et al*. 2003). Large areas of the river have little to no riparian vegetation as only 12% of the original forest cover remains. Strayer and Fetterman (1996) identified high sediment and nutrient loads and toxic chemicals from non-point sources, especially agricultural activities, as the primary threat to riverine mussels. Agricultural lands, particularly those with little riparian vegetation and large amounts of tile drain, allow large inputs of sediments into the watercourse. In tile drained land, the sediment is often very fine grained that can clog the gill structures of mussels and result in decreased feeding and respiration rates and reductions in growth efficiency. The Sydenham River has had high nutrient levels with total phosphorus levels consistently exceeding provincial water quality levels over the last 30 years while chloride levels have increased due to an increased use of road salt (Dextrase *et al*. 2003). Human population pressure within the watershed is low as the total population is less than 90,000 with roughly half occurring in urban settings. Although the watershed is not heavily populated, the lower portion of the river is subject to commercial shipping activities that tend to fluctuate in response to economic conditions.

Habitat trends for the Ausable River watershed are summarized from Nelson *et al*. (2003). Mussel habitat in the Ausable River has been dramatically altered over time. Prior to European settlement, 80% of the basin was covered in forest, 19% was in lowland vegetation and 1% was marsh. By 1983, 85% of the watershed was agricultural (70% in row crops), and only 13% remained in small, unconnected woodlots. Over 70% of the basin is now in tile drainage. The natural course of the lower portion of the river was destroyed in the late 1800s, when it was diverted in two places to alleviate flooding. The Ausable River has been described as “event responsive”, which means that there are large increases in flow during runoff events following storms. This “flashiness” has a negative impact on habitat conditions (e.g., substrate stability) and may be partially responsible for the apparent decline of the Northern Riffleshell population within the Ausable River. In contrast, the nearby Sydenham, Thames and Maitland rivers are more hydrologically stable (Richards 1990). There are 21 dams in the Ausable watershed that cause sediment retention upstream and scouring downstream, although all occur within lower order tributaries and upstream of areas occupied by the Northern Riffleshell. Water quality data collected since 1965 show that total phosphorus levels are consistently above the Provincial Water Quality Objective and have decreased only marginally over the past 35 years. Nitrate levels currently exceed federal guidelines for the prevention of eutrophication and the protection of aquatic life and are slowly rising. Mean total suspended solid concentrations in the lower Ausable River exceed levels required for healthy aquatic life (Nelson *et al.* 2003; Ausable River Recovery Team 2004).

BIOLOGY

Although the specific biology of *E. t. rangiana* is not well known, general unionid biology likely applies (USFWS 1994).

Life cycle and reproduction

This sexually dimorphic mussel lives for 15 years or more (USFWS 1993). Conversely, Crabtree and Smith (2009) calculated the maximum age for *E. t. rangiana* in French Creek (Pennsylvania) to be 7-11 years. Recent findings in the Sydenham River may contradict Crabtree and Smith's (2009) maximum ages, as marked individuals were collected 6 and 8 years after the initial marks were placed on already mature (>5 years old) individuals (D.T. Zanatta pers. obs.). It is not known at what age reproductive maturity is reached or when it ends (USFWS 1993). However, based on growth lines observed on *E. t. rangiana* in the Sydenham River, young animals begin to show sexual dimorphism at around age three (D.T. Zanatta pers. obs.). Therefore the generation time is somewhat higher than 3 years and in the range of 3 to 5 years. Although hermaphroditic individuals have been encountered for many unionid species (van der Schalie 1970), this condition has not been detected in *E. t. rangiana* (USFWS 1994).

During spawning, males release sperm into the water and females living downstream take in the sperm via their incurrent siphons. Fertilization success may be related to population density, with a threshold density required for successful reproduction (Downing *et al*. 1993). Female mussels brood their young from the egg to the larval stage in their gills, using the posterior portions of their outer gills as marsupia (USFWS 1993). *Epioblasma t. rangiana* is a long-term brooder (bradytictic), with a gravid period from late summer to the following spring (Ortmann 1919, as cited in USFWS 1993; Clarke 1981). The shell of the female is distended (broadly expanded) along the posterior ventral margin to accommodate the expanded gill pouches, a feature called a marsupial swelling. When the larvae (glochidia) are ready to be released, the female displays a spongy, pure white mantle lining visible from several metres which may attract host fishes (USFWS 1994). Once expelled into the water, the glochidia must attach to the gills of an appropriate host fish to complete metamorphosis.

The glochidia of *E. t. rangiana* are semicircular, having a straight hinge line without hooks (Clarke 1981), and are 230 μm high and 250 μm long (Hoggarth 1993). Hoggarth (1993) demonstrated that functional morphology in glochidia appears to be correlated with rarity in the Unionidae. Glochidia of rare species tend to be morphologically depressed (valve height minus valve length equals zero or less), an adaptation for holding on tightly to the host at the expense of ensuring initial attachment. This strategy apparently reduces the rate of successful parasitic encounters, thereby limiting recruitment. Hoggarth (1993) suggested that this factor "…may be responsible for much of the continuing decline in a population once numbers of breeding adults reaches a critically low level". He also stated that members of the genus *Epioblasma* provide the best example of this effect because most are currently listed as federally endangered in the U.S.

While most lampsiline mussels use some form of host attraction (Zanatta and Murphy 2006b), the genus *Epioblasma* has taken the process to the extreme by capturing a darter host and infesting it with glochidia (Barnhart *et al*. 2008). The lure and attraction behaviour in *E. t. rangiana* involves the female mussel exposing the posterior of her shell and gaping widely (Figure 2). This reveals a bright white mantle pad, visible from several metres away in clear water (D. T. Zanatta pers. obs.). Some species of *Epioblasma* have microlures (small moving papillae) at the base of the mantle pad, but *E. t. rangiana* lacks this feature (Jones *et al*. 2006). Host trapping occurs when a darter approaches the gaping female mussel; the mussel will clamp shut on the head of the fish, using its cymapallium to prevent the fish from escaping. Once the potential host is subdued, the mussel will form a gasket around the head of the fish and begin pumping glochidia into the mouth of the fish (Barnhart *et al*. 2008; for video of this behaviour see Barnhart 2009). Encystment of the glochidia on the gills of the host fish then proceeds as described above. Transformation requires a period of 27 to 33 days, after which the juvenile mussel detaches from its host and falls to the substrate to complete its development into a free-living adult (Watters 1996; McNichols and Mackie 2002, 2003; McNichols *et al.* 2004).

Until recently, the glochidial hosts for *E. t. rangiana* were unknown in Canada. Although Watters (1996) found four species of fishes to serve as host for the Northern Riffleshell, none were native to Canada. Host fish studies at the University of Guelph (McNichols and Mackie 2002, 2003; McNichols *et al.* 2004) found that *E. t. rangiana* may have seven host species, including the Blackside Darter (*Percina maculata*), Logperch (*P. caprodes*), Fantail Darter *(Etheostoma flabellare*), Iowa Darter (*E. exile*), Johnny Darter (*E. nigrum*), Rainbow Darter (*E. caeruleum*), and Mottled Sculpin *(Cottus bairdii*). Of these potential host species, only the Blackside Darter, Johnny Darter, and Logperch are common in the Sydenham and Ausable rivers. McNichols and Mackie (2002, 2003) and McNichols *et al.* (2004) showed that Mottled Sculpin and Iowa Darter are superior hosts, thus suggesting that the Sydenham and Ausable river populations of *E. t. rangiana* may be persisting on marginal hosts. The Mottled Sculpin may have served as a host historically, but now is likely restricted to the colder headwater regions where the Northern Riffleshell does not occur (Figure 5).

Feeding

Both respiration and feeding in mussels occurs with the gills. As water is pumped through the gills by the inhalant siphon, food and oxygen are removed. Because water flow may aid filtration and elimination, many mussels prefer flowing water. Although the exact food preferences and optimum particle sizes taken by adult *E. t. rangiana* are unknown, they are probably similar to those of other freshwater mussels, (i.e., suspended organic particles such as detritus, bacteria and algae) (Strayer *et al.* 2004).

