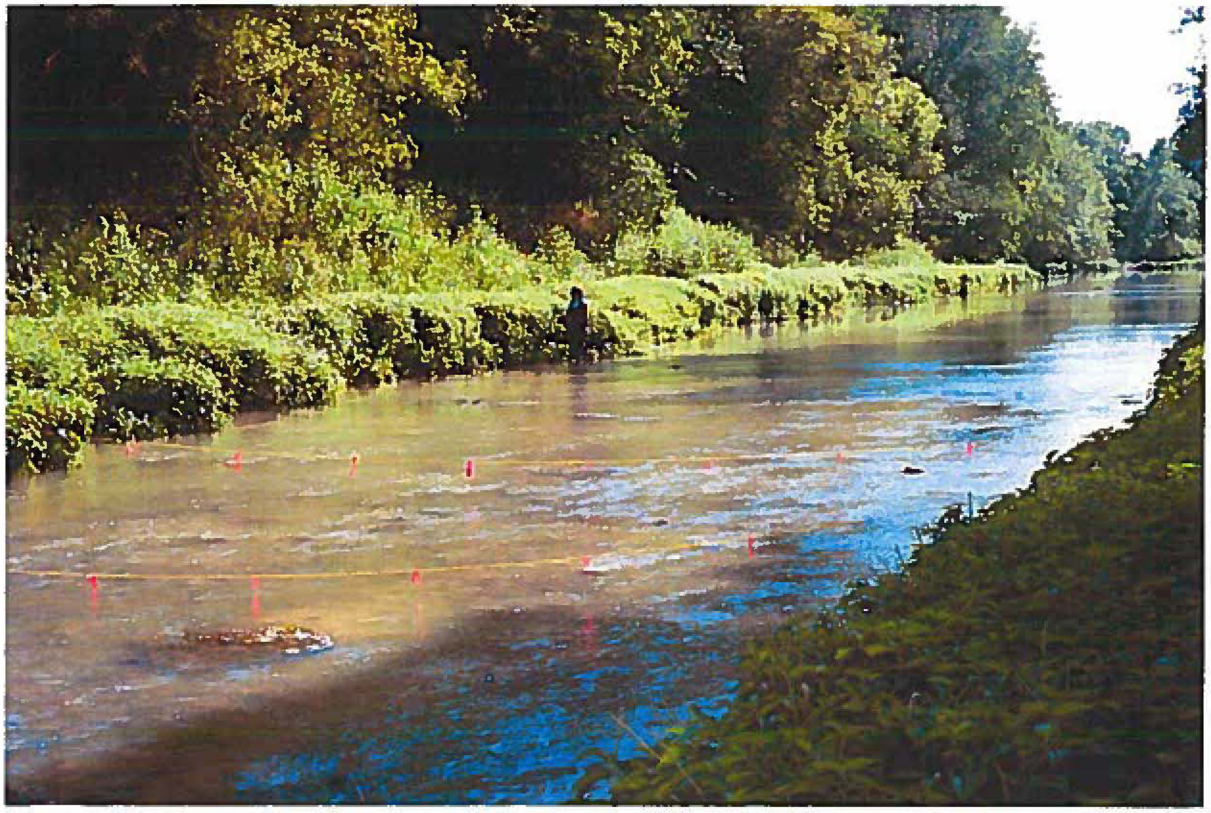
Development of a Monitoring Program for Tracking the Recovery of Endangered Freshwater Mussels in the Sydenham River, Ontario



Prepared for the Sydenham River Recovery Team, the Interdepartmental Recovery Fund and Fisheries and Oceans Canada

by

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ABSTRACT

The occurrence of 14 Canadian Species at Risk (8 fishes, 5 freshwater mussels and one turtle) in the Sydenham River prompted the development of an aquatic ecosystem recovery strategy for the river – the first of its kind in Canada. The long-term goal of the Recovery Strategy is to sustain and enhance the native aquatic communities of the Sydenham River through an ecosystem approach that focuses on Species at Risk (SAR). Short-term objectives include mitigating threats, promoting good stewardship to maintain current distributions and abundances of aquatic SAR, and establishing a broad-based monitoring program to track changes in the physical, chemical and biological characteristics of the system as recovery actions are implemented. The purpose of this project was to establish a 15-site network of monitoring sites for mussel SAR throughout the Sydenham River and collect baseline data on the distribution, abundance, population demographics and habitat requirements of these species. A 400 m^2 area was sampled at each site using 1 m^2 quadrats and a systematic sampling design. All mussels found alive were counted, measured and sexed (if sexually dimorphic), and current velocity, water depth, substrate composition and percent macrophyte cover were recorded. Hierarchical cluster analysis, kriging and an indicator species analysis were used to examine relationships between mussels and habitat features. A total of 5453 mussels of 30 species were found alive at the 15 sites; richness ranged from 2 to 23 species/site and density from 0.12-14 mussels/m^2. Results showed that the Rayed Bean (*Villosa fabalis*) and possibly the Northern Riffleshell (*Epioblasma torulosa rangiana*) are "holding their own" in the river, whereas populations of the Kidneyshell (*Ptychobranchus fasciolaris*), Snuffbox (*Epioblasma triquetra*) and Round Pigtoe (*Pleurobema sintoxia*) are in decline. The Wavyrayed Lampmussel (*Lampsilis fasciola*) is believed to be extirpated from the river and the Round Hickorynut (*Obovaria subrotunda*) nearly so. The Mudpuppy Mussel (*Simpsonaias ambigua*) was inadequately sampled and may require a different approach due to its specialized habitat. The greatest richness and density of mussels, including the SAR, occurred in shallow water with relatively swift flows, high proportions of sand, moderate amounts of boulder, rubble, gravel and silt, and very little clay, muck or detritus. Two contiguous sites in the middle reach of the East Sydenham River supported the healthiest populations of most SAR and may represent critical habitat for endangered mussels in this system. Associations between certain SAR and other more common mussel species were also identified, suggesting that the common species could serve as indicators of the potential presence of the SAR. Baseline data collected during this study will help the Sydenham River Recovery Team identify critical habitat for mussel SAR, direct recovery actions where they are needed most and track the species' responses to these actions. The design of this monitoring program could be applied to other small to medium-sized river systems in Canada.

RÉSUMÉ

La présence de 14 espèces canadiennes en péril (huit poissons, cinq moules d'eau douce et une tortue) dans la rivière Sydenham est à l'origine de l'élaboration d'un programme de rétablissement de l'écosystème aquatique de la rivière, le premier dans son genre au Canada. L'objectif à long terme du Programme de rétablissement consiste à maintenir et à renforcer les communautés aquatiques indigènes de la rivière Sydenham en utilisant une approche écosystémique qui met l'accent sur les espèces en péril. Parmi les objectifs à court terme, on retrouve l'atténuation des menaces, la promotion de bonnes pratiques d'intendance pour maintenir les répartitions et les niveaux d'abondance actuels des espèces aquatiques en péril, ainsi que l'établissement d'un programme de surveillance à grande échelle en vue d'assurer le suivi des changements de caractéristiques physiques, chimiques et biologiques du système au cours de la mise en œuvre des mesures de rétablissement. Ce projet avait pour but d'établir un réseau de 15 sites de surveillance pour les espèces de moules en péril dans l'ensemble de la rivière Sydenham et de recueillir des données de référence sur la répartition, l'abondance, les effectifs des populations et les besoins de l'habitat de ces espèces. Une région de 400 m2 a fait l'objet de prélèvements d'échantillons sur chaque site au moyen de quadrats de 1 m2 et d'une conception d'échantillonnage systématique. Toutes les moules trouvées vivantes ont été dénombrées, mesurées, et leur sexe déterminé (pour les espèces dimorphes). De plus, la force du courant, la profondeur de l'eau, la composition du substrat et le pourcentage de couverture des macrophytes ont été consignés. La classification hiérarchique des points d'échantillonnage, le krigeage et une analyse des espèces indicatrices ont été utilisés pour examiner les relations entre les moules et les caractéristiques de l'habitat. Un total de 5 453 moules de 30 espèces ont été trouvées vivantes sur les 15 sites, la richesse variant de 2 à 23 espèces par site et la densité variant de 0,12 à 14 moules par m2. Les résultats ont indiqué que la Villeuse haricot (Villosa

fabalis) et possiblement la Dysnomie ventrue jaune (Epioblasma torulosa rangiana) se « portent bien » dans la rivière, alors que les populations du Ptychobranche réniforme (Ptychobranchus fasciolaris), de l'Épioblasme tricorne (Epioblasma triquetra) et du Pleurobème écarlate (Pleurobema sintoxia) sont en déclin. On croit que la Lampsile fasciolée (Lampsilis fasciola) est disparue de la rivière et que l'Obovarie ronde (Obovaria subrotunda) l'est presque également. Les échantillons de la Mulette du Necturus (Simpsonaias ambigua) ont été prélevés de façon inappropriée et il se peut qu'une approche différente soit nécessaire en raison de son habitat spécialisé. La plus grande richesse et la plus grande densité de moules, y compris celles des espèces en péril, étaient présentes dans l'eau peu profonde à un débit rapide, des proportions élevées de sable, une quantité moyenne de rochers, de pierres, de gravier et de limon, ainsi que comportant très peu d'argile, de boue ou de débris. Deux sites contigus dans le tronçon du milieu de la rivière Sydenham de l'est abritaient les populations les plus saines de la majorité des espèces en péril et peuvent représenter un habitat essentiel pour les moules en péril dans ce système. Les liens entre certaines espèces en péril et d'autres espèces de moules plus communes ont également été relevés, laissant entrevoir que les espèces communes pourraient servir d'indices de la présence éventuelle des espèces en péril. Les données de référence recueillies au cours de cette étude aideront l'Équipe de rétablissement de la rivière Sydenham à désigner l'habitat essentiel des espèces de moules en péril, à diriger des mesures de rétablissement là où elles sont le plus nécessaire et à assurer le suivi des réactions des espèces à ces mesures. La conception de ce programme de surveillance pourrait s'appliquer à d'autres réseaux hydrographiques de petite à moyenne dimension au Canada.

INTRODUCTION

The Sydenham River, which flows through the Carolinian Zone of southwestern Canada en route to Lake St. Clair, supports one of the most diverse aquatic ecosystems in Canada. It is believed to be one of the richest small river systems for freshwater mussels in North America (Clarke 1992) and is home to an outstanding remnant – 31 species – of the Great Lakes mussel fauna. Eight species of mussels native to the Sydenham River have been designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2006) and are on Schedule 1 of *The Species at Risk Act* (SARA). These species are the Northern Riffleshell

(*Epioblasma torulosa rangiana*), Snuffbox (*Epioblasma triquetra*), Wavyrayed Lampmussel (*Lampsilis fasciola*), Round Hickorynut (*Obovaria subrotunda*), Round Pigtoe (*Pleurobema sintoxia*), Kidneyshell (*Ptychobranchus fasciolaris*), Mudpuppy Mussel (*Simpsonaias ambigua*), and Rayed Bean (*Villosa fabalis*). To the best of our knowledge, the Sydenham River supports the only known population of the Mudpuppy Mussel in Canada, the largest populations of the Northern Riffleshell and Rayed Bean, and among the most significant populations of the Snuffbox, Round Pigtoe and Kidneyshell. The Northern Riffleshell and Rayed Bean are globally endangered species (G2T2 and G2, respectively; NatureServe 2006) and the Northern Riffleshell is listed as Critically Endangered on the IUCN Red List of Threatened Species (IUCN 2006); thus, Canada has a particular responsibility for protecting and restoring Canadian populations of these mussels. Results of an earlier study suggested that that the mussel community of the Sydenham River is beginning to show signs of decline (Metcalfe-Smith *et al.* 2003). The Wavyrayed Lampmussel is believed to be extirpated from the system (Metcalfe-Smith and McGoldrick 2003) and seven other species, including the Round Hickorynut, are declining in one or both branches of the river. Several pollution/siltation-tolerant species such as the Pink Heelsplitter (*Potamilus alatus*) and White Heelsplitter (*Lasmigona complanata*) are expanding their ranges, indicating that water and habitat quality may be deteriorating.

The occurrence of 14 Canadian Species at Risk, i.e., eight fishes, five mussels and one turtle, in the Sydenham River prompted a multi-agency team to develop an aquatic ecosystem recovery strategy for the river – the first of its kind in Canada (Dextrase *et al.* 2003). Prior to the development of the Recovery Strategy, the team reviewed all available information on current and historical distributions of aquatic species at risk (SAR) and their environmental requirements as well as water quality trends and changes in land use patterns over time, and commissioned a fluvial geomorphology assessment. Analysis of this information indicated that the principal stresses impacting populations of aquatic SAR in the Sydenham River watershed are: suspended solids that cause turbidity and siltation, nutrient loads, toxic chemicals, thermal changes, and exotic species (Staton *et al.* 2003). Threats specific, or particularly significant, to various species were also identified. In the case of mussel SAR, some threats may affect mussels directly whereas others affect the hosts on which they depend for survival. All threats have been described in detail in the status reports and are summarized in the recovery strategy. Examples of potential threats and the species that would be particularly impacted are: poor water clarity (Wavyrayed Lampmussel), toxic chemicals (Rayed Bean), siltation of riffle habitat and loss or decline of fish hosts (Northern Riffleshell, Snuffbox), and lack of habitat for the amphibian host (Mudpuppy Mussel).

The long-term goal of the Sydenham River Recovery Strategy is "to sustain and enhance the native aquatic communities of the Sydenham River through an ecosystem approach that focuses on species at risk" (Dextrase *et al.* 2003). Short-term (5-year) recovery objectives include maintaining the current distributions and abundances of aquatic SAR, improving water and habitat quality by reducing sediment, nutrient and chemical inputs and ensuring base flow is maintained, reducing the risk of introduction of exotic species, and promoting good stewardship of the watershed and awareness of its natural heritage significance. Another important objective is to establish a broad-based monitoring program to track changes in the physical, chemical and biological characteristics of the system as recovery actions are implemented and to follow the subsequent recovery of aquatic SAR. Establishment of a monitoring program is essential to the adaptive management approach embraced by the recovery team and was identified as an urgent priority in the Recovery Strategy.

The main objective of this project was to establish a 15-site network of index monitoring sites for mussel SAR throughout the Sydenham River and to collect baseline data on the distributions, population demographics, and habitat requirements of these species. The eight Endangered species mentioned earlier were the main focus of the study, but data were also gathered on the richness, abundance, composition and habitat requirements of the mussel community as a whole. These data, in combination with data from other components of the broad-based monitoring program, will allow the recovery team to track changes over time as the system recovers. Such data will also contribute to a better understanding of the major threats to aquatic SAR and their mode of impact. This information will be used to direct the activities of the Management and Stewardship Recovery Implementation Groups (RIGs) toward mitigating the most significant threats to these species, and will also feed back into the Research and Monitoring RIG for empirical testing of cause/effect relationships.

METHODS

Selection of Monitoring Sites

In 1997-98, semi-quantitative surveys for mussels were conducted at 17 sites on the Sydenham River, including 12 sites on the East Sydenham River, 4 sites on Bear Creek and one site on Black Creek (Metcalfe-Smith *et al.* 1998, 1999, 2003). As the purpose of these initial surveys was to determine the occurrence and distributions of rare species, sites that had supported rare species or diverse mussel communities in the past were targeted. Surveys were conducted using 4.5 person-hour (p-h) timed searches, which is known to be an efficient method for detecting rare species (Metcalfe-Smith *et al.* 2000). Results of these surveys were used to help identify suitable index sites for the mussel monitoring program.

A short-term objective of the Sydenham River Recovery Strategy is to maintain the current distributions and abundances of SAR in the system, while the long-term goal is to restore these species to their original distributions and population sizes if feasible (Dextrase *et al.* 2003). Thus, it was determined that index sites should be located in both currently- and historically-occupied reaches of the river. Twelve of the 17 sites surveyed in 1997-98 were selected as index sites. The five sites that were not chosen included three sites with very low richness and abundance of mussels (SR-8, 14 and 16) and two sites that were located near other sites that had already been selected (SR-4 and 11); see Figure 3 in Metcalfe-Smith *et al.* (1999) for the locations of all sites surveyed in 1997-98. Three sites that had not been surveyed previously were also chosen as index sites. Two of these sites were in the deep, lower reaches of the East Sydenham River that were only accessible by SCUBA divers (SR-20 and 21). The final site (SR-19) was chosen because biologists with Fisheries and Oceans Canada, who are developing sampling protocols for fish SAR in the Sydenham River, found that it supported a particularly diverse and abundant fish community. The locations of all 15 index sites are shown in Figure 1.

Sampling Methods

The monitoring program employed an intensive quantitative sampling technique that would allow for the collection of precise and detailed baseline data on the distribution, abundance, demographics and habitat requirements of mussel populations in the Sydenham River. Such data will provide the foundation for detecting changes in the health of mussel populations over time in response to recovery actions. The sampling protocol was developed in consultation with Dr. David R. Smith, a biostatistician with the U.S. Geological Survey who advises the U.S. Army Corps of Engineers on methods for assessing the impacts of development projects on federally endangered mussels in the United States. A probability-based sampling design known as systematic sampling was used. Systematic sampling is recommended for many applications because it is easy to implement in the field, provides good spatial coverage of the area of interest and provides precise estimates of population parameters such as density or abundance for patchily distributed populations (Strayer and Smith 2003). The sampling protocol is described in detail below:

Sampling was conducted by a 3-person team and required approximately 2 days of work per site. At each site, the most productive portion of the reach for mussels was selected for sampling. For 12 of the 15 sites, the most productive area was already known from the results of earlier timed search surveys (see above). As sites SR-19, 20 and 21 had not been sampled previously, a brief reconnaissance survey was conducted prior to selecting the sampling area at these sites. In most cases, the area chosen for sampling included a riffle. Quantitative sampling was conducted using 1 m^2 quadrats and a systematic sampling design with three random starts. This design is useful for determining variation throughout a site, because sampling coverage is consistent. At each site, the area to be sampled was divided into blocks of equal size. As more variation in the mussel community was expected to occur across the river than in an upstream/downstream direction, it was advantageous to position the sampling units closer together along the former gradient. Thus, the blocks were rectangular in shape, with the shorter dimension across the width of the river (3 m wide and 5 m long). Each block consisted of 15 – 1 m^2 quadrats, and the same three randomly chosen quadrats were sampled in each block. Coverage was 20%, which is quite extensive but thought to be appropriate for a baseline survey. A total area of ~ 400 m^2 was sampled at each site, as this area could be reasonably sampled within 2 days. The number of transects across the river varied from site to site due to variation in the width of the river, but the total sampling area remained constant. Figure 2 illustrates the sampling design used at site SR-17. Sampling commenced at the downstream end of each site to minimize disturbance of the substrate. Each quadrat was searched by two people until all live mussels had been recovered (~ 8 person-minutes/quadrat). All embedded stones that were smaller than boulders (defined as 25 cm in diameter; Ontario Ministry of Natural Resources 1987), were removed and the substrate was then excavated to a depth of 10-15 cm in order to obtain any juveniles present. Juvenile mussels remain buried in the substrate until they are sexually mature, at which point they move to the surface for the dispersal/intake of gametes (Watters *et al.* 2001). All live mussels found in each quadrat were identified to species and sexed where possible (some species are sexually dimorphic), and shell lengths were measured to the nearest mm using vernier calipers. All animals were returned to the river alive. Current speed, water depth, % macrophytes, % periphyton, % shading and substrate composition were determined for each quadrat. Substrate composition was characterized by estimating the relative proportions of bedrock, boulder, rubble, gravel, sand, silt, clay, muck and detritus using the Ontario Ministry of Natural Resources' (1987) classification scheme. The third member of the team measured current speed and water depth and also recorded the field data.

