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Status of the Freshwater Mussel Communities of the
Sydenham River, Ontario

J.L. Metcalfe-Smith, J. Di Maio, S.K. Staton and S.R. de Solla

NWRI Contribution No. 01-328

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COMMUNITIES OF THE SYDENHAM RIVER,
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MANAGEMENT PERSPECTIVE

Under Environment Canada's Wildlife/Biodiversity Research Mandate, departmental research is to be focused on understanding and reporting to Canadians on what is changing in our ecosystems, why it is changing, and what is needed to conserve, protect and rehabilitate ecosystems, wildlife and biodiversity. Specific research directions include measuring, assessing and reporting on the status and trends of wildlife in Canada to comply with legislation, conventions and agreements with priorities on migratory birds, species that are or maybe at risk, and other species of significant national or international interest; and assessing the effects of agriculture on the health and productivity of aquatic ecosystems.

Freshwater mussels have declined in diversity and abundance at an alarming rate throughout North America due to the destruction of their habitat by human activities. Six species are now listed as Canadian Species at Risk. The Sydenham River historically supported the richest freshwater mussel fauna of any river in Canada. Earlier surveys suggested that the community was in decline and many species were extirpated. We surveyed 17 sites on the river in 1997-1999 using a more intensive sampling effort than previous researchers, and found the fauna to be essentially intact; *i.e.*, 30 of 34 native species were found alive. Four of five species recently designated as endangered in Canada, *i.e.*, *Epioblasma triquetra*, *Villosa fabalis*, *Simpsonaias ambigua* and *Epioblasma torulosa rangiana* were found alive in the east branch of the river; the former three species are found nowhere else in Canada. Although the mussel community is healthier than previously thought, one nationally endangered species (*Lampsilis fasciola*) appears to be extirpated and several other species are beginning to decline. Several pollution- and siltation-tolerant species are significantly expanding their ranges in the system, which leads us to speculate that increases in opportunistic species may provide an earlier warning of environmental degradation than the gradual decline of sensitive species that are often rare to begin with. The east branch of the river currently supports more species (28) than the north branch (15), due to better water quality, swifter flows and a greater variety of habitat types. Agriculture (mainly row crops) is the primary land use in the Sydenham River basin. Comparison of the mussel communities of the Sydenham River with those of the more urbanized Grand River suggest that municipal and industrial wastes pose a greater threat to mussels than agricultural activities. The mussel fauna of the Sydenham River is nationally, and perhaps globally, important and should be preserved.

Information from this study will help define the critical habitat of several nationally endangered species.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Dans le cadre du mandat d'Environnement Canada pour la recherche sur les espèces sauvages et la biodiversité, les travaux de recherche du Ministère ont mis l'accent sur la compréhension et l'explication au public canadien des changements en cours dans nos écosystèmes, des raisons de ces changements et des mesures nécessaires pour conserver, protéger et remettre en état les écosystèmes, les espèces sauvages et la biodiversité. Les orientations des recherches sont notamment la mesure, l'évaluation et la déclaration de l'état et des tendances des espèces sauvages du Canada, conformément à la législation, aux conventions et aux accords, en accordant la priorité aux oiseaux migrateurs, aux espèces menacées ou soupçonnées de l'être, ainsi qu'à d'autres espèces d'intérêt significatif à l'échelle nationale ou internationale et, enfin, à l'évaluation des effets de l'agriculture sur la santé et la productivité des écosystèmes aquatiques.

Dans toute l'Amérique du Nord, la diversité et l'abondance des moules d'eau douce ont baissé à un rythme alarmant à cause de la destruction de l'habitat par les activités humaines; six espèces figurent maintenant sur la liste des espèces canadiennes en danger. La rivière Sydenham abritait jadis la faune de moules d'eau douce la plus riche de toutes les rivières du Canada. Des relevés plus anciens semblaient indiquer que ces communautés étaient en déclin et que beaucoup d'espèces étaient disparues. Dans le cadre d'un effort d'échantillonnage plus intensif que ceux des autres études, on a effectué, en 1997-1999, des relevés à 17 sites de cette rivière, et on a constaté que la faune était à peu près intacte, car on a trouvé des spécimens vivants de 30 des 34 espèces indigènes. Dans le bras est de la rivière, on a trouvé des spécimens vivants de quatre des cinq espèces récemment désignées comme des espèces en danger au Canada, c.-à-d. *Epioblasma triquetra*, *Villosa fabalis*, *Simpsonaias ambigua* et *Epioblasma torulosa rangiana*; or, on ne trouve plus ces trois dernières espèces nulle part ailleurs au Canada. Bien que la communauté des moules soit en meilleure santé qu'on ne le croyait, une espèce menacée à l'échelle nationale (*Lampsilis fasciola*) semble avoir disparu, et plusieurs autres espèces commencent à décliner. Toutefois, plusieurs autres espèces tolérant la pollution et l'envasement ont élargi de façon

significative leur aire de répartition dans ce système, ce qui nous porte à croire que les augmentations d'espèces opportunistes sont plus utiles comme signes d'avertissement précoce de la dégradation de l'environnement que le déclin graduel d'espèces sensibles souvent rares. Le bras est de la rivière abrite actuellement plus d'espèces (28) que le bras nord (15), à cause de la meilleure qualité de l'eau, de l'écoulement plus rapide et d'une plus grande variété des habitats. L'agriculture (surtout des cultures en lignes) est la principale utilisation des terres dans le bassin de la rivière Sydenham. La comparaison des communautés de moules de cette rivière avec celles de la rivière Grand, plus urbaine, suggère que les déchets municipaux et industriels menacent davantage les moules que les activités agricoles. La faune des moules de la rivière Sydenham est importante à l'échelle nationale, voire mondiale, et on devrait prendre les mesures nécessaires pour la préserver. Les informations obtenues grâce à cette étude contribueront à définir l'habitat critique de plusieurs espèces menacées à l'échelle nationale.

ABSTRACT

The Sydenham River, a tributary to Lake St. Clair in southwestern Ontario, historically supported the richest freshwater mussel community of any river in Canada. Surveys conducted between 1971 and 1991 suggested that the mussel fauna was in decline, with only 13 to 26 of the 33 native species still present. We surveyed 17 sites for mussels in 1997-1998 using the timed search method and a more intensive sampling effort than previous surveyors (4.5 person-h/site vs. an average of 1.0 - 2.4 p-h/site) and found 30 live species, including one new record for the system (*Obliquaria reflexa*). Four of five species recently designated as endangered in Canada, i.e., *Epioblasma triquetra*, *Villosa fabalis*, *Simpsonaias ambigua* and *Epioblasma torulosa rangiana* were found alive in the east branch; the former three species are found nowhere else in Canada. Although the mussel community is in better health than previously thought, there are signs that conditions are starting to deteriorate. *Lampsilis fasciola* appears to be extirpated from the system, although it is still found in other Ontario rivers. *Obovaria subrotunda* and *Lampsilis siliquoidea* have significantly declined in the east branch, and there is some evidence that *Lampsilis cardium*, *Strophitus undulatus* and *Villosa iris* may be declining in the east branch and *Actinonaias ligamentina*, *Truncilla truncata* and *Leptodea fragilis* may be declining in the north branch. Furthermore, several tolerant species, i.e., *Potamilus alatus*, *Quadrula quadrula*, *Lasmigona complanata complanata* and *Lasmigona costata* are significantly expanding their ranges in the river. The latter finding leads us to suggest that increases in opportunistic species may provide an earlier warning of environmental degradation than the gradual decline of sensitive species that are often rare to begin with. The primary land use in the Sydenham River basin is agriculture (mainly row crops), and there is an extensive tile drainage system. Increased sedimentation, reduced water clarity and the loss of fish hosts are likely causes of the observed changes in the mussel community. The east branch of the river currently supports 28 species, while the smaller north branch sustains only 15 species. These differences were attributed to better water quality, swifter flows and a greater variety of habitat types in the east branch. Comparison of these results with the results of surveys in the more urbanized Grand River basin suggest that municipal and industrial sewage pose a greater threat to the health of mussel communities than agricultural

activities. The mussel fauna of the Sydenham River is nationally, and perhaps globally, important and should be preserved.

RÉSUMÉ

La rivière Sydenham, qui se jette dans le lac Sainte-Claire, dans le sud-ouest de l'Ontario, abritait jadis la faune de moules d'eau douce la plus riche de toutes les rivières du Canada. Des relevés effectués entre 1971 et 1991 semblent indiquer que la faune des moules était en déclin, car on n'observait plus que 13 à 26 des 33 espèces indigènes. Dans le cadre d'un effort d'échantillonnage plus intensif que ceux des autres études (4,5 personnes-h/site, contre 1,0 – 2,4 p-h/site, en moyenne) et en utilisant la méthode de la recherche chronométrée, on a effectué, de 1997 à 1999, des relevés à 17 sites de cette rivière et on a observé des spécimens vivants de 30 espèces, avec, notamment, une nouvelle espèce signalée pour ce réseau (*Obliquaria reflexa*). Dans le bras est de la rivière, on a trouvé des spécimens vivants de quatre des cinq espèces récemment désignées comme espèces en danger au Canada, c.-à-d. *Epioblasma triquetra*, *Villosa fabalis*, *Simpsonaias ambigua* et *Epioblasma torulosa rangiana*; or, on ne trouve plus ces trois dernières espèces nulle part ailleurs au Canada. Bien que la communauté des moules soit en meilleure santé qu'on ne le croyait, on note des signes de détérioration du milieu. *Lampsilis fasciola* semble être disparue du réseau, même si on la trouve encore dans d'autres rivières de l'Ontario. On a observé un déclin significatif de *Obovaria subrotunda* et de *Lampsilis siliquoidea* dans le bras est. D'après d'autres observations, *Lampsilis cardium*, *Strophitus undulatus* et *Villosa iris* pourraient être en déclin dans le bras est, et *Actinonaias ligamentina*, *Truncilla truncata* et *Leptodea fragilis*, dans le bras nord. Toutefois, plusieurs espèces tolérantes, soit *Potamilus alatus*, *Quadrula quadrula*, *Lasmigona complanata complanata* et *Lasmigona costata*, ont élargi leur aire de répartition de façon significative dans cette rivière. Cette dernière constatation nous porte à croire que les augmentations d'espèces opportunistes sont plus utiles comme signes d'avertissement précoce de la dégradation de l'environnement que le déclin graduel d'espèces sensibles souvent rares. Dans le bassin de la rivière Sydenham, l'agriculture (surtout des cultures en lignes) est la principale utilisation des terres, et elle utilise un réseau de tuyaux de drainage étendu. Les causes probables des changements observés dans les communautés de moules sont une sédimentation accrue, une réduction de la limpidité de l'eau et la perte de poissons hôtes. Le

bras est de la rivière abrite actuellement 28 espèces et le bras nord, plus petit, seulement 15 espèces. On a attribué ces différences à une meilleure qualité de l'eau, à des écoulements plus rapides et à une plus grande variété d'habitats dans le bras est. La comparaison de ces résultats avec ceux des relevés effectués dans le bassin de la rivière Grand, plus urbaine, semble indiquer que les eaux usées municipales et industrielles sont plus dangereuses pour la santé des communautés de moules que les activités agricoles. La faune des moules de la rivière Sydenham est importante à l'échelle nationale, voire mondiale, et on devrait prendre les mesures nécessaires pour la préserver.