POPULATION SIZES AND TRENDS

Sampling effort and methods

Timed-Searches

Timed search methods produce data on species presence/absence and provide relative measures of abundance. Metcalfe-Smith *et al*. (2000) describe the methods in detail but they can be summarized as follows. The riverbed is searched by a team (usually 3-5 individuals) for a period equal to 4.5 person-hours (p-h). Searches may be conducted using only the naked eye when conditions are favourable or may be assisted by polarized sunglasses, view boxes, or even by manually searching the substrate when turbidity is high. Individual mussels are collected, held in mesh diver's bags until the end of the sampling period and then identified to species, sexed if possible, counted, measured, and finally returned to the river alive. Since 1997 these methods have been employed at 104 riverine sites within the historic Canadian range of *E. t. rangiana* (Table 2).

Quadrat Excavations

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

Abundance

Epioblasma t. rangiana is a rare mussel (Clarke 1981; USFWS 1993). It is occasionally abundant, but is usually a minor component of the unionid community (Strayer and Jirka 1997). Ahlstrom (1930, as cited in USFWS 1994) once remarked that the Northern Riffleshell "…was everywhere, but not common…" in the vicinity of the Bass Islands in western Lake Erie. A "sizable" population of *E. t. rangiana* was relocated from the Black River, Michigan in 1988 as part of a rescue effort to protect this and other rare species from an impending dredging operation (Trdan and Hoeh 1993). Of nearly 8000 mussels collected over a 10 day period, only 12 (0.15%) were *E. t. rangiana*. A total of 118 specimens of this species were eventually captured after 22 more days of sampling. The Black River (St. Clair River drainage, the same drainage as the Sydenham River, Ontario) population in Michigan is now likely extirpated (Badra 2004; Zanatta and Woolnough unpubl. data).

Detailed information on the remaining known populations of *E. t. rangiana* in the U.S. (USFWS 1994) is summarized here to give a complete picture. Populations in the Allegheny River and French Creek (Pennsylvania) are apparently the largest remaining populations, estimated at more than 1.5 million (Allegheny) and 500,000 (French Creek) animals (Crabtree and Smith 2009). In French Creek, the species is abundant in several reaches where hundreds of shells may be found in Muskrat middens over a short distance. In the Allegheny River, populations are more variable with an overall known broken range of 128 km. In Fish Creek (Maumee River drainage, Ohio) living and fresh dead individuals have been reported only rarely, and the most recent surveys have not confirmed its continued existence. The species was once common in the Green River (Kentucky) and Big Darby Creek (Ohio). Big Darby Creek has recently been the site of a relocation of 1,700 individuals from the Allegheny River (Watters pers. comm. 2009). The mussel was recently found alive in the Elk and Oak rivers (West Virginia); however, additional surveys are required to determine the status of these populations. The mean densities of *E. t. rangiana* in the upper Allegheny River and French Creek are more than an order of magnitude higher than those in the Sydenham or Ausable rivers in Ontario (Metcalfe-Smith *et al.* 2007; Crabtree and Smith 2009; Staton and Woolnough unpubl. data).

Lake St. Clair

Relative abundance of *E. t. rangiana* in the delta area of Lake St. Clair can be estimated but it is clear that *E. t. rangiana* represented only a very small component of the mussel fauna in this region of the lake. Zanatta *et al*. (2002) found 1356 live unionids at 33 different sites between 1998 and 2001 but only a single *E. t. rangiana*. Similarly, Metcalfe-Smith *et al*. (2004) found 1778 live unionids at 18 sites in the delta but no *E. t. rangiana* for a relative abundance of 0.00024% (Zanatta *et al.* 2002 and Metcalfe-Smith *et al.* 2004 combined) of the unionid community. Focusing only on the Canadian waters of the delta where the single specimen was located still yields a relative abundance of only 0.12% of the total unionid community. Densities cannot be estimated as Zanatta *et al.* (2002) used timed searches in initial surveys of the delta region. Metcalfe-Smith *et al.* (2004) returned to the same sites, but did not find any living or dead *E. t. rangiana* and assumed the Lake St. Clair population is extirpated.

Sydenham River

Time Search Surveys – 1997

In 1997, Metcalfe-Smith *et al*. (1998) surveyed 37 sites on the Grand, Thames, and Sydenham rivers to assess the conservation status of rare freshwater mussels in southern Ontario. They used the timed-search sampling method, and an intensive effort of 4.5 p-h/site. Sites that were known to support rare species in the past were specifically targeted. Low numbers of live *E. t. rangiana* were found at four of nine sites on the Sydenham River, confirming the persistence of a remnant population. Of the three historic sites that were resurveyed, live animals were found at Stein's 1965 site and fresh shells were found at Stein's 1967 site and Athearn's 1963 site. A total of 11 live animals, numbering 2-5 individuals/site, were encountered at four sites along a 40 km reach of the river. Both specimens from site SR-97-5 (SR = Sydenham River) were males, as were both specimens from site SR-97-6. Both specimens from site SR-97-3 were females. Of the five specimens at site SR-97-7, three were males, one was female, and one was a juvenile of indeterminate sex (Figure 8). Although densities were low, the fact that specimens ranged from 35 to 74 mm in shell length suggests recruitment within the last few years. Based on the number of annual growth rings visible on the shells (Haag and Commens-Carson 2008), at least one of the specimens appears to be less than 5 years old. This was encouraging because dying populations commonly consist only of larger, senescent individuals of a restricted size class. Based on these data, the species was assigned a subnational conservation status rank of S1 (<5 localities) in Ontario by the Natural Heritage Information Centre (Metcalfe-Smith *et al.* 1998).

Figure 8. Five specimens of Northern Riffleshell taken at a site in the Sydenham River during timed-search sampling (1997). The range in size classes and presence of a juvenile indicates active recruitment. (photo credit: J. Jones, Virginia Tech)

Because of the lack of information commonly associated with historic records (e.g., whether specimens were live or dead at the time of collection and what survey techniques and sampling efforts were used, etc.), comparisons with current data are often difficult. However, Stein (personal records) and Metcalfe-Smith *et al.* (1998) surveyed the same site on the Sydenham River 32 years apart using similar survey techniques and effort, thus allowing an assessment of population change over time. In 1965, Stein observed a healthy population of *E. t. rangiana* at this site. She collected 23 live specimens, which represented almost 30% of all live mussels encountered in a 6 hour sampling period. In contrast, 4.5 p-h of sampling effort in 1997 yielded only two individuals (less than 2% of the 124 live mussels encountered). Capture rates were 3.8 specimens/h in 1965 as compared with only 0.4 specimen/h in 1997, representing a decline in relative abundance of nearly 90% over the past 30 years at this site. The fact that only 12 weathered valves and one fresh shell were found at the site in 1997, whereas 21 fresh whole shells were found in 1965, provides further evidence of a declining population. Although the decline of *E. t. rangiana* over time could only be documented quantitatively for a single site on the Sydenham River, the paucity of live animals (maximum five) and fresh shells (no more than a single valve or whole shell at any site) encountered in 1997 and the complete absence of the species from the 1991 collections of Clarke (1992) suggest that the entire Sydenham River population has suffered serious declines.

Quadrat surveys: *1999-2003*

A total of 46 live *E. t. rangiana* were found at seven of 15 sites in the Sydenham River between 1999 and 2003 (Metcalfe-Smith *et al*. 2007). Mean density over the seven sites was 0.091 m^{-2} (SE = 0.013). Assuming that the distribution of *E. t. rangiana* is continuous within the reach bounded by those seven sites on the east branch (72 km, Dawn Mills to Sexton Road) and the average width of the river in this stretch is approximately 20 m yields a potential of 1.44×10^6 m^2 of habitat and a maximum population estimate of 131,000 (±19,000, SE) individuals (Metcalfe-Smith *et al.* 2007). This is likely an over-estimate of population size as the reach of river is not entirely suitable habitat for *E. t. rangiana*. The size frequency distribution for the Sydenham River (Figure 9) indicates recruitment and multiple size classes. However, these results should be viewed with caution. Evidence of recent recruitment was noted for only two of seven sites and the total number of juveniles was relatively small. Metcalfe-Smith *et al*. (2007) also noted sex ratios of Northern Riffleshell skewed toward males (73% M:27% F) and suggested that the paucity of females in the Sydenham River “may have serious consequences for the continued survival” of this species in the system.

