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Status of the Northern Riffleshell, *Epioblasma torulosa rangiana* (Bivalvia: Unionidae), in Ontario and Canada†

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The Northern Riffleshell, *Epioblasma torulosa rangiana*, is a small, colourful, sexually-dimorphic freshwater mussel that lives in highly-oxygenated riffle areas of rivers and streams. Its host fish in Canada is unknown. It has suffered dramatic declines in North America over the past century, with the current distribution representing a range reduction of more than 95%. It was listed as Endangered under the U.S. Endangered Species Act in 1993. Causes of its decline include the Zebra Mussel, *Dreissena polymorpha*, which has infested a large portion of the subspecies' former range, and agricultural impacts. All rivers where the subspecies still occurs are located in areas of intense agriculture and forestry, which makes them susceptible to siltation and runoff of agricultural chemicals. The distribution of *E. t. rangiana* in Canada is now restricted to the middle reaches of the Sydenham and Ausable rivers in southwestern Ontario. The Sydenham River population is one of only three populations in North America that still show evidence of successful reproduction, hence the preservation of this population is important for the global survival of the subspecies. It is predicted that *E. t. rangiana* will become globally extinct within 10 years unless measures are taken soon to protect it.

Key Words: Northern Riffleshell, *Epioblasma torulosa rangiana*, Unionidae, freshwater mussels, endangered species, COSEWIC, Great Lakes, Ontario.

In 1994, the Committee On the Status of Endangered Wildlife In Canada (COSEWIC) expanded its mandate to include invertebrates. The Mollusc Working Group of the Lepidoptera and Mollusca Subcommittee was formed in 1995 to develop a national list of Canadian mollusc species at risk and prepare status reports on them. The Committee On the Status of Species At Risk in Ontario (COSSARO) was also established in 1995, and it recently began to consider aquatic species for listing, including invertebrates. In response to these initiatives, Metcalfe-Smith et al. (1998a) examined recent and historical data on the distributions of the freshwater mussels (Unionidae) of southern Ontario and prepared a prioritized list of the most imperiled species. This region was chosen for study because it historically supported 75% of Canada's 53 species of freshwater mussels. Nine species, most having current sub-jurisdictional ranks of S1 (NHIC 1997)*, were proposed for national status designation by COSEWIC. It was recommended that six other species known only from historical records (ranked SH) be given a lower priority for listing, because they may already be extinct and beyond help. The Northern Riffleshell fell into the latter group.

In 1997 and 1998, Metcalfe-Smith et al. (1998b, 1999) conducted intensive surveys at 66 sites on the Grand, Thames, Sydenham, Ausable and Maitland Rivers of southwestern Ontario to determine the conservation status of their mussel communities. During this work, five species that were thought to be extirpated from Ontario (and Canada) were found alive, including *Epioblasma torulosa rangiana*. The Northern Riffleshell is the only species or subspecies of freshwater mussel in Canada that is currently listed as federally endangered in the United States. As such, it is appropriate that *E. t. rangiana* should be one of the first species of freshwater mussel to be officially designated as a Canadian species at risk.

Description

According to Clake (1981), *Epioblasma torulosa rangiana* is "Unmistakable among Canadian unionids because of its extreme and unique sexual dimorphism and small size." Stansbery et al. (1982)* describes the shell as small to medium-sized, subcompressed to subinflated, and solid. Males are irregularly ovate, with a wide, shallow sulcus just anterior to the posterior ridge. Females are obovate, greatly expanded post-ventrally with the expansion very broadly rounded, and transversely swollen after about the third year of growth. In both sexes, the periostracum is brownish yellow to yellowish green with diffuse, fine green rays. The umbonal structure is finely double-looped. The nacre is white, the pseu-

†Endangered status assigned by COSEWIC 19 April 1999.
*See Documents Cited section

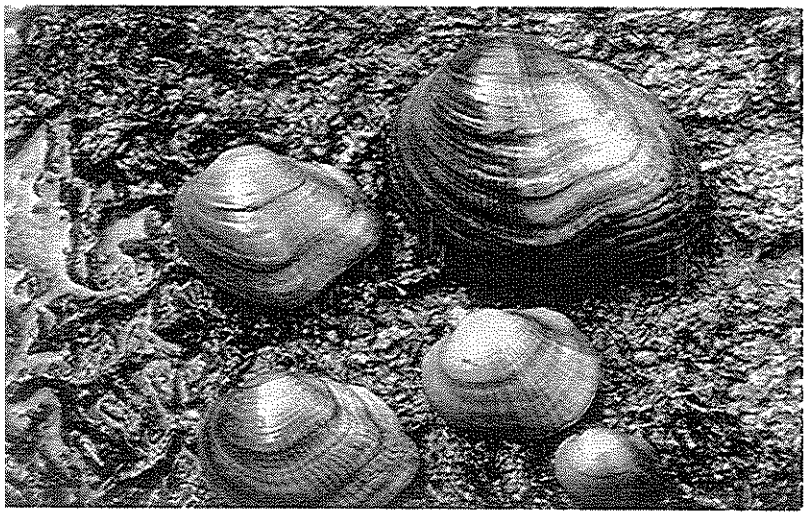

FIGURE 1. Live specimens of *Epioblasma torulosa rangiana* found in the Sydenham River near Florence, Ontario in August, 1998. Specimen in the middle of the photograph is a female; specimen at the lower right is a juvenile; other specimens are males.

docardinal teeth are small, and the lateral teeth are fairly short and moderately thick. Clarke (1981) adds that the beaks are elevated above the hinge line and moderately excavated. Mature individuals have been reported to vary in shell length from 45 to 76 mm (Clarke 1981; Cummings and Mayer 1992; USFWS 1994), although surveys in southwestern Ontario in 1997-1998 produced specimens up to 90 mm long. Figure 1 shows five living specimens of *E. t. rangiana* from the Sydenham River. Three of the five animals are males (the largest is 59 mm in length); the smaller specimen in the middle of the photograph is a young female (35 mm); and the smallest specimen (17 mm) is a juvenile of indeterminate sex.

