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ABSTRACT. *The Grand River, a major tributary to Lake Erie in southwestern Ontario, historically supported a diverse and abundant freshwater mussel fauna, with 34 species recorded from the system since 1885. A recent study suggested that the number of species inhabiting the Grand River has declined over time. The present study provides a detailed assessment of changes over time in the diversity and distribution of mussels throughout the Grand River, by comparing the results of surveys conducted at 94 sites in 1995 and 1997–98 with those from a survey conducted 25 years earlier and with the historical data. Timed searches were conducted in both 1995 and 1997–98, using sampling efforts of 1.5 and 4.5 person-hours, respectively. Only 17 species had been found alive in 1970–72, probably because of the impacts of sewage from a rapidly-growing human population. At that time, only six species occurred in the lower reaches of the main stem. Mussel populations have since rebounded, with 25 species found alive throughout the system in 1995/1997–98, including 21 in the previously impoverished lower reaches. This recovery is attributed to significant improvements in water quality over the past 25 years. The recent addition of fishways to some of the dams and weirs on the river should improve the reproductive success of mussels, by eliminating barriers to the movement of host fishes. Although environmental conditions in the Grand River appear more favorable now for mussels than they have in decades, there is concern that the growing pressures of urbanization and agriculture may slow, stop, or even reverse these hard-won gains.*

INDEX WORDS: *Freshwater mussels, Unionidae, biodiversity, Grand River, water quality, trends.*

INTRODUCTION

According to The Nature Conservancy (TNC), freshwater organisms in North America have, as a whole, been far more impacted by human activities than terrestrial organisms (Master *et al.* 1998). In the United States, 37% of fishes, 51% of crayfishes, and 40% of amphibians are at risk of extinction, as compared with only about 15% of birds and mammals. Freshwater mussels are the most imperiled group of all, with 67% of species vulnerable to extinction or already extinct. Ontario's Natural Heritage Information Centre (NHIC), an affiliate of TNC that monitors the status of rare, threatened, and endangered species in Ontario, currently tracks 65% of native mussel species, as compared with only 30% of reptiles and fishes, 26% of mammals, 23% of amphibians, and 16% of birds (NHIC 1999). Unfortunately, most of our conservation efforts to date have been directed at terrestrial organisms. For example, Canada's committee on the Recovery of Nationally Endangered Wildlife focuses primarily on ". . . the protection and recovery of terrestrial vertebrates, which includes mammals, birds, reptiles and amphibians" (RENEW 1996/1997).

The most significant cause of the decline of

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freshwater mussels across North America is the destruction of their habitat by siltation, dredging, channelization, the creation of impoundments, and pollution (Williams *et al.* 1993). Reservoir construction in particular has eliminated the long reach of flowing water that is necessary for their survival. Dams alter water velocity and temperature downstream, and isolate upstream populations of mussels from their fish hosts (Biggins *et al.* 1995). Erosion due to deforestation, poor agricultural practices, and urban development cause an increase in siltation that can suffocate mussels, interfere with their feeding, and create unstable substrates (Dennis 1984). The continuing spread of the nonindigenous zebra mussel, *Dreissena polymorpha*, may drive many of the remaining species and populations of native mussels beyond the brink of extinction (Neves 1993).

The lower Great Lakes drainage basin historically supported the most unique and diverse mussel fauna in Canada. Approximately three-quarters of Canada's 53 native mussel species occur in this region, and 21 species are found nowhere else in the country (Clarke 1981). Metcalfe-Smith *et al.* (1998a) examined changes over time in the diversity and composition of mussel communities throughout the region using species occurrence records collected between 1860 and 1996. Their analysis revealed a pattern of species losses and changing community composition, particularly in the species-rich Lake Erie and Lake St. Clair drainages. River systems that once supported many species characteristic of a wide variety of habitats were now dominated by fewer, pollution-tolerant species. Data for the Grand River, which is a major tributary to Lake Erie in southwestern Ontario, appeared to reflect this general trend.

The Grand River is of national significance with respect to its mussel fauna. Over 60% of the mussel species in Canada, including the federally-endangered wavy-rayed lampmussel, *Lampsilis fasciola* (Metcalfe-Smith *et al.* 2000b), include the Grand River in their ranges (Clarke 1981). This study provides an in-depth assessment of changes over time in the diversity and distribution of freshwater mussels throughout the Grand River system. Results of surveys conducted at 70 sites in 1995 and 24 sites in 1997–98 are compared with those from a survey conducted 25 years earlier and with the historical data. The most likely causes of the changes observed are identified. Data from the 1995 survey, but not the 1997–98 survey, were considered in the earlier assessment by Metcalfe-Smith *et al.* (1998a).

METHODS

Study Area

The Grand River watershed is the largest watershed in southwestern Ontario, contributing 10% of the drainage to Lake Erie (GRCA 1998). The river drains an area of 6,800 km^2 and flows over a distance of 298 km from source (near the Village of Dundalk) to mouth (at Port Maitland on Lake Erie), with a drop in elevation of approximately 352 m (Coker and Portt 1999). For the purpose of this study, the river was divided into three regions—Upper Region (UR), Middle Region (MR), and Lower Region (LR)—corresponding to the designations of Kidd (1973; Fig. 1).

The Grand River is joined by three major tributaries in the UR (Conestogo River, Willow Brook, Irvine Creek), two major tributaries in the MR (Nith River, Speed-Eramosa River), and three major tributaries in the LR (Mackenzie-Boston Creek, Fairchild Creek, Big Creek; Fig. 1). There are numerous smaller tributaries emptying into the major tributaries and the main stem, especially in the UR.

An estimated 787,000 people were living in the Grand River watershed in 1996, primarily in the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo (GRCA 1998; Fig. 1). Eighty-one percent of the population occupies only 7% of the land, and 93% of the watershed is considered rural (GRCA 1998).