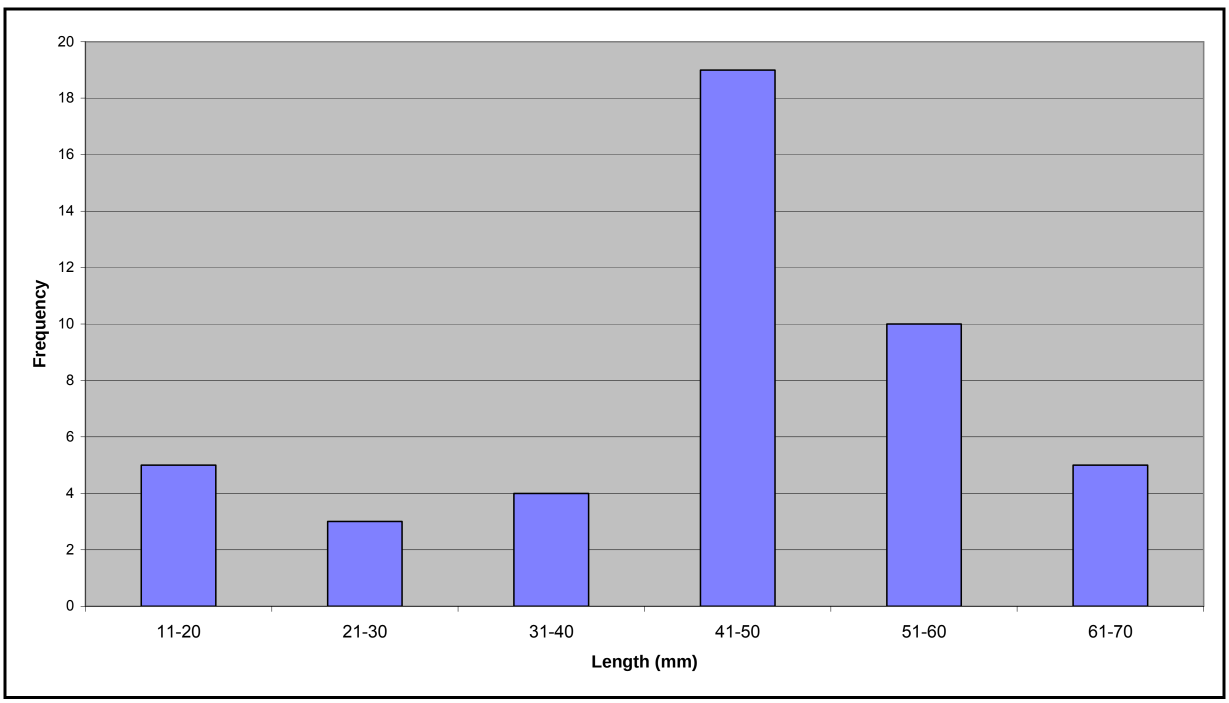

Figure 9. Size distribution of Northern Riffleshell recorded from the Sydenham River using quadrat excavations (n=46) from 1999 to 2003 (Metcalfe-Smith *et al.* 2007).

Ausable River

The first *E. t. rangiana* in the Ausable River was discovered in 1998 near Brinsley. Timed-searches at 21 sites between 1998 and 2004 found just three live animals at two sites. Shells were found at nine additional sites covering a reach of 70 km (Figure 5).

A total of 12 live *E. t. rangiana* were found at four of 10 sites surveyed by systematic quadrat sampling in the Ausable River between 2006 and 2008 (Staton *et al.* unpubl. data). Mean density at the six sites (bounded by the four where live *E. t. rangiana* was found) was 0.029 m^{-2} (SE = 0.005). Assuming that the distribution of *E. t. rangiana* is continuous within the reach bounded by those six sites (70 km, Arkona to Brinsley) and the average width of the river in this stretch is approximately 7.5 m yields a potential of 5.3×10^5 m^2 of habitat and a maximum population estimate of 15,400 (±2,700, SE) individuals (Staton unpubl. data). Again, this is likely an over-estimate of population size as the river reach is not entirely suitable habitat for *E. t. rangiana*. The size frequency distribution in the Ausable River (Figure 10) indicates some evidence of recruitment (a single juvenile was encountered) with multiple size classes (20 – 65 mm). However, with weak recruitment and overall low densities (approximately one third of average densities found in the Sydenham River), the short-term persistence of the Ausable River population is questionable.

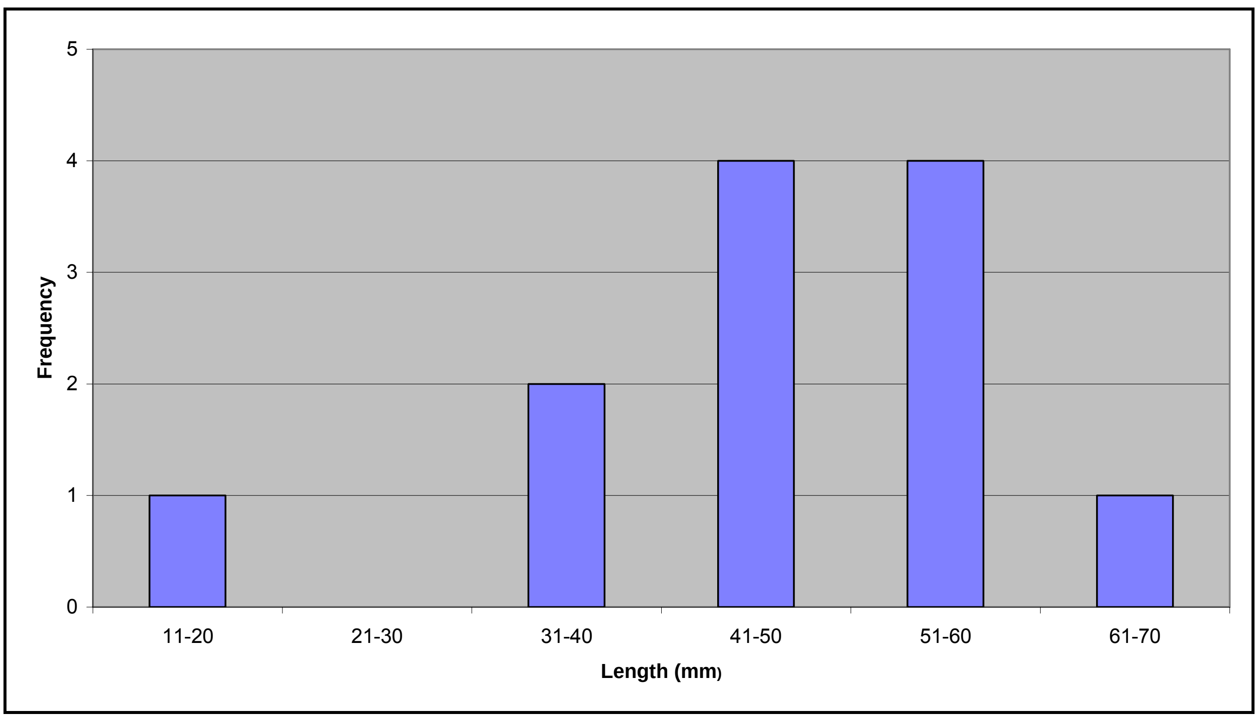

Figure 10. Size distribution of Northern Riffleshell recorded from the Ausable River using quadrat excavations (n=12) from 2006 to 2008 (Staton *et al.* unpubl. data).