Status of the Freshwater Mussel Communities of the Sydenham River, Ontario

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ABSTRACT

The Sydenham River, a tributary to Lake St. Clair in southwestern Ontario, historically supported the richest freshwater mussel community of any river in Canada. Surveys conducted between 1971 and 1991 suggested that the mussel fauna was in decline, with only 13 to 26 of the 33 native species still present. We surveyed 17 sites for mussels in 1997-1998 using the timed search method and a more intensive sampling effort than previous surveyors (4.5 person-h/site vs. an average of 1.0 - 2.4 p-h/site) and found 30 live species, including one new record for the system (*Obliquaria reflexa*). Four of five species recently designated as endangered in Canada, i.e., *Epioblasma triquetra*, *Villosa fabalis*, *Simpsonaias ambigua* and *Epioblasma torulosa rangiana* were found alive in the east branch; the former three species are found nowhere else in Canada. Although the mussel community is in better health than previously thought, there are signs that conditions are starting to deteriorate. *Lampsilis fasciola* appears to be extirpated from the system, although it is still found in other Ontario rivers. *Obovaria subrotunda* and *Lampsilis siliquoidea* have significantly declined in the east branch, and there is some evidence that *Lampsilis cardium*, *Strophitus undulatus* and *Villosa iris* may be declining in the east branch and *Actinonaias ligamentina*, *Truncilla truncata* and *Leptodea fragilis* may be declining in the north branch. Furthermore, several tolerant species, i.e., *Potamilus alatus*, *Quadrula quadrula*,

Lasmigona complanata complanata and *Lasmigona costata* are significantly expanding their ranges in the river. The latter finding leads us to suggest that increases in opportunistic species may provide an earlier warning of environmental degradation than the gradual decline of sensitive species that are often rare to begin with. The primary land use in the Sydenham River basin is agriculture (mainly row crops), and there is an extensive tile drainage system. Increased sedimentation, reduced water clarity and the loss of fish hosts are likely causes of the observed changes in the mussel community. The east branch of the river currently supports 28 species, while the smaller north branch sustains only 15 species. These differences were attributed to better water quality, swifter flows and a greater variety of habitat types in the east branch. Comparison of these results with the results of surveys in the more urbanized Grand River basin suggest that municipal and industrial sewage pose a greater threat to the health of mussel communities than agricultural activities. The mussel fauna of the Sydenham River is nationally, and perhaps globally, important and should be preserved.

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INTRODUCTION

Carolinian Canada is the name given to the extreme southwestern region of Ontario where the Eastern Deciduous Forest reaches its northernmost limits. This region supports the greatest diversity of flora and fauna in Canada, including 2200 species of herbaceous plants, 70 species of trees and 400 species of birds (Carolinian Canada, 2001). The Sydenham River flows through Carolinian Canada en route to Lake St. Clair. According to Clarke (1977, 1992), the Sydenham is the richest river system in Canada for freshwater mussels. It is home to four federally endangered mussels, the Northern Riffleshell (*Epioblasma torulosa rangiana*), Rayed Bean (*Villosa fabalis*), Snuffbox (*Epioblasma triquetra*) and Mudpuppy Mussel (*Simpsonaias ambigua*) (COSEWIC 1999, 2001), and other aquatic species at risk such as the Spiny Softshell Turtle, Eastern Sand Darter, and Spotted Gar (Bowles, 1992; Holm and Mandrak, 1996).

The collections of H.D. Athearn (Tennessee Academy of Science) and C.B. Stein (Ohio State University Museum of Zoology) in the 1960s were the first to draw attention to the richness of the Sydenham River's mussel community. Their findings prompted Clarke (1973) to conduct an extensive survey in 1971. Fifteen years later, Mackie and Topping (1988) reported a sharp decline in the number of species found alive in the drainage and raised concerns about the health of the mussel fauna. Clarke (1992) re-surveyed the river in 1991, and declared that five riffle-dwelling species previously recorded from the river were likely extirpated. He found the riffles to be covered in silt, and attributed the disappearance of these species to a loss of habitat for the mussels and/or their host fishes.

The purpose of this study was to determine if the trend identified in earlier surveys is real, *i.e.*, if the mussel community of the Sydenham River is in decline. Surveys were conducted between 1997 and 1999, and results were compared with the historical data to determine if some

species previously known from the river were now extirpated, and if other species were declining in frequency of occurrence or experiencing range reductions. We were especially interested in determining the current status of several species believed to be at risk in Canada (Metcalf-Smith *et al.*, 1998b). Relationships between water quality and mussel communities were also explored.

METHODS

STUDY AREA

The Sydenham River basin is approximately 100 km long, and drains an area of 2725 km² (DERM, 1965). The river has two branches that join together at the Town of Wallaceburg in the lower portion of the basin, before emptying into Lake St. Clair (Fig. 1). The smaller north branch drains an area of 617 km² and flows mainly through highly erodable clay plains. It is known as the North Sydenham River below the confluence with its main tributary, Black Creek, and as Bear Creek above the confluence. The larger east branch, or East Sydenham River, arises from the Lucan moraine and flows alternately through clay and sand plains. The entire drainage basin is a plain of low relief, resulting in low stream gradients and relatively shallow valleys. Land use in the watershed is predominantly agricultural, *i.e.*, cash crops, pasture and woodlot, and 96% of the land is privately owned. About half of the current population of 74,000 is rural, and the other half is concentrated in several towns and villages (Muriel Andreae, St. Clair Region Conservation Authority, Strathroy, Ontario, pers. comm.). Flooding is a problem in some areas, so there is an extensive land drainage system (DERM, 1965).

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 Sydenham River (see Metcalf-Smith *et al.*, 1998b for 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. A total of 425 records collected from 77 sites between 1929 and 1991 were available (Table 1). Many sites were sampled on more than one occasion, so the number of *different* sites for which data are available is 33. For some of the surveys, the numbers of species found alive and dead at each site were recorded. Where this information was missing, we assumed that all species were found alive. Sampling effort was reported for seven of the surveys, five of which also provided data on abundance. Although Mackie and Topping (1988) surveyed 32 sites in 1985, detailed information was only available for 10 sites.

CURRENT SURVEYS

Seventeen sites on the Sydenham River were surveyed for mussels in the late summer of 1997 and 1998, including four sites on Bear Creek, one on Black Creek, and 12 on the East Sydenham River (Fig. 1). Sites known to support rare species or diverse communities in the past, as well as sites in promising reaches that had not been previously surveyed, were selected for study. All sites were wadable. Each site was searched by a 3- person team for a period of 1.5 h, or a total sampling effort of 4.5 person-h (p-h). Where visibility was good (9 sites), the riverbed was visually searched with the aid of polarized sunglasses and Waterview™ underwater viewers. Where visibility was poor (8 sites), the substrate was searched by feel. To the best of our knowledge, most historical surveys also used the timed search method. All live mussels collected were identified to species, counted, and returned to the river, with the exception of a few animals that were sacrificed for voucher specimens. Shells were also collected, but not in a quantitative manner: a few shells of common species, most or all shells of rare species and representative shells of any species not found alive, were retained from each site.

Some of the East Sydenham River sites were revisited in 1998 and/or 1999 to collect specimens for other studies. Sampling methods and efforts varied. Occasionally, new species were found that had not been detected during our formal surveys; in such cases, the new species were added to the species list for that site.

At each site, water velocity was measured at the time of sampling using a Price Model 1210 AA current meter. Water clarity, defined as the maximum depth at which the streambed was clearly visible, was also measured. Water samples were collected from all 17 sites on 21 and 22 September 1998, and submitted (unfiltered) to Environment Canada's National Laboratory for Environmental Testing in Burlington, Ontario, for analysis of alkalinity, turbidity, hardness, chloride (Cl), sulphate (SO₄), silica (SiO₂), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), total Kjeldahl nitrogen (TKN), nitrate/nitrite (NO₃NO₂), ammonia (NH₃), total phosphorus (TP) and soluble reactive phosphorus (SRP). Several of these parameters are known to be critical determinants of benthic invertebrate community structure in rivers (Reynoldson *et al.*, 1999), or have been suggested as possible predictors of species richness in mussel communities (Strayer and Fetterman, 1999).

DATA TREATMENT

Current (1997-1999) and historical (1929-1991) occurrence records for mussels in the north and east branches of the Sydenham River were compared to determine if there have been changes in species richness over time. We also examined the records for evidence of change over time in the range and/or frequency of occurrence of individual species. These comparisons were problematic because (a) sampling effort varied among historical surveys or was unknown; (b) twice as many sites were surveyed historically as currently (34 vs. 17), and there were only eight sites in common; and (c) one-third of the historical sites were located in reaches or tributaries that

were not surveyed in 1997-1999. We used a two-tailed binomial test (Zar, 1996) to determine if the proportion of sites currently occupied by a species differed significantly from the proportion of sites occupied by that species historically; *i.e.*, the proportion of historically occupied sites was considered to be the "expected" frequency of occurrence for the species. Eleven historical sites and one current site that were located in reaches surveyed in only one time period were excluded from this analysis. A comparison of current and past abundance was possible for only five sites, since abundance was seldom recorded during the earlier surveys (*see* Table 1).

Current species richness and abundance in the north and east branches of the river were compared using a *t*-test, and the degree of community similarity between branches was compared using the overlap index " C_h " of Horn (1966; *see* Metcalfe-Smith *et al.*, 1998a for a description of this index). An index value of 1 indicates that the communities are identical, whereas an index value of 0 indicates that they are dissimilar. Average values for 17 water quality parameters in the north and east branches were also compared using a *t*-test, and relationships between species richness (based on the 4.5 p-h timed search surveys) and water quality were tested using Pearson correlation coefficients.

RESULTS

CHANGES OVER TIME IN RICHNESS AND ABUNDANCE

Species richness has changed little over time in the Sydenham River drainage. A total of 33 species of unionids were recorded from the river between 1929 and 1991, with 32 species found alive and one represented by shells only (Table 2). In the north branch, 16 species were found alive and two were found dead, while in the east branch, 31 species were found alive and one was found dead. During our surveys of 1997-1999, we found a total of 30 species alive and three dead, including 15 species alive and two dead in the north branch and 28 alive and three

dead in the east branch (Table 2). One species found alive in 1997-1999 had not been reported previously (*Obliquaria reflexa*), so the total number of species ever reported from the Sydenham River currently sits at 34.