Sampling was conducted in mid- to late summer at each of the 15 monitoring sites. The starting dates for each site are as follows: SR-1 – 22 July 2002; SR-10 – 7 August 2001; SR-2 – 2 September 2003; SR-3 – 9 August 1999; SR-7 – 26 August 2003; SR-17 – 30 July 2001; SR-5 – 13 August 2003; SR-19 – 19 August 2002; SR-6 – 22 July 2002; SR-12 – 27 July 1999; SR-20 – 4 September 2002; SR-21 – 2 September 2003; SR-9 – 12 September 2001; SR-15 – 12 August 2002; SR-13 – 12 August 2003.

Statistical Analyses

Hierarchical cluster analysis was used to identify optimal habitat for mussels, i.e., the habitat type(s) that supported the greatest richness and density of mussels at each site. Hierarchical cluster analysis is a multivariate procedure that detects natural groupings in data (SYSTAT©, SPSS Inc. 1998). Groupings are arranged in a dendrogram or tree. Hierarchical methods are the most commonly used classification procedures because they provide information on the relationships among groups (Norris and Georges 1993). Initially, each case (quadrat) is considered a separate cluster. The SYSTAT© program begins by joining the two "closest" objects as a cluster and continues in a stepwise manner by joining an object with another object, an object with a cluster or a cluster with another cluster until all objects are combined into one cluster. The type of joining algorithm used to amalgamate clusters must be specified. The linkage method used here was Ward's method, which averages all distances between pairs of objects in different clusters, with adjustments for covariances, to determine how far apart the clusters are. The distance metric used was Euclidean, whereby clustering is computed using normalized Euclidean distance (root mean squared distances); this metric is appropriate for use with quantitative variables. The biological variables (unionid density and richness) and habitat variables (all variables listed in the previous section except % periphyton and % shading, which were considered too coarse) used in each analysis were standardized by z-transformation, i.e., the mean value for each variable subtracted from and divided by the sample standard deviation.

A second cluster analysis was performed on pooled habitat data from all 15 monitoring sites using the above-described methods. The purpose of this analysis was to determine species-specific habitat preferences, with emphasis on the target species. Unionid density and richness were omitted from the analysis as otherwise the clusters would be driven by the habitat preferences of mussels as a whole. Habitat variables were clustered at the block level using mean values calculated from measurements made in the 3 quadrats in each block. The clusters (habitat groups) were then used to calculate the indicator value (INDVAL) for each species (Dufresne and Legendre 1997). The indicator species analysis derives the species most indicative of each habitat group by multiplying each species' relative abundance within each habitat group by its frequency of occurrence across all habitat groups. The INDVAL for a particular species is at the maximum (100%) when all individuals of that species belong to the same habitat group. Indicator values were calculated using the statistical software package PC-ORD© v.4.25 (McCune and Mefford 1999). In this program, the significance of the INDVAL assigned to each species is assessed by a Monte Carlo randomization test. To meet the requirements of PC-ORD©, all blocks that did not contain any live mussels were removed from the dataset.

Although the indicator species analysis described above did derive significant indicator species for several habitat groups, only the most abundant target species, *V. fabalis*, was among those identified. Further analyses were therefore performed to investigate the associations, if any, between the target species and other more common species. Species occurrence and abundance data from the 15 sites were examined for species associations at the block level. Five species that occurred at only one site, namely, the Cylindrical Papershell (*Anodontoides ferussacianus*), Creek Heelsplitter (*Lasmigona compressa*), Threehorn Wartyback (*Obliquaria reflexa*), Fawnsfoot (*Truncilla donaciformis*) and Paper Pondshell (*Utterbackia imbecillis*), and all blocks that did not contain any live mussels, were removed from the dataset. Analyses were conducted on the abundance data for 25 mussel species from 340 blocks, following the methods of Legendre (2005). Abundance data were transformed using the 2-step Hellinger transformation, whereby the abundance of each species in a block is expressed as a proportion of the total abundance of mussels in the block and the square root of the proportion is then calculated. This transformation is appropriate for community composition data that contain many zeros, and it also reduces the weighting of very high species abundances. A test of concordance among the species was conducted using Kendall's W statistic to determine if the species were independent of one another, i.e., not associated (H_o) or not independent of one another (H_1). The null hypothesis was rejected (Kendall's $W = 0.08815$; $p = 0.0001$), indicating that the species were not all independent of one another. To determine which species were associated with which other species, a Spearman correlation matrix was computed using the transformed abundance data. The correlation coefficients were then used in Ward's agglomerative clustering in order to visualize these associations.

"Kriging" is a geostatistical term that refers to the use of interpolation in spatial prediction. It is often applied in ecological studies whereby "observations of animals or plants at a sample of sites can be used to predict the abundance in the vicinity of a new site or in the entire study region" (Thompson 1992). Values for points not sampled are interpolated using knowledge about the underlying spatial relationships in a dataset. Variograms (variances of differences) provide this knowledge. Kriging is superior to other methods of interpolation because it provides an optimal interpolation estimate for a given coordinate location as well as a variance estimate for the interpolated value. In the present study, we used the software package GS^+

GeoStatistics for the Environmental Sciences© (v.5.1, Gamma Design Software 2000) to generate a series of maps showing the spatial distributions of mussels and habitat features at each of the study sites. These maps serve as an aid for visualizing associations among mussels and between mussels and various habitat features.

RESULTS AND DISCUSSION

Distribution, Abundance and General Habitat Requirements of Freshwater Mussels in the Sydenham River

A total of 5453 mussels of 30 species were found alive at the 15 monitoring sites (Table 1). Richness ranged from 2 to 23 species per site and density ranged from 0.12 - 14 mussels/m^2. The richest mussel communities were found in a 50 km reach of the East Sydenham River between Alvinston (site SR-3) and Dawn Mills (site SR-12), which is consistent with the results of the timed search surveys (see Metcalfe-Smith *et al.* 1999). Detailed information on the composition of the mussel community at each site, i.e., relative abundance and density of each species and the proportion of quadrats where each species occurred, is presented in Appendix 1. Appendix 2 presents information on the geographical location of each site, numbers of quadrats searched, total search time expended, overall and mean (± SE) richness and abundance of mussels, and mean (± SE) water velocity, depth and substrate composition. These baseline data will serve as a reference point for evaluating the results of future surveys.

Hierarchical cluster analysis was used to identify the habitat type(s) that supported the greatest richness and density of mussels at each site. The data fell into 3 to 5 natural groups of biological and physical features at each site, yielding a total of 63 groups from the 15 index sites (Appendix 3). As mussel richness and density were highly correlated ($r = 0.98$), only density was considered in the following analysis. The 63 groups were arranged according to their mean mussel density, from a high of 32.3 mussels/m^2 in Group B from site SR-17 to a low of 0 mussels/m^2 in several groups from sites SR-20 and SR-21 (Figure 3). Based on Figure 3, the 63 groups appeared to fall into four categories of density, i.e., very high (>10 mussels/m^2; n = 7 groups), high (>5-10 mussels/m^2; n = 12 groups), moderate (>1.5-5 mussels/m^2; n = 24 groups) and low (0-1.5 mussels/m^2; n = 20 groups). Table 2 summarizes the attributes of the habitats that supported very high, high, moderate and low densities of mussels. Although there was a considerable amount of variation in habitat type within each category, several broad relationships emerged. Habitats with the highest current velocities tended to support the greatest densities of mussels, whereas all habitats with very low velocities (< 0.10 m/s) supported low or occasionally moderate densities of mussels. The highest densities of mussels were found in shallow water (~ 10-20 cm depth), with the deepest habitats consistently supporting the fewest animals. Substrates with moderate proportions of boulder, rubble and gravel, high proportions of sand, and low proportions of clay, muck and detritus tended to support higher densities of mussels. The highest densities were found in substrates with almost no clay, muck or detritus. Mussels appeared to prefer at least moderate amounts of silt (10-15%); however, only 10% of the habitats supporting high or very high densities of mussels had more than 20% silt. In contrast, 25% of the habitats supporting low to moderate densities of animals had > 20% silt. Macrophytes were found in only a few (10 of 63) habitat groups and were most frequently associated with moderate densities of mussels. Bedrock was present in only one group (Group D from site SR-2), where it accounted for 78% of the substrate composition. The density of mussels in this group was 0.6/m^2.

Distribution, Abundance, Population Demographics and Habitat Preferences of the Target Species

Two of the eight target species, namely, the Wavyrayed Lampmussel and Round Hickorynut, were not found alive at any site. However, each of the other species was found at between 4 and 10 sites in numbers ranging from a total of 11 for the Mudpuppy Mussel to 646 for the Rayed Bean (Table 1). The 50 km reach of the river between Alvinston (site SR-3) and Dawn Mills (site SR-12) supported the largest number of target species, and all 6 species were found alive at sites SR-6 , SR-19 and SR-5 in the lower part of this reach.

Size frequency distributions for five of the target species are shown in Figure 4. The Mudpuppy Mussel, *S. ambigua*, was excluded from the figure because only 11 specimens were found. Shell lengths of *V. fabalis* were normally distributed, indicating a healthy, reproducing population.

Size frequency distributions for the other species, especially *E. triquetra* and *P. fasciolaris*, were skewed towards larger animals, suggesting that the rate of recruitment may be declining for these species. Table 3 presents the range of sizes for each of the target species at all sites where they occurred. For the purpose of the following discussion, the presence of specimens < 25 mm in shell length is considered to be indicative of recent recruitment. Both *E. t. rangiana* and *E. triquetra* showed evidence of recent recruitment at only two sites, and the total number of juveniles involved was small (5 *E. t. rangiana* and 3 *E. triquetra*). Almost all specimens of *P. fasciolaris* were large, with only 3 juveniles found at two of the index sites. Most specimens of *P. sintoxia* were very large and none were juveniles; only 4 specimens from two sites were smaller than 50 mm. These results suggest that populations of the Snuffbox, Round Pigtoe and Kidneyshell are in decline and that the Northern Riffleshell population may also be starting to show signs of declining recruitment. *Villosa fabalis* and *S. ambigua* are much smaller mussels, with an average adult size of 20 and 25 mm, respectively (Metcalfe-Smith *et al.* 2005); thus, specimens measuring 10-12 mm would probably be considered juveniles. It is clear from Table 3 that *V. fabalis* is reproducing successfully at most of the index sites. Little can be said about *S. ambigua* because so few specimens were collected.

Sites SR-19 and SR-5 supported reproducing populations of more of the target species than any of the other sites (Table 3). Examination of size frequency distributions for other mussel species indicated that almost all of these species are reproducing successfully at sites SR-7, SR-17, SR-5, SR-19 and SR-6, but not necessarily at some of the other sites. For example, Figure 5 shows that there has been ongoing recruitment of the Threeridge (*Amblema plicata*) at sites SR-17 and SR-19, but populations at sites SR-12 and SR-10 consist almost entirely of older adults. As noted earlier, the richest and most abundant mussel communities are found in the East Sydenham River between sites SR-3 and SR-12 (see Figure 1). As stated above, successful reproduction of most species is occurring at five contiguous sites within this reach (SR-7 to SR-6). Sites SR-5 and SR-19 in the centre of this area of good recruitment support the healthiest populations of most of the target species and may therefore represent critical habitat for endangered mussels in the Sydenham River.

Six species, including three SAR and three of the more common species, are sexually dimorphic; thus, it was possible to determine sex ratios for these species. Sex ratios were close to 1:1 for *V. fabalis* (52%M:48%F; n = 646), *Ligumia recta* (58%M:42%F; n = 66), *Lampsilis siliquoidea* (60%M:40%F; n = 65) and *Lampsilis cardium* (43%M:57%F; n = 16). However, sex ratios were skewed towards males for both *E. triquetra* (77%M:23%F; n = 17) and *E. t. rangiana* (73%M:27%F; n = 46). The sex ratio for specimens of *E. t. rangiana* collected during the earlier timed search surveys was similar (80%M:20%F; n = 25). Only three specimens of *E. triquetra* had been collected during the timed search surveys and all were males. Trdan and Hoeh (1993) calculated sex ratios of 59%M:41%F for 144 live *E. t. rangiana* from the Black River in southeastern Michigan and 52%M:48%F for 799 *E. triquetra* from the nearby Clinton River. Comparisons suggest that there is a paucity of female specimens of the Northern Riffleshell and Snuffbox in the Sydenham River and this may have serious consequences for the continued survival of these SAR in the system.

In order to determine species-specific habitat preferences, hierarchical cluster analysis was performed using pooled habitat data from all 15 monitoring sites. A plot of the cumulative Euclidean distance among clusters revealed that noticeable differences in the clusters began to appear with 13 groupings. Thus, the clustering analysis and the INDVAL index for each species were calculated using 13 cluster groups. Table 4 summarizes the habitat characteristics for each of the cluster groups and indicates the habitat types that tended to support the target species. In general, the target species appeared to prefer the same types of habitats as most other mussels, i.e., shallow water with relatively swift currents, high proportions of sand, moderate amounts of silt and very little clay, muck or detritus (compare Tables 2 and 4). The INDVAL analysis identified significant indicator species for five of the 13 habitat groups (Table 5). One of the target species, *V. fabalis*, was identified as an indicator species for Cluster Group 1. Unfortunately, no other target species were identified as indicator species for any habitat group, probably because their abundances were too low. Cluster Group 1 supported the highest overall density of mussels (10.7/m^2; Table 4) and the highest relative abundance of each of the target species (33% of *E. t. rangiana*, 35% of *E. triquetra*, 23% of *P. sintoxia*, 21% of *P. fasciolaris*, 42% of *S. ambigua* and 31% of *V. fabalis*; data not shown), suggesting that Cluster Group 1 represents optimal habitat for endangered mussels in the Sydenham River. Several more common species such as the Elktoe (*Alasmidonta marginata*) and Purple Wartyback (*Cyclonaias tuberculata*) were found to be significant indicators of Cluster Group 1; thus, the occurrence of large populations of these species may indicate the presence of high quality habitat that could support endangered species.

Associations between the target species and other species of mussels were investigated by comparing the relative abundances of all species across all 340 blocks that contained live mussels. Results are presented in Figure 6. The species fell into two groups, one of which contained all of the target species. Within this latter group, *V. fabalis* was found to be closely associated with *A. marginata* and *C. tuberculata* (as also determined using the INDVAL analysis); *P. sintoxia* was strongly associated with the Spike (*Elliptio dilatata*); *E. t. rangiana* and *E. triquetra* were frequently found together and in blocks that also contained the Black Sandshell (*Ligumia recta*); *P. fasciolaris* was associated with the Plain Pocketbook (*Lampsilis cardium*); and *S. ambigua* tended to be found in blocks that contained the Pink Heelsplitter (*Potamilus alatus*). The discovery of associations between the target species and other more common species of mussels is important because the common species could be used as indicators of the potential occurrence of the much rarer target species.

Results of the Kriging analysis were useful for visualizing relationships between the target species and various features of their habitat. Maps for site SR-19, one of most productive sites for mussels (see Table 1), are shown in Figure 7. These maps also show the specific locations where each of the target species was found at each of the index sites, thus providing the basis for assessing changes in the distributions of these species over time.

SUMMARY AND CONCLUSIONS

The objective of this project was to establish a network of monitoring sites for freshwater mussel Species at Risk (SAR) throughout the Sydenham River and to collect baseline data on the distribution, abundance, population demographics and habitat requirements of these species. Eight "target" species were considered during the development of this monitoring program, i.e., the Northern Riffleshell, Snuffbox, Mudpuppy Mussel, Rayed Bean, Wavyrayed Lampmussel, Round Hickorynut, Kidneyshell and Round Pigtoe. All of these species have been designated as Endangered by COSEWIC and are on Schedule 1 of SARA. Since baseline data were collected on *all* members of the mussel community, the program could be used to monitor additional species that may be listed by COSEWIC in the future.

Fifteen sites were selected as monitoring sites, based largely on the results of timed search surveys conducted at 17 sites on the river in 1997 and 1998. Two sites were sampled in 1999, three in 2001, five in 2002 and five in 2003. The sampling protocol was developed in consultation with experts from the Guidelines and Techniques Committee of the Freshwater Mollusk Conservation Society. Quantitative sampling was conducted using 1 m^2 quadrats and a systematic sampling design with three random starts. A 400 m^2 area was sampled at each site over a 2-day period by a 3-person team using 20% coverage. Quadrats were excavated to ensure recovery of juvenile mussels, which tend to burrow deeply. All mussels of all species found alive in each quadrat were counted, measured and sexed (if sexually dimorphic), and current velocity, water depth, % macrophyte cover, % periphyton, % shading and substrate composition were recorded. Hierarchical cluster analysis, kriging and an indicator species analysis were used to examine relationships between mussels and physical features of their habitat. Associations between the target species and other more common species were also investigated.