Fluctuations and trends

The Sydenham River population of *E. t. rangiana* may have had serious declines in the 1970s and 1980s (Mackie and Topping 1988; Clarke 1992), but recruitment recently occurred at several sites (Figure 9). However, the skewed sex ratios are cause for concern and the perceived recovery may be an artifact of intensive and increased sampling effort over the past 13 years (Staton *et al.* 2003; Metcalfe-Smith *et al.* 2007). The current trajectory of *E. t. rangiana* in the Sydenham is uncertain; additional quantitative sampling at the established monitoring sites is required (Metcalfe-Smith *et al*. 2007).

As *E. t. rangiana* in the Ausable River was only discovered in 1998, little can be concluded about population fluctuations or trends. It is apparent that this population survives at extremely low densities. Large numbers of empty shells suggest that the population was once much larger. There is some evidence of limited recruitment with a single juvenile *E. t. rangiana* found in recent quantitative sampling.

Crabtree and Smith (2009) found that populations of *E. t. rangiana* in French Creek (Pennsylvania) with densities less than 0.13 m^{-2} had little evidence of recruitment and were not likely viable. Despite population estimates for *E. t. rangiana* in the thousands for the Sydenham and Ausable rivers (see above), only two of the sites in the Sydenham River surpassed Crabtree and Smith's (2009) threshold of 0.13 m^{-2}: Florence (0.19 m^{-2}) and Oil Springs Road near Alvinston (0.25 m^{-2}). These two sites are perhaps the most important as they may serve as source populations for the rest of the river. Regular monitoring of these populations is critical to ensure that they do not drop below Crabtree and Smith's (2009) threshold levels. None of the localities in the Ausable River (maximum density 0.09 m^{-2}) had densities above the minimum threshold densities for population viability. Ultimately, captive propagation will likely be necessary to increase densities to viable levels (i.e., >0.13 m^{-2}).

Rescue effect

All Canadian populations of *E. t. rangiana* are isolated from one another and from U.S. populations by large areas of unsuitable habitat (including dry land), making the likelihood of re-establishment of extirpated populations by natural immigration negligible. The darter hosts of *E. t. rangiana* are not capable of the large-scale movements required to connect populations. Furthermore, *E. t. rangiana* populations in adjacent U.S. states are all endangered or extirpated (USFWS 1993, 1994).

THREATS AND LIMITING FACTORS

Siltation, impoundments, in-stream sand and gravel mining, pollutants from municipal, industrial and agricultural sources, and the invasion of the dreissenid mussels have been identified as threats to the continued existence of *E. t. rangiana* (USFWS 1994). These are all either imminent or ongoing threats to the persistence of *E. t. rangiana*. Access to suitable host fishes may also be a factor, but it cannot be assessed for Canadian populations until the functional host species has/have been confirmed in the wild. Members of the genus *Epioblasma* are particularly sensitive to river regulation because they are riffle/run inhabitants that cannot tolerate fine substrates. The Sydenham and Ausable rivers, which are the last refuges for this mussel in Canada, are dammed but dams are upstream of occupied reaches. Thus, dams and reservoirs do not limit the distribution of this mussel in the last two rivers in Canada.

The main factor limiting the occurrence of *E. t. rangiana* is likely the availability of silt-free, riffle habitat. According to the USFWS's Recovery Plan for *E. t. rangiana* (USFWS 1994), all rivers in which this species is found are susceptible to runoff and siltation. Poor agricultural and forestry practices contribute to siltation (USFWS 1993, 1994), which can bury and smother mussels and/or interfere with feeding (Dennis 1984). Susceptibility to siltation differs among species (Marking and Bills 1980, as cited in USFWS 1994); however, Clarke (1992) correlated increased siltation in the Sydenham River with the disappearance of riffle-inhabiting species such as *E. t. rangiana*.

Siltation is the most immediate threat to *E. t. rangiana* in the Ausable and Sydenham rivers, although eutrophication and pesticides may also be significant factors (Nelson *et al*. 2003; Staton *et al*. 2003). Detailed reports on the geology, land use and water quality of the Ausable and Sydenham rivers are available (Dextrase *et al*. 2003; Nelson *et al*. 2003). It can be concluded that there are, and always will be, intense pressures on the Ausable and Sydenham rivers from agriculture. Therefore there is an inferred continuing decline in quality of habitat..

Anthropogenic pollutants are also believed to be responsible for declines in mussel populations (USFWS 1994). Much of the range of *E. t. rangiana* in the U.S. and Canada is in areas of intense agricultural activity, subject to pesticide- and fertilizer-laden runoff (USFWS 1994). Although the specific effects of many of these contaminants are unknown, there is evidence that compounds such as PCBs, DDT, Malathion and Rotenone inhibit respiration and accumulate in the tissues of mussels (USFWS 1994). During the glochidial stage, mussels are particularly sensitive to heavy metals (Keller and Zam 1990), ammonia from wastewater treatment plants (Goudreau *et al*. 1993), acidic water from mine runoff and sandy soils (Huebner and Pynnönen 1992), salinity (Liquori and Insler 1985, as cited in USFWS 1994; Gillis pers. comm. 2008), and chlorine (Valenti *et al.* 2006). Northern Riffleshell has never been subjected to toxicity tests; therefore, its sensitivity to environmental pollutants is unknown.

Crabtree and Smith (2009) suggest that the relatively short lifespan (compared to decades for many other unionids) of *E. t. rangiana* may be partially responsible for the extirpation of several populations while the overall unionid community remains intact. Their size-at-age models revealed that just a few years of reproductive failure caused by habitat perturbations like heavy siltation or a toxic contaminant could lead to rapid population declines within a decade or less. This hypothesis is consistent with the rapid decline and extinction of many species of *Epioblasma*.

Although human impacts have been causing the reduction and extirpation of mussel populations for many years (Nalepa and Gauvin 1988), the introduction of the Zebra Mussel to the Great Lakes in the late 1980s (Hebert *et al*. 1989) led to catastrophic declines of native mussels in infested waters. Zebra Mussels now occur in most of the major river systems of 19 states and two provinces, in addition to the Great Lakes (Strayer and Malcom 2007). Zebra Mussels have had a devastating effect on native freshwater mussel communities. They attach to the shells of unionids and interfere with normal activities, such as feeding, respiration and burrowing (Strayer and Malcom 2007). Ricciardi *et al*. (1998) postulated that Zebra Mussels kill native mussels by robbing them of the energy reserves they need to survive the winter.

Zebra Mussels have devastated native mussel communities in Lake St. Clair (Nalepa *et al*. 1996), western Lake Erie (Schloesser and Nalepa 1994), Detroit River (Schloesser *et al.* 1998, 2006) and the upper St. Lawrence River (Ricciardi *et al*. 1996). Heavy infestations of Zebra Mussels have been known to destroy live unionids in less than one year. This impact was clearly illustrated in 1988 when 118 live *E. t. rangiana* were transferred from the Black River (Michigan), to the Detroit River near Detroit (Michigan), to protect the population from a dredging operation planned for the headwaters of the Black River (Trdan and Hoeh 1993). A large corral was constructed on the bottom of the Detroit River and the caged mussels were monitored every spring. No evidence of Zebra Mussels was observed in 1989, 1990 or 1991; however, in the summer of 1992, all of the relocated individuals were dead and heavily encrusted with Zebra Mussels. Although the Detroit River population was previously considered to be one of the few remaining reproducing populations of this species, it appears to have been eliminated (Schloesser *et al*. 2006) as were the caged mussels.

Several coastal wetlands around Lake Erie and Lake St. Clair serve as refuges for unionids from Zebra Mussels. Nichols and Wilcox (1997) discovered a large surviving community of native mussels comprised of 6000 individuals of 21 species at Metzger Marsh (Ohio) in western Lake Erie (species composition not given at that time). They found unionids at this location burrowed into the sediment for at least part of the day and few were infested with Zebra Mussels. This led them to hypothesize that warm water encouraged the unionids to burrow, and the soft, silt-clay sediments allowed encrusted animals to burrow successfully. They demonstrated in laboratory experiments that attached Zebra Mussels were either smothered or were dislodged during the process. Zanatta *et al.* (2002) found a single live *E. t. rangiana* in the St. Clair delta, but no additional findings have been reported since 2000 (McGoldrick *et al.* 2009). Refuges have also been located in coastal wetlands of western Lake Erie, but *E. t. rangiana* have not been reported (Bowers and de Szalay 2005).