Epioblasma torulosa rangiana was originally described by Lea in 1837 and named after the French malacologist Sander Rang (USFWS 1994). The type locality for the subspecies is the Ohio River near Cincinnati, and Yellow Creek of the Mahoning River near Poland, Ohio. Three distinct subspecies of *Epioblasma torulosa* are generally recognized: *E. t. torulosa*, *E. t. rangiana*, and *E. t. gubernaculum* (Turgeon et al. 1988), but many consider *E. t. rangiana* to be the headwater form of *E. t. torulosa* (USFWS 1994). Neither *E. t. torulosa* nor *E. t. gubernaculum* have ever been found in Canada, and both are presumed extinct (Williams et al. 1993).

Distribution

The Northern Riffleshell was historically known from Alabama, Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania, Tennessee (questionable records), West Virginia, and Ontario (USFWS 1993*); see inset, Figure 2A. Although the subspecies has never been found in New York, it is believed to have occurred there at one time since it was found in two rivers only a few kilometres from the New York border (Strayer and Jirka 1997). It was found 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 was found in the Maumee River basin and tributaries to western Lake Erie such as the Huron River and the River Raison (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, it was historically known from western Lake Erie and the Detroit River (museum records), Lake St. Clair (La Rocque and Oughton 1937) and the Sydenham River (Clarke 1973) in southwestern Ontario. A previously unknown population was discovered in the Ausable River, a tributary to lower Lake Huron, in 1998 (Metcalfe-Smith et al. 1999).

Figure 2A illustrates the historical distribution of *E. t. rangiana* in Ontario (and Canada) based on occurrence records from the National Water Research Institute's Lower Great Lakes Unionid Database. The database and its data sources are described in detail in Metcalfe-Smith et al. (1998a). At present, the database consists of over 5000 records for 40 species of mussels collected from the Canadian waters of the lower Great Lakes drainage basin between 1860 and 1998. A total of 14 historical records for *E. t. rangiana* were available from the holdings of the Canadian Museum of Nature (CMN), the Ohio State

University Museum of Biological Diversity (OSUM) and the University of Michigan Museum of Zoology (UMMZ), as well as the personal records of Carol B. Stein (retired from the OSUM) and the private collections of Herbert D. Athearn, Emeritus, Tennessee Academy of Science and Michael J. Oldham, Natural Heritage Information Centre, Ontario Ministry of Natural Resources.

Protection

Canada does not have federal endangered species legislation at this time. However, Ontario is one of several provinces that have stand-alone Endangered Species Acts (Aniskowicz 1997). Species classified as provincially Endangered, and their habitats, are protected from willful destruction under these acts, but there is currently no protection for Threatened or Vulnerable species. 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. The Northern Riffleshell is currently being considered for Endangered status in Ontario by the Committee On the Status of Species At Risk in Ontario (COSSARO) and, if approved, would receive provincial protection. Other mechanisms for protecting mussel habitat in Ontario include the Ontario Lakes and Rivers Improvement Act, which prohibits the impoundment or diversion of a watercourse if it would cause siltation; and the voluntary Land Stewardship II program of the Ontario Ministry of Agriculture, Food and Rural Affairs, which is designed to reduce the erosion of agricultural lands. Stream-side development in Ontario is managed through flood plain regulations enforced by local conservation authorities. Most land along the reach of the Sydenham River where *E. t. rangiana* presently occurs is privately owned and in agricultural use. Two small properties, the 7 ha Shetland Conservation Area and the 20 ha Mosa Township forest, are publicly owned (Muriel Andreae, St. Clair Region Conservation Authority, personal communication, March 1998). The Ausable-Bayfield Conservation Authority (ABCA) owns a number of properties totalling 1830 ha throughout the Ausable basin (K. Vader, ABCA, personal communication, March 1999).

The federal Fisheries Act may represent the most important legislation protecting the habitat of *E. t. rangiana* in Canada. Under this Act, freshwater mussels are considered to be shellfish, which are included in the definition of "fish" and are therefore afforded protection in theory. In practice, application of the Fisheries Act tends to focus on the protection of habitats that support recreational or commercial fisheries. As *E. t. rangiana* presently occurs in rivers that support recreational fisheries, its habitat should be indirectly protected by the Fisheries Act.

In the United States, *E. t. rangiana* is listed as Federally Endangered and is protected under the Endangered Species Act (USFWS 1994). This Act provides for possible land acquisition, and requires that recovery actions be carried out for all listed species. The Northern Riffleshell is also listed as endangered in Ohio (Ohio DNR 1997*), Illinois, Indiana, Kentucky and Michigan (TNC 1997*) and Proposed Endangered in Pennsylvania, and is therefore afforded protection in these states. In Michigan, for example, the destruction or possession of any species listed as endangered or threatened in the state is prohibited under the Natural Resources Environmental Protection Act (Michigan DNR 1998*).