Relative abundance (catch/p-h) of mussels declined at four of the five sites for which past and present data were available for comparison (Fig. 2). At one site (SR-12), the catch/p-h decreased continuously over four surveys conducted between 1973 and 1998.

SPECIES ACCOUNTS

Fifteen species are known only from the east branch of the Sydenham River (Table 3a). *Obliquaria reflexa* was found alive at one site during the current surveys, representing a new record for the system. *Truncilla donaciformis* was also found alive at one site, whereas only dead shells of this species had been reported previously. Our surveys extended the known ranges of *V. fabalis* (Fig. 3a) and *S. ambigua* further downstream, and the ranges of *E. t. rangiana* (Fig. 3b) and *E. triquetra* further upstream. Except for *E. triquetra*, these species were found more frequently during the current surveys than in earlier surveys (Table 3a). Distributions of *Ligumia recta* (Fig. 3c), *Alasmidonta marginata* and *Ptychobranhus fasciolaris* appear to be the same now as in the past. Although shells of *A. marginata* were also found in the north branch, it has never been seen alive here. A single fresh shell of *Alasmidonta viridis* was found during the present surveys; in earlier surveys it had been found at two sites, one of which was upstream of all sites surveyed in 1997-1999. *Quadrula pustulosa pustulosa* was found at four sites in the past. It was found at all but the most upstream site during the present surveys. *Cyclonaias tuberculata* was found at 92% of current sites as compared with only 64% of historical sites in the same reach, but this difference was not statistically significant.

Three species showed evidence of decline in the East Sydenham River. Although *Lampsilis cardium* was found at a similar proportion of sites in 1997-1999 as in the past, it may have been lost from the lower portion of its historical range (Fig. 3d). Stein (personal field notes) found nine live specimens and 30 fresh shells at two sites in the lower river during intensive (3.0-6.0 p-h) surveys in 1965 and 1973, whereas we found only one fresh shell at these and one other site in this reach. This species has never been reported alive in the north branch, but shells were found at one site in 1985. *Lampsilis fasciola* (Fig. 3e) was found alive at three sites between 1967 and 1971 (number of specimens not known), but we only found a few shells in 1997-1999. *Obovaria subrotunda* appears to have declined dramatically (Fig. 3f). Only one live animal was seen in 1997-1999, whereas 29 or more live animals had been found alive at 11 sites between 1965 and 1991. Stein (personal field notes) found this species to be quite common at one site in the lower reaches in 1973, accounting for 10% (18 animals) of 165 live mussels collected in 6.0 p-h sampling effort. Eighteen years later, Clarke (1992) found only two live specimens (2.7% of total) in 3.5 p-h of searching at the same site. Live specimens were neither found during a 12 p-h search at this site in 1998, nor during quadrat surveys (11.0 p-h) in 1999, although one live individual was observed just outside the sampling area in 1999.

Nineteen species are known from both the east and north branches of the Sydenham River (Table 3b). Our surveys resulted in new records for three species in the north branch, namely *Lasmigona compressa* (1 site), *Lasmigona costata* (1 site) and *Fusconaia flava* (2 sites). *Lasmigona compressa* was not found in the east branch during our surveys, although it had been found alive at two sites in the past. *Utterbackia imbecillis* has never been seen alive in the east branch, although we found 9 weathered shells at three sites in 1997-1998. This species was found alive at two different sites in the north branch in 1967 and 1991, but we found neither live animals

nor shells. *Toxolasma parvus* was found at one site in each branch in the past, but was not found alive during our surveys. Since both historical sites were downstream of all sites surveyed in 1997-99, the current status of this species is unknown. Similarly, *Anodontoides ferussacianus* was found at three sites in the east branch in the past as compared with one site currently, but two of the historical sites were in headwater areas that we did not search. This species was also found at one site in the north branch in both time periods.

Most species showed no significant change in frequency of occurrence over time in either the east branch alone, or in both branches combined (Table 3b). Data for the north branch could not be tested separately because there were too few sites. *Pyganodon grandis* was, and still is, very common in both branches; it is also the most widely distributed species in the system (Fig. 4a). *Amblema plicata plicata*, *Elliptio dilatata* and *Actinonaias ligamentina* were much more common historically in the east branch than the north branch, and their distributions have not changed significantly over time. *Pleurobema sintoxia* has a similar distribution, although it is a less common species. There is some evidence that *A. ligamentina*, *Truncilla truncata* and *Leptodea fragilis* may have declined over time in the north branch. Mackie and Topping (1988) found one live *A. ligamentina* at each of two sites in 1985, but we found no trace of this species (not even weathered shells) during our surveys (Fig. 4b). *Truncilla truncata* (Fig. 4c) was reported from five of 12 sites surveyed in this branch between 1929 and 1991, but we found just a single shell at one of five sites surveyed in 1997-1999. *Leptodea fragilis* was found alive at two of our five survey sites on the north branch, as compared with six of 12 sites visited in the past.

Strophitus undulatus and *V. iris* were found at one-half or fewer sites during the current surveys than historically, although differences in frequency of occurrence over time were not statistically significant. Current distributions of both species suggest that their ranges may have

contracted in the east branch. *Villosa iris* was found alive at five sites within a 60 km reach of this branch historically, whereas we found single specimens at two sites 3 km apart. *Strophitus undulatus* was found alive at five sites in the upper reaches of the east branch between 1963 and 1991, but we encountered no live specimens at any of the five sites we surveyed this reach (Fig. 4d). *Lampsilis siliquioidea* has declined significantly in the east branch, where it used to be one of the most common species (Fig. 4e).

Potamilus alatus (Fig. 4f), *Quadrula quadrula* and *Lasmigona complanata complanata* were encountered more frequently during our surveys than in previous surveys, particularly in the east branch. *Lasmigona costata* showed a similar trend, being found at all 12 of our survey sites in the east branch plus one site in the north branch (a new record).

COMPARISON OF THE PRESENT MUSSEL COMMUNITIES OF THE EAST AND NORTH BRANCHES

The mussel communities of the east and north branches of the Sydenham River differ in richness, abundance and composition. Average richness per site (based on the 4.5 p-h timed search surveys) differed significantly ($P = 0.0014$) between branches, with a mean of 6 species/site (range 2-11) found in the north branch and 14 species/site (range 8-21) in the east branch. Average abundance per site was also greater in the east than the north branch (143 vs. 97 mussels/site, respectively), but this difference was not significant ($P = 0.36$). Twenty-eight species were found alive in the east branch and 15 in the north branch, with 13 species common to both branches. The degree of similarity in community composition between the two branches was relatively low ($C_{\lambda} = 0.27$). Only one species, *A. p. plicata*, was among the five most abundant species in both branches (Fig. 5). The community in the north branch was relatively simple, with six species accounting for 90% of the 486 mussels found. In contrast, 13 species accounted for 90% of the 1713 mussels collected from the east branch. *Lasmigona c. complanata*, *P. grandis*

and *A. p. plicata* dominated the mussel community in the north branch, while *L. costata*, *A. p. plicata* and *C. tuberculata* dominated the community in the east branch (Fig. 5).

RELATIONSHIPS BETWEEN SPECIES RICHNESS AND WATER QUALITY

Water quality differed between the two branches of the Sydenham River. Concentrations of TKN, SO₄, K and Cl were significantly higher in the north branch (Table 4), while alkalinity, hardness, clarity, Ca levels, and water velocity were significantly higher in the east branch. Total phosphorus and turbidity were also higher in the north than the east branch, but the difference was not statistically significant. Species richness was negatively correlated with TKN, SO₄, K, NO₃NO₂, TP, turbidity, SRP and Cl, and positively correlated with velocity and Mg (Table 5).

DISCUSSION

Thirty-four species of freshwater mussels have been reported from the Sydenham River since 1929. Most of our knowledge of the mussel communities of this system comes from the surveys of Clarke (1973, 1992) and Mackie and Topping (1988). Clarke (1973) collected 26 live species from 11 sites in 1971, using a sampling effort averaging 1.1 p-h/site (range = 0.7-1.8 p-h). He noted that *E. t. rangiana*, *E. triquetra* and *V. fabalis*, which had been reported by Athearn and Stein in the 1960s, were missing from his collections. Mackie and Topping (1988) surveyed 32 sites in 1985 using a sampling effort of 1.0 p-h/site, and found a mere 13 species alive. Although 18 of their sites were in the east branch, they detected only two of the 15 species we found in the east branch but not the north branch in 1997-1999 (see Table 3a). They described both of these species (*C. tuberculata* and *Q. p. pustulosa*) as "very rare in the study area." *Lasmigona costata* occurred at 13 of our 17 survey sites, representing nearly 25% of the mussels collected from the east branch. The absence of *L. costata* from the collections of Mackie and Topping (1988) is puzzling, and raises the possibility that some of their specimens were misidentified.

Clarke (1992) conducted the most intensive survey of the river to date in 1991, visiting 16 sites and investing an average of 2.4 p-h of search time (range = 0.4-8.0 p-h) at each site. He found 22 species alive, two as fresh shells (which he counted as being alive), and one (*T. donaciformis*) as a weathered shell. He attributed the absence of the headwater species *A. viridis*, *A. ferussacianus* and *L. compressa* to inadequate coverage of their habitat. However, he concluded that five species previously recorded from the river (*E. t. rangiana*, *E. triquetra*, *L. fasciola*, *S. ambigua* and *V. iris*) were missing and "may now be gone from that System." He maintained that Mackie and Topping (1988) had found fewer live species than him because they had spent insufficient time at each locality. In view of our recent findings, it now appears that Clarke's (1992) sampling effort was also insufficient.

We surveyed 17 sites in the east and north branches of the river in 1997-1998 using a sampling effort of 4.5 p-h/site and found 2199 live mussels belonging to 29 species, including one new species (*O. reflexa*) and one species known only from shells in the past (*T. donaciformis*). Another species, *O. subrotunda*, was found alive during additional searches at one of the richest sites in 1999. Two of the missing species may now be extirpated (*L. fasciola* and *U. imbecillis*); however, the status of *A. viridis* and *T. parvus* cannot be determined because the reaches they occupied historically were not surveyed. Our results paint a much brighter picture of the status of the mussel communities of the Sydenham River than that portrayed by earlier studies. Nevertheless, there are signs that conditions may be starting to deteriorate.