Historical Data

The National Water Research Institute's Lower Great Lakes Unionid Database was used to identify historical species occurrence records for mussels in the Grand River. At present, the database consists of approximately 5,000 records for mussels collected from the lower Great Lakes drainage basin since 1860 (Metcalfe-Smith *et al.* 1998a provide a description of the database and its data sources). A record is defined here as the occurrence of a given species at a given location on a given date. Nearly 900 records dating back to 1885 were identified for the Grand River, excluding those collected during the present study. About 40% of the records were based on collections made between 1885 and 1969. Information on sampling location, sampling effort, and/or whether or not the specimens were collected alive, was missing or incomplete for most of these records. Abundance data were virtually absent. As a result, the "historical" (pre-1970) data were only

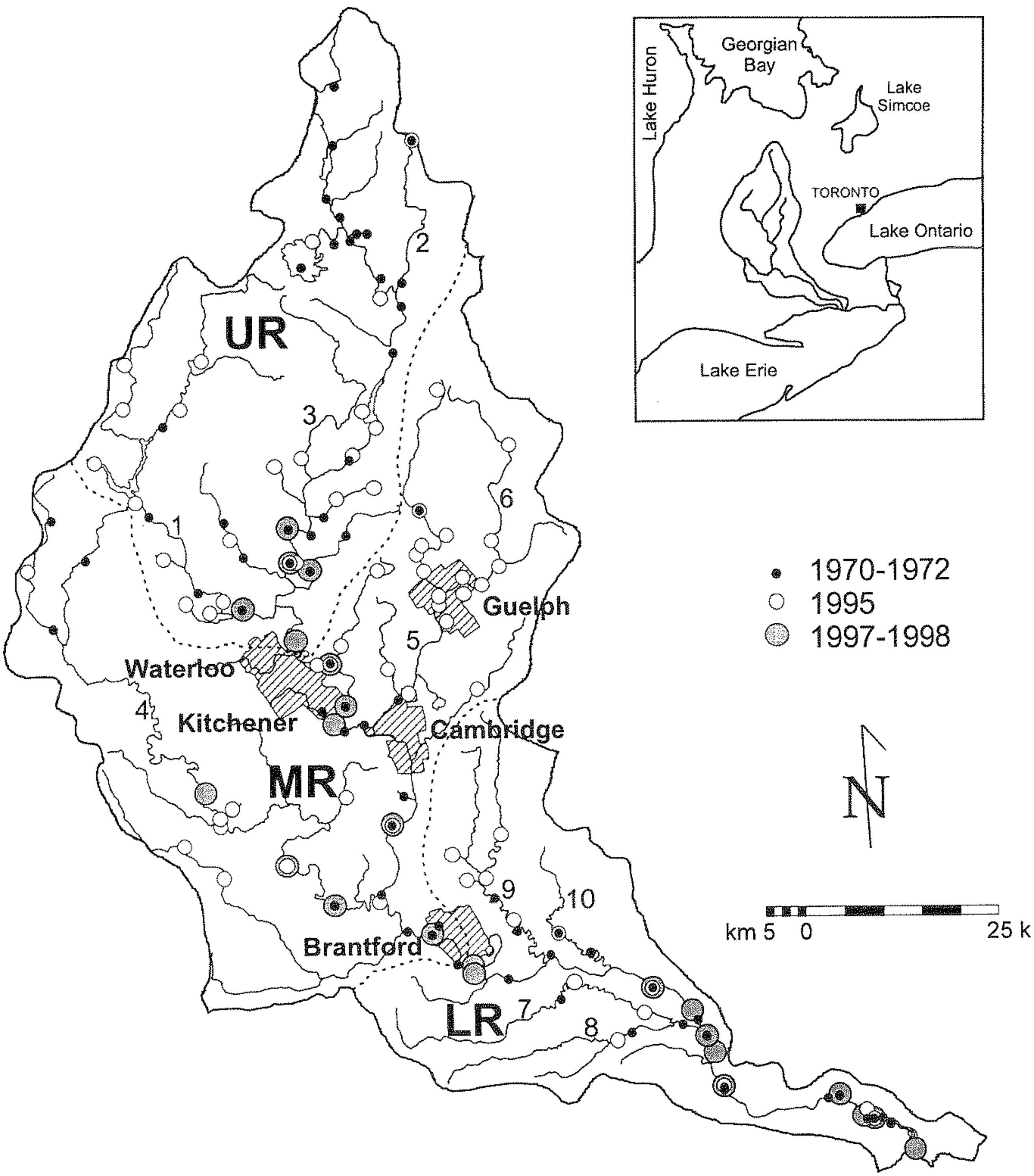

FIG. 1. Grand River watershed showing locations of sites surveyed for mussels in 1970-72 (by Kidd 1973), 1995 and 1997-98. UR = Upper Region; MR = Middle Region; LR = Lower Region. Major tributaries are: 1 = Conestogo River, 2 = Willow Brook, 3 = Irvine Creek, 4 = Nith River, 5 = Speed River, 6 = Eramosa River, 7 = McKenzie Creek, 8 = Boston Creek, 9 = Fairchild Creek, and 10 = Big Creek. Locations of the five major urban centres are shown.

TABLE 1. Selected information on the site locations, sampling efforts, and results of mussel surveys conducted on the Grand River in 1970–72, 1995, and 1997–98.

	1970-72	1995	1997-98
No. of sites surveyed	68[a]	70	24
No. of sites where live mussels found	48	47	23
No. of sites on tributaries	31	59	5
No. of sites on main stem	37	11	19
Total no. live mussels found	917	479	1,568
Total no. shells collected	2,304	few[b]	few[b]
Sampling effort (person-hours)	see text	1.5	4.5
Mean no. live mussels found/site[c]	19	10	68
Mean no. live species found/site[c]	3.0	2.5	6.0
Overall species diversity (live)	17	18	25

[a]115 sites were actually surveyed, but no information is available for 47 of these sites (see text); [b]for taxonomic verification and/or to confirm past occurrence; [c]excludes sites where no living mussels of any species were found (see text).

used to indicate which mussel species had inhabited the Grand River in the past.