The distribution *of E. t. rangiana* in Canada is severely limited by the Zebra Mussel because Lake St. Clair, the Detroit River and the shoals of western Lake Erie are heavily infested and uninhabitable. Populations of Northern Riffleshell in the Sydenham and Ausable rivers are not significantly at risk from Zebra Mussels at this time. Even if Zebra Mussels were introduced to these rivers, there are no reservoirs in these systems that could serve as a continuous source of Zebra Mussel veligers.

Predation by Muskrats is a potential limiting factor for some mussels. For example, in the Tippecanoe River (Indiana), Muskrat predation appeared to be a major cause of death for the endangered Clubshell (*Pleurobema clava*) at many sites, based on numerous shells in middens (USFWS 1994). Similarly, in the Tennessee River drainage, Muskrat predation seems to be inhibiting the recovery of endangered mussels and is likely contributing to further population declines (Neves and Odum 1989). Historically, Muskrat predation probably had little, if any, effect on healthy mussel populations; however, similar levels of predation today pose a serious threat to endangered species already reduced to low densities and isolated by anthropogenic impacts (Neves and Odum 1989). Consequently, the removal of Muskrats has been undertaken at some U.S. sites identified as important refugia for endangered mussels (Tolin pers. comm. 1998). Recent findings from French Creek (Pennsylvania) suggest that female *E. t. rangiana* may be more heavily preyed upon due to their display behaviour (Crabtree and Smith 2009).

Without rigorous investigation, it is difficult to assess the impact of Muskrat predation on populations of *E. t. rangiana* in the Sydenham River. However some anecdotal evidence exists. During her 1973 visit to the Sydenham River, Stein reported finding a "…midden heap consisting mainly of fine fresh *Epioblasma torulosa rangiana* shells!" – 32 fresh whole shells in all. Although abundance of prey species in shell middens is generally related to the relative abundance of that species at the site, there is some evidence for the selection of mid-sized specimens/species such as *E. t. rangiana* by Muskrats. Convey *et al.* (1989) and Neves and Odum (1989) suggest mussels with a shell length of 45-65 mm are selected while Watters (1993-1994) suggested 70-120 mm. *Epioblasma. t. rangiana* span both of these ranges. Regardless of whether *E. t. rangiana* is preferred by Muskrats, Muskrat predation could be a contributing factor to the observed decline in abundance of the species in the Sydenham River. At current low densities, any level of predation could jeopardize the mussel's continued existence.

Shell and/or pearl collecting could potentially be a threat to *E. t. rangiana* and other rare mussels. Although this pastime is less common than it once was, its popularity may increase now that so many species are becoming rarer and therefore more valuable to collectors. According to Cummings (pers. comm. 1998), shell collectors are often among the strongest advocates for mollusc conservation. Erickson and Fetterman (1996) provide a contrasting example of the severity of this threat. According to an anecdotal but well-substantiated claim, three individuals from Scotland visited the Grass River, a tributary to the St. Lawrence River in New York, in 1989 for the purpose of collecting shells and/or freshwater pearls. Eastern Pearlshell (*Margaritifera margaritifera*) was believed to be their target species. A site, at which scientists had collected and released 100 living specimens of *M. margaritifera* a few years earlier, produced no living specimens in 1992. Erickson and Fetterman (1996) estimated that it would take 30 to 40 years to reestablish a stable population of this species at the collection site. This example illustrates that public awareness can sometimes be a threat to endangered species.

PROTECTION, STATUS AND RANKS

Legal protection and status

Epioblasma t. rangiana is currently listed as Endangered on Schedule 1 of Canada's *Species at Risk Act* (SARA). Under the SARA prohibitions, it is currently an offence to kill, harm, capture, take, possess, collect, buy, sell or trade *E. t. rangiana*. Once described or identified, SARA includes provisions to protect the residence and critical habitat of the species but neither have been delineated. *Epioblasma t. rangiana* is also listed as Endangered under Ontario's *Endangered Species Act, 2007*. When the Act came into force on June 30, 2008, the species itself received protection. Under both acts, permits are required to survey or conduct studies that may violate prohibitions.

In the U.S., *E. t. rangiana* was listed as federally Endangered in 1993 and is protected under the *Endangered Species Act*. This Act provides for possible land acquisition, and requires that recovery actions be carried out for all listed species (USFWS 1994).

Cross-border trade is controlled as the species is listed under CITES Appendix II.

Non-legal status and ranks

The global status of *E. t. rangiana* is G2T2 – Imperilled; the national rank in the U.S. is N2; the national rank in Canada is N1 and the subnational rank is S1 in Ontario. It has subnational rankings for six U.S. states ranging from presumed extirpated through imperiled (Table 3). It is also extirpated from Illinois and Indiana, endangered in Michigan and Ohio, and listed globally as Critically Endangered under the IUCN Red List (NatureServe 2009).

Table 3. Subnational conservation rankings for *Epioblasma torulosa rangiana* in the U.S. Tied rankings have been assigned the higher conservation rank. All information from NatureServe (2009). Great Lakes States are in bold.

Conservation rank	Description	Jurisdiction
SX	Presumed extirpated	**Indiana**
S1	Critically imperiled	Kentucky, **Michigan**, **Ohio**, West Virginia
S2	Imperiled	**Pennsylvania**
S3	Vulnerable	N/A
S4	Apparently secure	N/A
S5	Secure	N/A
SNR	Not ranked	**Illinois**

Habitat protection and ownership

Because Northern Riffleshell is listed as Endangered on Schedule 1 of *SARA,* once described or identified, the residence and critical habitat of the species will be protected under that Act. In addition, the species is listed as Endangered under the province of Ontario's *Endangered Species Act, 2007*, which came into force on June 30, 2008. However, the habitat of the Northern Riffleshell will not be protected under this new provincial Act until five years from this date unless a specific habitat regulation is developed by the provincial government at an earlier date. Until the habitat provisions of these new statutes come into effect, the federal *Fisheries Act* may represent the most important legislation currently protecting the habitat of the Northern Riffleshell. Under this Act, freshwater mussels are considered to be shellfish, which are included in the definition of "fish" and therefore their habitat is protected from harmful alteration, disruption or destruction unless authorized by the Minister of Fisheries and Oceans. In Ontario, the Provincial Policy Statement under Section 3 of *The Planning Act* prohibits development and site alteration in the habitats of threatened and endangered species. Another law that protects mussel habitat is the Ontario *Lakes and Rivers Improvement Act*, which prohibits the impoundment or diversion of watercourses that would lead to siltation.

Streamside development in Ontario is managed through flood plain regulations enforced by local conservation authorities. The land along the reaches of the Sydenham and Ausable rivers where *E. t. rangiana* currently occurs is mainly privately owned. Along the Sydenham River, there are only two publicly owned properties: Mosa Township Forest (50 acres = 20 ha) and Shetland Conservation Area (17 acres = 6.9 ha) (Dextrase *et al.* 2003). Along the Ausable River, there are substantial public land holdings managed by the Ausable Bayfield Conservation Authority within the Arkona Gorge (894 acres = 362 ha) where the Northern Riffleshell is present (Nelson *et al.* 2003); smaller tracts of public lands along the upper reaches of the Ausable River include Crediton Conservation Area (4.5 acres = 1.8 ha), the Dixon Tract (100 acres = 40.5 ha) and Lion's Park near Ailsa Craig (~ 10 acres = ~ 4 ha).

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

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INFORMATION SOURCES

Ausable River Recovery Team. 2004. Recovery strategy for species at risk in the Ausable River: an ecosystem approach, 2004-2009. Recovery of Nationally Endangered Wildlife (RENEW), Ottawa, Ontario.