Population Sizes and Trends

Epioblasma torulosa rangiana is a rare subspecies (Clarke 1981; USFWS 1993*). Although occasionally abundant, it 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. The only density estimate available for this mussel is 0.09 individuals/m^2 from a site on the upper Allegheny River in northwestern Pennsylvania that supports 17 species of mussels, including the endangered Clubshell (*Pleurobema clava*) and Northern Riffleshell (G. F. Zimmerman, EnviroScience, Inc., Cuyahoga Falls, Ohio, personal communication, March 1999). The site was described as having a low to moderate diversity and density of unionids for this river. A population of *E. t. rangiana* described only as "sizable" 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). Only 12 of the nearly 8000 mussels collected over a 10-day period were *E. t. rangiana*, and a total of 118 specimens of this subspecies were eventually captured after 22 more days of sampling. As the size of the area searched was not provided, density estimates could not be derived.

The Northern Riffleshell 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 remaining known populations in the United States is presented in USFWS (1994), and summarized here. Populations in the Allegheny River and French Creek, Pennsylvania are apparently the largest that remain. In French Creek, the subspecies 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 bro-

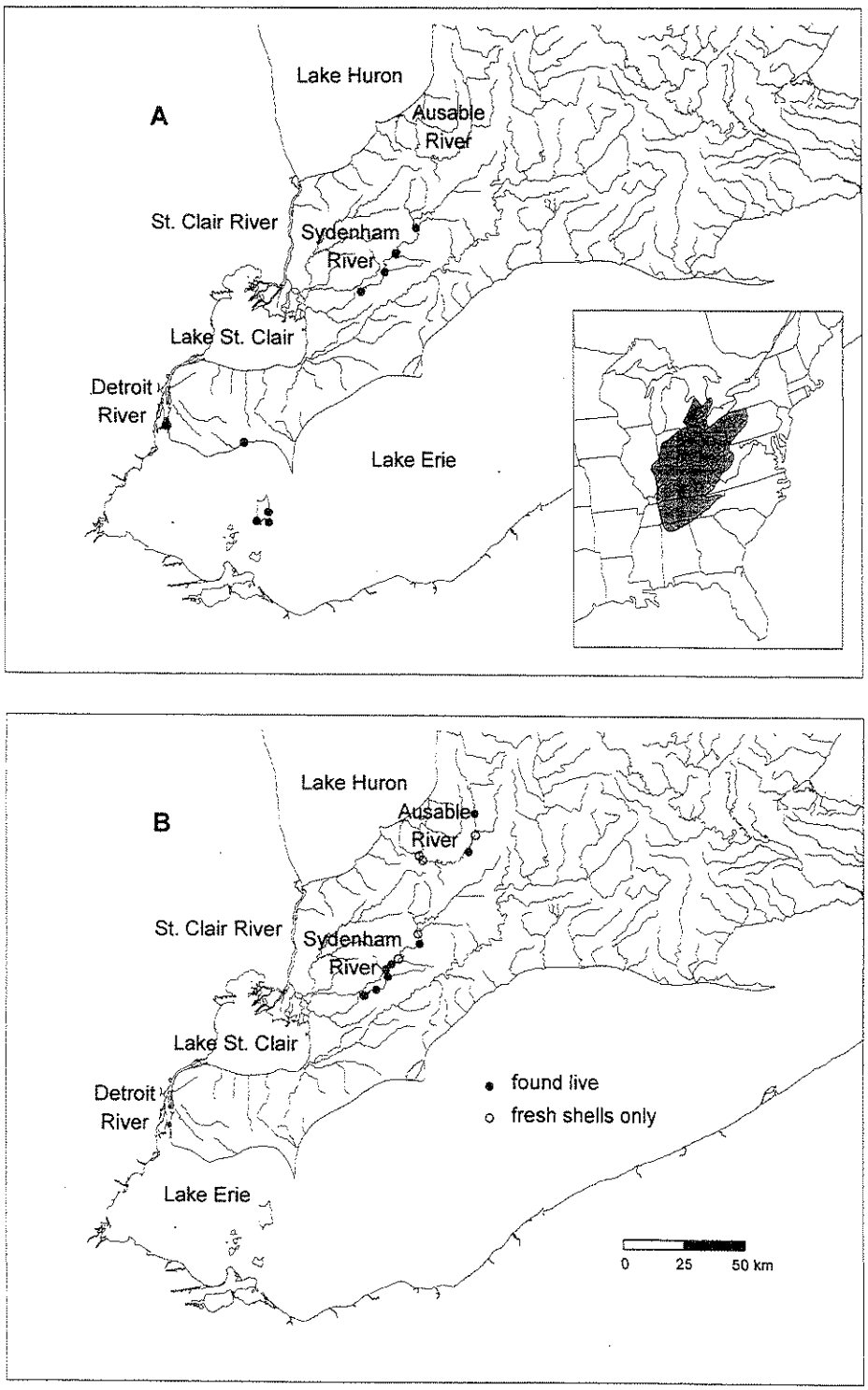

FIGURE 2. Distribution of *Epioblasma torulosa rangiana* in Ontario. A. Historical distribution (inset shows historical North American distribution). B. Presumed current distribution, based on the results of 1997-1998 surveys.

ken range of 128 km. In contrast, the presence of *E. t. rangiana* in LeBouef Creek, Pennsylvania, and the Green River, Kentucky in recent years is indicated by dead shells only. In Fish Creek in the Maumee River drainage of Ohio, living and fresh dead individuals have been reported only rarely, and the most recent surveys have not confirmed its continued existence. The subspecies was once common in Big Darby Creek, Ohio, but is now represented by a declining population in a 24 to 32 km stretch of the creek. It was recently found alive in the Elk and Oak Rivers, West Virginia (G. T. Watters, Ohio State University, personal communication, March 1998); however, additional surveys are required to determine the status of these populations.