Comparisons of relative abundance between our surveys and earlier surveys were only possible for a few sites, but the results suggest that productivity has decreased over time. Two species, *O. subrotunda* and *L. siliquioidea*, are clearly declining in the east branch. *Obovaria subrotunda* is disappearing from many areas in the Midwest (Cummings and Mayer 1992), and

was extirpated from the Clinton River, a tributary to Lake St. Clair in southeastern Michigan, by the late 1970s (Strayer 1980). Clark (1977) suggested that the Eastern Sand Darter (*Ammocrypta pellucida*) may be a host, since the two species frequently co-occur. The Eastern Sand Darter was assigned threatened status in Canada in 1994; it is still found in the lower Sydenham River but has been lost from the upper reaches and from many other locations throughout its former range in Ontario and Quebec (Holm and Mandrak, 1996). *Lampsilis siliquoidea* is one of the most widespread and abundant species throughout the lower Great Lakes drainage basin. It was found at 30% of over 1400 sites surveyed between 1860 and 1996 (Metcalf-Smith *et al.*, 1998a) and at 30% of 66 sites surveyed by us in the Grand, Thames, Sydenham, Maitland and Ausable rivers in 1997-1998 (Metcalf-Smith *et al.*, 1999), so its decline in the East Sydenham River seems odd. Thirteen of the 14 known fish hosts for this species (Hoggarth 1992; Watters 1994) occur in the Sydenham River system. Eight of these fishes, four of which were once common, have declined in incidence over the past 20 years (de Solla *et al.*, manuscript in preparation). Thus, the decline in *L. siliquoidea* may be due to changes in the fish community. The ranges of *L. cardium*, *S. undulatus* and *V. iris* may be contracting in the east branch. Morris and Corkum (1996) found *L. siliquoidea* and *L. cardium* to be characteristic of rivers with forested riparian zones, although *S. undulatus* was more common in areas with little or no stream-side vegetation. *Villosa iris* is known to be sensitive to environmental pollutants (Goudreau *et al.*, 1993; Jacobson *et al.*, 1997), and has also been lost from tributaries to the lower reaches of the nearby Grand River (Metcalf-Smith *et al.*, 2000b). We have no explanation for the apparent declines of *A. ligamentina*, *T. truncata* and *L. fragilis* in the north branch.

Lampsilis fasciola was missing from our collections, although it was rare in the past and could have been overlooked. This species was assigned endangered status in Canada in 1999

(COSEWIC, 1999). We found 33 live specimens at 11 sites in the upper Grand and upper Thames rivers in 1997-1998 (Metcalf-Smith *et al.*, 2000c). All sites where it occurred had a water clarity reading (defined as the maximum depth at which the streambed was clearly visible) of greater than 45 cm, whereas only one site on the Sydenham River had water this clear. *Lampsilis fasciola* relies on a lure to attract its glochidial hosts, the Smallmouth Bass and Largemouth Bass, and may therefore have a critical requirement for clear water during glochidial release. The Smallmouth Bass has declined significantly in the upper Grand River over the past 10 years due to angling pressure (Cooke *et al.*, 1998), and has not been seen alive in the Sydenham River since 1975 (E. Holm, Royal Ontario Museum, Toronto, Ontario, pers. comm.).

Four of the nationally endangered species, namely, *E. t. rangiana*, *E. triquetra*, *S. ambigua*, and *V. fabalis* were found at several more sites during our surveys than in past surveys. We do not believe that these species have expanded their ranges; rather, we submit that our longer search time resulted in their being detected more frequently. We have shown elsewhere that increasing the sampling effort in timed search surveys can dramatically improve the detection of rare species (Metcalf-Smith *et al.*, 2000a).

Lampsilis c. complanata, *L. costata*, *Potamilus alatus* and *Q. quadrula* may be expanding their ranges in the system. There is evidence that these species, along with *A. p. plicata*, *F. flava* and *P. grandis* are among the most tolerant and opportunistic of unionids. For example, Goodrich and van der Schalie (1932) reported that *F. flava*, *L. c. complanata* and *P. alatus* were found in Lake Michigan's Saginaw Bay in 1931 but not in 1908, and that many of the species found in the earlier survey had become more abundant. They credited this increase in productivity to an increase in phytoplankton densities, which in turn was due to greater inputs of domestic sewage from the cities of Monroe and Toledo. In a study on the Thames River in southwestern Ontario,

Morris (1994) found that *L. c. complanata* increased significantly in abundance as the landscape changed from forest-dominated to predominantly agricultural. Kidd (1973) reported major increases in the numbers of *L. costata*, *P. grandis* and *S. undulatus* in the Grand River in the early 1970s, when water quality was poor (GRCA, 1998) and sewage treatment facilities were in the process of being upgraded. The only species surviving in the heavily-polluted lower reaches at the time of Kidd's (1973) survey were *A. ferussacianus*, *A. p. plicata*, *F. flava*, *P. alatus*, *P. grandis* and *Q. quadrula*. Taylor (1989) reported a 50% change in the composition of the mussel fauna of the upper Ohio River over the past 200 years, with most of the change occurring in the last 75 years. The river was originally shallow and free-flowing, but has been converted into a series of deep, still pools due to the construction of a series of dams between 1885 and 1976. Eighteen species, including *E. t. rangiana*, *E. triquetra*, *L. cardium*, *L. fasciola*, *P. fasciolaris*, *P. sintoxia* and *T. truncata* have been lost, while other species that can tolerate the slow current and increased sedimentation have appeared. *Quadrula quadrula*, for example, did not occur in the upper Ohio River historically, but it is now the most common species. Finally, Nalepa *et al.* (1991) reported a decline in the richness and abundance of the mussel community of Lake Erie's western basin between 1930 and 1982, which they blamed on frequent low oxygen events and a general decline in water quality. Richness decreased from 12 species in 1930 to 10 in 1961, 6 in 1972, and 5 in 1982. Species that survived to 1982 were *L. siliquioidea*, *Ligumia nasuta*, *A. p. plicata*, *P. alatus* and *P. grandis*. Although *A. p. plicata* was not seen prior to 1982, it represented 15% of all mussels collected in that year. We speculate that the appearance of tolerant/opportunistic species, or their rapid expansion into newly altered habitats, may provide an earlier warning that environmental conditions have begun to deteriorate than the gradual decline of sensitive species that are often rare to begin with.

The east branch of the Sydenham River supports a richer and more abundant mussel fauna than the north branch. Four of the 15 species restricted to the east branch (*E. triquetra*, *O. subrotunda*, *V. fabalis* and *S. ambigua*) are believed to occur nowhere else in Canada, although the remaining species have been found alive in at least one nearby river in recent years. For example, *C. tuberculata* was found in the Ausable and Thames rivers in 1997-1998, while *L. cardium* was found in the Ausable, Grand, Maitland and Thames rivers (Metcalf-Smith *et al.*, 1999). The results suggest that these 15 species are not geographically restricted to the east branch; rather, it is more likely that water quality and/or habitat factors are preventing them from expanding into the north branch.

Species richness was correlated with water quality in the Sydenham River. Richness was significantly greater at sites with lower levels of nutrients, Cl and turbidity, and higher at sites with swifter currents and higher concentrations of Mg. Sites on the north branch had significantly higher concentrations of Cl and several nutrients than the east branch, as well as slower flows. Levels of other nutrients and turbidity also tended to be higher, and Mg lower, in the north branch. It is clear from these data that water quality is one of the factors influencing the structure of mussel communities in the Sydenham River. Osmond (1969) used macroinvertebrate community structure as an indicator of water quality in the river. Sites on the east branch were found to have satisfactory water quality, with the healthiest communities occurring in the reach between Alvinston and Dresden (see Fig. 1). In contrast, water quality was impaired above and below Petrolia on Bear Creek and below Brigden (at the confluence of Bear and Black creeks), and seriously impaired downstream of Oil Springs on Black Creek. Conditions in the north branch were attributed to septic tank runoff and incomplete treatment of municipal waste. This region was once a major producing area for oil and natural gas. The first commercial oil field in North

America was operational in 1858 in the town of Oil Springs (WQB-OR, 1990). Production has been significantly reduced over the years, but production wells still exist and oil spills have occurred as recently as 1991. As noted earlier, the north branch flows through clay plains, while the east branch flows alternately through clay and sand plains. Substrates are therefore more variable in the east branch, and the gravelly, riffle habitats preferred by such species as *A. marginata*, *C. tuberculata*, *E. t. rangiana*, *E. triquetra* and *P. fasciolaris* (Strayer and Jirka, 1997) are more likely to be present. Composition of the fish community may also be a factor limiting the distribution of mussels in the system. However, the fish hosts for many unionids in Canada have not been identified. For example, the only known hosts for *E. t. rangiana* are the Bluebreast Darter (*Etheostoma caeruleum*), Banded Darter (*Etheostoma zonale*), Banded Sculpin (*Cottus caroliniae*) and Brown Trout (*Salmo trutta*) (Watters, 1996a), but none of these fishes occur in the Sydenham River (E. Holm, Royal Ontario Museum, Toronto, Ontario, pers. comm.).

The mussel communities of the Sydenham River have remained relatively unchanged since the 1960s and 1970s. Most species known historically from the system can still be found, and only a few species are showing signs of decline. In contrast, the mussel communities of the Grand River (a nearby tributary to Lake Erie) declined dramatically from a historical total of 31 species to only 17 species in 1970-1972 (Kidd, 1973), then rebounded to 25 species at present (Metcalf-Smith *et al.* 2000c). We believe that differences in the responses of the mussel fauna of these two systems are due to differences in anthropogenic impacts. The Grand River watershed supports an estimated 787,000 people, with 81% of the population living in five cities and an overall population density of 115 people/km². About 75% of the land is in agricultural use (GRCA, 1998). Water quality was described as poor during the late 1960s and early 1970s, mainly due to the discharge of untreated or poorly treated municipal and industrial effluents into the river. As a

result of improvements to sewage treatment facilities, water quality is now described as satisfactory or good throughout the basin, and excellent in the most upstream reaches (GRCA, 1998). As noted earlier, the Sydenham River watershed supports only 74,000 people, with approximately 50% of the population living in urban centres. The population density is only 27 people/km². In 1983, 84% of the watershed was in agricultural use, primarily for row crops (OMAF, 1983). The population has increased by 50% since 1967 (Table 6), while the population of the Grand River watershed doubled over the same time period. Despite a low rate of population growth, all municipalities in the Sydenham River watershed have also upgraded their sewage treatment facilities over the past 30 years. Results of these comparisons imply that municipal and industrial wastes may be a greater threat to the health of freshwater mussels than agricultural activities.