A total of 5453 mussels of 30 species were found alive at the 15 sites sampled between 27 July 1999 and 2 September 2003. Richness ranged from 2 to 23 species per site and density ranged from 0.12 - 14 mussels/m^2. The richest mussel communities were found in a 50 km reach of the East Sydenham River between Alvinston and Dawn Mills. Two of the target species, the Wavyrayed Lampmussel and Round Hickorynut, were not found alive at any site. The status of the remaining six species is as follows:

A total of 646 live Rayed Beans were collected from 10 sites on the East Sydenham River. The ratio of males to females was roughly 1:1 and size frequency analysis showed that the species is successfully reproducing most of these sites. Sixty-nine Kidneyshells were found alive at 9 sites on the East Sydenham River, but only 4% of specimens from two sites were juveniles. The sex ratio could not be determined because this species is not sexually dimorphic. The Snuffbox was found alive at 7 sites on the East Sydenham River, but only 17 specimens were collected. The sex ratio was nearly 4:1 (M:F) and only 3 animals from two sites were juveniles. Forty-six Northern Riffleshells of a wide range of sizes were found at 7 sites in the middle reaches of the East Sydenham River. Recruitment was apparent at 2 of the sites, but the sex ratio was 3:1 M:F. Healthy populations of the latter two species are known to have sex ratios of ~ 1:1. Only 11 Mudpuppy Mussels were found alive at 4 sites in the East Sydenham River. Mudpuppy Mussels are very difficult to find due to their specialized habitat (under large flat rocks or debris) and a different approach may be needed to effectively track population trends for this species. The Round Pigtoe was found alive at 8 of the monitoring sites, including one site on Bear Creek. All 26 specimens found were older adults. This species is not sexually dimorphic. In summary, the Rayed Bean and possibly the Northern Riffleshell appear to be "holding their own" in the Sydenham River, whereas populations of the Kidneyshell, Snuffbox and Round Pigtoe are in decline. The Wavyrayed Lampmussel is believed to be extirpated from the system and the Round Hickorynut nearly so (a few live specimens have been encountered during other work on the river over the past few years). There are too few data available on the Mudpuppy Mussel to determine its status.

The greatest density and diversity of mussels occurred in shallow water with relatively swift currents in substrates consisting of moderate proportions of boulder, rubble, gravel and silt, high proportions of sand, and very little clay, muck or detritus. The habitat type supporting the greatest abundance of all six target species had a mean depth of 15 cm, current velocity of 0.212 m/s, 0.1% macrophyte cover and a substrate composition of 5.0% boulder, 18.5% rubble, 29.3% gravel, 32.7% sand, 13.2% silt, 0.1% muck and 1.3% detritus. Sites SR-5 and SR-19 supported reproducing populations of more target species than any of the other sites and may therefore represent critical habitat for endangered mussels in the Sydenham River. These sites many also make good "nursery" habitats for releasing laboratory-reared specimens of target species back into the wild. Associations between the target species and other more common species were also identified. For example, the Kidneyshell was often found in close proximity to the Plain Pocketbook and the Round Pigtoe was strongly associated with the Spike. The discovery of such associations is important for two reasons: (1) the common species could serve as indicators of the potential occurrence of the target species; and (2) if these "surrogate" species have environmental requirements similar to the target species, they may respond in similar ways to recovery actions – and since they are more abundant, it may be easier to detect changes in their populations.

The baseline collected during this study will help the Sydenham River Recovery Team identify critical habitat for mussel SAR, direct recovery actions where they are needed most, and track the species' responses to these actions. All field sheets and raw data generated during the course of this work will be provided to the Recovery Team in electronic format for their future use. We believe that the design of this monitoring program could be applied to other similar-sized river systems in Canada.

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Table 1. Numbers of mussels of each species found alive at each of the 15 monitoring sites on the Sydenham River. Sites are arranged in a downstream to upstream direction. Data for target species are highlighted. All 34 species known from the river historically are listed.

					East branch								Bear Creek		
Species	SR-21	SR-20	SR-12	SR-6	SR-19	SR-5	SR-17	SR-7	SR-3	SR-2	SR-10	SR-1	SR-13	SR-15	SR-9	TOTALS
Actinonaias ligamentina			42	43	89	104	36	29	18	1	19	3				384
Alasmidonta marginata			11	29	27	36	8	80	22	8	18	1				240
Alasmidonta viridis																0
Amblema p. plicata		6	17	28	23	33	18	83	36	15	51	8	1	48	54	421
Anodontoides ferussacianus															2	2
Cyclonaias tuberculata			33	341	298	136	47	170	11	80	49	14				1179
Elliptio dilatata			2	23	58	17	10	24	4	15	7				42	202
Epioblasma torulosa rangiana				2	5	13	6	2	17	1						46
Epioblasma triquetra			1	1	3	7	3		1			1				17
Fusconaia flava		1	3	22	11	17	8	26	4	9	6	1		20	31	159
Lampsilis cardium				3	3	2	2		3		2	1				16
Lampsilis fasciola																0
Lampsilis siliquoidea								1	1		1	1	5	24	32	65
Lasmigona c. complanata			10	10	4	25	10	26	1	1	6	9	118	27	64	311
Lasmigona compressa															2	2
Lasmigona costata		1	22	71	68	147	77	349	76	127	39	21	1			999
Leptodea fragilis		16	26	18	32	20	17	19	14	7	11	8	3			191
Ligumia recta			2	9	11	17	6	2	3	4	7	5				66
Obliquaria reflexa				1												1
Obovaria subrotunda																0
Pleurobema sintoxia			3	3	10	2		1	1		1				5	26
Potamilus alatus		5	8	2	8	12	4	8	4		1	1	1			54
Ptychobranchus fasciolaris			13	10	11	8	7	2	7	1	10					69
Pyganodon grandis	1	1		1	1						5	10	10	45	13	87
Quadrula pustulosa		4	10	6	7	3	2	4								36
Quadrula quadrula	9	5	6	42	19	19	13	40	1				12			166
Simpsonaias ambigua				2	3	1		5								11
Strophitus undulatus					2			1		1				2	3	9
Toxalasma parvus																0
Truncilla donaciformis			7													7
Truncilla truncata			16	3	2	3	2	5	2							33
Utterbackia imbecillis								3								3
Villosa fabalis			3	35	116	156	53	263	4	3	12	1				646
Villosa iris								1		4						5
Total Abundance	10	39	235	705	811	778	329	1144	230	277	245	85	151	166	248	5453
Total Diversity	2	8	19	23	23	21	19	23	20	15	17	15	8	6	10	30
Overall Density (#/m^2)	0.12	0.48	3.01	9.04	10.81	11.28	4.06	14.12	3.33	3.55	3.40	1.18	2.01	2.31	3.10	4.76

Table 2. Attributes of habitat groups that supported very high, high, moderate and low densities of mussels. Figure 3 shows how the 63 habitat groups were categorized.

Attribute	Very high density (> 10 mussels/m²) 7 habitat groups		High density (5-10 mussels/m²) 12 habitat groups		Moderate density (1.5-5 mussels/m2) 24 habitat groups		Low density (< 1.5 mussels/m²) 20 habitat groups	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Mussel Density (#/m²)	18.4	10.4 - 32.3	7.4	5.4 – 8.8	2.8	1.7 - 4.5	0.6	0 - 1.4
Mussel Richness	7	6 – 9	4	4 – 5	2	0.6 - 3.4	0.5	0 - 1.4
Velocity (m/s)	0.35	0.23 - 0.70	0.24	0.10 – 0.50	0.24	0.01 - 1.2	0.09	0.01 - 0.23
Depth (cm)	13	11 - 16	16	9 - 28	20	11 - 36	83	7 - 257
% Boulder	17.4	3.6 – 62.6	7.6	0 – 26.5	14.2	0 - 63.0	6.6	0 - 17.8
% Rubble	18.6	5.5 – 30.2	18.0	7.8 - 41.0	17.2	1.5 - 52.9	11.9	0 - 50.9
% Gravel	25.7	12.4 - 45.7	32.3	15.9 - 55.8	27.3	3.8 - 66.5	19.1	0 - 76.8
% Sand	24.1	9.2 – 33.8	24.9	14.0 - 37.6	15.5	2.0 - 41.3	18.3	1.2 - 53.5
% Silt	13.7	9.7 – 16.7	10.8	1.1 - 27.0	12.5	0 - 26.7	14.1	0 - 34.6
% Clay	0	0	2.9	0 – 31.7	16.4	0 - 60.6	7.7	0 - 65.2
% Muck	0.1	0 - 0.5	0.6	0 - 4.0	1.2	0 - 13.3	7.8	0 - 83.3
% Detritus	0.5	0 - 1.8	3.0	0 – 20.0	2.9	0 - 18.8	10.5	0 - 63.8
% Macrophytes	0	0	5.4	0 – 42.0	43.8	0 - 97.4	0.4	0 - 8.6

Table 3. Range of sizes, as shell length in mm, of target mussel species at the 11 sites where at least one species was found alive (number of specimens in brackets). Highlighted data indicate evidence of recent recruitment for that species.

Site[a]	*E. t. rangiana* (n = 46)	*E. triquetra* (n = 17)	*P. sintoxia* (n = 26)	*P. fasciolaris* (n = 69)	*S. ambigua* (n = 11)	*V. fabalis* (n = 646)
SR-12	-	63 (1)	64-86 (3)	25-109 (13)[b]	-	18-27 (3)
SR-6	44-59 (2)	51 (1)	111-133 (3)	26-114 (10)[b]	18-26 (2)	5-32 (35)[c]
SR-19	15-50 (5)	24-62 (3)	30-108 (10)	13-118 (11)	24-31 (3)	7-30 (116)
SR-5	30-65 (13)	18-61 (7)	96-118 (2)	12-118 (8)	23 (1)	8-34 (156)
SR-17	41-67 (6)	49-60 (3)	-	92-117 (7)	-	10-37 (53)
SR-7	50-55 (2)	-	80 (1)	108-121 (2)	24-32 (5)	9-38 (263)[c]
SR-3	16-68 (17)	54 (1)	90(1)	55-106 (7)	-	18-31 (4)
SR-10	-	-	110 (1)	32-118 (10)[b]	-	13-29 (11)
SR-2	54 (1)	-	-	100 (1)	-	12-23 (3)
SR-1	-	61 (1)	-	-	-	24 (1)
SR-9	-	-	43-124 (5)	-	-	-

[a]all sites are on the East Sydenham River except for Site SR-9 which is on Bear Creek.

Table 4. Results of hierarchical cluster analysis on pooled habitat data from the 15 monitoring sites. Mean values are presented for each variable. The density of mussels (all species) and number of target species found in each cluster group are also shown. For each monitoring site, the percentage of blocks falling into each cluster group is also presented.

	Cluster Group													
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Empty***
Mussel density (#/m^2)	10.7	5.8	5.2	8.2	4.0	1.6	3.2	0.5	3.1	2.8	2.7	0.7	2.6	0
# Target species present	6	6	6	6	4	0	2	0	1	3	0	0	4	0
Velocity (m/s)	0.212	0.289	0.250	0.346	0.144	0.192	0.063	0.000	0.010	0.137	0.008	0.008	0.138	0.031
Depth (cm)	15	20	7	13	15	23	22	205	23	13	27	123	29	159
Bedrock (%)	0.0	0.0	0.0	0.0	0.0	50.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boulder (%)	5.0	20.7	4.3	12.7	11.6	5.7	5.8	2.9	4.1	6.8	1.4	12.6	32.1	5.3
Rubble (%)	18.5	26.7	12.8	27.7	12.7	12.6	10.3	1.0	7.3	13.0	4.5	35.0	22.9	8.6
Gravel (%)	29.3	25.8	43.0	29.7	29.0	15.5	31.9	8.8	22.1	44.2	11.8	21.5	27.6	15.4
Sand (%)	32.7	18.3	24.0	19.1	16.6	8.6	16.2	8.1	19.9	25.8	3.0	10.9	13.9	17.4
Silt (%)	13.2	7.0	13.4	10.6	19.0	6.9	15.5	4.0	21.0	9.6	20.6	13.4	1.3	15.7
Clay (%)	0.0	0.1	1.1	0.0	3.4	0.0	12.0	25.5	17.3	0.0	48.6	5.7	0.0	16.3
Muck (%)	0.1	0.1	0.3	0.0	1.0	0.0	2.0	41.0	4.9	0.0	1.1	0.0	0.5	12.9
Detritus (%)	1.3	1.3	0.8	0.4	6.6	0.2	6.3	8.8	3.6	0.6	8.8	0.7	1.5	7.5
Macrophytes (%)	0.1	0.2	0.9	0.0	1.3	0.0	1.3	0.0	7.7	78.6	65.1	0.0	0.8	0.0

Percentage of blocks in each cluster group:

	1	2	3	4	5	6	7	8	9	10	11	12	13	Empty*
Site SR-21	-	-	-	-	-	-	-	25.0	-	-	-	-	-	75.0
Site SR-20	-	-	-	-	-	-	-	-	-	-	-	70.4	-	29.6
Site SR-12	3.8	23.1	-	-	-	-	7.7	-	-	61.5	-	-	3.8	-
Site SR-6	26.9	38.5	3.8	15.4	11.5	-	-	-	3.8	-	-	-	-	-
Site SR-19	28.0	8.0	12.0	48.0	4.0	-	-	-	-	-	-	-	-	-
Site SR-5	26.1	52.2	8.7	13.0	0.0	-	-	-	-	-	-	-	-	-
Site SR-17	3.7	18.5	-	33.3	29.6	-	3.7	-	-	-	-	-	3.7	7.4
Site SR-7	14.8	37.0	-	25.9	18.5	-	3.7	-	-	-	-	-	-	-
Site SR-3	8.7	21.7	-	-	4.3	-	4.3	-	4.3	-	-	-	56.5	-
Site SR-2	3.8	26.9	7.7	26.9	3.8	26.9	3.8	-	-	-	-	-	-	-
Site SR-10	8.0	44.0	-	-	16.0	-	8.0	-	-	-	-	-	20.0	4.0
Site SR-1	29.2	4.2	4.2	12.5	25.0	-	16.7	-	4.2	-	-	-	-	4.2
Site SR-13	-	-	20.0	0.0	44.0	-	24.0	-	-	-	-	-	-	12.0
Site SR-15	-	-	4.2	-		-	4.2	-	41.7	4.2	45.8	-	-	-
Site SR-9	-	-	45.0	-	10.0	-	45.0	-	-	-	-	-	-	-

* Empty blocks were removed from the cluster and INDVAL analyses but are shown here for reference.

Table 5. Habitat cluster groups (see Table 4) for which significant indicator species were identified. The Indicator Value (INDVAL) for each indicator species is also shown. Target species highlighted.

Cluster Group	Indicator Species*	INDVAL
1	*Actinonaias ligamentina*	20.2
	Alasmidonta marginata	15.2
	Cyclonaias tuberculata	24.0
	Lasmigona costata	19.9
	Villosa fabalis	23.7
4	*Elliptio dilatata*	14.2
7	*Lasmigona complanata*	26.8
10	*Truncilla donaciformis*	20.7
	Truncilla truncata	13.9
11	*Fusconaia flava*	12.8
	Lampsilis siliquoidea	31.9
	Pyganodon grandis	44.9

* Monte Carlo test of significance ($p<0.05$; 1000 permutations).

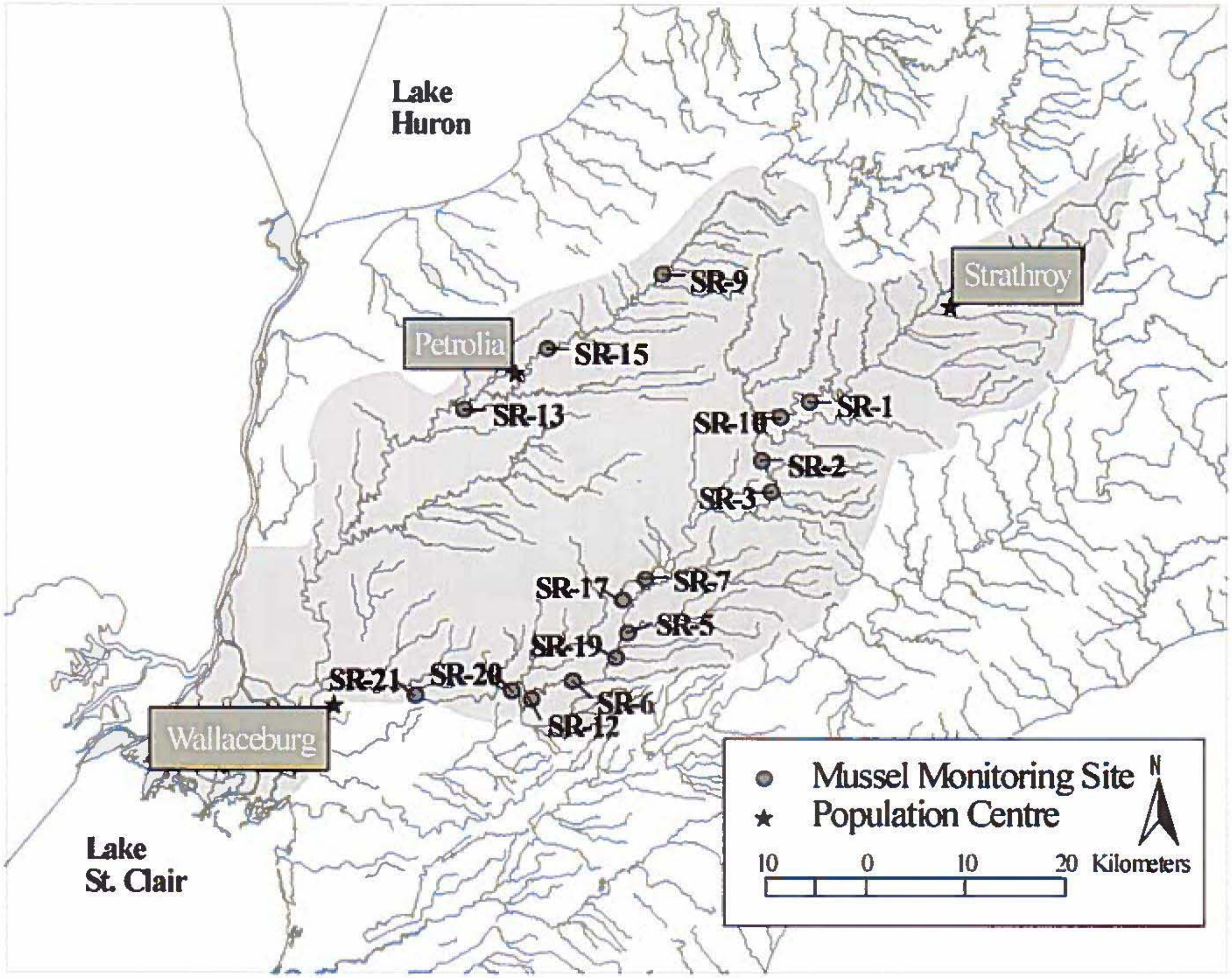


Figure 1. Locations of the 15 mussel monitoring sites on the Sydenham River that were sampled between 1999 and 2003.