The Northern Riffleshell has been collected only sporadically in the Canadian waters of the lower Great Lakes drainage basin over the past century. It was first collected in Lake Erie at Kingsville, Ontario, in 1890 by J. T. McQueen (CMN Catalogue # CMNML002450). Three other occurrences of the subspecies were recorded from Pelee Island in Lake Erie between 1934 and 1960, but there have been no subsequent records. It was also reported from the Canadian waters of the Detroit River at Bois Blanc Island by Bryant Walker in 1934 (UMMZ Catalogue # 906617), but has not been reported since. It may be reasonably assumed that *E. t. rangiana*, like so many other native mussel species, has been eradicated from Lake Erie, Lake St. Clair, and the Huron-Erie corridor by the Zebra Mussel, *Dreissena polymorpha* (see section on limiting factors).

Sydenham River

The Northern Riffleshell was first collected from the Sydenham River in 1963 by H. D. Athearn near the town of Shetland (Clarke 1973). Between 1965 and 1973, live specimens and/or fresh shells were collected from three sites near Alvinston, Florence and Dawn Mills (C. B. Stein, personal communication, September 1997). Clarke (1973) conducted the first extensive survey of the Sydenham River in 1971, visiting 11 sites. He did not find *E. t. rangiana*, but it should be noted that he used a smaller sampling effort than previous collectors (Clarke averaged 1h per site, whereas Athearn conducted a 4h survey and Stein searched for up to 6h). Similar results were reported by Mackie and Topping (1988), who surveyed 20 sites on the Sydenham River in 1985 using a sampling effort of 1h per site. They were unable to locate live specimens of *E. t. rangiana* or three other rare species, and concluded that these species may no longer be present in the Sydenham River. This alarming news prompted a further survey of 16 sites on the river in 1991 by Clarke (1992). He spent between 0.4 and 8.0 person-hours (p-h) at each site, and although he found many more live species than Mackie and Topping (1988), he did not find any trace of *E. t. rangiana*. Based on these findings, the subspecies was assigned a sub-jurisdictional conservation status rank of SH (no verified occurrences in the past 20 years) in Ontario by the Natural Heritage Information Centre (NHIC 1997*).

With the discovery of live *E. t. rangiana* in the Sydenham River in 1997, the subspecies was confirmed extant in Ontario and downlisted from SH to S1 (extremely rare) by the NHIC (D. A. Sutherland, Natual Heritage Information Centre, Ontario Ministry of Natural Resources, personal communication, April 1999). Metcalfe-Smith et al. (1998b, 1999) surveyed 66 sites on the Grand, Thames, Sydenham, Ausable and Maitland Rivers in 1997 and 1998 to assess the current conservation status of rare species of freshwater mussels in southwestern Ontario. They used the timed-search sampling method because of its documented effectiveness for detecting rare species (Strayer et al. 1997), and an intensive sampling effort of 4.5 p-h/site. Sites that were known to support these species in the past were targeted, including the four sites on the Sydenham River where *E. t. rangiana* had been found between 1963 and 1973. According to the results of these surveys, the current range of *E. t. rangiana* in the Sydenham River extends over a 50 km stretch of the river between Alvinston and Dawn Mills (see Figure 2B). A total of 26 live animals numbering 2-11 individuals/site were encountered at six of seven sites surveyed within this reach. Fresh shells were found at the seventh site, and at another site 5 km upstream of the reach. As no live animals or shells were found at four other sites surveyed above Alvinston, the upstream limit of the subspecies appears to have been defined. The downstream limit is likely at Dawn Mills, as there is little gradient (and thus no riffle habitat) below this point and water levels fluctuate with the levels in Lake St. Clair. Five sites were also surveyed on the North Sydenham River (Bear Creek) in 1997-1998. The Nothern Riffleshell was not found at any of these sites, nor had it been in the past.

It appears that the current distribution of *E. t. rangiana* in the Sydenham River is essentially the same as the historical distribution (compare Figures 2A and 2B); however, there is evidence to suggest that abundance has declined. Sites surveyed at Florence and Alvinston in 1997 and Dawn Mills in 1998 had been surveyed several decades earlier by Stein using similar survey techniques and sampling efforts, thus allowing an assessment of changes in abundance over time. In 1965, Stein collected 23 live specimens of *E. t. rangiana* from the Florence site (6 p-h of sampling effort), representing nearly 30% of all live mussels encountered. In 1973, she collected 32 fresh whole shells from a muskrat midden at the same site (3 p-h of sampling effort), but did not find any live animals. In contrast, only two individuals (less than 2% of the 124 live unionids encountered) were found