According to Clarke (1992), the Sydenham River "...is still the richest system for Unionidae in Canada and one of the richest small river systems in North America." As the river is non-navigable and has few dams, it also represents an important refugium for native mussels from the exotic Zebra Mussel, *Dreissena polymorpha*. Results of the present study show that the Sydenham River still supports at least 30 of its 34 native species, making it the most important "mussel river" in the Great Lakes region. The two largest rivers in southwestern Ontario, the Thames and the Grand, currently sustain 23 and 25 mussel species, respectively. The St. Joseph River, a tributary to the Maumee River that flows into Lake Erie at Toledo, Ohio, historically supported 35 species of unionids. Recent surveys of the formerly rich Fish Creek and West Branch subwatersheds showed that 25 and 23 species, respectively, are still present (Watters, 1996b, 1998). The Clinton River, a tributary to Lake St. Clair in southeastern Michigan, supported 31 species of mussels in the past - a number that Strayer (1980) said was "...greater

than that of any other stream in the Great Lakes drainage, the Maumee River excepted." He surveyed 76 sites in the Clinton River in 1978, and found 26 species alive. Marangelo and Strayer (2000) surveyed Tonawanda Creek in the Niagara River drainage in western New York in 1998 and found evidence of 20 species, with *E. triquetra* represented by only a weathered shell. They declared Tonawanda Creek "...an outstanding remnant of the Great Lakes basin mussel fauna..."

Clarke (1992) urged that the Sydenham River be made an ecological preserve, so that its unique mussel fauna would be protected. Although agricultural activities have not had a major impact on the mussel community to date, increased sediment loads and nutrient inputs from agricultural sources are known to be among the main threats to the survival of freshwater mussels in the United States (Richter *et al.*, 1997). We must therefore ensure that any such threats in the Sydenham basin are identified and controlled, and that critical habitat is protected and degraded areas are restored. These are the goals of a multi-agency aquatic ecosystem recovery plan currently being developed for the Sydenham River.

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LITERATURE CITED

- BOWLES, J.M. 1992. Life science inventory of Sydenham River Corridor Carolinian Canada site. St. Clair Region Conservation Authority, Strathroy, Ontario. 62 p.
- CAROLINIAN CANADA. 2001. Carolinian Canada, London, Ontario. Website, <http://www.carolinian.org/Cc1/htm>
- CLARK, C.F. 1977. The freshwater naiads of Ohio, Part 1: St. Joseph River of the Maumee. *Sterkiana*, 65-55: 14-36.
- CLARKE, A.H. 1973. On the distribution of Unionidae in the Sydenham River, southern Ontario, Canada. *Malacol. Rev.*, 6: 63-64.
- . 1977. The endangered molluscs of Canada, p.148-150. In: T. Mosquin and C. Suchal (eds.). Canada's threatened species and habitats. Canadian Nature Federation Special Publication Number 6.
- . 1992. Ontario's Sydenham River, an important refugium for native freshwater mussels against competition from the zebra mussel *Dreissena polymorpha*. *Malacol. Data Net*, 3: 43-55.
- COOKE, S.J., C.M. BLUNT AND S. MCKINLEY. 1998. Derby-determined vital statistics and trends of the smallmouth bass, determined vital statistics and trends of the smallmouth bass, *Micropterus dolomieu*, recreational fishery in the middle reaches of the Grand River, Ontario. *Can. Field-Nat.*, 112: 451-458.
- COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 1999. Canadian Species at Risk, April 1999. COSEWIC Secretariat, Canadian Wildlife Service, Ottawa, Ontario. 26 p.

- . 2001. Canadian Species at Risk, May 2001. COSEWIC Secretariat, Canadian Wildlife Service, Ottawa, Ontario (*in press*).
- CUMMINGS, K.S. AND C.A. MAYER. 1992. Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey Manual 5. 194 p.
- DERM. (Department of Energy and Resources Management). 1965. Sydenham Valley conservation report. Ontario Department of Energy and Resources Management. 77 p.
- GOODRICH, C. AND H. VAN DER SCHALIE. 1932. I. On an increase in the naiad fauna of Saginaw Bay, Michigan. II. The naiad species of the Great Lakes. Occasional papers of the Museum of Zoology, Number 238. University of Michigan, Ann Arbor, Michigan. 14 p.
- GOUDREAU, S.E., R.J. NEVES and R.J. SHEEHAN. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, USA. *Hydrobiologia*, 252: 211-230.
- GRCA (Grand River Conservation Authority). 1998. State of the watershed report: background report on the health of the Grand River watershed, 1996-97. Grand River Conservation Authority, Cambridge, Ontario.
- HOGGARTH, M.A. 1992. An examination of the glochidia-host relationships reported in the literature for species of Unionids. *Malacol. Data Net*, 3: 1-30.
- HOLM, E. AND N.E. MANDRAK. 1996. The status of the Eastern Sand Darter, *Ammocrypta pellucida*, in Canada. *Can. Field-Nat.*, 110: 462-469.
- HORN, H.S. 1966. Measurement of "overlap" in comparative ecological studies. *Amer. Nat.*, 100: 419-424.

- JACOBSON, P.J., R.J. NEVES, D.S. CHERRY AND J.L. FARRIS. 1997. Sensitivity of glochidial stages of freshwater mussels (Bivalvia: Unionidae) to copper. *Environ. Toxicol. Chem.*, 16: 2384-2392.
- KIDD, B.T. 1973. Unionidae of the Grand River drainage, Ontario, Canada. M.Sc. Thesis. Carleton University, Ottawa, Ontario. 172p.
- MACKIE, G.L. AND J.M. TOPPING. 1988. Historical changes in the unionid fauna of the Sydenham River watershed and downstream changes in shell morphometrics of three common species. *Can. Field-Nat.*, 102: 617-626.
- MARANGELO, P.J. AND D.L. STRAYER. 2000. The freshwater mussels of the Tonawanda Creek basin in western New York. *Walkerana*, 11: 97-106.
- METCALFE-SMITH, J.L., S.K. STATON, G.L. MACKIE AND N.M. LANE. 1998a. Changes in the biodiversity of freshwater mussels in the Canadian waters of the lower Great Lakes drainage basin over the past 140 years. *J. Great Lakes Res.*, 24: 845-858.
- . 1998b. Selection of candidate species of freshwater mussels (Bivalvia: Unionidae) to be considered for national status designation by COSEWIC. *Can. Field-Nat.*, 112: 425-440.
- METCALFE-SMITH, J.L., S.K. STATON, G.L. MACKIE AND I.M. SCOTT. 1999. Range, population stability and environmental requirements of rare species of freshwater mussels in southern Ontario. Environment Canada, National Water Research Institute, Burlington, Ontario. NWRI Contribution No: 99-058. 55p.
- METCALFE-SMITH, J.L., J. DI MAIO, S.K. STATON AND G.L. MACKIE. 2000a. Effect of sampling effort on the efficiency of the timed search method for sampling freshwater mussel communities. *J. N. Am. Benthol. Soc.* 19: 725-732.

- METCALFE-SMITH, J.L., G.L. MACKIE, J. DI MAIO AND S.K. STATON. 2000b. Changes over time in the diversity and distribution of freshwater mussels (Unionidae) in the Grand River, southwestern Ontario. *J. Great Lakes Res.*, 26: 445-459.
- METCALFE-SMITH, J.L., S.K. STATON AND E.L. WEST. 2000c. Status of the Wavy-rayed Lampmussel, *Lampsilis fasciola* (Bivalvia: Unionidae), in Ontario and Canada. *Can. Field-Nat.*, 114: 457-470.
- MORRIS, T.J. 1994. Factors affecting the distribution and abundance of freshwater bivalves (Unionidae and Sphaeriidae) of the Dingman Creek, London, Ontario. M.Sc. Thesis. University of Western Ontario, London, Ontario.
- MORRIS, T.J. AND L.D. CORKUM. 1996. Assemblage structure of freshwater mussels (Bivalvia: Unionidae) in rivers with grassy and forested riparian zones. *J. N. Benthol. Soc.*, 15: 576-586.
- NALEPA, T.F., B.A. MANNY, J.C. ROTH, S.C. MOZLEY AND D.W. SCHLOESSER. 1991. Long-term decline in freshwater mussels (Bivalvia: Unionidae) of the western basin of Lake Erie. *J. Great Lakes Res.*, 17: 214-219.
- OMAF (Ontario Ministry of Agriculture and Food). 1983. Agricultural Land Use System Map. Ontario Ministry of Agriculture and Food, Toronto, Ontario.
- OSMOND, D.S. 1969. Biological survey of the Sydenham River watershed (St. Clair drainage) 1967. The Ontario Water Resources Commission, Toronto, Ontario. 30p.
- REYNOLDSON, T.B., C. LOGAN, T. PASCOE AND S.P. THOMPSON. 1999. Methods Manual I: Creation of Reference-Condition databases for benthic invertebrate community structure. Environment Canada, National Water Research Institute, Burlington, Ontario. NWRI Contribution No: 99-211. 41p.

- RICHTER, B.D., D.P. BRAUN, M.A. MENDELSON AND L.L. MASTER. 1997. Threats to imperiled freshwater fauna. *Conserv. Biol.*, 11: 1081-1093.
- STRAYER, D.L. 1980. The freshwater mussels (Bivalvia: Unionidae) of the Clinton River, Michigan, with comments on man's impact on the fauna, 1870-1978. *The Nautilus*, 94: 142-149.
- STRAYER, D.L. AND A.R. FETTERMAN. 1999. Changes in the distribution of freshwater mussels (Unionide) in the Upper Susquehanna River Basin, 1955-1965 to 1996-1997. *Amer. Midl. Nat.*, 142: 328-339.
- STRAYER, D.L. AND K.J. JIRKA. 1997. The pearly mussels of New York State. *Mem. N.Y. State Mus.*, 26: xiii + p. 1-113 + plates 1-27.
- TAYLOR, R.W. 1989. Changes in freshwater mussel populations of the Ohio River: 1,000 BP to recent times. *Ohio J. Sci.*, 89: 188-191.
- WQB-OR (Water Quality Branch - Ontario Region). 1990. The application of an interdisciplinary approach to the selection of potential water quality sampling sites in the Bear Creek drainage basin. Environment Canada, Water Quality Branch - Ontario Region. 70 p.
- WATTERS, G.T. 1994. An annotated bibliography of the reproduction and propagation of the Unionoidea (primarily of North America). Ohio Biological Survey Miscellaneous Contribution 1: vi + 158 p.
- . 1996a. Hosts for the Northern Riffleshell (*Epioblasma torulosa rangiana*). Triannual Unionid Report 10: 14.
- . 1996b. 1996 survey of the mussels of the Fish Creek drainage. Final report to the Indiana Chapter of The Nature Conservancy.

———. 1998. Freshwater mussel survey of the St. Joseph River drainage, exclusive of Fish Creek.

Final report to the Indiana Chapter of The Nature Conservancy.

ZAR, J.H. 1996. Biostatistical analysis, 3rd ed. Prentice Hall, Upper Saddle River, NJ. 662 p.