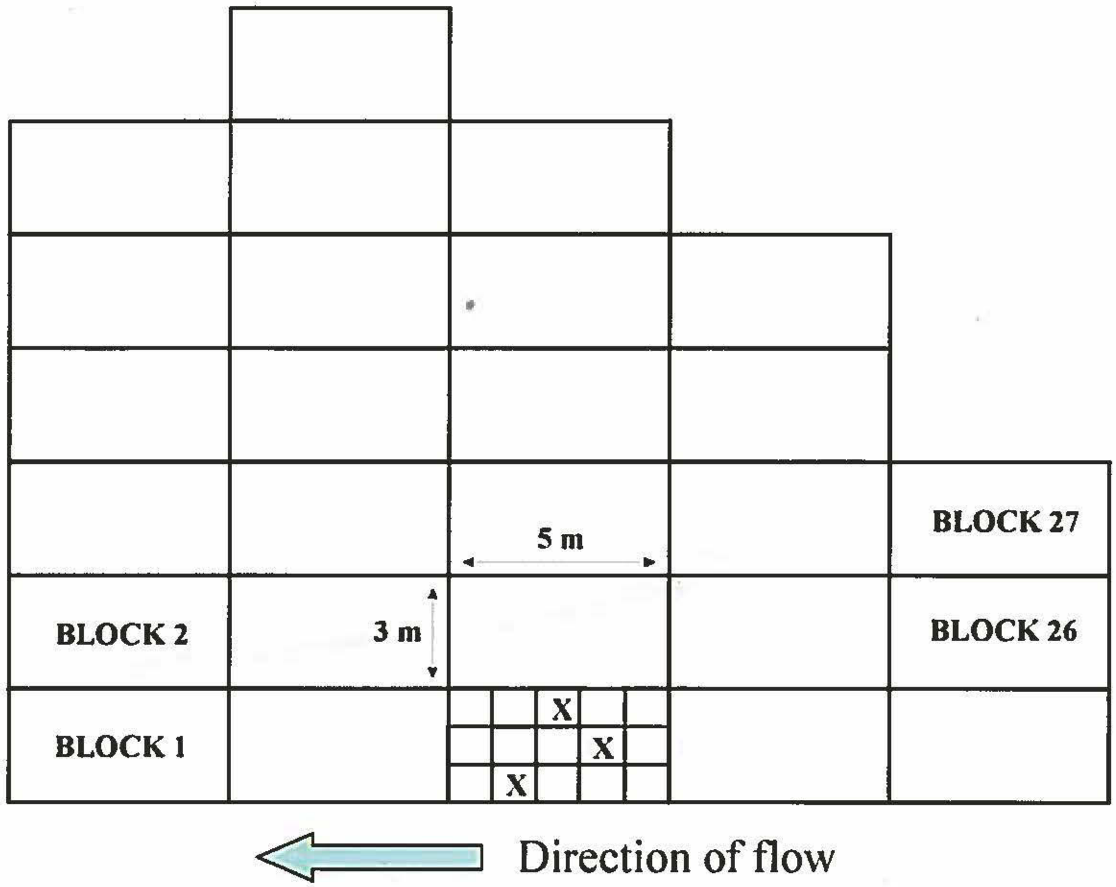


Figure 2. Sampling design used at site SR-17. The Xs mark the locations of the quadrats sampled in each of the 27 blocks.

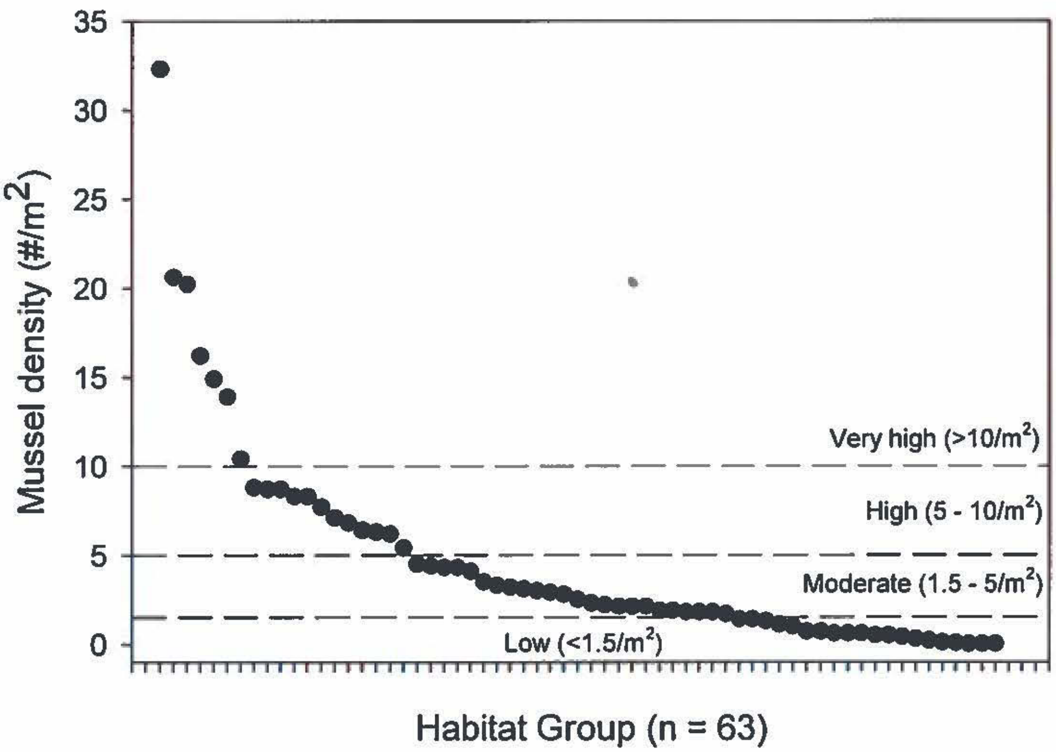


Figure 3. Densities of mussels found in each of the 63 habitat groups from the 15 index sites identified using hierarchical cluster analysis. Habitat groups are separated into 4 categories based on mussel density (very high, high, moderate, and low).

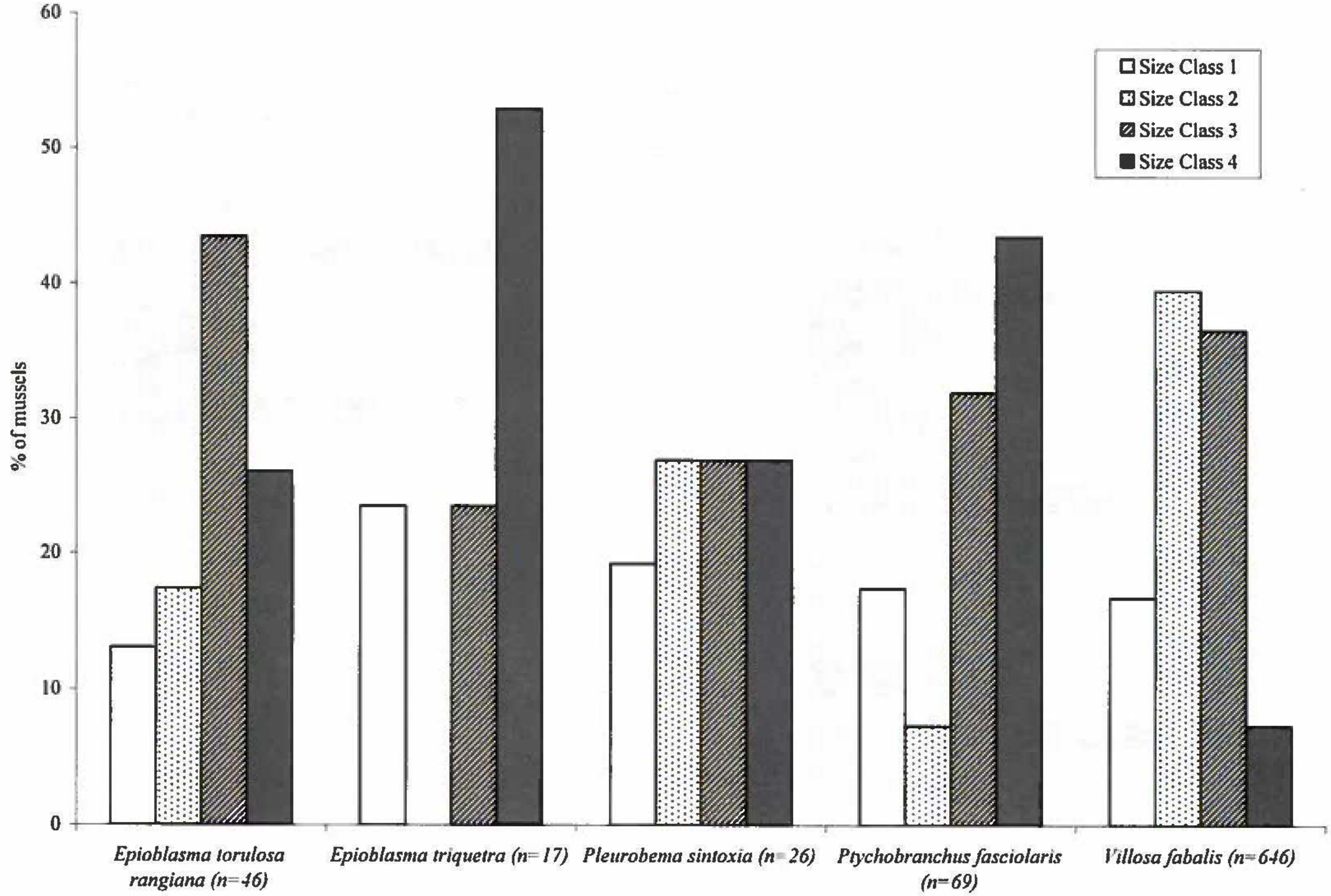


Figure 4. Size frequency distributions for five of the target species. For each species, the size range of animals collected was divided into 4 equal size classes (Size class 1 = smallest).

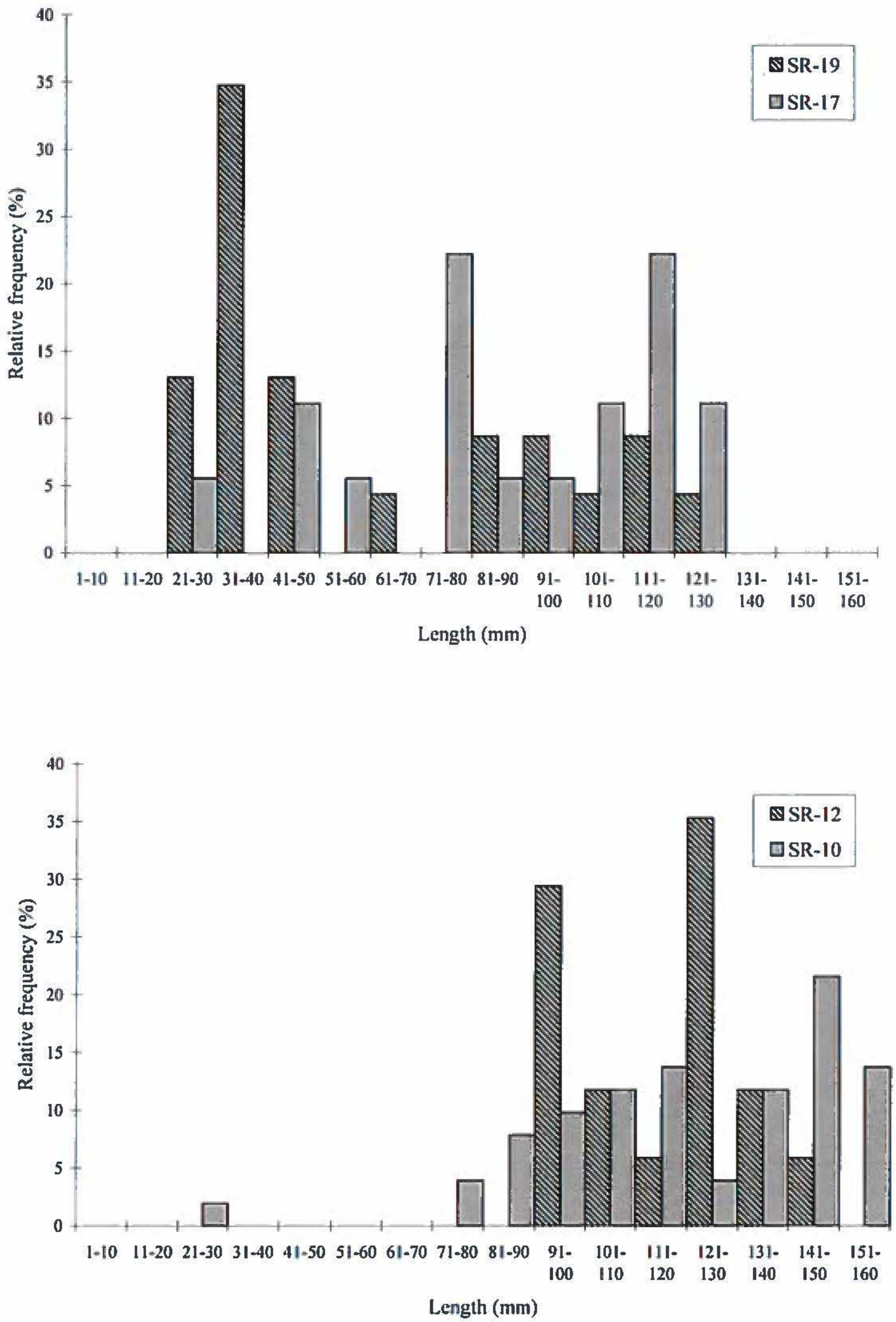


Figure 5. Size frequency distributions of *Amblema plicata* from sites SR-19 (n = 23) and SR-17 (n = 19) vs. sites SR-12 (n = 17) and SR-10 (n = 51).