One of the most comprehensive surveys of the mussel fauna of the Grand River was conducted by Kidd (1973), who visited 115 sites on the main stem and major tributaries between 1970 and 1972. For 68 of these sites (Fig. 1) he recorded the sampling location and the diversity and abundance of live specimens and shells collected. Approximately half of these sites were on tributaries and half on the main stem (Table 1). No information on the remaining 47 sites was provided, possibly because neither live mussels nor shells were found. Voucher specimens were deposited in the Canadian Museum of Nature (CMN), Ottawa, Ontario. Although Kidd (1973) did not specify the amount of time he spent collecting at each site, the description of his sampling effort suggests it was considerable: "Collecting usually began along one shoreline and proceeded upstream gradually going further from shore. At a depth of approximately one and a half meters, collecting continued upstream, but gradually proceeded toward shallow water again. This zig-zag pattern continued for approximately 75 meters along the shores of large river habitats, 50 meters along medium-sized rivers and at least 25 meters in creeks and streams. The pattern was reversed when returning to the starting position, in order to collect in previously unsampled areas." Kidd used a variety of sampling methods, depending on depth, flow, water clarity, and substrate composition. In clear, shallow water, he conducted a visual search using a glass bottom bucket and polarized sunglasses; at a few sites with clear, deep water, he sampled by snorkeling; in muddy water, he sampled by feel and also scraped the bottom with a net; at a few sites where the river was fast-flowing and wide, he dropped an Ekman dredge off a bridge. Because Kidd's (1973) survey was extensive, thorough, well-documented, and conducted approximately 25 years ago, it provided an excellent basis of comparison with the present surveys to determine if the mussel communities of the Grand River have changed over time. About 100 scattered records are available from the period 1972–1995, but no formal surveys were conducted. As these records did not include any new species, they were not considered further.

Present Surveys

Two independent mussel surveys were conducted. The first was an extensive survey of 70 sites in 1995, and the second was an intensive survey of 24 sites in 1997–98. Selected information about both surveys is summarized in Table 1; further details about the sampling sites and methods are available in Mackie (1996) for the 1995 survey and in Metcalfe-Smith *et al.* (1998b, 1999) for the 1997–98 survey. There are a number of similarities between the two surveys, but also several important differences.

The locations of all sampling sites from both surveys are shown in Figure 1. The 1995 survey encompassed a larger area of the drainage basin than the 1997–98 survey. While 85% of the sites surveyed in 1995 were on tributaries, 80% of those surveyed in 1997–98 were on the main stem. Thus, good coverage of the drainage basin was obtained by combining the results of the two surveys. Both surveys were conducted to determine if there have been changes over time in the diversity and distribution of mussels in the Grand River drainage. The timed search sampling method was used in both cases.

The 1995 survey was conducted by a three-person team. Each person visually searched each site for 0.5 h, for a total sampling effort of 1.5 person-hours (p-h) per site. Another 1.5 p-h of searching was necessary at sites greater than stream order 4 (about 15% of the sites) to search the deep areas with scoop nets. Four sites were sampled by both the timed search method and quadrat method (five 1 m^2 quadrats taken at random locations). At two deep sites near the mouth of the Grand River, 10 to 13 quadrats were sampled by SCUBA divers. The 1997–98 survey was also conducted by a three-person team, none of whom had been involved in the 1995 survey. As this survey focused more specifically on detecting rare species, a greater sampling effort was used: each person searched for a period of 1.5 h, for a total sampling effort of 4.5 p-h per site. At most sites, the riverbed was visually searched using waders, polarized sunglasses, and Waterview™ underwater viewers. At three fairly deep and silty sites in the lower Grand River, garden rakes were drawn through the silt until the tines touched a mussel, which the surveyor then retrieved. Two other deep, lower river sites were surveyed by two divers for a period of 1 h, for a total sampling effort of 2.0 p-h. As diving is generally considered to be the most efficient sampling method for mussels, it was estimated that 2 p-h of diving was roughly equivalent to 4.5 p-h of searching while wading. With the exception of *Truncilla donaciformis*, all species detected by divers were also detected by wading or raking at other lower rivers sites.

All live mussels collected during both the 1995 and 1997–98 surveys were identified to species and returned to the river alive, with the exception of a very few animals that were sacrificed for voucher specimens. Shells were also collected, but not in a quantitative manner. In 1995, all shells were kept if only a few were present; otherwise, only representative shells were kept. In 1997–98, only a few shells of the common species and most or all shells of rare species were retained from each site. The purpose of collecting shells was to confirm taxonomic identifications, and to provide evidence that a species had occurred at, or upstream of, the study site sometime in the past.

Although the 1970–72, 1995 and 1997–98 surveys employed similar sampling methods, differences in sampling effort may have implications for determining trends over time. For example, it must have taken Kidd (1973) a great deal of time to collect over 2,300 shells. It is possible that this activity interfered with the amount of time he spent searching for live mussels. Also, the search time used in the 1997–98 survey was three times longer than that used in the 1995 survey. Judging by the information presented in Table 1, the 1970–72 and 1997–98 surveys were more comprehensive than the 1995 survey.

RESULTS

Changes in the Diversity of the Grand River Mussel Community Over Time

A total of 34 species of freshwater mussels have been reported from the Grand River since 1885, according to records from the Lower Great Lakes Unionid Database. Records for two species, *Elliptio complanata* and *Lampsilis radiata radiata*, appear to be erroneous as these are Atlantic drainage species that should not occur here. The *E. complanata* specimens were collected by E.M. Walker and J.P. Oughton in 1934 and deposited in the Royal Ontario Museum (ROM Catalogue No. M2299). *Lampsilis radiata radiata* was collected on two occasions, and voucher specimens were deposited in the CMN; it was collected by J. Macoun in 1894 and identified by C.B. Stein, Ohio State University Museum of Biological Diversity (CMN Catalogue No. 002521), and by A.H. Clarke and L.R. Clarke in 1958 (CMN Catalogue No. 014323). Because these specimens were identified by expert malacologists, it was decided to include both *E. complanata* and *L. r. radiata* in the species list for the Grand River (Table 2).

Kidd (1973) found 17 live species and the shells of 11 others in the Grand River in 1970–72 (Table 2). A total of 25 species were found alive during the present surveys, including all of those found in 1970–72. Three other species were represented by shells only. All 18 species that were found alive in 1995 were also found alive in 1997–98. No live animals or shells of *E. complanata*, *Epioblasma triquetra*, *L. r. radiata*, *Lasmigona complanata complanata*, or *Obovaria olivaria* were found during any of these surveys. Shells of *Ptychobranchus fasciolaris* and *Utterbackia imbecillis* were found in 1970–72 and again in 1997–98, but no live specimens were encountered. Kidd (1973) found one shell of *Obovaria subrotunda*, but it was not seen during either of the later surveys. The only occurrence of *Ligumia nasuta* was one half shell in 1995.