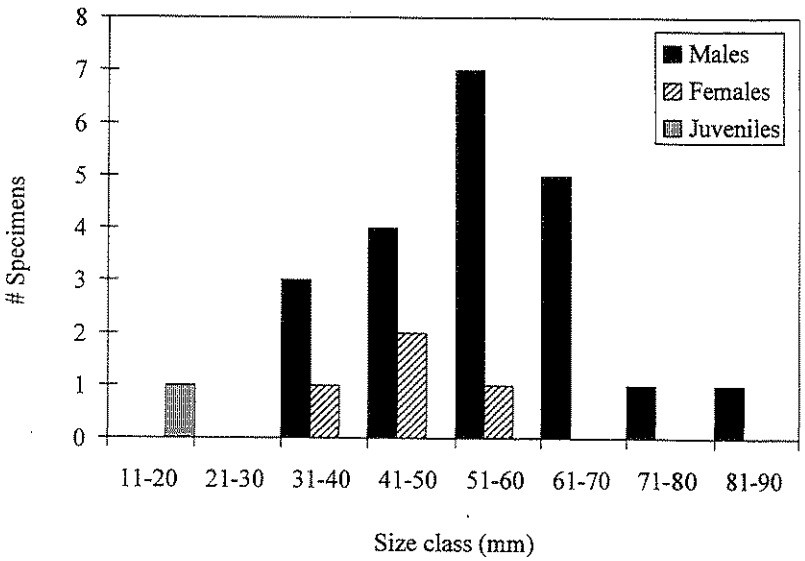

FIGURE 3. Size class distributions for live *E. t. rangiana* found in the Sydenham River in 1997–1998.

at this site in 1997. Capture rates were 3.8 specimens/h in 1965 vs. 0.4 specimens/h in 1997, suggesting a decline in abundance of nearly 90% over the past 32 years at this site. The fact that only 12 weathered valves and one fresh shell were found at the site in 1997, whereas 21 and 32 fresh whole shells were found in 1965 and 1973, respectively, provides further evidence of a declining population. Stein collected one live animal and no shells from the Dawn Mills site in 1973, using 3 p-h of sampling effort. In 1998, two live specimens (and no shells) were found during 12 p-h of searching (six people for two hours); thus, the capture rate in 1973 was twice that in 1997 (0.33 vs. 0.17 specimens/h, respectively). Stein also collected one fresh half shell from the site at Alvinston in 1967. One fresh whole shell was collected from the same site 30 years later. Although a decline in the numbers of *E. t. rangiana* over time has only been documented for two sites on the Sydenham River, the paucity of live animals (maximum 11/site) and fresh shells (no more than a single valve or whole shell at any site) found in 1997-1998, as well as the complete absence of the subspecies from the collections of Mackie and Topping (1988) and Clarke (1992), suggest that the entire Sydenham River population has suffered a decline in abundance.

Using the 1997-1998 data, sex ratios and sex-specific size class distributions were examined for the Sydenham River population. The M:F (male:female) sex ratio for live animals was heavily skewed towards males at 21:4 (or 81% male), while the sex ratio for shells was more balanced at 14:13 (or 52% male). Although the Sydenham River population shows signs of recent recruitment, with a juvenile as small as 17 mm found (Figure 3), the apparent lack of females is disconcerting. There is little information in the literature on normal sex ratios for any mussel species. Trdan and Hoeh (1993) studied the demographics of *E. torulosa rangiana* and *E. triquetra* in the nearby Black and Clinton rivers, in southeastern Michigan. A M:F sex ratio of 59%:41% was reported for *E. t. rangiana* in the Black River, which is impacted by agriculture, based on a sample size of 114 live specimens. In the much cleaner Clinton River, a nearly even M:F sex ratio of 52%:48% was observed for 799 live *E. triquetra*. These results suggest that females of *E. t. rangiana* may be unnaturally scarce in the Sydenham River.

Shell lengths of the 21 live males collected from the Sydenham River ranged from 35 to 90 mm (mean = 56 mm). The four females ranged in length from 35 to 54 mm (mean = 46 mm). Although total lengths reported in the literature vary, lengths greater than 76 mm had not been previously reported. The only Canadian publication (Clarke 1981) states that mature males are 45 mm and mature females 50 mm in length. In the Black River, Michigan, *E. t. rangiana* ranged in length from 36 to 68 mm (sexes combined), with an average length of 52 mm for males and 48 mm for females (Trdan and Hoeh 1993). Thus, females in the Sydenham River appear to be average in size, or a little small, whereas the size distribution of males clearly shows a tendency towards very large animals — well beyond sizes reported in the literature. The size class distribution

for males (Figure 3) indicates the presence of several year classes, but with a bias towards larger, older animals. The co-occurrence of old, large males and fewer, smaller females implies that males may have a better survival rate than females. As females are considerably smaller than males for many species of mussels, including the related Purple Catspaw, *Epioblasma obliquata obliquata* (M. A. Hoggarth, Otterbein College, Westerville, Ohio, personal communication, March 1999), and as females of some species do not live as long as males (e.g., the Mudpuppy Mussel, *Simpsonaias ambigua*; M. C. Barnhart, Southwest Missouri Statue University, Springfield, Missouri, personal communication, March 1999), further studies would be needed to determine if the sex ratios and sizes of Northern Riffleshells in the Sydenham River are within normal parameters.