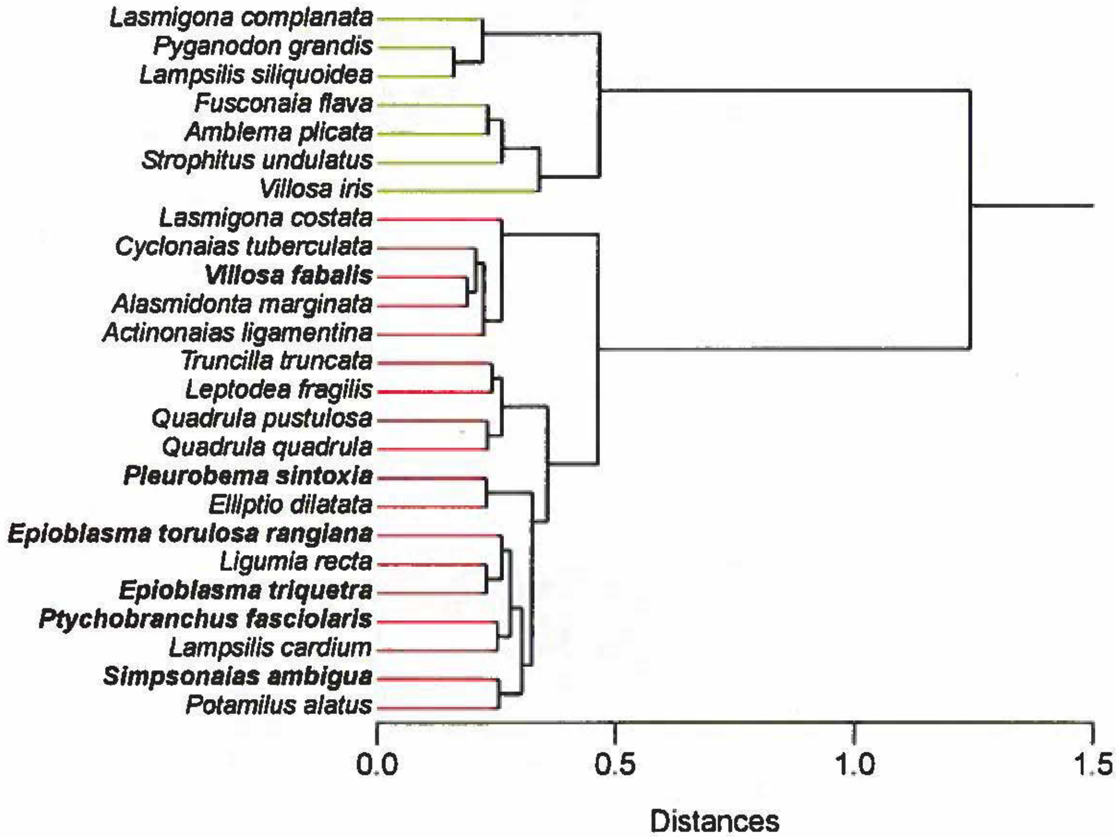
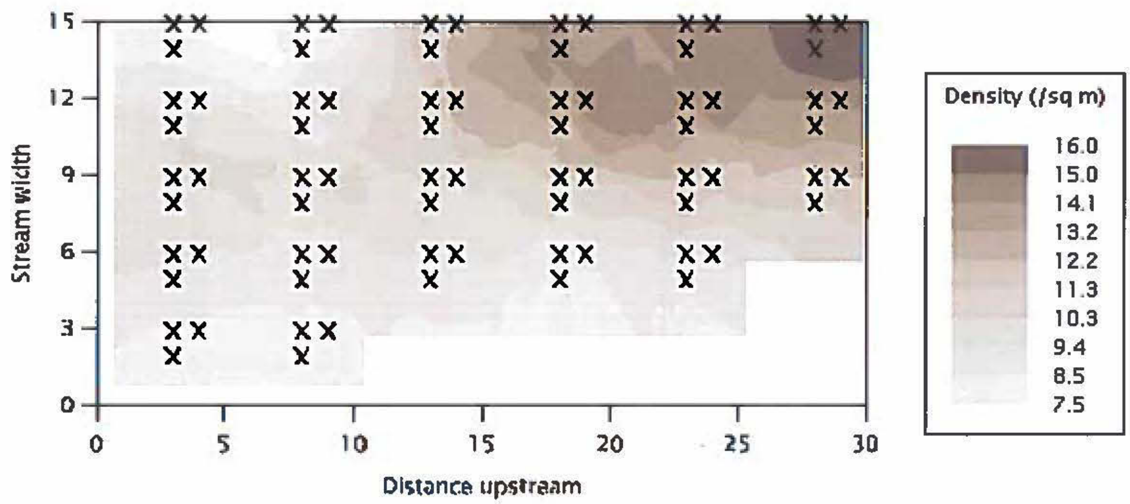
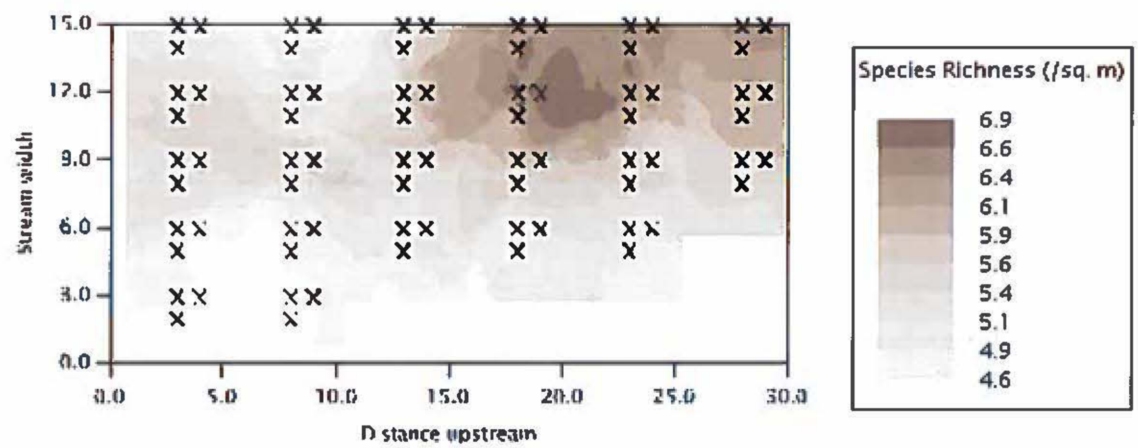
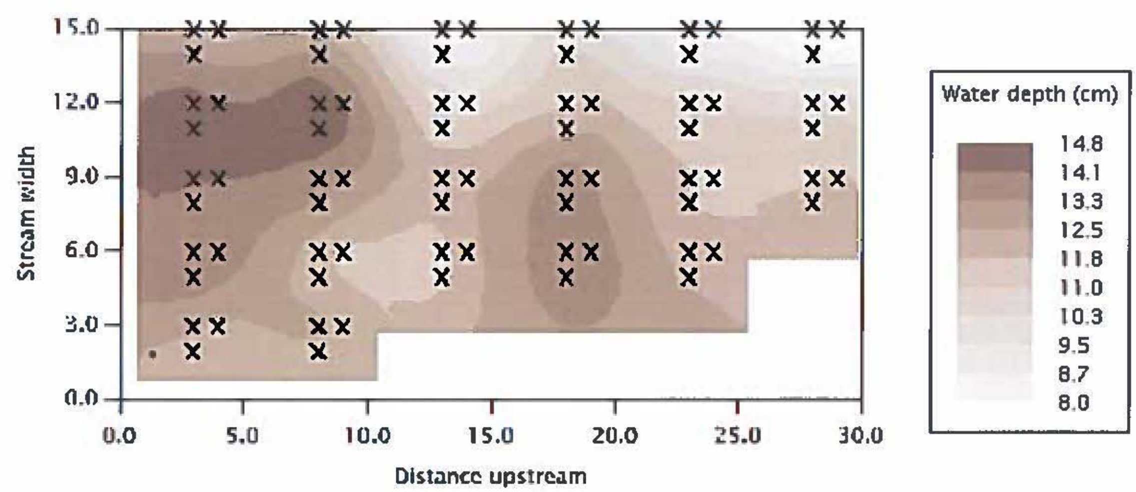
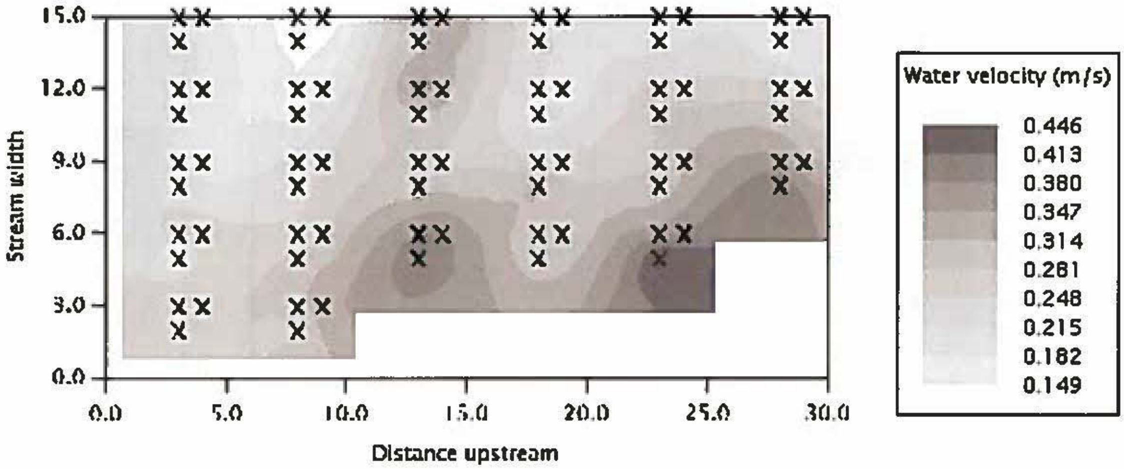


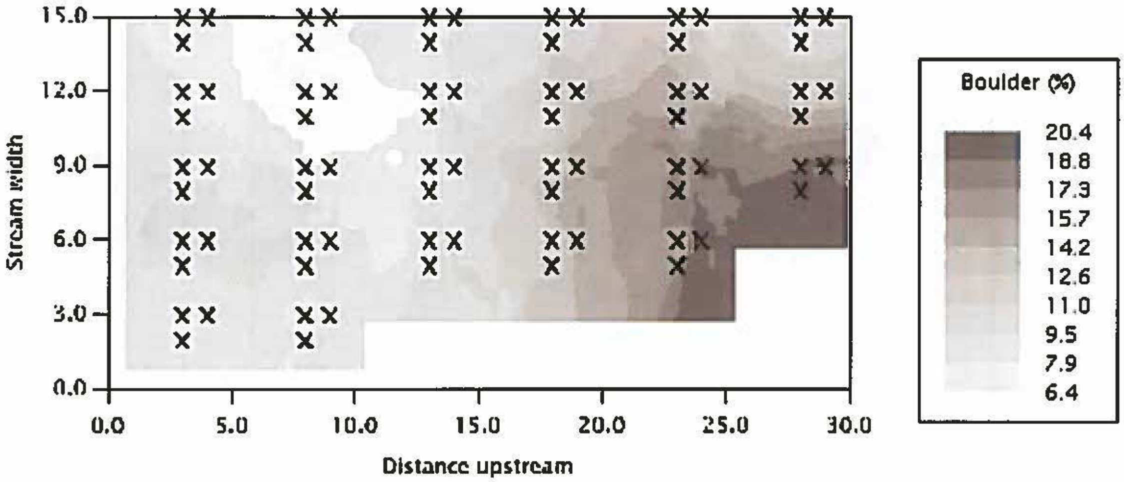
Figure 6. Dendogram showing associations among mussel species in the Sydenham River. Results are based on Ward's agglomerative clustering of Spearman r correlation coefficients between species (see text). Names of target species are bolded.

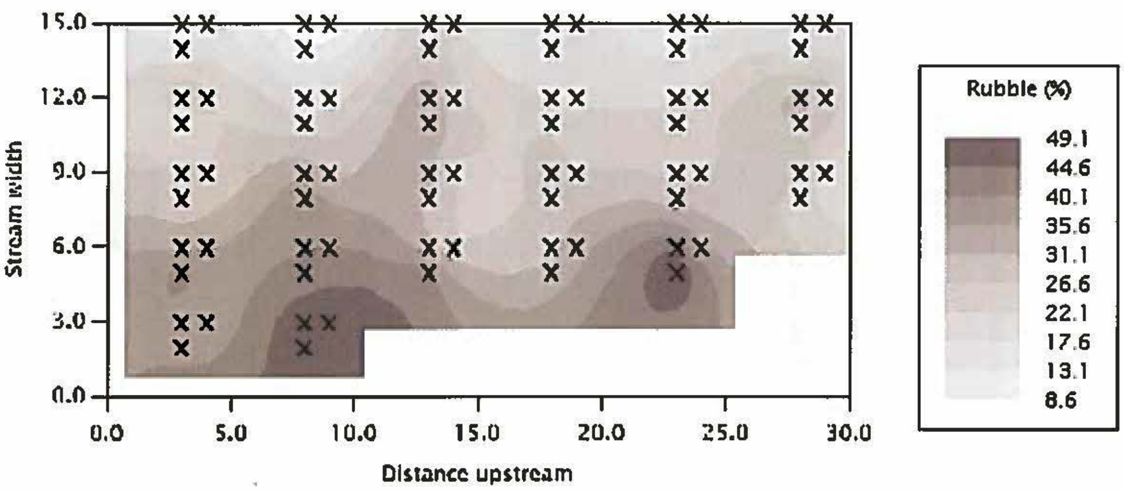

Density (/sq m)
16.0
15.0
14.1
13.2
12.2
11.3
10.3
9.4
8.5
7.5
Stream width
Distance upstream

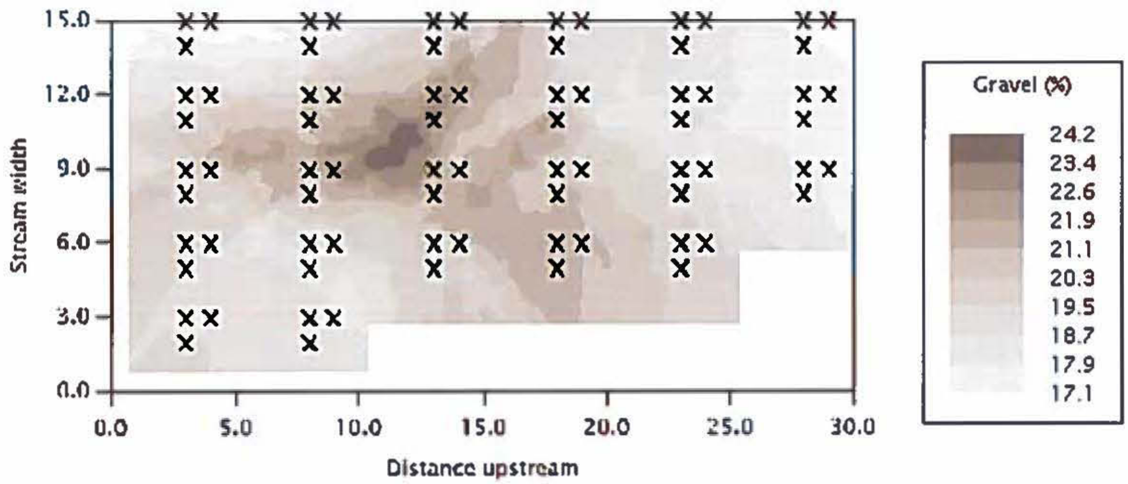

Species Richness (/sq. m)
6.9
6.6
6.4
6.1
5.9
5.6
5.4
5.1
4.9
4.6
Stream width
Distance upstream

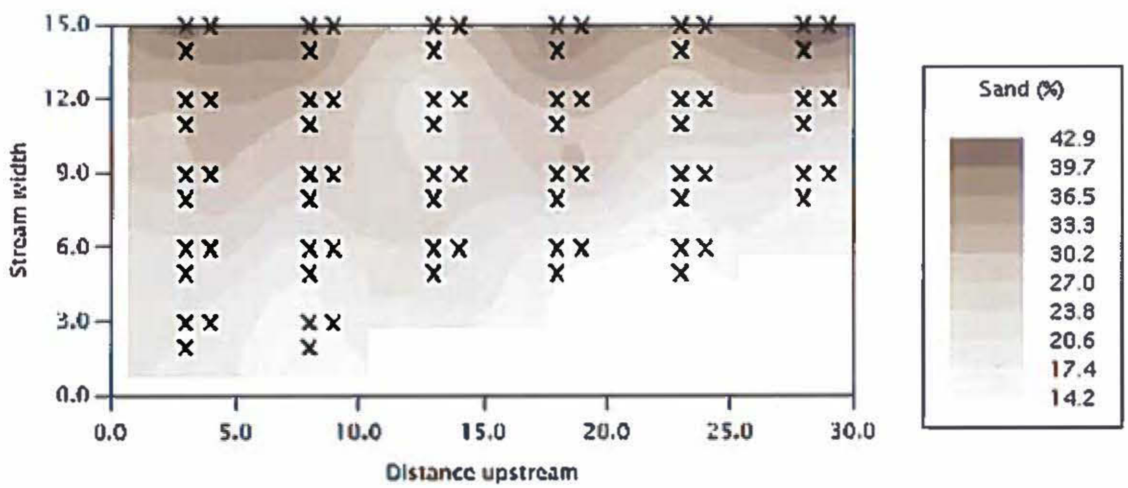

Water depth (cm)
14.8
14.1
13.3
12.5
11.8
11.0
10.3
9.5
8.7
8.0
Stream width
Distance upstream

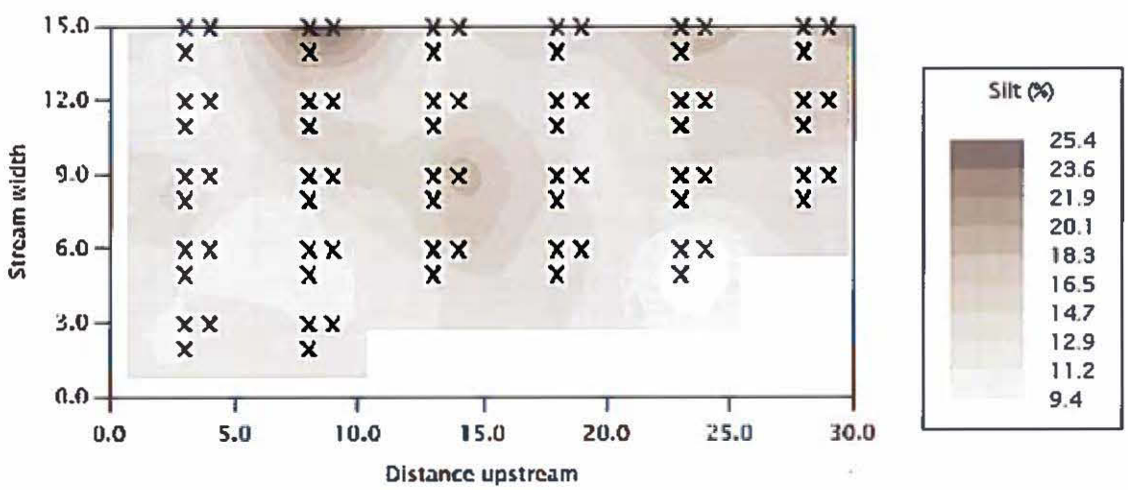

Water velocity (m/s)
0.446
0.413
0.380
0.347
0.314
0.281
0.248
0.215
0.182
0.149
Stream width
Distance upstream
0.0
3.0
6.0
9.0
12.0
15.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0

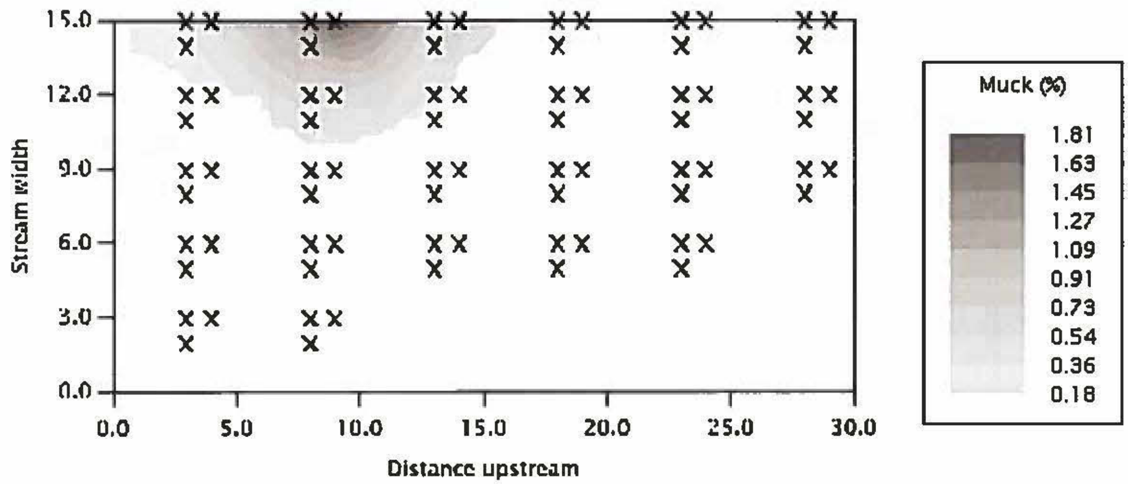

Boulder (%)
20.4
18.8
17.3
15.7
14.2
12.6
11.0
9.5
7.9
6.4
Stream width
Distance upstream
0.0
3.0
6.0
9.0
12.0
15.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0