Of the eight species found alive in 1995 and/or 1997–98 but not in 1970–72, four appear to be quite rare at present: *Toxolasma parvus* and *T. donaciformis* were each found at only one of the 94 sites surveyed, while *Obliquaria reflexa* and *Pleurobema sintoxia* were each found at three sites. However, the other four species, *Lampsilis*

TABLE 2. Mussel species known historically (1885 to 1969) from the Grand River drainage, and their occurrence as live animals (L) or shells (S) during the surveys of 1970-72 and 1995/1997-98. The provincial conservation status rank (S-RANK) for each species is also shown.

	S-RANK[a]	1970-72	1995/1997-98
Subf. Ambleminae:			
Amblema plicata plicata	S4	L	L
Elliptio complanata	S5	—[b]	—
Elliptio dilatata	S5	L	L
Fusconaia flava	S2S3	L	L
Pleurobema sintoxia	S1	S	L
Quadrula pustulosa pustulosa	S3	S	L
Quadrula quadrula	S3	L	L
Subf. Anodontinae:			
Alasmidonta marginata	S3	L	L
Alasmidonta viridis	S3	L	L
Anodontoides ferussacianus	S4	L	L
Lasmigona complanata complanata	S4	—	—
Lasmigona compressa	S5	L	L
Lasmigona costata	S5	L	L
Pyganodon grandis	S5	L	L
Strophitus undulatus	S5	L	L
Utterbackia imbecillis	S2	S	S
Subf. Lampsilinae:			
Actinonaias ligamentina	S3	L	L
Epioblasma triquetra	S1	—	—
Lampsilis fasciola	S1	L	L
Lampsilis cardium	S4	S	L
Lampsilis radiata radiata	S4	—	—
Lampsilis radiata siliquoidea	S5	L	L
Leptodea fragilis	S4	S	L
Ligumia nasuta	S2S3	—	S
Ligumia recta	S3	L	L
Obliquaria reflexa	S1	S	L
Obovaria olivaria	S1	—	—
Obovaria subrotunda	S1	S	—
Potamilus alatus	S3	L	L
Ptychobranchus fasciolaris	S1	S	S
Toxolasma parvus	S1	S	L
Truncilla donaciformis	S2	S	L
Truncilla truncata	S3	S	L
Villosa iris	S2S3	L	L

[a]S1 = extremely rare (≤ 5 occurrences), S2 = very rare (5-20 occurrences), S3 = rare to uncommon (20-100 occurrences), S4 = common (>100 occurrences), S5 = very common (demonstrably secure at present); ranks courtesy of D.A. Sutherland, NHIC, Peterborough, ON, September 1999

[b]neither live specimens nor shells found

cardium, *Leptodea fragilis*, *Quadrula pustulosa pustulosa*, and *Truncilla truncata* were relatively common: 46 specimens of *L. fragilis* were found at nine sites, 41 *Q. p. pustulosa* at seven sites, 62 *T. truncata* at six sites, and 12 *L. cardium* at five sites. While some species have become more abundant in recent years (153 *Quadrula quadrula* were found alive in 1995/1997–98 vs. only 10 in 1970–72), others have experienced declines (only one specimen of *Villosa iris* was found at each of two sites in 1995/1997–98, whereas 15 animals had been collected from six sites in 1970–72).

Changes in the Composition of the Grand River Mussel Community Over Time

Changes in the composition of the mussel community over time were assessed by comparing the combined results of the 1995 and 1997–98 surveys with those of Kidd's (1973) 1970–72 survey. Trends were examined separately for tributary sites and main stem sites within each of the three regions of the river, because it is well known that different species of mussels are associated with different sizes of rivers and streams (Dennis 1984). The presence/absence of each species in each time period is presented in Table 3 for the six sections of the river (UR tributaries, UR main stem, MR tributaries, etc.), while Figure 2a–f shows the percent of sites occupied by each species in each time period for each river section. Sites where no live mussels were found were excluded from the totals used to calculate these percentages, because such sites may not have offered suitable habitat for any species.

Mussel communities in the UR have changed little over time. All of the species found alive in the tributaries of the UR in 1970–72 were also found in 1995/1997–98 and vice versa, except that *L. fasciola* and *V. iris* were found in 1995/1997–98 but not 25 years earlier (Table 3). There were changes in the frequency of occurrence of several species: *Lasmigona compressa*, *Pyganodon grandis*, *Strophitus undulatus*, and *Alasmidonta viridis* were found at a greater proportion of sites in the tributaries of the UR in 1970–72 than 1995/1997–98, whereas *Elliptio dilatata, Lasmigona costata,* and *Lampsilis siliquoidea* were found more often during the later surveys (Fig. 2a).

All species found in the main stem of the UR in 1970–72 were also found in 1995/1997–98, but several species, including *L. costata*, *L. siliquoidea,* and *Anodontoides ferussacianus*, were more frequently encountered during the recent surveys (Fig. 2b). These comparisons may be inappropriate, since Kidd (1973) surveyed more sites in the headwaters but fewer sites on the Conestogo River than were surveyed in 1995/1997–98 (Fig. 1).

With the exception of *L. fragilis*, all species found in the tributaries of the MR in 1995/1997–98 were also found in 1970–72 (Table 3). Many more sites were surveyed in this section than by Kidd (23 vs. 6), but most were on the Speed-Eramosa system that Kidd (1973) sampled at only two locations. Nevertheless, the only notable difference between time periods was that *P. grandis* and *S. undulatus* were found at a greater proportion of sites in 1970–72 than in 1995/1997–98 (Fig. 2c).

In general, the main stem of the MR is depauperate. Only six species were found alive in this region in 1970–72, and only nine species were found in 1995/1997–98 (Table 3, Fig. 2d). One of the species found alive in 1997–98 was the federally endangered *L. fasciola*. Interestingly, Kidd (1973) actually found live mussels at more sites than in this study in this section of the river (8 of 11 sites vs. 4 of 9 sites).