TABLE 1. Summary of information on mussel collections and surveys conducted in the Sydenham River between 1929 and 1991

Collectors and data sources	Year sampled	Number of sites visited	Number of records ⁸	Sampling effort (p-h/site) ⁹	Number of species found ¹⁰
Cain, R. ¹	1929	1	2	n.a.	2
Lathrop, G.A. ²	1931	1	1	n.a.	1
Athearn, H.D. ³	1963	1	18	4	18
Stein, C.B., and Stillwell, J.E. ⁴	1965	1	25	6 ¹¹	21L; 4D
Athearn, H.D. and Athearn, M.A. ³	1967	2	27	n.a.	25
Stein, C.B. and Heffelfinger, K.A. ⁴	1967	1	20	6 ¹¹	19L; 1D
Clarke, A.H. ⁵	1971	11	78	0.7-1.8	26L
Gruchy, C.G. and Bowen, R.H. ⁶	1972	1	2	n.a.	2
Scott, M.W. ⁶	1973	2	6	n.a.	6
Stein, C.B. ⁴	1973	2	4	n.a.	3L, 1D
Stein, C.B. ³	1973	2	43	3 ¹¹	21; 2D
Clarke, A.H. ⁶	1974	3	20	n.a.	15
Gruchy, C.G. ⁶	1975	1	2	n.a.	2
Kilgour, B. and Turland, R. ^{6,7}	1985	32	70	1 ¹¹	13L; 14D
Clarke, A.H. ⁸	1991	16	107	0.4-8.0 ¹¹	24L; 1D

¹Royal Ontario Museum, Toronto, ON; ²University of Michigan Museum of Zoology, Ann Arbor, MI; ³collector's personal records; ⁴Ohio State University Museum of Biological Diversity, Columbus, OH; ⁵Clarke (1972); ⁶Canadian Museum of Nature, Aylmer, PQ; ⁷Mackie and Topping (1988); ⁸Clarke (1992); ⁹defined in the text; ⁹p-h = person-hours (n.a. = not available); ¹⁰number of species found alive (L) or dead (D), where known; ¹¹abundance data available

TABLE 2. Mussel species known historically (1929-1991) from the Sydenham River drainage and their occurrence as live animals (L) or fresh spent shells (D) during the surveys of 1997-1999; L* denotes species that were assumed to have been found alive; "-" indicates species not found live or dead

	North Branch 1929-1991	North Branch 1997-1999	East Branch 1929-1991	East Branch 1997-1999
AMBLEMINAE				
<i>Amblesma plicata plicata</i>	L	L	L	L
<i>Cyclonaias tuberculata</i>	-	-	L	L
<i>Elliptio dilatata</i>	L*	L	L	L
<i>Fusconaia flava</i>	-	L	L	L
<i>Pleurobema sintoxia</i>	L*	L	L	L
<i>Quadrula pustulosa pustulosa</i>	-	-	L	L
<i>Quadrula quadrula</i>	L	L	L	L
ANODONTINAE				
<i>Alasmodonta marginata</i>	D	D	L	L
<i>Alasmodonta viridis</i>	-	-	L*	D
<i>Anodontoidea ferussacianus</i>	L	L	L	-
<i>Lasmigona complanata complanata</i>	L	L	L	L
<i>Lasmigona compressa</i>	-	L	L	-
<i>Lasmigona costata</i>	-	L	L	L
<i>Pyganodon grandis</i>	L	L	L	L
<i>Simpsonaias ambigua</i>	-	-	L*	L
<i>Strophitus undulatus</i>	L	L	L	L
<i>Utterbackia imbecillis</i>	L	-	-	D
LAMPSILINAE				
<i>Actinonaias ligamentina</i>	L	-	L	L
<i>Epioblasma torulosa rangiana</i>	-	-	L	L
<i>Epioblasma triquetra</i>	-	-	L	L
<i>Lampsilis fasciola</i>	-	-	L	D
<i>Lampsilis cardium</i>	D	-	L	L
<i>Lampsilis siliquoidea</i>	L	L	L	L
<i>Leptodea fragilis</i>	L	L	L	L
<i>Ligumia recta</i>	-	-	L	L
<i>Obliquaria reflexa</i>	-	-	-	L
<i>Obovaria subrotunda</i>	-	-	L	L
<i>Potamilus alatus</i>	L	L	L	L
<i>Ptychobranhus fasciolaris</i>	-	-	L	L
<i>Toxolasma parvus</i>	L*	-	L	-
<i>Truncilla donaciformis</i>	-	-	D	L
<i>Truncilla truncata</i>	L	D	L	L
<i>Villosa fabalis</i>	-	-	L	L
<i>Villosa iris</i>	L*	L	L	L
TOTALS	16L; 3D	15L; 2D	31L; 1D	28L; 3D

TABLE 3a. Numbers and proportions of sites where each species known only from the east branch of the Sydenham River was found alive historically (1929-1991) and during the current surveys (1997-1999). We tested the hypothesis of no change over time in frequency of occurrence in the reach surveyed during both time periods. Significant differences are indicated in bold-face type

Species	Historical (21 sites)	Historical (14 sites) ¹	Current (12 sites)	p value (2-tailed binomial test)
<i>Ligumia recta</i>	12 (57%)	10 (71%)	10 (83%)	0.528
<i>Alasmidonta marginata</i>	11 (52%)	10 (71%)	10 (83%)	0.528
<i>Obovaria subrotunda</i>	11 (52%)	10 (71%)	1 (8%)	<0.0001
<i>Cyclonaias tuberculata</i>	11 (52%)	9 (64%)	11 (92%)	0.067
<i>Ptychobranchnus fasciolaris</i>	9 (43%)	8 (57%)	9 (75%)	0.383
<i>Lampsilis cardium</i>	8 (38%)	8 (57%)	6 (50%)	0.772
<i>Quadrula p. pustulosa</i>	4 (19%)	4 (29%)	3 (25%)	1.000
<i>Villosa fabalis</i>	4 (19%)	4 (29%)	7 (58%)	0.047
<i>Epioblasma torulosa rangiana</i>	3 (14%)	3 (21%)	6 (50%)	0.027
<i>Epioblasma triquetra</i>	3 (14%)	3 (21%)	4 (33%)	0.481
<i>Lampsilis fasciola</i>	3 (14%)	3 (21%)	0	0.148
<i>Alasmidonta viridis</i>	2 (10%)	1 (7%)	0	0.621
<i>Simpsonaias ambigua</i>	1 (5%)	1 (7%)	3 (25%)	0.049
<i>Obliquaria reflexa</i>	0	0	1 (8%)	-
<i>Truncilla donaciformis</i>	0	0	1 (8%)	-

¹sites located within the reach surveyed in 1997-99

TABLE 3b. Numbers and proportions of sites where each species known from both the east and north branches of the Sydenham River was found alive historically (1929-1991) and during the current surveys (1997-1999). We tested the hypothesis of no change over time in frequency of occurrence in the reaches surveyed during both time periods. Significant differences are emphasized in bold-face type

Species	East Branch:				East and North Branches:			
	Historical (21 sites)	Historical (14 sites) ¹	Current (12 sites)	p value (2-tailed binomial test)	Historical (33 sites)	Historical (22 sites) ¹	Current (16 sites) ²	p value (2-tailed binomial test)
<i>Amblema p. plicata</i>	16 (76%)	14 (100%)	12 (100%)	-	20 (61%)	16 (73%)	14 (88%)	0.264
<i>Pyganodon grandis</i>	13 (62%)	8 (57%)	8 (67%)	0.772	24 (73%)	16 (73%)	12 (75%)	1.000
<i>Lasmigona costata</i>	12 (57%)	11 (79%)	12 (100%)	0.148	12 (36%)	11 (50%)	13 (81%)	0.021
<i>Actinonaias ligamentina</i>	12 (57%)	10 (71%)	11 (92%)	0.199	14 (42%)	11 (50%)	11 (69%)	0.210
<i>Lampsilis siliquoides</i>	11 (52%)	10 (71%)	5 (42%)	0.047	15 (46%)	12 (55%)	8 (50%)	1.000
<i>Leptodea fragilis</i>	10 (48%)	10 (71%)	11 (92%)	0.199	16 (49%)	16 (73%)	13 (81%)	0.581
<i>Fusconaias flava</i>	10 (48%)	10 (71%)	7 (58%)	0.528	10 (30%)	10 (46%)	9 (56%)	0.620
<i>Elliptio dilatata</i>	10 (48%)	9 (64%)	8 (67%)	1.000	12 (36%)	10 (46%)	9 (56%)	0.620
<i>Lasmigona c. complanata</i>	10 (48%)	8 (57%)	11 (92%)	0.037	19 (58%)	15 (68%)	15 (94%)	0.056
<i>Truncilla truncata</i>	8 (38%)	7 (50%)	8 (67%)	0.388	13 (39%)	11 (50%)	8 (50%)	1.000
<i>Pleurobema sintoxia</i>	7 (33%)	7 (50%)	5 (42%)	0.774	8 (24%)	8 (36%)	6 (38%)	1.000
<i>Strophitus undulatus</i>	6 (29%)	6 (43%)	3 (25%)	0.383	8 (24%)	8 (36%)	4 (25%)	0.441
<i>Villosa iris</i>	5 (24%)	5 (36%)	2 (17%)	0.233	6 (18%)	6 (27%)	3 (19%)	0.581
<i>Quadrula quadrula</i>	4 (19%)	3 (21%)	7 (58%)	0.006	8 (24%)	6 (27%)	9 (56%)	0.020
<i>Potamilus alatus</i>	3 (14%)	3 (21%)	8 (67%)	0.0009	6 (18%)	5 (23%)	9 (56%)	0.004
<i>Anodontoides ferussacianus</i>	3 (14%)	1 (7%)	0	0.621	4 (12%)	1 (5%)	1 (6%)	1.000
<i>Lasmigona compressa</i>	2 (10%)	2 (14%)	0	0.397	2 (6%)	2 (9%)	1 (6%)	1.000
<i>Toxolasma parvus</i>	1 (5%)	0	0	-	2 (6%)	0	0	-
<i>Utterbackia imbecillis</i>	0	0	0	-	2 (6%)	1 (5%)	0	1.000

¹ sites located within the reach surveyed in 1997-99; ² site in Black Creek was excluded (no historical equivalent)

TABLE 4. Mean values for water quality parameters measured at 5 sites on the north branch and 12 sites on the east branch of the Sydenham River (mg/L except where otherwise indicated)

Parameter	North Branch	East Branch
TKN ¹	1.129	0.462
SO ₄ ¹	55.3	48.0
K ¹	5.41	3.78
NO ₃ NO ₂	2.415	1.437
TP	0.1477	0.0619
Turbidity (JTU)	75.4	10.7
Velocity ¹ (m/s)	0.0864	0.3880
SRP	0.0854	0.0185
Mg	15.5	17.4
Cl ¹	38.3	29.8
Alkalinity ¹	155.0	200.3
Na	20.48	15.76
SiO ₄	3.99	4.70
Hardness ¹	226.6	258.9
Clarity ¹ (m)	0.10	0.23
Ca ¹	65.1	75.0
NH ₃	0.093	0.060

¹significant difference between branches at $P < 0.05$

TABLE 5. Correlations between species richness and water quality parameters at 17 sites on the Sydenham River