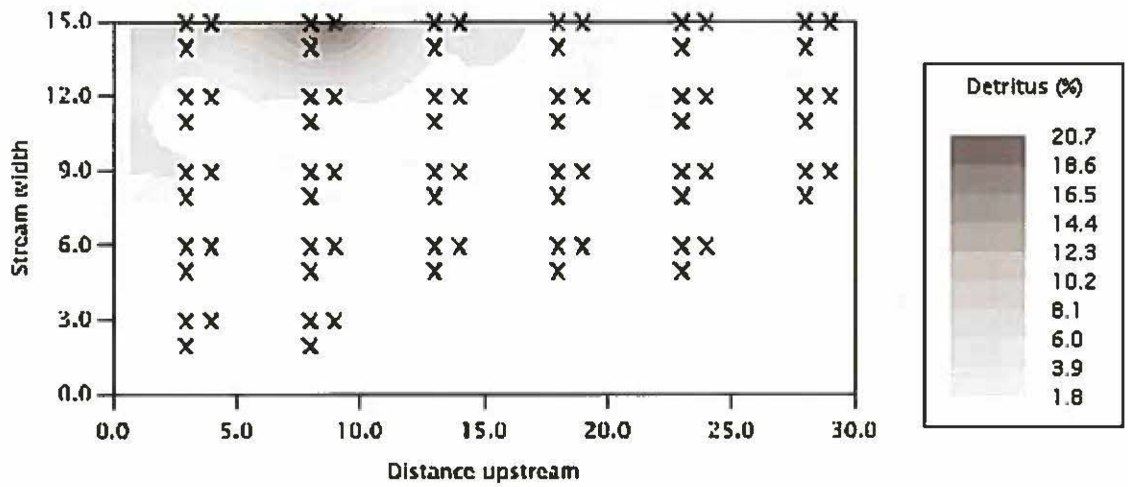

Rubble (%)
49.1
44.6
40.1
35.6
31.1
26.6
22.1
17.6
13.1
8.6
Stream width
Distance upstream
0.0
3.0
6.0
9.0
12.0
15.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0

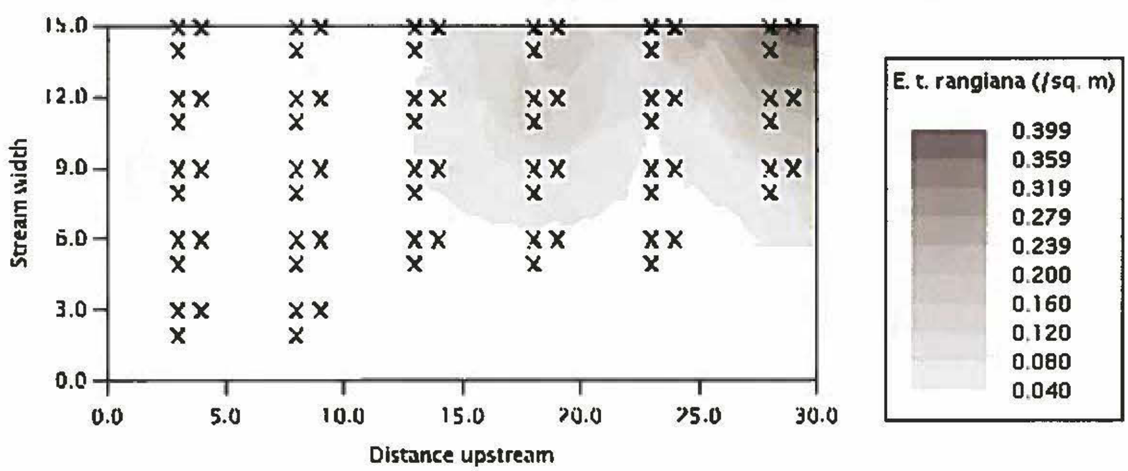

Gravel (%)
24.2
23.4
22.6
21.9
21.1
20.3
19.5
18.7
17.9
17.1
Stream width
Distance upstream

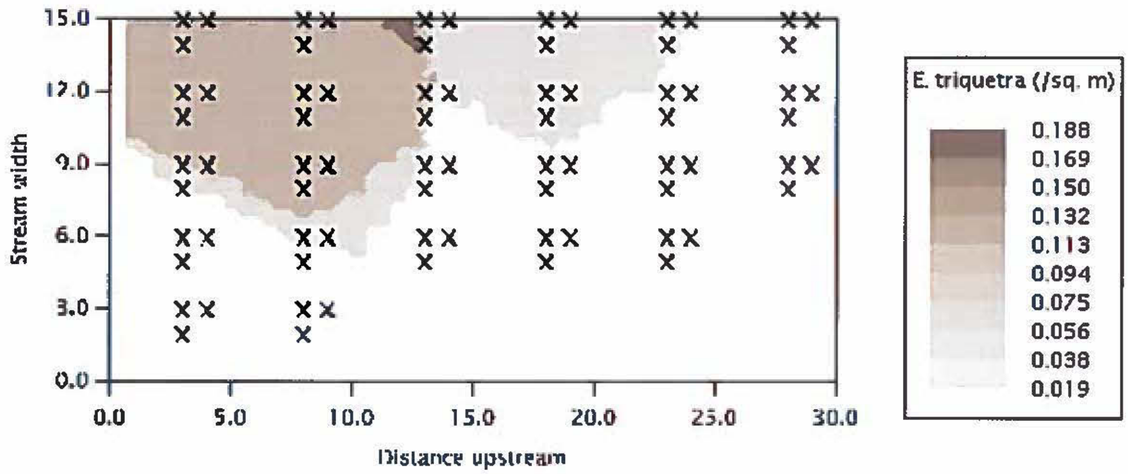

Sand (%)
42.9
39.7
36.5
33.3
30.2
27.0
23.8
20.6
17.4
14.2
Stream width
Distance upstream

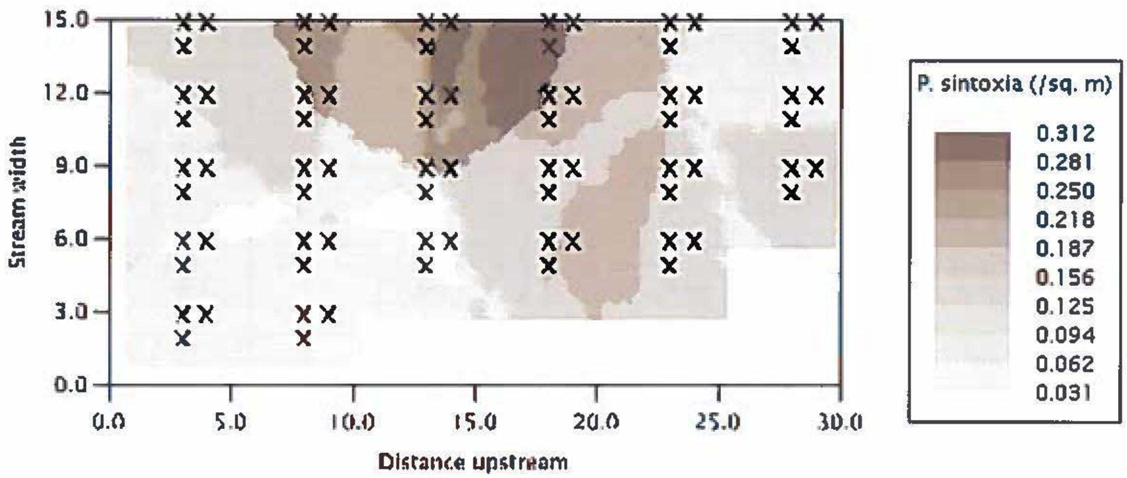

Silt (%)
25.4
23.6
21.9
20.1
18.3
16.5
14.7
12.9
11.2
9.4
Stream width
Distance upstream

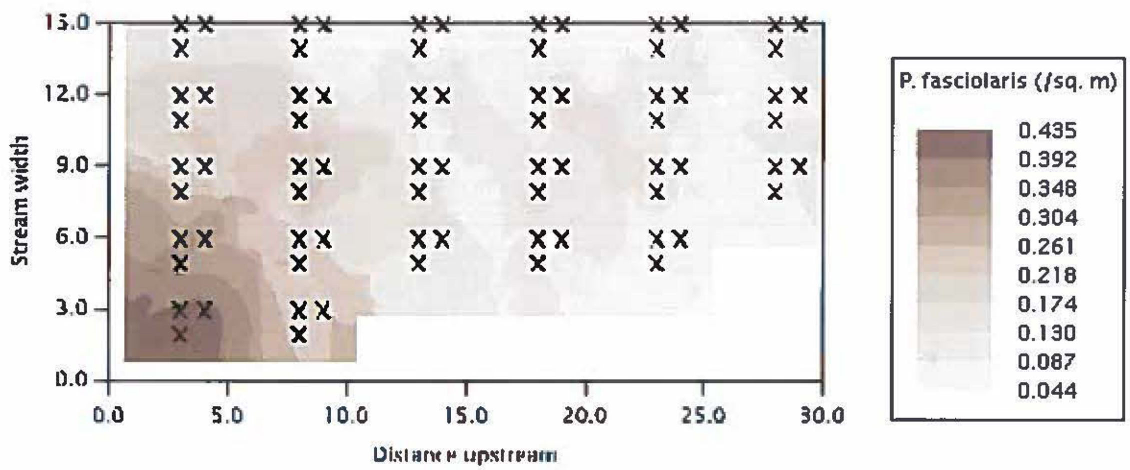

Stream width
Distance upstream
15.0
12.0
9.0
6.0
3.0
0.0
5.0
10.0
20.0
25.0
30.0
Muck (%)
1.81
1.63
1.45
1.27
1.09
0.91
0.73
0.54
0.36
0.18


Stream width
Distance upstream
15.0
12.0
9.0
6.0
3.0
0.0
5.0
10.0
20.0
25.0
30.0
Detritus (%)
20.7
18.6
16.5
14.4
12.3
10.2
8.1
6.0
3.9
1.8


Stream width
Distance upstream
15.0
12.0
9.0
6.0
3.0
0.0
5.0
10.0
20.0
25.0
30.0
E. t. rangiana (/sq. m)
0.399
0.359
0.319
0.279
0.239
0.200
0.160
0.120
0.080
0.040


Stream width
Distance upstream
E. triquetra (/sq. m)
0.188
0.169
0.150
0.132
0.113
0.094
0.075
0.056
0.038
0.019


Stream width
Distance upstream
P. sintoxia (/sq. m)
0.312
0.281
0.250
0.218
0.187
0.156
0.125
0.094
0.062
0.031


Stream width
Distance upstream
P. fasciolaris (/sq. m)
0.435
0.392
0.348
0.304
0.261
0.218
0.174
0.130
0.087
0.044

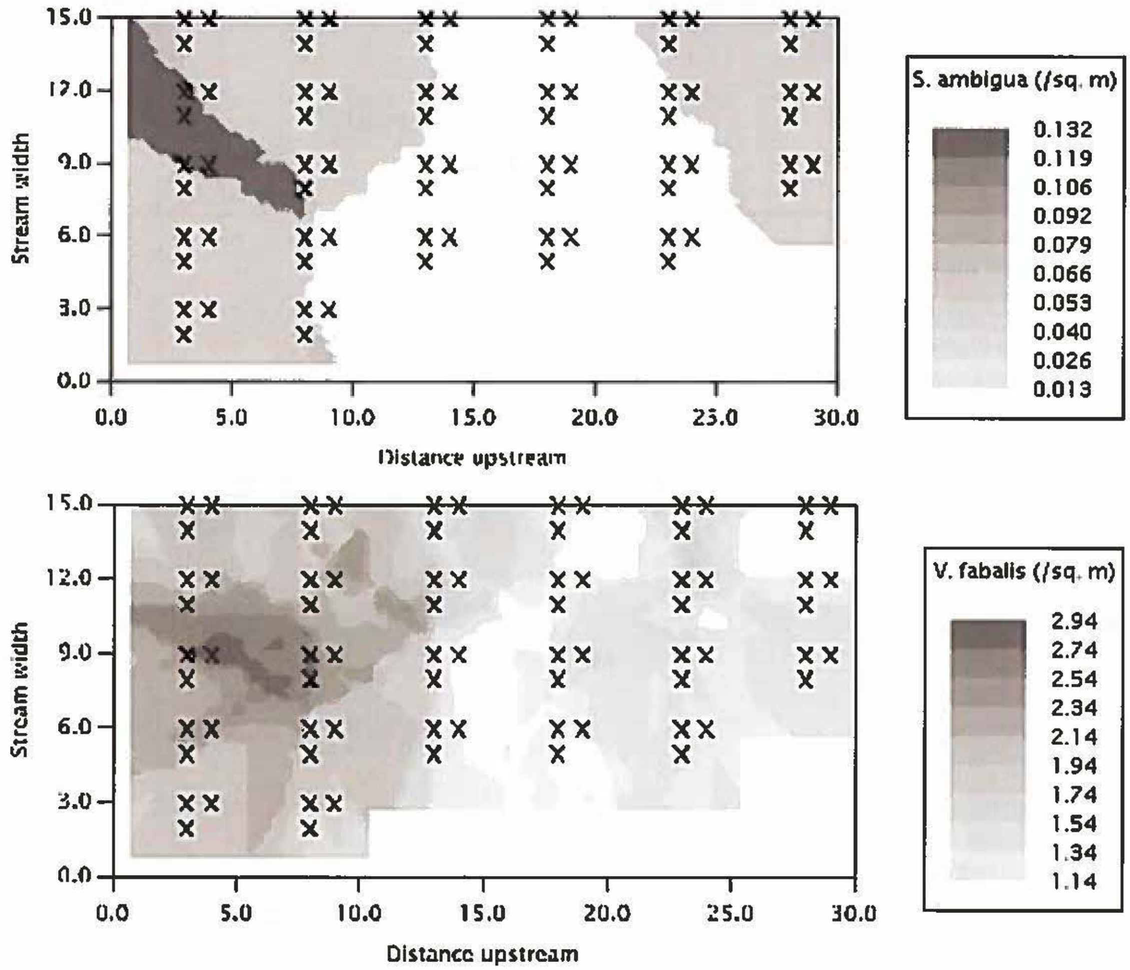


Figure 7. Results of Kriging analysis on the data from site SR-19. Relationships between various habitat features and the distributions of mussels as a whole as well as individual target species are shown.

Appendix 1. Composition of the mussel community at each of the monitoring sites. Data for target species are highlighted.

Site SR-21: Tupperville				
Species	Abundance	Relative Abundance	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	-	-	-	-
Elliptio dilatata	-	-	-	-
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Leptodea fragilis	-	-	-	-
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	1	10.0%	0.01	1.2%
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	9	90.0%	0.11	8.3%
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	-	-	-	-
Villosa iris	-	-	-	-

Site SR-20: Dresden				
Species	Abundance	Relative Abundance	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Amblema plicata	6	15.4%	0.07	6.2%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	-	-	-	-
Elliptio dilatata	-	-	-	-
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	1	2.6%	0.01	1.2%
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	1	2.6%	0.01	1.2%
Leptodea fragilis	16	41.0%	0.20	16.0%
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	5	12.8%	0.06	6.2%
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	1	2.6%	0.01	1.2%
Quadrula pustulosa	4	10.3%	0.05	3.7%
Quadrula quadrula	5	12.8%	0.06	6.2%
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	-	-	-	-
Villosa iris	-	-	-	-

Site SR-12: Dawn Mills				
Species	**Abundance**	**Relative Abundance**	**Density (mussels/m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	41	17.4%	0.53	42.3%
Alasmidonta marginata	11	4.7%	0.14	12.8%
Alasmidonta viridis	-	-	-	-
Amblema plicata	17	7.2%	0.22	20.5%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	33	14.0%	0.42	32.1%
Elliptio dilatata	2	0.9%	0.03	2.6%
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	1	0.4%	0.01	1.3%
Fusconaia flava	3	1.3%	0.04	3.8%
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	10	4.3%	0.13	12.8%
Lasmigona compressa	-	-	-	-
Lasmigona costata	22	9.4%	0.28	25.6%
Leptodea fragilis	26	11.1%	0.33	24.4%
Ligumia recta	2	0.9%	0.03	2.6%
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	3	1.3%	0.04	3.8%
Potamilus alatus	8	3.4%	0.10	7.7%
Ptychobranchus fasciolaris	13	5.5%	0.17	15.4%
Pyganodon grandis	-	-	-	-
Quadrula pustulosa	10	4.3%	0.13	11.5%
Quadrula quadrula	6	2.6%	0.08	6.4%
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	7	3.0%	0.09	9.0%
Truncilla truncata	16	6.8%	0.21	17.9%
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	3	1.3%	0.04	3.8%
Villosa iris	-	-	-	-

Site SR-6: Croton				
Species	**Abundance**	**Relative Abundance**	**Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	43	6.1%	0.55	32.1%
Alasmidonta marginata	29	4.1%	0.37	24.4%
Alasmidonta viridis	–	–	–	–
Amblema plicata	28	4.0%	0.36	21.8%
Anodontoides ferussacianus	–	–	–	–
Cyclonaias tuberculata	341	48.4%	4.37	76.9%
Elliptio dilatata	23	3.3%	0.29	17.9%
Epioblasma t. rangiana	2	0.3%	0.03	2.6%
Epioblasma triquetra	1	0.1%	0.01	1.3%
Fusconaia flava	22	3.1%	0.28	17.9%
Lampsilis cardium	3	0.4%	0.04	3.8%
Lampsilis fasciola	–	–	–	–
Lampsilis siliquoidea	–	–	–	–
Lasmigona complanata	10	1.4%	0.13	11.5%
Lasmigona compressa	–	–	–	–
Lasmigona costata	71	10.1%	0.91	44.9%
Leptodea fragilis	18	2.6%	0.23	19.2%
Ligumia recta	9	1.3%	0.12	11.5%
Obliquaria reflexa	1	0.1%	0.01	1.3%
Obovaria subrotunda	–	–	–	–
Pleurobema sintoxia	3	0.4%	0.04	3.8%
Potamilus alatus	2	0.3%	0.03	2.6%
Ptychobranchus fasciolaris	10	1.4%	0.13	12.8%
Pyganodon grandis	1	0.1%	0.01	1.3%
Quadrula pustulosa	6	0.9%	0.08	7.7%
Quadrula quadrula	42	6.0%	0.54	28.2%
Simpsonaias ambigua	2	0.3%	0.03	2.6%
Strophitus undulatus	–	–	–	–
Toxolasma parvus	–	–	–	–
Truncilla donaciformis	–	–	–	–
Truncilla truncata	3	0.4%	0.04	3.8%
Utterbackia imbecillis	–	–	–	–
Villosa fabalis	35	5.0%	0.45	24.4%
Villosa iris	–	–	–	–