Ausable River

In 1998, a previously unknown population of *E. t. rangiana* was discovered in the Ausable River of the lower Lake Huron drainage (Metcalfe-Smith et al. 1999). Eight sites were surveyed, and one live specimen was found at each of two sites in the middle reaches of the river near Nairn and Brinsley, respectively (Figure 2B). Fresh shells were found at these and three other sites near Arkona and Ailsa Craig, whereas weathered shells were found at all sites except one in the headwaters near Exeter. Weathered shells were most numerous at the sites near Arkona (34 of 59 weathered shells found at all sites), where they may have accumulated from sites further upstream. These results suggest that the range of *E. t. rangiana* in the Ausable River once covered a distance of approximately 55 km between Brinsley and Arkona. As the gradient flattens out below Arkona, it is unlikely that the lower portion of the river would have offered suitable riffle habitat for the Northern Riffleshell. Although many more live specimens were found in the Sydenham River (26 from 17 sites) than the Ausable River (2 from 8 sites), the reverse was true for shells (27 from the Sydenham and 95 from the Ausable). These comparisons suggest that: (i) the population of *E. t. rangiana* in the Ausable River may once have been larger than that in the Sydenham River, and (ii) the Ausable River population has declined in recent years to a level far below that in the Sydenham River. With so few live animals in evidence, the sustainability of the Ausable River population appears doubtful.

Habitat

It is widely accepted that the Northern Riffleshell 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 has been described as rocky and sandy bottoms (Clarke 1981), and as firmly packed sand and fine to coarse gravel (Cummings and Mayer 1992). Recent observations in the Sydenham River confirmed these claims: all live animals encountered in 1997 and 1998 were found in stable substrates of coarse sand to fine gravel in shallow (generally < 30 cm), flowing waters in or near riffles. This subspecies is purported to occur in streams of various sizes, from small to medium (Ortmann 1919, as cited in USFWS 1993*; Stansbery et al. 1982*) and medium to large (Cummings and Mayer 1992). Its existence in the western basin of Lake Erie was apparently due to sufficient wave action to produce continuously moving water (USFWS 1994). There is no information available on the thermal tolerance of *E. t. rangiana*; however, water temperatures at sites where live specimens were found in the Sydenham and Ausable rivers in August of 1997 and 1998 ranged from 18-27°C. The extent of preferred habitat in the 50 km stretch of the Sydenham River where *E. t. rangiana* still occurs is unknown. As this reach has a relatively low gradient of about 0.4 m/km (DERM 1965*), riffle habitat would likely constitute only a small proportion of the total habitat.

General Biology

Although the specific biology of *E. t. rangiana* is not well known, general unionid biology is applicable (USFWS 1994). The Northern Riffleshell is a small to medium-sized, sexually dimorphic mussel that tends to live for 15 years or more (USFWS 1993*). It is not known at what age reproductive maturity is reached or when it ends (USFWS 1993*). Although hermaphroditic individuals have been encountered for many unionid species (Kat 1983), 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 in mussels may be related to population density, with a threshold density required for successful reproduction to occur (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 torulosa rangiana* is a long term brooder (bradytictic), with a gravid period extending from late summer to the following spring (Ortmann 1919, as cited in USFWS 1993*; Clarke 1981). The shell of the female is distended along the posterior ventral margin to accommodate the expanded gill pouches, a feature that is called a marsupial swelling. When the larvae, or glochidia, are ready to be released, the female displays a spongy, pure white mantle lining that can be seen from several metres away and may function to attract fish hosts (USFWS 1994). Once expelled into the water by the female, the glochidia must attach to the fins of an appropriate fish host in order to complete their metamorpho-

sis. Transformation requires a period of 27 to 33 days, after which the juvenile mussels detach from their host and fall to the substrate to complete their development into free-living adults.

The glochidia of *E. t. rangiana* are semicircular, have 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. The majority of such glochidia attach to the fins, rather than the gills, of their host fish. 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 noted that members of the genus *Epioblasma* provide the best example of this effect, as most are currently listed as federally endangered in the United States.

Until recently, the glochidial fish hosts for *E. t. rangiana* were completely unknown. However, Watters (1996)* has now identified four species of fish that serve as hosts in the United States: the Bluebreast Darter (*Etheostoma camurum*), Banded Darter (*Etheostoma zonale*), Banded Sculpin (*Cottus carolinae*) and Brown Trout (*Salmo trutta*). None of these species are native to Ontario; thus, the endemic fish host(s) for Canadian populations of the subspecies remain unknown. Brown Trout were introduced into Ontario in 1913 (Scott and Crossman 1973), and may now serve as hosts. Because darters and sculpins are frequently associated with *Epioblasma* species (G. T. Watters, Ohio State University, personal communication, June 1998), data on the distributions of these fishes in the Sydenham and Ausable rivers were obtained from the Royal Ontario Museum and the Ontario Ministry of Natural Resources' Ontario Fisheries Information System for comparison with the distribution of *E. t. rangiana* in these rivers.

Ten species of darters have been reported from the Sydenham and/or Ausable rivers. Three of these species, the Greenside Darter (*Etheostoma blenniodes*), Rainbow Darter (*Etheostoma caeruleum*), and Logperch (*Percina caprodes*), are unlikely candidates as they did not serve as hosts in laboratory tests (Watters 1996*). Three other species, the Least Darter (*Etheostoma microperca*), Johnny Darter (*Etheostoma nigrum*) and Blackside Darter (*Percina maculata*), are common to both watersheds and are therefore the most likely hosts. The Eastern Sand Darter (*Ammocrypta pellucida*) is an interesting possibility. This darter has suffered severe population declines (Holm and Mandrak 1996), and is now listed as "Threatened" in Canada. It historically inhabited the Sydenham and Ausable rivers, but has apparently disappeared from the latter. It may be more than a coincidence that the current ranges of the Eastern Sand Darter and Northern Riffleshell in the Sydenham River roughly correspond (compare Figure 2 in Holm and Mandrak (1996) with Figure 2b in this paper), and that the Northern Riffleshell is following the Eastern Darter's path to extirpation in the Ausable River. The Mottled Sculpin (*Cottus bairdi*) and/or the Slimy Sculpin (*Cottus cognatus*) may have served as hosts in the past, but are likely now restricted to colder headwater regions where *E. t. rangiana* does not occur.