A similar number of species was found alive in the tributaries of the LR in 1970–72 and 1995/1997–98 (10 vs. 11), but many of the species differed. *Villosa iris, E. dilatata,* and *S. undulatus* were found in 1970–72, while *A. ferussacianus*, *L. fragilis*, *A. viridis,* and *L. compressa* were found in 1995/1997–98. Most species were encountered infrequently in both time periods (Fig. 2e); however, it seems significant that *V. iris* was found at 60% of the sites surveyed in 1970–72, but was absent from all nine sites surveyed in 1995/1997–98.

The most dramatic changes over time in the mussel community of the Grand River have occurred in the main stem of the LR. Over three times as many species were found alive in this reach in 1995/1997–98 than in 1970–72 (Table 3). Fourteen species represented by shells only in Kidd's collections, and two others that he found no trace of, were found alive in 1995/1997–98. Many of these species were found quite frequently in the later time period (Fig. 2f). Furthermore, live mussels were found at 80% of the sites surveyed in this reach in 1995/1997–98, whereas Kidd found live animals at only 38% of his sites. With the exception of *A. ferussacianus*, all species found alive in 1970–72 were also found alive in 1995/1997–98.

Site-specific Comparisons

Fourteen sites were surveyed in both 1970–72 and 1997–98, so the mussel communities inhabiting these sites could be directly compared between time periods. Four sites were located in the UR, five sites in the MR, and five sites in the LR. Three other sites that were surveyed in both 1970–72 and 1995 were not considered, because of the lower sampling effort in 1995.

Mussels were more abundant in 1997–98 than 1970–72 at 11 of the 14 sites, and at 10 of these sites species richness was also greater (Table 4). Species richness differed significantly between the two time periods (< 0.05) but abundance did not,

TABLE 3. Mussel species found alive (L) or as shells only (S) in the tributaries and main stem of three regions of the Grand River drainage in 1970-1972 and in 1995/1997-98.

	Upper Region (UR)				Middle Region (MR)				Lower Region (LR)			
	Tributaries		Main stem		Tributaries		Main stem		Tributaries		Main stem	
Species	1970–1972	1995/1997–1998	1970–1972	1995/1997–1998	1970–1972	1995/1997–1998	1970–1972	1995/1997–1998	1970–1972	1995/1997–1998	1970–1972	1995/1997–1998
Actinonaias ligamentina	—[a]	—	—	—	L	L	L	L	L	L	S	L
Alasmidonta marginata	S	S	L	L	L	L	L	L	S	—	S	L
Alasmidonta viridis	L	L	L	L	L	L	S	S	S	L	—	L
Amblema p. plicata	—	—	—	—	—	—	—	—	L	L	L	L
Anodontoides ferussacianus	L	L	L	L	L	L	—	—	—	L	L	—
Elliptio dilatata	L	L	L	L	L	L	S	S	L	—	S	S
Fusconaia flava	—	—	—	—	—	—	L	S	L	L	L	L
Lampsilis fasciola	—	L	L	L	S	S	S	L	—	—	—	S
Lampsilis cardium	—	—	—	—	—	—	S	L	S	—	S	L
Lampsilis siliquoidea	L	L	L	L	L	L	L	L	L	L	S	L
Lasmigona compressa	L	L	L	L	L	L	S	S	—	L	—	L
Lasmigona costata	L	L	L	L	L	L	L	L	L	L	S	L
Leptodea fragilis	—	—	—	—	—	L	—	—	—	L	S	L
Ligumia nasuta	—	—	—	—	—	—	—	—	—	S	—	—
Ligumia recta	—	—	—	—	—	—	—	L	L	L	S	L
Obliquaria reflexa	—	—	—	—	—	—	—	—	—	—	S	L
Obovaria subrotunda	—	—	—	—	—	—	—	—	—	—	S	—
Pleurobema sintoxia	—	—	—	—	—	—	—	—	—	—	S	L
Potamilus alatus	—	—	—	—	—	—	—	—	S	—	L	L
Ptychobranchus fasciolaris	—	—	—	—	—	—	—	—	—	—	S	S
Pyganodon grandis	L	L	L	L	L	L	S	L	L	L	L	L
Quadrula p. pustulosa	—	—	—	—	—	—	—	—	—	—	S	L
Quadrula quadrula	—	—	—	—	—	—	—	—	—	—	L	L
Strophitus undulatus	L	L	L	L	L	L	L	L	L	—	S	L
Toxolasma parvus	—	—	—	—	—	—	—	—	—	—	S	L
Truncilla donaciformis	—	—	—	—	—	—	—	—	—	—	S	L
Truncilla truncata	—	—	—	—	—	—	—	S	—	—	S	L
Utterbackia imbecillis	—	—	—	—	—	—	—	—	—	—	S	S
Villosa iris	S	L	L	L	—	S	S	—	L	—	S	S
Number of species found alive	8	10	11	11	10	11	6	9	10	11	6	21
Number of species found dead	2	1	0	0	1	2	7	5	4	1	19	5
Number of sites surveyed	15	24	13	6	9	31	11	9	7	9	13	15
Number of sites with live mussels	12	16	11	5	6	23	8	4	6	6	5	12