Parameter	r
TKN (mg/L)	-0.781 ¹
SO ₄ (mg/L)	-0.737 ¹
K (mg/L)	-0.661 ¹
NO ₃ NO ₂ (mg/L)	-0.641 ¹
TP (mg/L)	-0.637 ¹
Turbidity (JTU)	-0.617 ¹
Velocity (m/s)	0.594 ¹
SRP (mg/L)	-0.527 ¹
Mg (mg/L)	0.513 ¹
Cl (mg/L)	-0.484 ¹
Alkalinity (mg/L)	0.413
Na (mg/L)	-0.395
SiO ₄ (mg/L)	-0.334
Hardness (mg/L)	0.158
Clarity (m)	0.158
Ca (mg/L)	0.044
NH ₃ (mg/L)	0.028

¹correlation significant at $P < 0.05$

TABLE 6. Populations of main urban centres in the Sydenham River watershed, and types of sewage treatment in place in the 1960s vs. 1990s

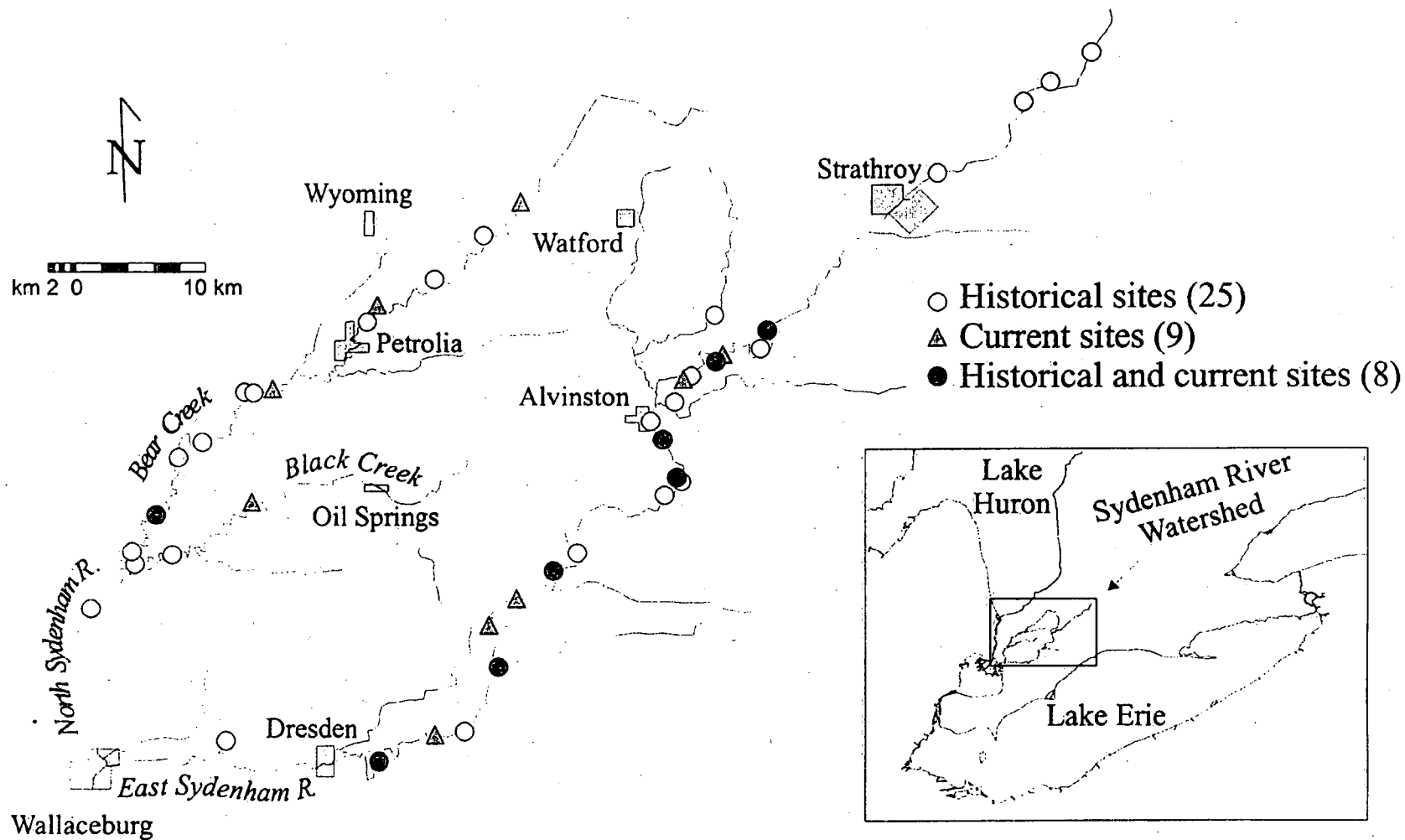
Municipality	Population (1967) ¹	Sewage Treatment (1965) ²	Population (1996) ³	Sewage Treatment (1999) ⁴
<u>East Branch:</u>				
Strathroy	5,646	lagoon	11,852	lagoons
Alvinston	641	none	1,037	secondary
Dresden	2,378	none	2,589	secondary
<u>North Branch:</u>				
Watford	1,260	none	1,660	lagoons
Wyoming	950	none	2,131	tertiary
Petrolia	3,669	lagoon	4,908	tertiary
Oil Springs	523	none	773	lagoon
<u>Main Branch:</u>				
Wallaceburg	10,746	under construction	11,772	secondary

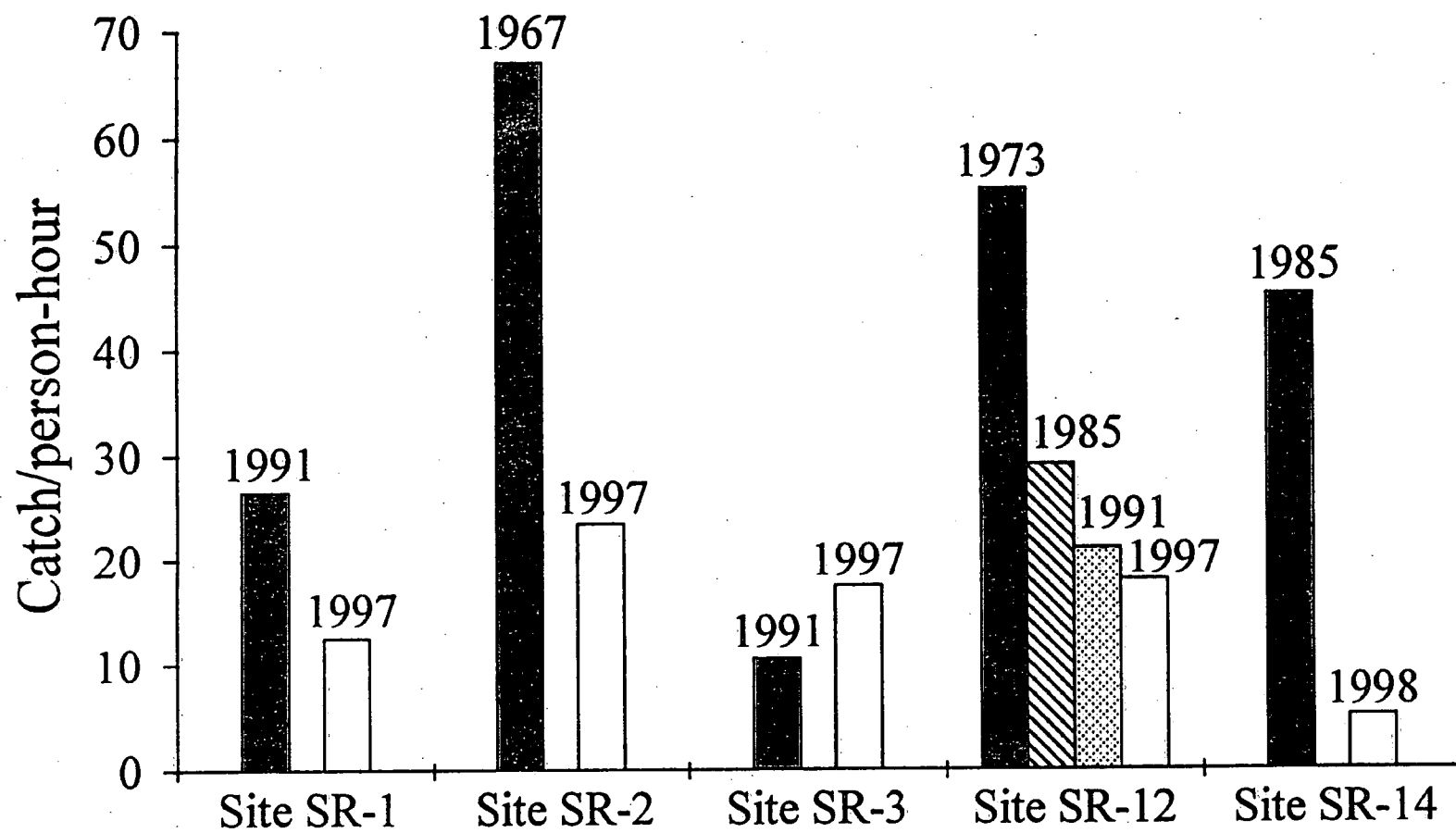
¹Osmond (1969); ²DERM (1965); ³Statistics Canada's 1996 Census of Population;