Badra, P.J. 2004. Monitoring of Clubshell (*Pleurobema clava*) populations and surveys for the Northern Riffleshell (*Epioblasma torulosa rangiana*) in Michigan. Michigan Natural Features Inventory Report Number 2004-17. Report to U.S. Fish and Wildlife Service, East Lansing, Michigan. 15 pp.

Badra, P.J. 2006a. Status of native and exotic mussels, including the northern riffleshell (*Epioblasman torulosa rangiana*) and rayed bean (*Villosa fabalis*), at the Detroit River International Wildlife Refuge: Sites 15-36. Michigan Natural Features Inventory Report Number MNFI 2006-23. Report to: U.S. Fish and Wildlife Service, Ft. Snelling, Minnesota. 15 pp.

Badra, P.J. 2006b. Status of native and exotic mussels, including the northern riffleshell (*Epioblasma torulosa rangiana*) and rayed bean (*Villosa fabalis*), at the Detroit River International Wildlife Refuge: Sites 1-14. Michigan Natural Features Inventory Report Number MNFI 2006-12. Report For: Michigan Department of Natural Resources, Nongame Wildlife Fund. Lansing, Michigan. 12 pp.

Barnhart, M.C. 2009. Unio Gallery. Missouri State University. Web site: http://unionid.missouristate.edu/gallery/Epioblasma/default.htm [accessed August 2009].

Barnhart, M.C., W.R. Haag, and W.N. Roston. 2008. Adaptations to host infection and larval parasitism in Unionoida. Journal of the North American Benthological Society 27(2):370-394.

Biggins, R.G., R.J. Neves, and C.K. Dohner. 1995. Draft national strategy for the conservation of native freshwater mussels. U.S. Fish and Wildlife Service, Washington, DC.

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

Bogan, A.E. 1997. A resolution of the nomenclatural confusion surrounding *Plagiola* Rafinesque, *Epioblasma* Rafinesque, and *Dynosomia* Agassiz (Mollusca: Bivalvia: Unionidae). Malacological Review 30:77-86.

Bowers, R., and F.A. de Szalay. 2005. Effects of water level fluctuations on zebra mussel distribution in a Lake Erie coastal wetland. Journal of Freshwater Ecology 20(1):85-92.

Bowles, J.M. 1994. Dingman Creek between Lambeth and Delaware, Life Science Inventory. McIlwraith Field Naturalists of London Inc., Ontario Ministry of Natural Resources, The Richard Ivey Foundation, Upper Thames River Conservation Authority. iv + 86 pp

Clarke, A.H. 1973. On the distribution of Unionidae in the Sydenham River, southern Ontario, Canada. Malacological Review 6:63-64.

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

Clarke, A.H. 1992. Ontario's Sydenham River, an important refugium for native freshwater mussels against competition from the zebra mussel *Dreissena polymorpha*. Malacology Data Net 3(1-4):43-55.

Convey, L.E., J.M. Hanson, and W.C. MacKay. 1989. Size-selective predation on unionid clams by muskrats. Journal of Wildlife Management 53(3):654-657.

COSEWIC. 2000. COSEWIC assessment and status report on the Northern Riffleshell *Epioblasma torulosa rangiana* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 33 pp. (www.sararegistry.gc.ca/status/status_e.cfm)

COSEWIC. 2006. COSEWIC assessment and status report on the Mapleleaf Mussel *Quadrula quadrula* (Saskatchewan-Nelson population and Great Lakes-Western St. Lawrence population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 58 pp. (www.sararegistry.gc.ca/status/status_e.cfm)

Crabtree, D.L., and T.A. Smith. 2009. Population attributes of an endangered mussel, *Epioblasma torulosa rangiana*, in French Creek and implications for its recovery. Northeastern Naturalist 16(3):339-354.

Cummings, K.S., pers. comm. 1998. *Email correspondence with J.L. Metcalfe-Smith*. May 1998. Curator of Mollusks, Illinois Natural History Survey, Champaign, Illinois, USA.

Cummings, K.S., and C.A. Mayer. 1992. Field guide to the freshwater mussels of the Midwest. Illinois Natural History Survey, Manual 5.

Dennis, S.D. 1984. Distributional analysis of the freshwater mussel fauna of the Tennessee River system, with special reference to possible limiting effects of siltation. Ph.D. thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 245 pp.

Department of Energy and Resources Management. 1965. Sydenham Valley Conservation Report, Toronto, Ontario.

Dextrase, A., S.K. Staton, and J.L. Metcalfe-Smith. 2003. National recovery strategy for species at risk in the Sydenham River: an ecosystem approach. National Recovery Plan No. 25. Recovery of Nationally Endangered Wildlife (RENEW), Ottawa, Ontario.

Downing, J.A., Y. Rochon, and M. Perusse. 1993. Spatial aggregation, body size, and reproductive success in the freshwater mussel *Elliptio complanata*. Journal of the North American Benthological Society 12(2):148-156.

Eackles, M.S., and T.L. King. 2002. Isolation and characterization of microsatellite loci in *Lampsilis abrupta* (Bivalvia: Unionidae) and cross-species amplification within the genus. Molecular Ecology Notes 2:559-562.

Erickson, J.M., and A.R. Fetterman. 1996. The Unionacean fauna of the Grass River drainage, St. Lawrence County, New York. Pp. 211-223, *in* R.D. Needham and E.N. Novakowski (eds.). Sharing Knowledge, Linking Sciences: An International Conference on the St. Lawrence Ecosystem. Conference Proceedings. Institute for Research on Environment and Economy, University of Ottawa.

Gillis, P.L., pers. comm. 2008. *Discussion at Ontario Freshwater Mussel Recovery Team Meeting, Canada Centre for Inland Waters (attended by D.T. Zanatta and S.K. Staton).* November 2008. Research Scientist, Environment Canada, Burlington, ON.

Gillis, P.L., and G.L. Mackie. 1994. Impact of the zebra mussel, *Dreissena polymorpha*, on populations of Unionidae (Bivalvia) in Lake St. Clair. Canadian Journal of Zoology 72(7):1260-1271.

Goudreau, S.E., R.J. Neves, and R.J. Sheehan. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, USA. Hydrobiologia 252(3):211-230.

Graf, D.L. 1998. Freshwater pearly mussels: pigtoes and Ortmann's Law. American Conchologist 26(2):20-21.

Graf, D.L., and K.S. Cummings. 2007. Review of the systematics and global diversity of freshwater mussel species (Bivalvia: Unionoida). Journal of Molluscan Studies 73:291-314.

Haag, W.R., and A.M. Commens-Carson. 2008. Testing the assumption of annual shell ring deposition in freshwater mussels. Canadian Journal of Fisheries and Aquatic Sciences 65:493-508.

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

Hoeh, W.R., and R.J. Trdan. 1985. Freshwater mussels (Pelecypoda: Unionidae) of the major tributaries of the St. Clair River, Michigan. Malacological Review 18(1-2):115-116.

Hoggarth, M.A. 1993. Glochidial functional morphology and rarity in the Unionidae. Pp. 76-80, *in* K.S. Cummings, A.C. Buchanan and L.M. Koch (eds.). Conservation and management of freshwater mussels. Proceedings of an Upper Mississippi River Conservation Committee Symposium, October 1992, St. Louis, Misouri.

Huebner, J.D., and K.S. Pynnönen. 1992. Viability of glochidia of *Anodonta* exposed to low pH and selected metals. Canadian Journal of Zoology 70(12):2348-2355.

IUCN. 2001. IUCN red list categories and criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.

Johnson, R.I. 1978. Systematics and zoogeography of *Plagiola* (=*Dysnomia* =*Epioblasma*), an almost extinct genus of freshwater mussels (Bivalvia: Unionidae) from Middle North America. Bulletin of the Museum of Comparative Zoology 148(6):239-321.