The Northern Riffleshell, like all freshwater mussels, is a filter feeder. Although the exact food preferences of the adult form are unknown, they are probably similar to those of other freshwater mussels; i.e., suspended organic particles such as detritus, bacteria and algae (TNC 1986*). Although they are capable of moving short distances, mussels are basically sessile organisms that are highly dependent on their host fish for dispersal during the glochidial stage.

Limiting Factors

Siltation, impoundments, in-stream sand and gravel mining, pollutants from municipal, industrial and agricultural sources, and the invasion of the Zebra Mussel have been identified as threats to the continued existence of *E. t. rangiana* (USFWS 1994). Access to suitable fish hosts may also be a factor, but it cannot be assessed for Canadian populations until the host species have been identified. Members of the genus *Epioblasma* are particularly sensitive to river regulation because they are riffle/run inhabitants that cannot tolerate other substrates. The Sydenham and Ausable rivers, which are the last refugia for this subspecies in Ontario and Canada, are not regulated because of their small size and low gradient. Thus, dams and reservoirs do not limit the distribution of this mussel in Canada.

Much of *E. t. rangiana*'s range in the United States and Canada falls within areas of intensive agriculture and forestry, subjecting the animal to pesticide- and fertilizer-laden runoff as well as siltation (USFWS 1994). Siltation can bury and smother mussels and/or interfere with feeding (Dennis 1984). Because *E. t. rangiana* has never been subjected to toxicity testing, its sensitivity to specific environmental contaminants is not known. However, 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 in general (Bogan 1993).

Siltation is probably the most immediate threat to *E. t. rangiana* in the Sydenham River, although eutrophication and pesticide inputs may also be significant factors. Land use in the watershed is predominantly agricultural, i.e., cash crop, pasture and woodlot (Muriel Andreae, St. Clair Region Conservation Authority, personal communication, March 1998). Twenty years ago, Clarke (1978) found the river to be largely unpolluted. By 1985, Mackie and Topping (1988) reported that an extensive artificial drainage network had been created over the years to drain the predominantly agricultural land adjacent to the river. They observed diminishing dissolved oxygen concentrations with increasing distance downstream, and attributed the significant loss of mussel diversity (20 of the 33 species previously reported from the system were not found alive in 1985) to changing water and substrate quality. More recently, Clarke (1992) noted that all of the species missing from the Sydenham River (including *E. torulosa rangiana* and *Epioblasma triquetra*) during his 1991 survey were partly or wholly riffle-dwelling species, and that most of the riffles were now covered with silt. Thus, he stated that "...a correlation between loss of those species, and apparent loss of clean riffle habitat, appears to exist". Metcalfe-Smith et al. (1998b, 1999) found that water clarity (measured as maximum depth at which the stream-bed was clearly visible) was poor in 1997-1998, averaging 23 cm for all sites sampled and 18 cm for the sites where *E. t. rangiana* was found alive, indicating heavy suspended sediment loadings to the system.

Agriculture is the primary land use in the Ausable River watershed, with over 50% of the area being used for row crops (corn and beans) and only 13% remaining forested (ABCA 1995). Livestock farming is also intensive, particularly in the upper watershed. Water quality is generally poor because of runoff from agricultural lands, septic system seepage, and pollution from manure. About 60% of the soils are artificially drained, which decreases base flows in the river and contributes to flooding during storm events. Sediment loadings are high. The natural course of the lower portion of the river was destroyed in the late 1800s, when it was diverted in two places to alleviate flooding. Water clarity averaged about 30 cm in the Ausable River in 1997-1998 (20-25 cm at the sites where *E. t. rangiana* still occurs), which was slightly better than in the Sydenham. A combination of high suspended sediment loads and pollution are likely the limiting factors for *E. t. rangiana* in the Ausable River, acting either directly or indirectly through impacts on their host fish.

The recent invasion of the Great Lakes by the Zebra Mussel led to catastrophic declines of native mussels in infested waters, and severely contracted the range of *E. t. rangiana* in Canada. Zebra Mussels have decimated the native mussel communities of Lake St. Clair (Nalepa et al. 1996) and western Lake Erie (Schloesser and Nalepa 1994). Heavy infestations of Zebra Mussels have been known to kill unionids in less than one year. This was clearly illustrated in 1988, when 118 live specimens of *E. t. rangiana* were transferred from the Black River, Michigan to a large corral constructed on the bottom of the Detroit River near Detroit, Michigan to protect the population from a dredging operation (Trdan and Hoeh 1993). The caged mussels were monitored every spring with no evidence of Zebra Mussels observed until the summer of 1992, at which time all of the relocated individuals were found dead and heavily encrusted with Zebra Mussels. The Detroit River population was previously considered to be one of the few remaining reproducing populations of this subspecies, and it appears to have been eliminated. It has been recently suggested that coastal wetlands around Lake Erie may serve as refuges from the Zebra Mussel for many species of unionids (Nichols and Wilcox 1997). However, the soft, silt-clay sediments in these areas do not meet the substrate requirements of shoal-dwelling species such as *E. t. rangiana*. Populations of the Northern Riffleshell in the Sydenham and Ausable rivers are not significantly at risk of exposure to Zebra Mussels, because these rivers have no reservoirs that could support a permanent colony of these pests should they ever be introduced.