[a]neither live specimens nor shells found

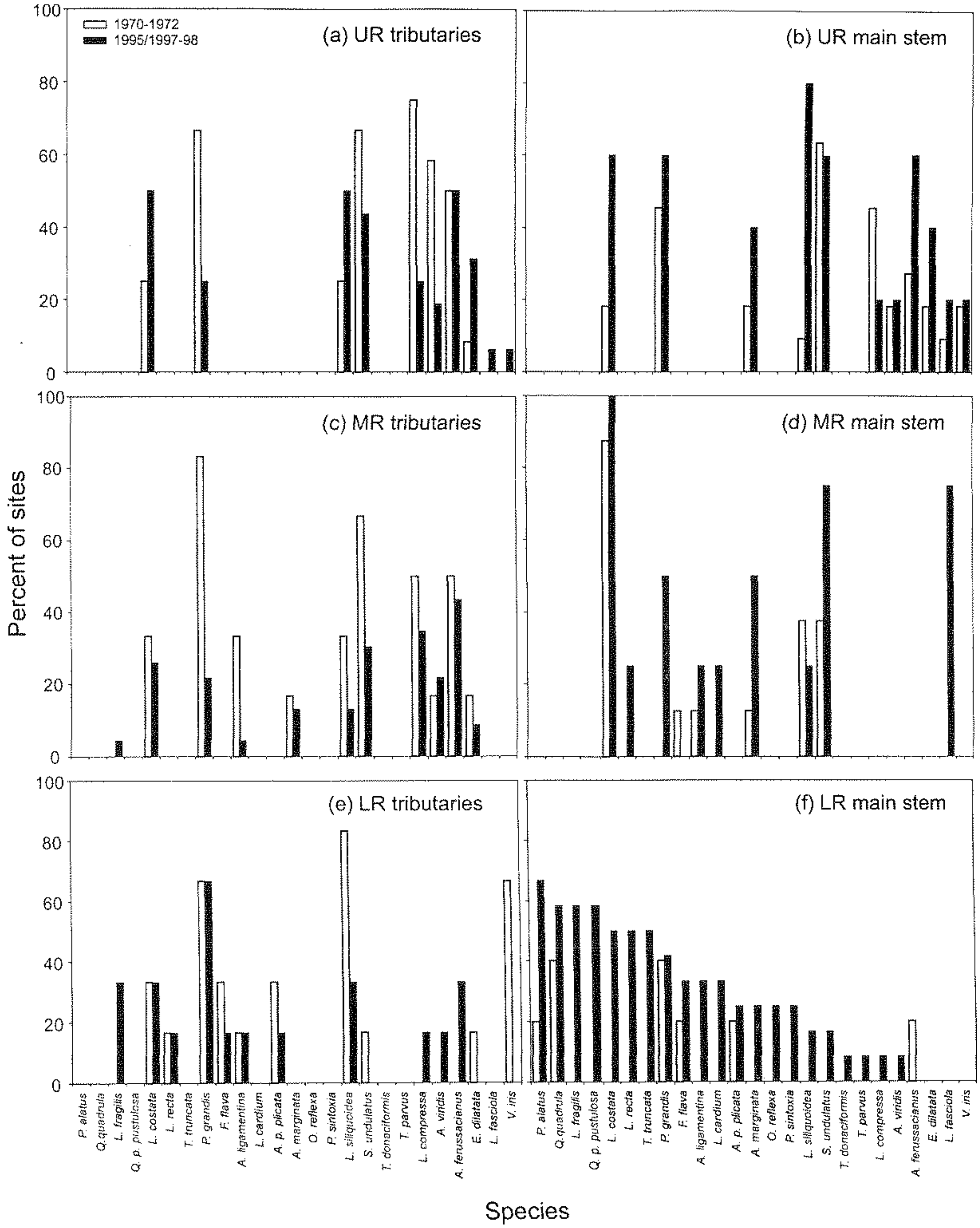

FIG. 2. Percent of sites where each species was found alive in the Grand River in: (a) tributaries of the Upper Region (UR) in 1970-72 (n = 12) and 1995/1997-98 (n = 16); (b) the main stem of the UR in 1970-72 (n = 11) and 1995/1997-98 (n = 5); (c) tributaries of the Middle Region (MR) in 1970-72 (n = 6) and 1995/1997-98 (n = 23); (d) the main stem of the MR in 1970-72 (n = 8) and 1995/1997-98 (n = 4); (e) tributaries of the Lower Region (LR) in 1970-72 (n = 6) and 1995/1997-98 (n = 6); (f) the main stem of the LR in 1970-72 (n = 5) and 1995/1997-98 (n = 12). Only those sites where live mussels were found are included in "n" (see text).

TABLE 4. Diversity and abundance of live mussels observed at 14 sites in the Grand River drainage during two surveys conducted approximately 25 years apart.

	1970–72		1997–98	
	No. Species	No. Mussels	No. Species	No. Mussels
Upper Region (UR):				
70-4[a] and GR-18[b]	7	16	7	354
70-2 and GR-13	7	78	8	288
70-3 and GR-15	6	168	5	70
71-77 and GR-23	0	0	4	14
Middle Region (MR):				
70-1 and GR-20	0	0	4	8
72-4 and GR-12	1	9	4	44
72-5 and GR-2	2	17	0	0
71-72 and GR-8	8	54	5	21
72-7 and GR-9	3	3	7	39
Lower Region (LR):				
72-9 and GR-4	0	0	5	16
72-10 and GR-21	0	0	10	133
72-11 and GR-10	1	1	4	12
71-61 and GR-11	2	5	3	61
71-104 and GR-7	2	12	4	33

[a]site number assigned in 1970-72; [b]site number assigned in 1997-98

based on the results of a two-sided Wilcoxon Signed Rank Test (Kvanli 1988). More species and more individuals were consistently found in the LR during the later survey. All five LR sites were located in a 40 km stretch of the main stem between Caledonia and Dunnville. At one site near the middle of this reach, where no living mussels had been found in 1970–72 (site 72-10), 133 mussels of 10 different species were recorded in 1997–98. The largest number of species found at any site in the system in 1997–98 was 12, and both sites that supported 12 species were in this reach (Metcalfe-Smith *et al.* 1998b, 1999).

There were three sites where fewer species and fewer individuals were found in 1997–98 than 1970–72; namely, site GR-15 on Cox Creek, site GR-2 at Glen Morris, and site GR-8 near Canning on the Nith River. Kidd (1973) found only one more species but many more individuals at the Cox Creek site, as well as three more species and twice as many individuals at the Nith River site. He also found 17 individuals of two species at Glen Morris, whereas no living mussels were found in 1997–98.

Conservation Status of Grand River Mussel Species

There are 40 species of freshwater mussels native to Ontario, 34 of which occur (or once occurred) in the Grand River. The conservation status ranks, or S-RANKs, for the Grand River species are presented and defined in Table 2. Ontario's NHIC ". . . compiles, maintains and provides information on rare, threatened and endangered species and spaces in Ontario" (NHIC 1994). The NHIC uses a ranking scheme developed by TNC to assign S-RANKs to rare species on the basis of their known distribution and abundance in the province. Ranking is a dynamic process, whereby ranks are continually revised as new information becomes available. Species ranked as SH (known from historical records only), S1, S2, and S3 are actively tracked by the NHIC. A total of 21 species, or 62% of the Grand River mussel fauna are sufficiently rare that they are currently tracked by the NHIC.