Jones, J.W. 2004. A holistic approach to taxonomic evaluation of two closely related endangered freshwater mussel species, the oyster mussel (*Epioblasma capsaeformis*) and tan riffleshell (*Epioblasma florentina walkeri*) (Bivalvia: Unionidae). M.Sc. Thesis, M.Sc. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Jones, J.W., M. Culver, V. David, J. Struthers, N.A. Johnson, R.J. Neves, S.J. O'Brien, and E.M. Hallerman. 2004. Development and characterization of microsatellite loci in the endangered oyster mussel *Epioblasma capsaeformis* (Bivalvia: Unionidae). Molecular Ecology Notes 4(4):649-652.

Jones, J.W., R.J. Neves, S.A. Ahlstedt, and E.M. Hallerman. 2006. A holistic approach to taxonomic evaluation of two closely related endangered freshwater mussel species, the oyster mussel *Epioblasma capsaeformis* and tan riffleshell *Epioblasma florentina walkeri* (Bivalvia: Unionidae). Journal of Molluscan Studies 72:267-283.

Keller, A.E., and S.G. Zam. 1990. Simplification of in vitro culture techniques for freshwater mussels. Environmental Toxicology and Chemistry 9(10):1291-1296.

La Rocque, A., and J. Oughton. 1937. A preliminary account of the Unionidae of Ontario. Canadian Journal of Research 15(8):147-155.

Mackie, G.L., and J.M. Topping. 1988. Historical changes in the unionid fauna of the Sydenham River watershed and downstream changes in shell morphometrics of three common species. Canadian Field Naturalist 102(4):617-626.

Martel, A.L., J.-M. Gagnon, M. Gosselin, A. Paquet, and I. Picard. 2007. Liste des noms français révisés et des nom latins et anglais à jour des mulettes du Canada (Bivalvia; Familles : Margaritiféridés, Unionidés). Le Naturaliste Canadien 131(2):79-84.

McGoldrick, D.J., pers. comm. 2009. *Email correspondence with D.T. Zanatta*. January 2009. Research Biologist, Environment Canada, Burlington, Ontario.

McGoldrick, D.J., J.L. Metcalfe-Smith, M.T. Arts, D.W. Schloesser, T.J. Newton, G.L. Mackie, E.M. Monroe, J. Biberhofer, and K. Johnson. 2009. Characteristics of a refuge for native freshwater mussels (Bivalvia: Unionidae) in Lake St. Clair. Canadian Journal of Fisheries and Aquatic Sciences 35:137-146.

McNichols, K.A., and G.L. Mackie. 2002. Fish host determination of endangered freshwater mussels in the Sydenham River Ontario, Canada. Final Report for a study funded by Endangered Species Recovery Fund in 2002. 20 pp.

McNichols, K.A., and G.L. Mackie. 2003. Fish host determination of endangered freshwater mussels in the Sydenham River Ontario, Canada. Final Report for a study funded by Endangered Species Recovery Fund in 2003. 26 pp.

McNichols, K.A., G.L. Mackie, and J.D. Ackerman. 2004. Fish host determination of endangered freshwater mussels in the Sydenham River Ontario, Canada. Final Report for a study funded by Endangered Species Recovery Fund in 2004. 25 pp.

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

Metcalfe-Smith, J.L., J. Di Maio, S.K. Staton, and S.R. De Solla. 2003. Status of the freshwater mussel communities of the Sydenham River, Ontario, Canada. American Midland Naturalist 150:37-50.

Metcalfe-Smith, J.L., D.J. McGoldrick, M. Williams, D.W. Schloesser, J. Biberhofer, G.L. Mackie, M.T. Arts, D.T. Zanatta, K. Johnson, P. Marangelo, and T.D. Spencer. 2004. Status of a refuge for native freshwater mussels (Unionidae) from impacts of the exotic zebra mussel (*Dreissena polymorpha*) in the delta area of Lake St. Clair, Technical Note No. AEI-TN-04-001, National Water Research Institute, Burlington, Ontario.

Metcalfe-Smith, J.L., D.J. McGoldrick, D.T. Zanatta, and L.C. Grapentine. 2007. Development of a monitoring program for tracking the recovery of endangered freshwater mussels in the Sydenham River, Ontario, Environment Canada, WSTD Contribution No. 07-510, Burlington, Ontario. 40 pp. + appendices.

Metcalfe-Smith, J.L., S.K. Staton, G.L. Mackie, and E.L. West. 1998. Assessment of the current status of rare species of freshwater mussels in southern Ontario, NWRI Contribution No. 98-019, National Water Research Institute, Burlington, Ontario.

Moritz, C. 1994. Defining 'evolutionary significant units' for conservation. Trends in Ecology and Evolution 9:373-375.

Morris, T.J. 1996. The unionid fauna of the Thames River drainage, southwestern Ontario. Prepared for Aquatic Ecosystems Branch, Ontario Ministry of Natural Resources. 59 pp.

Morris, T.J., and M. Burridge. 2006. Recovery strategy for Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean in Canada. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa, x + 76 pp.

Morris, T.J., and J. Di Maio. 1998-1999. Current distributions of freshwater mussels (Bivalvia: Unionidae) in Rivers of southwestern Ontario. Malacological Review 31/32(1):9-17.

Morris, T.J., and A. Edwards. 2007. Freshwater mussel communities of the Thames River, Ontario: 2004-2005. Canadian Manuscript Report on Fisheries and Aquatic Sciences 2810:v + 30 pp.

Nalepa, T.F., and J.M. Gauvin. 1988. Distribution, abundance, and biomass of freshwater mussels (Bivalvia: Unionidae) in Lake St. Clair. Journal of Great Lakes Research 14(4):411-419.

Nalepa, T.F., D.J. Hartson, G.W. Gostenik, D.L. Fanslow, and G.A. Lang. 1996. Changes in the freshwater mussel community of Lake St. Clair: from Unionidae to *Dreissena polymorpha* in eight years. Journal of Great Lakes Research 22(2):354-369.

Natural Heritage Information Centre. 1997. Draft report on the conservation status of Ontario Unionids, Peterborough, Ontario.

NatureServe. 2009. NatureServe Explorer: An online encyclopedia of life. Version 7.1. NatureServe, Arlington, Virginia. Web site: http://www.natureserve.org/explorer. [accessed: August 16, 2009].

Nelson, M., M. Veliz, S.K. Staton, and E. Dolmage. 2003. Towards a recovery strategy for species at risk in the Ausable River: Synthesis of background information. Prepared for the Ausable River Recovery Team. 92 pp.

Neves, R.J., and M.C. Odum. 1989. Muskrat predation on endangered freshwater mussels in Virginia. Journal of Wildlife Management 53(4):934-941.

Nichols, S.J., and D.A. Wilcox. 1997. Burrowing saves Lake Erie clams. Nature 389(6654):921.

Oldham, M.J., pers. comm. 1997. *Email correspondence with J.L. Metcalfe-Smith*. June 1997. Biologist, Natural Heritage Information Centre, Ontario Ministry of Natural Resources, Peterborough, Ontario.

Parmalee, P.W., and A.E. Bogan. 1998. The Freshwater Mussels of Tennessee. The University of Tennessee Press, Knoxville, Tennessee, USA.

Peacock, E., W.R. Haag, and L. Melvin. 2005. Prehistoric decline in freshwater mussels coincident with the advent of maize agriculture. Conservation Biology 19(2):547-551.

Ricciardi, A., R.J. Neves, and J.B. Rasmussen. 1998. Impending extinctions of North American freshwater mussel (Unionoida) following the zebra mussel (*Dreissena polymorpha*) invasion. Journal of Animal Ecology 67:613-619.

Ricciardi, A., F.G. Whoriskey, and J.B. Rasmussen. 1996. Impact of the *Dreissena* invasion on native unionid bivalves in the upper St. Lawrence River. Canadian Journal of Fisheries and Aquatic Sciences 53(6):1434-1444.

Richards, R.P. 1990. Measures of flow variability and a new flow-based classification of Great Lakes tributaries. Journal of Great Lakes Research 16(1):53-70.

Salmon, A., and R.H. Green. 1983. Environmental determinants of unionid clam distribution in the Middle Thames River, Ontario. Canadian Journal of Zoology 61: 832-838.