Site SR-19: Brick Road				
Species	Abundance	Relative Abundance	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	89	11.0%	1.19	62.7%
Alasmidonta marginata	27	3.3%	0.36	29.3%
Alasmidonta viridis	–	–	–	–
Amblema plicata	23	2.8%	0.31	29.3%
Anodontoides ferussacianus	–	–	–	–
Cyclonaias tuberculata	298	36.7%	3.97	90.7%
Elliptio dilatata	58	7.2%	0.77	52.0%
Epioblasma t. rangiana	5	0.6%	0.07	6.7%
Epioblasma triquetra	3	0.4%	0.04	4.0%
Fusconaia flava	11	1.4%	0.15	13.3%
Lampsilis cardium	3	0.4%	0.04	4.0%
Lampsilis fasciola	–	–	–	–
Lampsilis siliquoidea	–	–	–	–
Lasmigona complanata	4	0.5%	0.05	5.3%
Lasmigona compressa	–	–	–	–
Lasmigona costata	68	8.4%	0.91	52.0%
Leptodea fragilis	32	3.9%	0.43	36.0%
Ligumia recta	11	1.4%	0.15	12.0%
Obliquaria reflexa	–	–	–	–
Obovaria subrotunda	–	–	–	–
Pleurobema sintoxia	10	1.2%	0.13	12.0%
Potamilus alatus	8	1.0%	0.11	10.7%
Ptychobranchus fasciolaris	11	1.4%	0.15	13.3%
Pyganodon grandis	1	0.1%	0.01	1.3%
Quadrula pustulosa	7	0.9%	0.09	8.0%
Quadrula quadrula	19	2.3%	0.25	24.0%
Simpsonaias ambigua	3	0.4%	0.04	4.0%
Strophitus undulatus	2	0.2%	0.03	2.7%
Toxolasma parvus	–	–	–	–
Truncilla donaciformis	–	–	–	–
Truncilla truncata	2	0.2%	0.03	2.7%
Utterbackia imbecillis	–	–	–	–
Villosa fabalis	116	14.3%	1.55	69.3%
Villosa iris	–	–	–	–

Site SR-5: Florence				
Species	Abundance	Relative Abundance	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	104	13.4%	1.51	53.6%
Alasmidonta marginata	36	4.6%	0.52	30.4%
Alasmidonta viridis	-	-	-	-
Amblema plicata	33	4.2%	0.48	34.8%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	136	17.5%	1.97	72.5%
Elliptio dilatata	17	2.2%	0.25	23.2%
Epioblasma t. rangiana	13	1.7%	0.19	13.0%
Epioblasma triquetra	7	0.9%	0.10	10.1%
Fusconaia flava	17	2.2%	0.25	24.6%
Lampsilis cardium	2	0.3%	0.03	2.9%
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	25	3.2%	0.36	26.1%
Lasmigona compressa	-	-	-	-
Lasmigona costata	147	18.9%	2.13	75.4%
Leptodea fragilis	20	2.6%	0.29	27.5%
Ligumia recta	17	2.2%	0.25	21.7%
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	2	0.3%	0.03	2.9%
Potamilus alatus	12	1.5%	0.17	15.9%
Ptychobranchus fasciolaris	8	1.0%	0.12	11.6%
Pyganodon grandis	-	-	-	-
Quadrula pustulosa	3	0.4%	0.04	4.3%
Quadrula quadrula	19	2.4%	0.28	20.3%
Simpsonaias ambigua	1	0.1%	0.01	1.4%
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	3	0.4%	0.04	4.3%
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	156	20.1%	2.26	65.2%
Villosa iris	-	-	-	-

Site SR-17: Mawlam Road				
Species	Abundance	Relative Abundance	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	36	10.9%	0.44	32.1%
Alasmidonta marginata	8	2.5%	0.10	9.9%
Alasmidonta viridis	–	–	–	–
Amblema plicata	18	5.5%	0.22	18.5%
Anodontoides ferussacianus	–	–	–	–
Cyclonaias tuberculata	47	14.3%	0.58	38.3%
Elliptio dilatata	10	3.1%	0.12	11.1%
Epioblasma t. rangiana	6	1.8%	0.07	7.4%
Epioblasma triquetra	3	0.9%	0.04	3.7%
Fusconaia flava	8	2.5%	0.10	7.4%
Lampsilis cardium	2	0.6%	0.02	2.5%
Lampsilis fasciola	–	–	–	–
Lampsilis siliquoidea	–	–	–	–
Lasmigona complanata	10	3.1%	0.12	11.1%
Lasmigona compressa	–	–	–	–
Lasmigona costata	77	23.4%	0.95	54.3%
Leptodea fragilis	17	5.2%	0.21	14.8%
Ligumia recta	6	1.8%	0.07	7.4%
Obliquaria reflexa	–	–	–	–
Obovaria subrotunda	–	–	–	–
Pleurobema sintoxia	–	–	–	–
Potamilus alatus	4	1.2%	0.05	4.9%
Ptychobranchus fasciolaris	7	2.2%	0.09	7.4%
Pyganodon grandis	–	–	–	–
Quadrula pustulosa	2	0.6%	0.02	2.5%
Quadrula quadrula	13	4.0%	0.16	13.6%
Simpsonaias ambigua	–	–	–	–
Strophitus undulatus	–	–	–	–
Toxolasma parvus	–	–	–	–
Truncilla donaciformis	–	–	–	–
Truncilla truncata	2	0.6%	0.02	2.5%
Utterbackia imbecillis	–	–	–	–
Villosa fabalis	53	16.1%	0.65	42.0%
Villosa iris	–	–	–	–

Site SR-7: Shetland				
Species	Abundance	Relative Abundance	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	29	2.5%	0.36	25.9%
Alasmidonta marginata	80	7.0%	0.99	49.4%
Alasmidonta viridis	-	-	-	-
Amblema plicata	83	7.2%	1.02	59.3%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	171	14.9%	2.11	79.0%
Elliptio dilatata	30	2.6%	0.37	25.9%
Epioblasma t. rangiana	2	0.2%	0.02	2.5%
Epioblasma triquetra	-	-	-	-
Fusconaia flava	26	2.3%	0.32	25.9%
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	1	0.1%	0.01	1.2%
Lasmigona complanata	26	2.3%	0.32	24.7%
Lasmigona compressa	-	-	-	-
Lasmigona costata	349	30.4%	4.31	86.4%
Leptodea fragilis	19	1.7%	0.23	19.8%
Ligumia recta	2	0.2%	0.02	2.5%
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	1	0.1%	0.01	1.2%
Potamilus alatus	8	0.7%	0.10	9.9%
Ptychobranchus fasciolaris	2	0.2%	0.02	2.5%
Pyganodon grandis	-	-	-	-
Quadrula pustulosa	4	0.3%	0.05	4.9%
Quadrula quadrula	39	3.4%	0.48	29.6%
Simpsonaias ambigua	5	0.4%	0.06	6.2%
Strophitus undulatus	1	0.1%	0.01	1.2%
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	4	0.3%	0.05	4.9%
Utterbackia imbecillis	3	0.3%	0.04	3.7%
Villosa fabalis	263	22.9%	3.25	81.5%
Villosa iris	1	0.1%	0.01	1.2%

Site SR-3: Alvinston				
Species	Abundance	Relative Abundance	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	18	8.1%	0.26	18.8%
Alasmidonta marginata	22	10.0%	0.32	26.1%
Alasmidonta viridis	-	-	-	-
Amblema plicata	36	16.3%	0.52	29.0%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	11	5.0%	0.16	15.9%
Elliptio dilatata	4	1.8%	0.06	5.8%
Epioblasma t. rangiana	17	7.7%	0.25	20.3%
Epioblasma triquetra	1	0.5%	0.01	1.4%
Fusconaia flava	4	1.8%	0.06	5.8%
Lampsilis cardium	3	1.4%	0.04	4.3%
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	1	0.5%	0.01	1.4%
Lasmigona complanata	1	0.5%	0.01	1.4%
Lasmigona compressa	-	-	-	-
Lasmigona costata	76	34.4%	1.10	53.6%
Leptodea fragilis	14	6.3%	0.20	15.9%
Ligumia recta	3	1.4%	0.04	4.3%
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	1	0.5%	0.01	1.4%
Potamilus alatus	4	1.8%	0.06	5.8%
Ptychobranchus fasciolaris	7	3.2%	0.10	10.1%
Pyganodon grandis	-	-	-	-
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	1	0.5%	0.01	1.4%
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	2	0.9%	0.03	2.9%
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	4	1.8%	0.06	5.8%
Villosa iris	-	-	-	-

Site SR-2: Courtright Road				
Species	**Abundance**	**Relative Abundance**	**Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	1	0.4%	0.01	1.3%
Alasmidonta marginata	8	2.9%	0.10	9.0%
Alasmidonta viridis	-	-	-	-
Amblema plicata	15	5.4%	0.19	14.1%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	80	28.9%	1.03	57.7%
Elliptio dilatata	15	5.4%	0.19	16.7%
Epioblasma t. rangiana	1	0.4%	0.01	1.3%
Epioblasma triquetra	-	-	-	-
Fusconaia flava	9	3.2%	0.12	10.3%
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	1	0.4%	0.01	1.3%
Lasmigona compressa	-	-	-	-
Lasmigona costata	127	45.8%	1.63	67.9%
Leptodea fragilis	7	2.5%	0.09	9.0%
Ligumia recta	4	1.4%	0.05	5.1%
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Ptychobranchus fasciolaris	1	0.4%	0.01	1.3%
Pyganodon grandis	-	-	-	-
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	1	0.4%	0.01	1.3%
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	3	1.1%	0.04	3.8%
Villosa iris	4	1.4%	0.05	5.1%

Site SR-10: Woodcock Road				
Species	**Abundance**	**Relative Abundance**	**Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	19	7.7%	0.26	18.1%
Alasmidonta marginata	18	7.3%	0.25	19.4%
Alasmidonta viridis	-	-	-	-
Amblema plicata	51	20.7%	0.71	50.0%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	49	19.9%	0.68	41.7%
Elliptio dilatata	7	2.8%	0.10	5.6%
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	6	2.4%	0.08	6.9%
Lampsilis cardium	2	0.8%	0.03	2.8%
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	1	0.4%	0.01	1.4%
Lasmigona complanata	6	2.4%	0.08	6.9%
Lasmigona compressa	-	-	-	-
Lasmigona costata	39	15.9%	0.54	34.7%
Leptodea fragilis	11	4.5%	0.15	13.9%
Ligumia recta	7	2.8%	0.10	9.7%
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	1	0.4%	0.01	1.4%
Potamilus alatus	1	0.4%	0.01	1.4%
Ptychobranchus fasciolaris	10	4.1%	0.14	11.1%
Pyganodon grandis	5	2.0%	0.07	6.9%
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	12	4.9%	0.17	13.9%
Villosa iris	-	-	-	-

Site SR-1: Sexton Road				
Species	Abundance	Relative Abundance	Density (mussels/m²)	Occurrence (% of quadrats)
Actinonaias ligamentina	3	3.53%	0.042	4.2%
Alasmidonta marginata	1	1.18%	0.014	1.4%
Alasmidonta viridis	-	-	-	-
Amblema plicata	8	9.41%	0.111	11.1%
Anodontoides ferussacianus	-	0.00%	0.000	0.0%
Cyclonaias tuberculata	14	16.47%	0.194	16.7%
Elliptio dilatata	-	-	-	-
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	1	1.18%	0.014	1.4%
Fusconaia flava	1	1.18%	0.014	1.4%
Lampsilis cardium	1	1.18%	0.014	1.4%
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	1	1.18%	0.014	1.4%
Lasmigona complanata	9	10.59%	0.125	12.5%
Lasmigona compressa	-	-	-	-
Lasmigona costata	21	24.71%	0.292	27.8%
Leptodea fragilis	8	9.41%	0.111	9.7%
Ligumia recta	5	5.88%	0.069	6.9%
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	1	1.18%	0.014	1.4%
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	10	11.76%	0.139	11.1%
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	1	1.18%	0.014	1.4%
Villosa iris	-	-	-	-

Site SR-13: Brigden				
Species	**Abundance**	**Relative Abundance**	**Density ($mussels/m^2$)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Amblema plicata	1	0.7%	0.01	1.3%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	-	-	-	-
Elliptio dilatata	-	-	-	-
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	5	3.3%	0.07	6.7%
Lasmigona complanata	118	78.1%	1.57	46.7%
Lasmigona compressa	-	-	-	-
Lasmigona costata	1	0.7%	0.01	1.3%
Leptodea fragilis	3	2.0%	0.04	4.0%
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	1	0.7%	0.01	1.3%
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	10	6.6%	0.13	9.3%
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	12	7.9%	0.16	12.0%
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	-	-	-	-
Villosa iris	-	-	-	-

Site SR-15: La Sallo Line				
Species	**Abundance**	**Relative Abundance**	**Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Amblema plicata	48	28.9%	0.67	45.8%
Anodontoides ferussacianus	-	-	-	-
Cyclonaias tuberculata	-	-	-	-
Elliptio dilatata	-	-	-	-
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	20	12.0%	0.28	23.6%
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	24	14.5%	0.33	29.2%
Lasmigona complanata	27	16.3%	0.38	27.8%
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Leptodea fragilis	-	-	-	-
Ligumia recta		-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	45	27.1%	0.63	41.7%
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	2	1.2%	0.03	2.8%
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	-	-	-	-
Villosa iris	-	-	-	-

Site SR-9: Warwick				
Species	**Abundance**	**Relative Abundance**	**Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Amblema plicata	54	21.8%	0.68	40.0%
Anodontoides ferussacianus	2	0.8%	0.03	2.5%
Cyclonaias tuberculata	-	-	-	-
Elliptio dilatata	42	16.9%	0.53	31.3%
Epioblasma t. rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	31	12.5%	0.39	27.5%
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	32	12.9%	0.40	18.8%
Lasmigona complanata	64	25.8%	0.80	40.0%
Lasmigona compressa	2	0.8%	0.03	2.5%
Lasmigona costata	-	-	-	-
Leptodea fragilis	-	-	-	-
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	5	2.0%	0.06	5.0%
Potamilus alatus	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	13	5.2%	0.16	13.8%
Quadrula pustulosa	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	3	1.2%	0.04	3.8%
Toxolasma parvus	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Villosa fabalis	-	-	-	-
Villosa iris	-	-	-	-

Appendix 2. Geographic location, search effort, mussel richness and abundance, and physical characteristics of the habitat at each monitoring site on the Sydenham River.

SR-21

Latitude	42.59155
Longitude	-82.26813
# of blocks	28
# of quadrats	84
Total unionids collected	10
Total species diversity	2
Unionid density (per m^2)	0.12
Species diversity (per m^2)	0.09
Total time searched (p-h)	3.3
Depth (cm)	225 ± 5SE
Water Velocity (m/s)	n/a
Boulder (%)	2.7 ± 1.1SE
Rubble (%)	3.6 ± 0.76SE
Gravel (%)	9.4 ± 1.6SE
Sand (%)	16.2 ± 2.1SE
Silt (%)	9.8 ± 1.4SE
Clay (%)	20.7 ± 3.8SE
Muck (%)	26.5 ± 4.3SE
Detritus (%)	10.9 ± 1.6SE

Latitude	42.58916
Longitude	-82.12639
# of blocks	26
# of quadrats	78
Total unionids collected	235
Total species diversity	19
Unionid density (per m^2)	3.01±0.22 SE
Species diversity (per m^2)	2.58±0.17 SE
Total time searched (p-h)	11
Depth (cm)	16.2±0.76 SE
Water Velocity (m/s)	0.161±0.010 SE
Boulder (%)	12.4±2.03 SE
Rubble (%)	15.2±1.62 SE
Gravel (%)	38.7±1.96 SE
Sand (%)	23.1±1.41 SE
Silt (%)	5.3±0.90 SE
Clay (%)	-
Muck (%)	0.6±0.64 SE
Detritus (%)	4.7±1.67 SE

SR-20

Latitude	42.59658
Longitude	-82.14986
# of blocks	27
# of quadrats	81
Total unionids collected	39
Total species diversity	8
Unionid density (per m^2)	0.48±0.07SE
Species diversity (per m^2)	0.44±0.08SE
Total time searched (p-h)	6.9
Depth (cm)	114.8±3.33SE
Water Velocity (m/s)	0.008±0.00SE
Boulder (%)	10.1±1.66SE
Rubble (%)	30.3±3.06SE
Gravel (%)	19.6±2.95SE
Sand (%)	12.6±2.34SE
Silt (%)	15.7±1.39SE
Clay (%)	10.3±2.19SE
Muck (%)	-
Detritus (%)	1.2±0.45SE

SR-6

Latitude	42.60517
Longitude	-82.07483
# of blocks	26
# of quadrats	78
Total unionids collected	705
Total species diversity	23
Unionid density (per m^2)	9.0 ±1.09SE
Species diversity (per m^2)	3.8 ±0.35SE
Total time searched (p-h)	11.4
Depth (cm)	14.3 ±0.53SE
Water Velocity (m/s)	0.241 ±0.011SE
Boulder (%)	4.8 ±0.99SE
Rubble (%)	34.9 ±2.49SE
Gravel (%)	23.1 ±1.01SE
Sand (%)	19.5 ±1.56SE
Silt (%)	12.9 ±0.70SE
Muck (%)	0.3 ±0.19SE
Detritus (%)	4.6 ±1.36SE

SR-12

Appendix 2 (cont'd).