DISCUSSION

One of the earliest written accounts of the mussels of the Grand River was by Detweiler (1918), who investigated the distribution and abundance of large, thick-shelled species that could be used in the pearl button industry. By 1916, which was the peak year of button production in the United States (Fassler 1997), a small mussel fishery had been established in the lower Grand River. Detweiler (1918) reported that 265 tons of live mussels had been taken from the Port Maitland area in 1915, and

260 tons from a location above Dunnville in 1916. He provided anecdotal evidence that large mussel beds could also be found near Brantford, between Brantford and Paris, and throughout the Speed River. Several later publications (e.g., La Rocque and Oughton 1937, Robertson and Blakeslee 1948) cataloged and described various collections of mussels from the Grand River that are now held by the CMN, ROM, University of Michigan Museum of Zoology, Ohio State University Museum of Biological Diversity, Buffalo Museum of Science, and Rochester Museum and Science Center. These collections were personally examined by Kidd (1973), who compared the distribution and abundance of mussels in the river historically (1885–1969) with the results of his own surveys in 1970–72. As data were available from approximately 70 sites in both time periods, he considered these comparisons valid.

Kidd (1973) found that the number of species living in the river had declined dramatically from a historical total of 31 (he did not include *E. complanata*, *L. r. radiata*, or *L. c. complanata* in his species list) to only 17 by 1970–72. All of the species losses occurred in the LR of the river. Historically, the greatest diversity of species had been found in the LR (25), with only five (mostly different) species occurring in each of the MR and UR. According to van der Schalie (1938), an increase in species diversity with increasing river size is the typical distribution pattern for mussels in a healthy river system. By 1970–72, this pattern had been reversed. Kidd (1973) found 11 species living in UR, six species in the MR, and only six species in the LR. He attributed the apparent increase in diversity over time in the UR and MR to a scarcity of historical data for these regions; i.e., to a sampling artifact. He also noted that many collectors did not survey the tributaries, so he did not attempt to draw conclusions about changes in mussel distributions in the tributaries. However, his observations for the LR are striking. Fully 19 species that had been found alive in this region in the past were missing from the collections of 1970–72, although a few of these species still occurred in other regions or the tributaries.

Kidd (1973) blamed the loss of mussel species from the Grand River on a combination of factors, including pollution, siltation, the presence of dams and reservoirs, and the mussel fishery. The latter factor can be discounted, as the fishery was very short-lived and most historical records were collected after it had closed. As noted earlier, dams impact mussel communities by destroying their habitat and restricting the free movement of their fish hosts. Kidd (1973) found few mussels living below dams or in the reservoirs in 1970–72, and noted that none of the dams or weirs in the system had fishways. He also examined provincial water quality data for the Grand River for the period 1964 to 1971, and found that dissolved oxygen concentrations were low and turbidity was high in the lower reaches of the river. He speculated that several high turbidity events (300–640 JTU), which were probably caused by runoff from agricultural lands, may have decimated the mussel community at some sites.

Sewage pollution was probably the major cause of the decline of mussels in the Grand River. It is well-known that sewage has an adverse effect on mussel communities (Fuller 1974). Kidd (1973) conducted his surveys at a time when significant improvements to sewage treatment were underway. He compared the sewage treatment facilities of 22 cities, towns and villages in the watershed in 1962 vs. 1972, and found that only seven had primary and secondary treatment in both years. Seven others had improved their treatment (from no treatment to primary treatment, or from primary to secondary treatment) during this decade, while eight others were in the process of installing new facilities in 1972. Freshwater mussels are slow-growing and sedentary, and must rely on the movements of their host fishes for the dispersal of their young. Neves (1993) stated that "Establishment of stable, self-sustaining populations, therefore, requires decades of immigration and recruitment . . ." and that "This extremely slow rate of population growth and attainment of carrying capacity makes recovery of decimated populations extremely difficult . . .". The mussel community in the Grand River may have just begun to respond to improvements in water quality at the time of Kidd's (1973) surveys in the early 1970s.

Combined results of the mussel surveys of 1995 and 1997–98 show that the mussel communities of the Grand River have rebounded over the past 25 years. A total of 25 species were found alive during these surveys, including eight that were not detected by Kidd (1973). Thirty-four species were known historically from the Grand River, suggesting that nine species, or 26% of the fauna, have been lost. This could be misleading, though, since most of the apparently extirpated species were known from only a few past records. Of the eight species found alive during the present surveys but missing from the collections of 1970–72, four are still very rare and could easily have been missed by Kidd (1973). However, the other four now occur with sufficient frequency and abundance to make it clear they are recovering. All but three of the 14 sites in various regions of the river that were surveyed in both 1970–72 and 1997–98 support a richer and more productive mussel community now than they did 25 years ago.

Changes in the diversity and composition of the mussel communities of the Grand River have been greatest in the LR, and are more pronounced in the main stem than the tributaries in both the MR and LR. Communities in the tributaries and main stem of the UR, as well as tributaries of the MR, changed very little during this period. Species richness increased over time in the main stem of the MR, suggesting that environmental conditions have generally improved in this reach. Although similar numbers of species were found in the tributaries of the LR, only seven species (50%) were common to both time periods. Whether this change in species composition reflects an improvement or worsening of conditions is not known. However, the loss of *V. iris,* which is known to be sensitive to environmental pollutants (Goudreau *et al.* 1993, Jacobson *et al.* 1997), implies the latter.

Recolonization of the LR of the main stem over the past 25 years has been particularly remarkable. Twenty-one species were found alive in this region in 1995/1997–98, which is 15 more than found alive by Kidd (1973) and only 4 fewer than historically known from the region. Sixteen species have apparently recolonized the main stem of the LR over the past 25 years, pointing to a dramatic improvement in mussel habitat in this reach. Many of these species are now relatively common and abundant (Metcalfe-Smith *et al.* 1998b, 1999). *Amblema plicata plicata*, *A. ferussacianus*, *Fusconaia flava*, *P. grandis*, *Potamilus alatus*, and *Q. quadrula* were living in the LR at the time of Kidd's (1973) surveys, suggesting that they may be among the most pollution-tolerant species in the river. Even some of these species have become more abundant in recent years.