Schloesser, D.W., W.P. Kovalak, G.D. Longton, K.L. Ohnesorg, and R.D. Smithee. 1998. Impact of Zebra and Quagga Mussels (*Dreissena* spp.) on Freshwater Unionids (Bivalvia: Unionidae) in the Detroit River of the Great Lakes. American Midland Naturalist 140:299-313.

Schloesser, D.W., J.L. Metcalfe-Smith, W.P. Kovalak, G.D. Longton, and R.D. Smithee. 2006. Extirpation of freshwater mussels (Bivalvia: Unionidae) following the invasion of dreissenid mussels in an interconnecting river of the Laurentian Great Lakes. American Midland Naturalist 155(2):307-320.

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

Stansbery, D.H., K.G. Borror, and K.E. Newman. 1982. Biological abstracts of selected species of unionid mollusks recovered from Ohio, Unpublished manuscript, prepared for the Ohio Heritage Foundation. Ohio Department of Natural Resources.

Staton, S.K., A. Dextrase, J.L. Metcalfe-Smith, J. Parish, B. Kilgour, and E. Holm. 2003. Status and trends of Ontario's Sydenham River ecosystem in relation to aquatic species at risk. Environmental Monitoring and Assessment 88(1-3):283-310.

Strayer, D.L., J.A. Downing, W.R. Haag, T.L. King, J.B. Layzer, T.J. Newton, and S.J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperilled animals. BioScience 54(5):429-439.

Strayer, D.L., and A.R. Fetterman. 1996. Changes in the distribution of freshwater mussels (Unionidae) in the Upper Susquehanna River Basin, 1955-1965 to 1996-1997. American Midland Naturalist 142:328-339.

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

Strayer, D.L., and H.M. Malcom. 2007. Effects of zebra mussels (*Dreissena polymorpha*) on native bivalves: the beginning of the end or the end of the beginning? Journal of the North American Benthological Society 26(1):111-122.

Tolin, W.A., pers. comm. 1998. *Email correspondence with J.L. Metcalfe-Smith*. Februrary 1998. Biologist, U.S. Fish and Wildlife Service.

Trdan, R.J., and W.R. Hoeh. 1993. Relocation of two state-listed freshwater mussel species (*Epioblasma torulosa rangiana* and *Epioblasma triquetra*) in Michigan. Pp. 100-105, *in* K.S. Cummings, A.C. Buchanan and L.M. Koch (eds.). Conservation and management of freshwater mussels. Proceedings of an Upper Mississippi River Conservation Committee Symposium, St. Louis, Missouri.

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

U.S. Fish and Wildlife Service [USFWS]. 1993. Endangered and threatened wildlife and plants; determination of endangered status for the Northern Riffleshell Mussel (*Epioblasma torulosa rangiana*) and the Clubshell Mussel (*Pleurobema clava*). Web site: http://www.fws.gov/endangered/federalregister/1993/fr93488.html [accessed December 15, 2008].

U.S. Fish and Wildlife Service [USFWS]. 1994. Clubshell (*Pleurobema clava*) and Northern Riffleshell (*Epioblasma torulosa rangiana*) recovery plan. Hadley, Massachusetts. 68 pp.

Valenti, T.W., D.S. Cherry, R.J. Currie, R.J. Neves, J.W. Jones, R. Mair, and C.M. Kane. 2006. Chlorine toxicity to early life stages of freshwater mussels (Bivalvia: Unionidae). Environmental Toxicology and Chemistry 25(9):2512–2518.

van der Schalie, H. 1970. Hermaphroditism among North American freshwater mussels. Malacologia 10:93-112.

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

Watters, G.T. 1996. Hosts for the Northern Riffleshell (*Epioblasma torulosa rangiana*). Triannual Unionid Report 10:14.

Watters, G.T., pers. comm. 2009. *Visit to Ohio State Museum by D.T. Zanatta*. April 2009. Curator of Mollusks, Ohio State University Museum of Zoology, Columbus, OH, USA.

Williams, J.D., A.E. Bogan, and J.T. Garner. 2008. Freshwater mussels of Alabama and the Mobile Basin in Georgia, Mississippi, and Tennessee. University of Alabama Press, Tuscaloosa, Alabama.

Williams, J.D., M.L. Warren, K.S. Cummings, J.L Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6-22

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

Zanatta, D.T., and R.W. Murphy. 2006a. Development and characterization of microsatellite markers for the endangered northern riffleshell mussel *Epioblasma torulosa rangiana* (Bivalvia: Unionidae). Molecular Ecology Notes 6(3):850-852.

Zanatta, D.T., and R.W. Murphy. 2006b. The evolution of active host-attraction strategies in the freshwater mussel tribe Lampsilini (Bivalvia: Unionidae). Molecular Phylogenetics and Evolution 41:195-208.

Zanatta, D.T., and R.W. Murphy. 2007. Range-wide population genetic analysis of the endangered northern riffleshell mussel, *Epioblasma torulosa rangiana* (Bivalvia: Unionoida). Conservation Genetics 8:1393-1404.

BIOGRAPHICAL SUMMARY OF REPORT WRITERS

David Zanatta is an Assistant Professor in the Biology Department at Central Michigan University. Dr. Zanatta has 10 years of experience working on unionid mussels. He has a Ph.D. from the University of Toronto where he researched the evolution and population genetics of lampsiline mussels. Dr. Zanatta has authored seven peer-reviewed papers on freshwater mussel biology, including a paper on the conservation genetics of the Northern Riffleshell. He has also co-authored three COSEWIC status reports on Ontario freshwater mussel species and is a member of the Mollusc Specialist Subcommittee of COSEWIC. Dr. Zanatta is a member of the recovery teams for Thames, Sydenham and Ausable Rivers as well as the Ontario Freshwater Mussel Recovery Team.

Shawn K. Staton has an Honors B.Sc. in Biology (specializing in Fisheries and Wildlife) from the University of Guelph, graduating in 1993. Since that time Mr. Staton has gained 14 years of experience as a freshwater biologist working for a variety of employers including conservation authorities, municipal and federal governments as well as private consulting firms. For the past 10 years, working with the National Water Research Institute and Fisheries and Oceans Canada, Mr. Staton's work has focused on the preparation of reports and publications related to research and/or the recovery of fishes and freshwater mussels. Through his work with DFO, Mr. Staton chairs several aquatic ecosystem-based recovery teams (addressing at-risk freshwater mussels and fishes), is a member of the Ontario Freshwater Mussel Recovery Team and collaborates with a wide range of researchers and resource managers.

COLLECTIONS EXAMINED

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

In 1996, all available historical and recent data on the occurrences of freshwater mussel species throughout the lower Great Lakes drainage basin were compiled into a computerized, GIS-linked database referred to as the Lower Great Lakes Unionid Database. The database is housed at Fisheries and Oceans Canada's Great Lakes Laboratory for Fisheries and Aquatic Sciences in Burlington, Ontario. Original data sources included the primary literature, natural history museums, federal, provincial, and municipal government agencies (and some American agencies), conservation authorities, Remedial Action Plans for the Great Lakes Areas of Concern, university theses and environmental consulting firms. Mussel collections held by six natural history museums in the Great Lakes region (Canadian Museum of Nature, Ohio State University Museum of Zoology, Royal Ontario Museum, University of Michigan Museum of Zoology, Rochester Museum and Science Center, and Buffalo Museum of Science) were the primary sources of information, accounting for over two-thirds of the initial data acquired. Janice Metcalfe-Smith personally examined the collections held by the Royal Ontario Museum, University of Michigan Museum of Zoology and Buffalo Museum of

Science, as well as smaller collections held by the Ontario Ministry of Natural Resources. The database continues to be updated with new field data and now contains approximately 8200 records of unionids from Lake Ontario, Lake Erie, Lake St. Clair and their drainage basins as well as several of the major tributaries to lower Lake Huron. The majority of records in the database are now from recent (post-1990) field collections made by Fisheries and Oceans Canada, Environment Canada, provincial agencies, universities and conservation authorities. This database is the source for all information on Canadian populations of the Northern Riffleshell discussed in this report.

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