SR-19	
Latitude	42.6265
Longitude	-82.0231
# of blocks	25
# of quadrats	75
Total unionids collected	811
Total species diversity	23
Unionid density (per m^2)	10.8 ±0.67 SE
Species diversity (per m^2)	5.4 ±0.24 SE
Total time searched (p-h)	16.0
Depth (cm)	12.0 ±0.30 SE
Water Velocity (m/s)	0.263 ±0.010 SE
Boulder (%)	10.5 ±1.19 SE
Rubble (%)	27.9 ±1.38 SE
Gravel (%)	19.3 ±0.79 SE
Sand (%)	26.6 ±1.22 SE
Silt (%)	14.3 ±0.57 SE
Muck (%)	0.1 ±0.13 SE
Detritus (%)	1.3 ±0.55 SE

SR-17	
Latitude	42.67917
Longitude	-82.01667
# of blocks	27
# of quadrats	81
Total unionids collected	329
Total species diversity	19
Unionid density (per m^2)	4.1 ± 0.3 SE
Species diversity (per m^2)	2.9 ± 0.2 SE
Total time searched (p-h)	10.6
Depth (cm)	17 ± 0.4 SE
Water Velocity (m/s)	0.247 ± 0.017SE
Boulder (%)	20.7 ± 2.3 SE
Rubble (%)	21.2 ± 1.5 SE
Gravel (%)	33.5 ± 2.3 SE
Sand (%)	13.6 ± 1.3 SE
Silt (%)	8.5 ± 0.9 SE
Clay (%)	0.7 ± 0.3 SE
Muck (%)	0.6 ± 0.4 SE
Detritus (%)	1.4 ± 0.5 SE

SR-5	
Latitude	42.65001
Longitude	-82.00874
# of blocks	23
# of quadrats	69
Total unionids collected	778
Total species diversity	21
Unionid density (per m^2)	11.3 ± 1.0 SE
Species diversity (per m^2)	5.4 ± 0.3 SE
Total time searched (p-h)	13.8
Depth (cm)	17.5 ± 0.6 SE
Water Velocity (m/s)	0.310 ± 0.009SE
Boulder (%)	9.28 ± 2.0 SE
Rubble (%)	20.1 ± 1.3 SE
Gravel (%)	32.5 ± 1.9 SE
Sand (%)	30.8 ± 1.8 SE
Silt (%)	7.2 ± 0.5 SE
Clay (%)	-
Muck (%)	-
Detritus (%)	0.1 ± 0.1 SE

SR-7	
Latitude	42.69901
Longitude	-81.98938
# of blocks	27
# of quadrats	81
Total unionids collected	1144
Total species diversity	23
Unionid density (per m^2)	14.1 ± 1.0 SE
Species diversity (per m^2)	5.5 ± 0.3 SE
Total time searched (p-h)	11.4
Depth (cm)	14 ± 0.4 SE
Water Velocity (m/s)	0.271 ± 0.013SE
Boulder (%)	27.2 ± 2.7 SE
Rubble (%)	18.0 ± 1.4 SE
Gravel (%)	21.8 ± 1.1 SE
Sand (%)	16.7 ± 1.1 SE
Silt (%)	15.5 ± 0.8 SE
Clay (%)	-
Muck (%)	0.7 ± 0.4 SE
Detritus (%)	0.5 ± 0.4 SE

Appendix 2 (cont'd).

SR-3

Latitude	42.77917
Longitude	-81.83528
# of blocks	23
# of quadrats	69
Total unionids collected	230
Total species diversity	20
Unionid density (per m^2)	3.33±0.40SE
Species diversity (per m^2)	2.32±0.22SE
Total time searched (p-h)	9.4
Depth (cm)	26.2±1.14SE
Water Velocity (m/s)	0.172±0.013SE
Boulder (%)	30.1±3.19SE
Rubble (%)	28.8±2.31SE
Gravel (%)	22.4±1.57SE
Sand (%)	13.6±2.08SE
Silt (%)	3.3±0.87SE
Clay (%)	-
Muck (%)	-
Detritus (%)	1.59±0.83SE

SR-10

Latitude	42.84583
Longitude	-81.825
# of blocks	25
# of quadrats	75
Total unionids collected	245
Total species diversity	17
Unionid density (per m^2)	3.28±0.25SE
Species diversity (per m^2)	2.37±0.19SE
Total time searched (p-h)	9.6
Depth (cm)	22.6±0.94SE
Water Velocity (m/s)	0.196±0.013SE
Boulder (%)	15.5+1.80SE
Rubble (%)	14.9±1.10SE
Gravel (%)	30.1±1.78SE
Sand (%)	24.6±1.42SE
Silt (%)	5.3±0.78SE
Clay (%)	1.8±0.72SE
Muck (%)	2.1±0.85SE
Detritus (%)	4.2±1.02SE

SR-2

Latitude	42.80663
Longitude	-81.84691
# of blocks	26
# of quadrats	78
Total unionids collected	277
Total species diversity	15
Unionid density (per m^2)	3.5±0.4 SE
Species diversity (per m^2)	2.1±0.2 SE
Total time searched (p-h)	13.0
Depth (cm)	16±0.7 SE
Water Velocity (m/s)	0.250±0.015 SE
Bedrock (%)	13.7±3.4 SE
Boulder (%)	12.4±1.2 SE
Rubble (%)	23.6±1.4 SE
Gravel (%)	23.8±1.2 SE
Sand (%)	13.7±1.0 SE
Silt (%)	12.6±1.1 SE
Clay (%)	-
Muck (%)	-
Detritus (%)	0.2±0.1 SE

SR-1

Latitude	42.86063
Longitude	-81.78848
# of blocks	24
# of quadrats	72
Total unionids collected	85
Total species diversity	15
Unionid density (per m^2)	1.2±0.12SE
Species diversity (per m^2)	1.1±0.11SE
Total time searched (p-h)	7.8
Depth (cm)	18.1±0.629SE
Water Velocity (m/s)	0.174±0.014SE
Boulder (%)	4.23±0.866SE
Rubble (%)	10.2±1.24SE
Gravel (%)	26.4±1.67SE
Sand (%)	25.3±2.71SE
Silt (%)	25.8±1.80SE
Clay (%)	0.14±0.10SE
Muck (%)	1.18±0.402SE
Detritus (%)	6.80±2.04SE

Appendix 2 (cont'd).

SR-13

Latitude	42.84895
Longitude	-82.21327
# of blocks	25
# of quadrats	75
Total unionids collected	151
Total species diversity	8
Unionid density (per m^2)	2.0±0.3 SE
Species diversity (per m^2)	0.8±0.1 SE
Total time searched (p-h)	5.74
Depth (cm)	17±1.3 SE
Water Velocity (m/s)	0.161±0.014 SE
Boulder (%)	0.1±0.1 SE
Rubble (%)	2.3±0.4 SE
Gravel (%)	43.7±2.0 SE
Sand (%)	16.7±1.2 SE
Silt (%)	16.9±0.8 SE
Clay (%)	16.3±2.6 SE
Muck (%)	0.9±0.5 SE
Detritus (%)	2.7±0.6 SE

Longitude	-81.97083
# of blocks	20
# of quadrats	80
Total unionids collected	248
Total species diversity	10
Unionid density (per m^2)	3.1±0.44SE
Species diversity (per m^2)	1.8±0.22SE
Total time searched (p-h)	7.5
Depth (cm)	11.6±0.91SE
Water Velocity (m/s)	0.158±0.013SE
Boulder (%)	5.6±1.16SE
Rubble (%)	14.8±1.63SE
Gravel (%)	50.5±2.12SE
Sand (%)	16.0±1.15SE
Silt (%)	9.9±0.79SE
Clay (%)	1.9±0.66SE
Muck (%)	0.5±0.5SE
Detritus (%)	0.75±0.32SE

SR-15

Latitude	42.9062
Longitude	-82.11107
# of blocks	24
# of quadrats	72
Total unionids collected	166
Total species diversity	6
Unionid density (per m^2)	2.31±0.20SE
Species diversity (per m^2)	1.71±0.14SE
Total time searched (p-h)	7.7
Depth (cm)	24.8±1.25SE
Water Velocity (m/s)	0.019±0.005SE
Boulder (%)	2.8±0.63SE
Rubble (%)	5.1±0.74SE
Gravel (%)	19.5±1.78SE
Sand (%)	13.5±1.77SE
Silt (%)	20.1±1.15SE
Clay (%)	31.7±3.10SE
Muck (%)	2.8±1.26SE
Detritus (%)	4.3±0.77SE

SR-9

Latitude	42.975

Appendix 3. Density and richness of mussels and physical features of the habitat groups at each of the 15 monitoring sites, as determined by hierarchical cluster analysis.

Site SR-21	Group A	Group B	Group C	Group D
Density (#/m^2)	0.1	0.0	0.06	0.2
Species Richness	0.1	0.0	0.06	0.2
Velocity (m/s)	0.01	0.01	0.01	0.01
Depth (cm)	204	257	255	208
% Boulder	9.4	0.0	0.0	0.8
% Rubble	6.9	1.7	5.6	0.8
% Gravel	9.4	16.0	18.5	0.4
% Sand	3.7	25.7	41.5	7.3
% Silt	1.7	19.0	27.9	0.4
% Clay	65.2	0.0	2.6	0.0
% Muck	0.4	0.0	0.0	83.3
% Detritus	3.3	37.7	3.8	7.1
# Quadrats	26	15	17	26

Site SR-21	Group A	Group B	Group C	Group D
Density (#/m^2)	0.1	0.0	0.06	0.2
Species Richness	0.1	0.0	0.06	0.2
Velocity (m/s)	0.01	0.01	0.01	0.01
Depth (cm)	204	257	255	208
% Boulder	9.4	0.0	0.0	0.8
% Rubble	6.9	1.7	5.6	0.8
% Gravel	9.4	16.0	18.5	0.4
% Sand	3.7	25.7	41.5	7.3
% Silt	1.7	19.0	27.9	0.4
% Clay	65.2	0.0	2.6	0.0
% Muck	0.4	0.0	0.0	83.3
% Detritus	3.3	37.7	3.8	7.1
# Quadrats	26	15	17	26

Site SR-12	Group A	Group B	Group C	Group D	Group E
Density (#/m^2)	1.0	3.0	6.2	2.1	3.2
Species Richness	1.0	2.5	4.6	1.9	2.8
Velocity (m/s)	0.11	0.30	0.22	0.14	0.13
Depth (cm)	18	22	18	15	15
% Boulder	1.3	62.5	6.9	11.2	4.1
% Rubble	6.3	5.0	24.2	16.8	10.3
% Gravel	0.0	18.3	46.2	42.0	42.1
% Sand	16.3	10.8	20.8	25.3	25.9
% Silt	0.0	0.0	1.2	3.0	16.5
% Muck	12.5	0.0	0.0	0.0	0.0
% Detritus	63.8	3.3	0.8	1.7	1.2
% Macrophyte	0.0	0.0	23.1	54.7	97.4
# Quadrats	4	6	13	38	17

Site SR-6	Group A	Group B	Group C	Group D
Density (#/m^2)	1.9	3.5	20.6	8.3
Species Richness	1.4	2.2	7.2	3.6
Velocity (m/s)	1.20	0.85	0.70	0.50
Depth (cm)	12	18	13	10
% Boulder	11.1	2.3	5.7	2.2
% Rubble	52.9	50.6	23.9	9.1
% Gravel	18.9	28.1	25.2	15.9
% Sand	8.6	10.8	29.3	29.7
% Silt	9.3	8.7	14.1	21.3
% Muck	0.0	0.0	0.0	1.6
% Detritus	0.0	0.0	1.8	20.0
# Quadrats	14	26	22	16

Site SR-19	Group A	Group B	Group C	Group D
Density (#/m^2)	2.3	13.9	10.4	8.3
Species Richness	2.0	6.7	5.5	4.3
Velocity (m/s)	0.13	0.23	0.32	0.30
Depth (cm)	12	12	11	13
% Boulder	2.5	6.4	25.0	8.1
% Rubble	5.0	23.0	23.3	41.0
% Gravel	6.3	21.4	14.0	22.1
% Sand	41.3	33.8	21.7	17.7
% Silt	23.8	15.3	14.7	11.0
% Muck	2.5	0.0	0.0	0.0
% Detritus	18.8	0.2	1.3	0.0
# Quadrats	4	32	15	24

Site SR-5	Group A	Group B	Group C	Group D
Density (#/m^2)	20.2	8.7	7.7	4.3
Species Richness	7.5	4.8	4.8	3.0
Velocity (m/s)	0.33	0.25	0.32	0.28
Depth (cm)	13	14	21	19
% Boulder	3.6	0.6	6.9	48.6
% Rubble	13.3	17.2	26.7	13.6
% Gravel	45.7	43.3	25.3	12.1
% Sand	26.9	32.2	35.8	17.9
% Silt	10.7	6.7	5.2	6.4
% Detritus	0.0	0.0	0.0	1.4
# Quadrats	21	9	32	7

Site SR-17	Group A	Group B	Group C	Group D
Density (#/m^2)	0.7	3.1	4.5	6.4
Species Richness	0.7	2.2	3.2	4.6
Velocity (m/s)	0.23	0.15	0.32	0.35
Depth (cm)	15	18	14	17
% Boulder	16.7	36.0	11.3	2.9
% Rubble	9.2	24.4	27.0	11.8
% Gravel	9.2	21.1	41.8	55.8
% Sand	16.7	5.8	14.8	26.1
% Silt	21.7	12.1	5.3	1.1
% Clay	5.8	0.3	0.0	0.5
% Muck	5.8	0.1	0.0	0.3
% Detritus	14.2	0.1	0.3	0.8
# Quadrats	6	36	20	19

Site SR-7	Group A	Group B	Group C	Group D	Group E
Density (#/m^2)	16.2	32.3	14.9	8.8	6.8
Species Richness	6.1	9.3	5.9	4.0	3.8
Velocity (m/s)	0.27	0.28	0.31	0.24	0.14
Depth (cm)	16	14	13	14	14
% Boulder	62.6	9.2	9.4	26.5	14.0
% Rubble	5.5	10.8	30.2	16.0	17.0
% Gravel	12.4	35.0	26.1	21.5	20.0
% Sand	9.2	30.0	17.6	18.8	14.0
% Silt	9.7	15.0	16.7	16.7	27.0
% Muck	0.5	0.0	0.2	0.8	4.0
% Detritus	0.0	0.0	0.2	0.2	6.0
% Macrophytes	0.0	0.0	0.0	0.2	42.0
# Quadrats	19	6	27	24	5

Site SR-3	Group A	Group B	Group C	Group D
Density (#/m^2)	1.8	4.1	1.7	6.3
Species Richness	1.4	3.4	1.4	3.5
Velocity (m/s)	0.14	0.31	0.17	0.10
Depth (cm)	36	21	28	19
% Boulder	21.1	22.1	63.0	7.6
% Rubble	33.9	47.9	22.5	15.3
% Gravel	35.0	21.1	12.1	22.4
% Sand	8.6	7.5	2.0	37.6
% Silt	1.4	1.4	0.3	10.3
% Detritus	0.0	0.0	0.3	6.2
# Quadrats	18	14	20	17

Site SR-2	Group A	Group B	Group C	Group D
Density (#/m^2)	8.7	2.9	4.4	0.6
Species Richness	4.4	1.7	2.7	0.5
Velocity (m/s)	0.12	0.22	0.41	0.22
Depth (cm)	9	15	15	26
% Bedrock	0.0	1.1	0.6	78.1
% Boulder	7.8	18.0	10.6	1.9
% Rubble	18.9	25.4	35.6	5.0
% Gravel	22.8	26.7	30.0	7.7
% Sand	17.8	15.5	15.0	3.5
% Silt	31.7	13.2	8.3	3.8
% Detritus	1.1	0.1	0.0	0.0
# Quadrats	18	20	27	13

Site SR-10	Group A	Group B	Group C	Group D
Density (#/m^2)	5.4	2.8	1.4	0.6
Species Richness	4.4	2.5	1.4	0.6
Velocity (m/s)	0.27	0.19	0.11	0.09
Depth (cm)	28	23	15	16
% Boulder	11.4	28.2	5.3	11.0
% Rubble	14.6	19.8	12.5	3.0
% Gravel	43.4	24.4	23.8	11.0
% Sand	27.0	20.0	33.1	12.0
% Silt	2.1	5.0	10.9	6.0
% Clay	0.2	0.4	3.1	14.0
% Muck	0.7	0.2	0.9	24.0
% Detritus	0.9	1.6	9.4	19.0
# Quadrats	28	25	16	6

Site SR-1	Group A	Group B	Group C	Group D
Density (#/m^2)	1.1	0.4	2.2	1.3
Species Richness	1.1	0.4	1.9	1.2
Velocity (m/s)	0.08	0.14	0.22	0.22
Depth (cm)	18	16	16	22
% Boulder	1.5	10.7	1.3	1.0
% Rubble	0.0	15.0	18.3	4.8
% Gravel	10.5	29.1	38.7	22.7
% Sand	5.5	8.9	18.7	53.5
% Silt	30.0	34.6	22.7	17.7
% Clay	1.0	0.0	0.0	0.0
% Muck	8.5	0.0	0.0	0.0
% Detritus	43.0	1.7	0.3	0.6
# Quadrats	10	23	15	24

Site SR-13	Group A	Group B	Group C
Density (#/m^2)	1.8	1.9	2.5
Species Richness	0.6	0.8	1.3
Velocity (m/s)	0.14	0.31	0.08
Depth (cm)	15	11	25
% Boulder	0.3	0.0	0.0
% Rubble	1.8	1.5	3.9
% Gravel	45.3	66.5	23.6
% Sand	22.8	16.8	6.6
% Silt	21.5	12.9	12.3
% Clay	5.4	1.5	45.7
% Muck	0.7	0.0	2.0
% Detritus	1.5	0.9	6.1
# Quadrats	36	17	22

Site SR-15	Group A	Group B	Group C	Group D	Group E
Density (#/m^2)	0.6	1.8	2.1	4.3	2.1
Species Richness	0.6	1.5	1.4	2.9	1.6
Velocity (m/s)	0.06	0.03	0.01	0.01	0.01
Depth (cm)	14	23	31	29	22
% Boulder	12.1	1.8	4.4	1.0	0.3
% Rubble	3.6	4.4	11.6	2.7	2.6
% Gravel	13.6	36.2	23.1	17.3	3.8
% Sand	36.4	29.1	5.9	6.0	2.4
% Silt	12.1	23.5	19.1	26.7	15.3
% Clay	0.7	3.5	35.0	42.0	60.6
% Muck	21.4	1.2	0.6	0.0	1.5
% Detritus	0.0	0.9	0.3	4.0	13.5
% Macrophytes	8.6	7.6	8.4	64.0	74.6
# Quadrats	8	16	16	15	17

Site SR-9	Group A	Group B	Group C	Group D
Density (#/m^2)	0.7	0.5	7.1	3.3
Species Richness	0.6	0.4	3.9	2.7
Velocity (m/s)	0.20	0.20	0.10	0.01
Depth (cm)	7	7	18	27
% Boulder	17.8	1.1	3.6	6.7
% Rubble	33.3	5.9	15.8	6.7
% Gravel	30.9	61.2	52.9	16.7
% Sand	10.6	19.6	15.7	8.3
% Silt	5.6	11.9	9.0	21.7
% Clay	1.6	0.0	2.9	13.3
% Muck	0.0	0.0	0.0	13.3
% Detritus	0.0	0.3	0.3	13.3
# Quadrats	44	13	16	7