Predation by Muskrats, *Ondatra zibethicus*, is a potential limiting factor for some mussel species. For example, Muskrat predation appeared to be a major cause of death for the endangered Clubshell (*Pleurobema clava*) in the Tippecanoe River, Indiana (USFWS 1994). 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 locations (Neves and Odom 1989). In the U.S., the removal of Muskrats has been undertaken at some sites identified as important refugia for endangered mussels (W. A. Tolin, U.S. Fish and Wildlife Service, personal communication, February 1998). Although it is difficult to assess the impact of Muskrat predation on Ontario populations of *E. t. rangiana* without further investigation, some anecdotal information exists. During her 1973 visit to the Sydenham River, C. B. Stein (personal communication, September 1997) 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 species at the site, there is some evidence for the selection of "mid-sized" specimens or species

[defined as 45-65 mm in shell length according to Convey et al. (1989) and Neves and Odom (1989); 70-120 mm according to Watters (1993-1994)] such as *E. t. rangiana*. Regardless of whether *E. t. rangiana* is preferred by Muskrats or not, it is conceivable that muskrat predation could be a contributing factor to the decline in abundance of the subspecies in the Sydenham River. At the present low densities, any level of predation could jeopardize its continued existence.

Special Significance of the Species

Epioblasma torulosa rangiana is one of the last remaining members of a near-extinct genus (Hoggarth 1993). Without intervention, it will undoubtedly follow the same path. All members of the genus *Epioblasma* are riffle-dwellers, whose habitat is being relentlessly destroyed. The Sydenham River population of *E. t. rangiana* is one of only three remaining populations in North America that show evidence of recruitment (as noted earlier, the other two are in Pennsylvania). As such, its preservation is important for the global survival of the subspecies. The Sydenham and Ausable river populations are the northern-most populations of *E. t. rangiana* in North America, and may represent unique genetic variation for the species (Barr 1996*). The time for recovery action is now; three related species, *E. t. torulosa*, *E. turgidula* and *E. florentina florentina* were federally listed in the United States in 1976, but by the time a recovery plan was prepared for them in 1985 (USFWS 1985), all were presumed extinct.

Evaluation

Epioblasma torulosa rangiana has suffered dramatic declines in North America over the past century, with the current distribution representing a range reduction of more than 95%. It was listed as "Endangered" under the federal Endangered Species Act in the United States in 1993, and is globally ranked as G2T2. Its current sub-national ranks in the United States are SX in Illinois and Indiana, and S1 in all other jurisdictions (TNC 1997*; K.S. Cummings, Illinois Natural History Survey, personal communication, May 1998). Until recently, the subspecies was thought to be extirpated from Canada. However, remnant populations were discovered in the Sydenham and Ausable rivers in southwestern Ontario in 1997-1998, and it was subsequently downlisted from SH to S1 in Ontario. The historical range of the Northern Riffleshell in Canada once included western Lake Erie, Lake St. Clair and the Detroit River. The presence of Zebra Mussels throughout the Great Lakes precludes the recovery of *E. t. rangiana* throughout much of its original range.

The Sydenham River population of *E. t. rangiana* occupies a 50-km stretch of the middle reaches of the river. The population appears to be continuous, as most sites surveyed within this stretch produced live animals. Densities ranged from ~1 to 11 live individuals/4.5 p-h of sampling effort, which would be considered low to moderate according to density categories set by The Nature Conservancy (TNC 1996*) for this subspecies (low to moderate = 1-2 live individuals/2-3 survey hours). Live specimens found in 1997-1998 were of a wide range of shell sizes, which suggests that recruitment is still occurring. As the sex ratio was strongly biased towards males, however, continued reproductive success is far from certain. Comparisons with historical data suggest that abundance may have declined by as much as 90% over the past three decades. The Sydenham River population of *E. t. rangiana* was once believed to be the healthiest extant population in North America (Clarke 1978). It may still be stronger than the majority of existing occurrences in North America (G. T. Watters, Ohio State University, personal communication, March 1998). The once abundant Ausable River population of *E. t. rangiana* has been reduced in recent years to only a few scattered individuals, with no signs of reproduction. The future of the Ausable River population therefore appears bleak.

Members of the genus *Epioblasma* have suffered an extraordinarily high rate of extinctions over the years (USFWS 1985). All members "...are riverine and typically found in streams which are shallow with sandy-gravel substrate with rapid currents" (Stansbery 1971, as cited in USFWS 1985), which means that they are extremely vulnerable to impoundments, siltation and pollution. It is also possible that their fish host(s) have been adversely affected by some of these perturbations. As the fish host(s) for in *E. t. rangiana* in Canada are not known, the decline of host fish populations cannot be evaluated as a possible factor in the decline of the subspecies in this country. All rivers in Canada and the United States where *E. t. rangiana* is found are located in areas of intense agriculture and forestry, and are susceptible to runoff and siltation. Agricultural chemicals and siltation are likely the most significant threats to the continued existence of this subspecies in North America, notwithstanding the impact of the Zebra Mussel.

According to Biggins (1992*), *E. t. rangiana* faces global extinction within the next decade unless measures are taken soon to protect it. As Ontario harbours one of only three known reproducing populations in North America, it is recommended that the Northern Riffleshell be classified as Endangered both in Ontario and Canada. This manuscript is based on the reports to COSEWIC and COSSARO, but has been updated to incorporate new data collected in 1998.

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