⁴courtesy of the Ontario Ministry of Environment and Energy

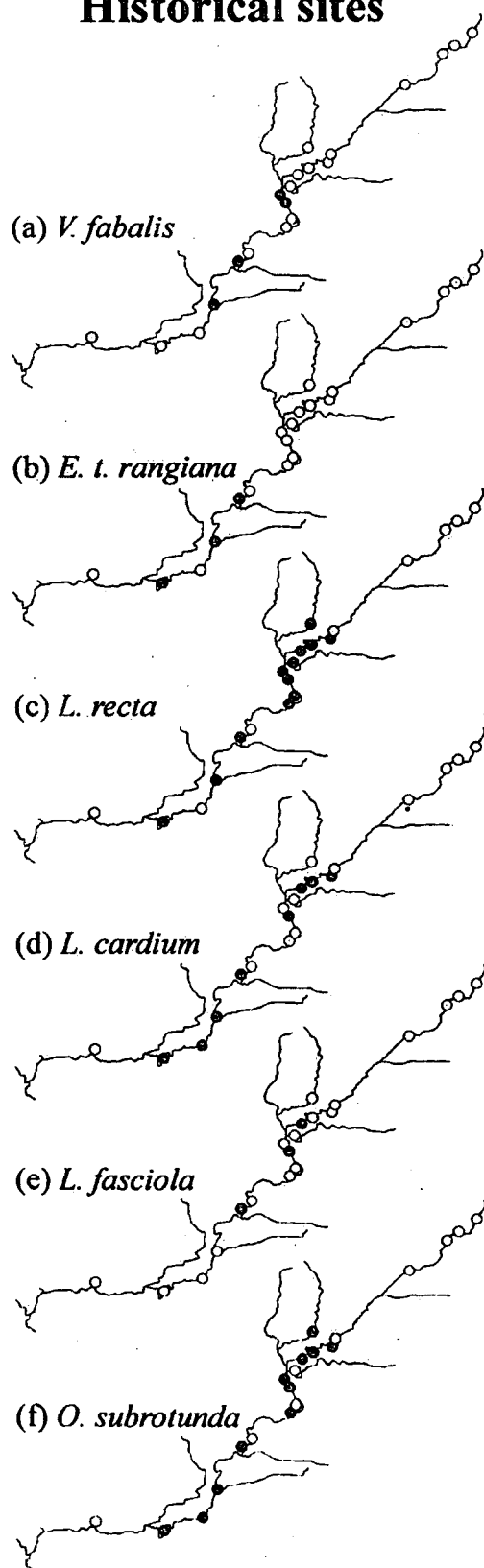
FIGURE CAPTIONS

- FIG. 1. Map of the study area showing all sites on the Sydenham River that were surveyed for mussels historically (1929-1991) and/or during the current study (1997-1999). A total of 42 different sites were surveyed
- FIG. 2. Relative abundance (catch/person-hour) of mussels at five sites for which current and historical data are available. Site SR-1 is above Alvinston, sites SR-2 and SR-3 are below Alvinston, site SR-12 is upstream of Dresden and site SR-14 is on Bear Creek (*see* black dots in Fig. 1)
- FIG. 3. Historical (1929-1991) and current (1997-1999) distributions of six representative species known only from the east branch of the Sydenham River. Closed circles and squares indicate sites where the species was present
- FIG. 4. Historical (1929-1991) and current (1997-1999) distributions of six representative species known from both the north and east branches of the Sydenham River. Closed circles and squares indicate sites where the species was present
- FIG. 5. Relative composition of the current mussel communities of the north and east branches of the Sydenham River

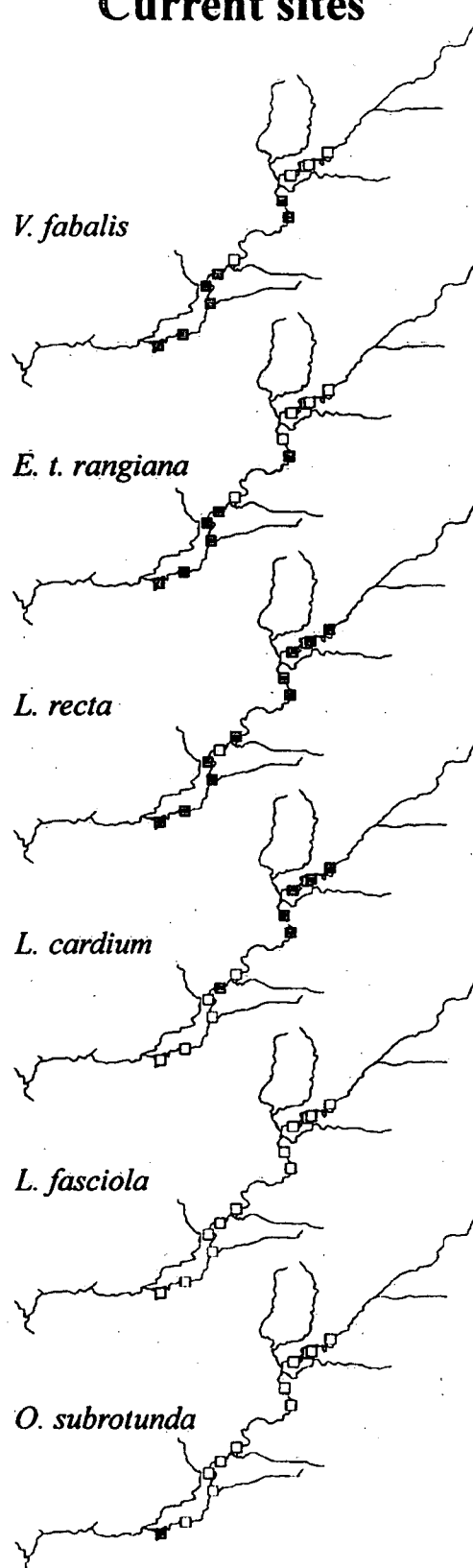




Historical sites

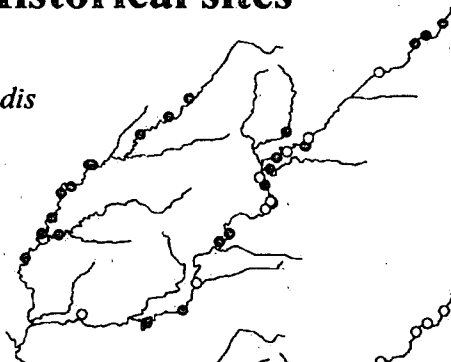


Current sites

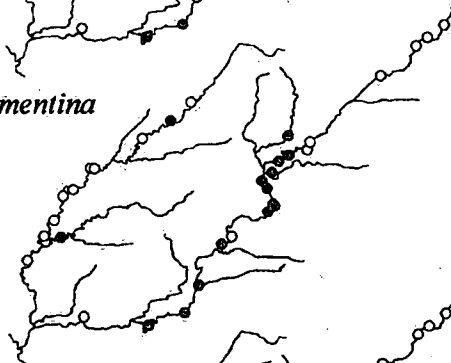


Historical sites

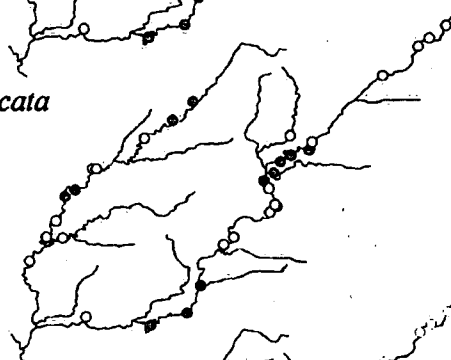
(a) *P. grandis*



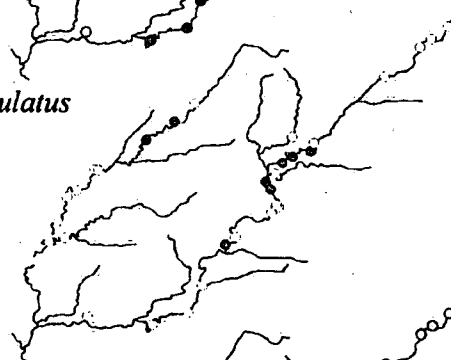
(b) *A. ligamentina*



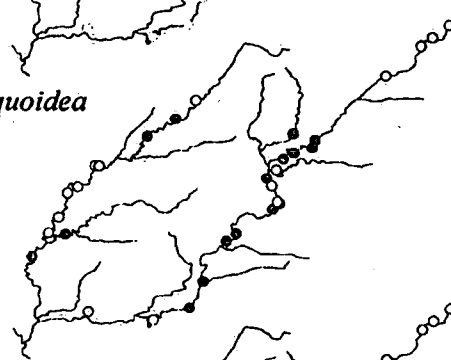
(c) *T. truncata*



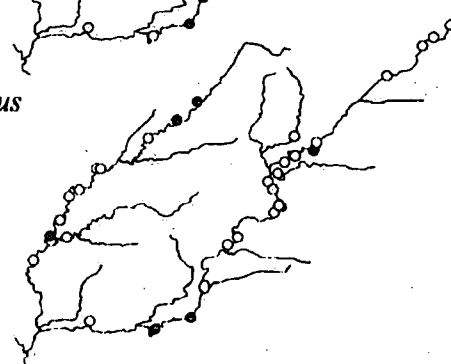
(d) *S. undulatus*



(e) *L. siliquoidea*

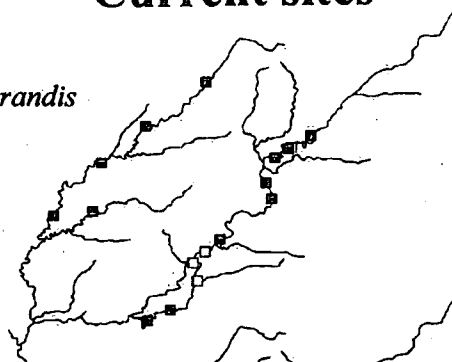


(f) *P. alatus*



Current sites

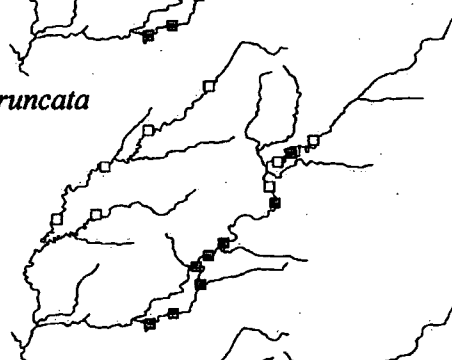
P. grandis



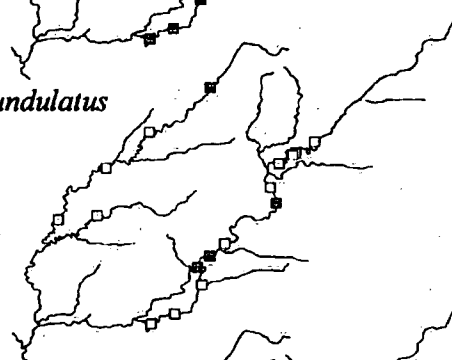
A. ligamentina



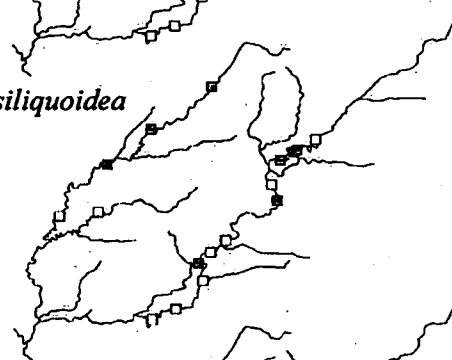
T. truncata



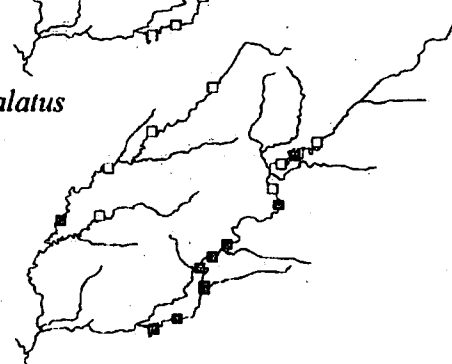
S. undulatus



L. siliquoidea



P. alatus



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