The mussel community of the Grand River appears to be much healthier than was predicted from the results of an earlier comparison of historical and recent data (Metcalfe-Smith *et al.* 1998a). This discrepancy may be related to sampling effort. The earlier analysis considered the results of the 1995 survey, but not those of the 1997–98 survey, which used three times the sampling effort. Only one more species was found alive in the river in 1995 than in 1970–72, and only two more species were found alive in the LR of the river. One would conclude from these comparisons that the community had changed little over the 25-year period. However, eight more species were found alive in 1997–98 than in 1970–72, and 14 more species were found alive in the LR, clearly showing that community health has improved. The issue of sampling effort is critical to assessing the conservation status of mussel communities, and has been dealt with elsewhere (Metcalfe-Smith *et al.* 2000a).

Recovery of the Grand River's mussel community over the past 25 years probably reflects significant improvements in water quality during the same time period. According to the Grand River Conservation Authority (GRCA 1998), water quality throughout much of the watershed was poor during the late 1960s and early 1970s. The main sources of pollution were municipal and industrial effluents, urban development, and agricultural activities. Conditions generally improved by the mid-1970s, then deteriorated again slightly in the mid-1980s, probably in response to the growing human population in the basin. By the late 1990s, conditions were described as satisfactory or good throughout the basin, and excellent in the most upstream reaches. Gunning and Suttkus (1985) reported that mussel communities in the heavily-polluted Pearl River, Louisiana, became reestablished within 10 years of the installation of water treatment facilities for domestic and industrial effluents. Numbers of "clean water" species of other invertebrates and fishes increased during the same period. The fish community in the Grand River has also responded to improvements in water and habitat quality. According to Coleman (1991), only 16 species were found in the river during a 1972 survey, but that number jumped to 26 by 1977 and has remained high. The Grand and its major tributaries now support a diverse warmwater fish community, and recent stream rehabilitation projects, as well as improvements in land use practices, have opened up new areas to coldwater species (GRCA 1998). The recovery of mussel communities in the Grand River is undoubtedly linked to the recovery of host fish populations.

The Grand River is significantly impounded, having 34 water control structures—ranging from overflow weirs to large multi-purpose dams—along its course (GRCA 1998). According to Watters (1995), dams as low as 1 m may prevent the upstream movement of some fishes, thus limiting the dispersal of mussels that use these fishes as hosts.

Fishways were constructed on the Nith River at New Hamburg in 1991 and at the Dunnville Dam in the lower river in 1994 to allow the passage of both jumping and non-jumping fish species. With the removal of these barriers to fish movement, there is potential for an improvement in the reproductive success of some mussel species.

Although conditions in the Grand River appear more favorable now for mussels than they have in decades, they are poised to worsen on several fronts. The population in the watershed continues to grow at a rapid rate. In 1971, the population was approximately 375,000 (Kidd 1973); by 1996 it had doubled to 787,000 (GRCA 1997). Over the next 25 years, the population is projected to grow by another 300,000 people (GRCA 1997). In 1993, the 26 municipal sewage treatment plants operating in the watershed discharged about 272,000 m^3 of sewage effluent into the river daily, with the percentage of the minimum daily flow consisting of treated effluent ranging from 1% to 22% (GRCA 1998). According to the GRCA (1997), "There is a serious question of river capacity to receive additional wastewater at reasonable cost in response to population growth."

The proportion of the Grand River basin in agricultural use increased from 68% in 1976 (WQB 1989) to 75% at present (GRCA 1998). Although the total number of farms in the watershed decreased by 25% between 1971 and 1991, the number of large farms increased substantially. As many farm lands are now rented, there is little incentive for long-term stewardship and the maintenance of woodlots and wetlands. Row crop farming has increased, and along with it the potential for greater soil erosion and runoff of pesticides and fertilizers. Livestock production has changed, becoming more concentrated and specialized, and focusing on pigs and sheep rather than cattle. There has also been a change in manure handling from solid to liquid, and inadequate management of these liquid wastes has become a problem in some areas. Livestock also break down stream banks and introduce silt, bacteria, phosphorus, and other pollutants into the river. Several programs have been introduced recently to assist farmers in implementing best management practices on their land (GRCA 1998).

The zebra mussel, *D. polymorpha*, is a looming threat to the aquatic community of the Grand River, particularly native freshwater mussels. Zebra mussels attach to the shells of native mussels and interfere with normal activities such as feeding, respiration, and burrowing (Nalepa *et al.* 1996), thus robbing them of the energy reserves they need to survive the winter (Ricciardi *et al.* 1996). The only location where zebra mussels were found attached to native mussels during the recent surveys was near Port Maitland at the mouth of the river. A few unattached specimens were also found below the Dunnville Dam in 1995. The potential for zebra mussels to colonize the Grand River is slight, provided they are not introduced into the reservoirs. Because dreissenids have planktonic veligers, water currents would normally sweep the veligers downstream as soon as they appeared. However, reservoirs with retention times greater than 20–30 days allow veligers to develop and settle, after which the impounded populations will seed downstream reaches on an annual basis. It is vital to prevent the introduction of zebra mussels into reservoirs on the Grand River.

The Grand River supports one of the most diverse mussel communities of any tributary to the Great Lakes at the present time. Only the Clinton River in Michigan at 26 live species (Strayer 1980), the Sydenham River in Ontario at 30 live species (Metcalfe-Smith *et al.* 1999), and the St. Joseph River in Indiana, Ohio, and Michigan at 35 live species (Watters 1998) support richer assemblages. The Grand River is also an important refuge for many of Canada's rarest mussel species, including *L. fasciola* (Metcalfe-Smith *et al.* 2000b). The healthiest remaining populations of *L. fasciola* in Canada occur in the clean, clear waters of the upper Grand River between Inverhaugh and Cambridge. In order to preserve this rich mussel fauna, which is an important part of our natural heritage, it will be critical to ensure that improvements to water and habitat quality continue. Because of the growing pressures of urbanization and agriculture on the Grand River and its aquatic ecosystem, this will be a major challenge.

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