Summary of initial surveys at index stations for long-term monitoring of freshwater mussels in southwestern Ontario between 2007 and 2018

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Between 2007 and 2018, Fisheries and Oceans Canada established 22 index stations as part of a long-term monitoring program for Ontario unionid populations. The objective of this program is to detect changes in the status of unionid populations, specifically Species at Risk, over time. Index stations were established across five watersheds in southwestern Ontario: 1) Saugeen River (four stations), 2) Maitland River (six stations), 3) Bayfield River (one station), 4) Grand River (seven stations), and 5) Thames River (four stations). Baseline data were collected through the completion of an initial quantitative quadrat survey at each station. These data form the foundation of the monitoring program to which future surveys will be compared. The monitoring program gathers invaluable long-term data on Ontario’s unionid populations which can be used to guide and support conservation efforts and recovery strategies.

RESUMÉ

Sheldon, M.N., McNichols-O’Rourke, K.A., and Morris, T.J. 2020. Summary of initial surveys for long-term monitoring of freshwater mussels at index stations in southwestern Ontario between 2007 and 2018. Can. Manuscr. Rep. Fish. Aquat. Sci. 3203: vii + 85 p.

Entre 2007 et 2018, Pêches et Océans Canada a établi 22 stations indicatrices dans le cadre d’un programme de surveillance à long terme des populations d’unionidés de l’Ontario. Le programme vise à détecter les changements dans l’état des populations d’unionidés au fil du temps, plus particulièrement en ce qui a trait aux espèces en péril. Les stations indicatrices ont été installées dans cinq bassins versants du Sud-Ouest de l’Ontario : 1) rivière Saugeen (quatre stations); 2) rivière Maitland (six stations); 3) rivière Bayfield (une station); 4) rivière Grand (sept stations); 5) rivière Thames (quatre stations). Des données de base ont été collectées pour chacune des stations lors d’un relevé quantitatif initial par quadrat. Celles-ci servent de fondement au programme de surveillance, et les résultats des relevés futurs y seront comparés. Le programme permet de rassembler, à long terme, des données précieuses sur les populations d’unionidés de l’Ontario qui pourront être utilisées pour orienter et appuyer les activités de conservation et les stratégies de rétablissement.

INTRODUCTION

Freshwater mussels are a unique and important component of aquatic ecosystems. They are natural environmental filters, provide habitat for algae and invertebrates, and transfer energy from aquatic to terrestrial environments (Neves and Odom 1989; Welker and Walz 1998; Vaughn and Hakenkamp 2001; Newton et al. 2011). Although mussels are critical features of our aquatic ecosystems they are among North America's most imperilled group of species (Ricciardi et al. 1998). Over 70% of native North American freshwater mussels are Threatened, Endangered, or Extinct (Williams et al. 1992).

Canada is home to 55 species of freshwater mussels and more than 65% of these are in need of conservation (Metcalfe-Smith and Cudmore-Vokey 2004; Metcalfe-Smith et al. 2005). Ontario has the highest richness of mussel species in Canada, with 42 species occurring in the province (Metcalfe-Smith et al. 2005; DFO unpublished data). Fifteen of these species have been federally listed as Special Concern, Threatened, or Endangered under the *Species at Risk Act* (SARA; Government of Canada 2020; Table 1). Despite the significance of Ontario's mussel fauna, formal surveys in many rivers did not begin in earnest until the 1990s (Mackie 1996; Morris 1996; Schueler 1996; Metcalfe-Smith et al. 1997; Metcalfe-Smith et al. 1998a; Morris and DiMaio 1998-1999; Metcalfe-Smith et al. 2000a). This coincided with the formation of the Mollusc Species Specialist Subcommittee (SSC) of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1995 (originally the Mollusc and Lepidopteran SSC until 2003). The need for data required for COSEWIC species assessment processes, as well as an increased awareness of the conservation status of freshwater mussels (Metcalfe-Smith et al. 1998b) and the losses of the Great Lakes populations following the invasion of Zebra Mussels (*Dreissena polymorpha*; Nalepa et al. 1996), drove the initial increase in unionid surveys in Canada. By the end of 2010, most of the large inland waterbodies of southwestern Ontario had been systematically surveyed including (from north to south) the Nottawasaga River (Minke-Martin et al. 2012)**,** Saugeen River (Morris and DiMaio 1998-1999; Morris et al. 2007)**,** Maitland River (McGoldrick and Metcalfe-Smith 2004; Epp et al. 2013), Bayfield River (Morris et al. 2012a), Grand River (Kidd 1973; Mackie 1996; Metcalfe-Smith et al. 2000a), Welland River (Morris et al. 2012b), Ausable River (Morris and DiMaio 1998-1999), Thames River (Morris 1996; Morris and Edwards 2007), Sydenham River (Mackie and Topping 1988; Clarke 1992; Metcalfe-Smith et al. 2003), Big Otter Creek (Morris and Di Maio 1998-1999), Catfish Creek (Morris and Di Maio 1998-1999), and Canard River (Morris and Di Maio 1998-1999).

All of the surveys listed above were completed using a qualitative timed-search method (Metcalfe-Smith et al. 2000b), which is useful for detecting the presence and absence of mussel species. This survey method, however, is limited in that densities and population estimates cannot be calculated for each species or at the community level. Additionally, juvenile mussels, small species, and burrowed individuals have a greater likelihood of remaining undetected as sampling is often restricted to the surface of the river bed. The ability to detect changes in mussel populations is an important objective in current recovery strategies (e.g., DFO 2018; DFO 2019). In order to detect changes or calculate densities and population estimates, an intensive, quantitative survey involving the excavation of the river bed must be completed. Between 1999 and 2003, Metcalfe-Smith et al. (2007) developed a monitoring program for the Sydenham River that would "…collect precise and detailed baseline data on the distribution, abundance, demographics and habitat requirements of mussel populations…", and allow for the detection of changes in the health of mussel populations over time. The inclusion of river bed excavation increases the likelihood that juveniles and burrowed individuals will be detected. Reid and Morris (2017) showed that 92-94% of individuals were encountered by excavation at two census sites in southern Ontario. The detection of these individuals is critical for accurately estimating population demographics and detecting changes in population health. Ideally, these index stations would be monitored every 5-10 years and it was suggested that this monitoring program could be applied to other systems. Since the initial surveys in the Sydenham River, this design has been successfully implemented in the Ausable River (Baitz et al. 2008; Upsdell et al. 2012) and the five watersheds discussed in this report.

The surveys described in this report were undertaken by Fisheries and Oceans Canada (DFO) between 2007 and 2018 across five watersheds: Saugeen River, Maitland River, Bayfield River, Grand River, and Thames River. The objective of these surveys was to establish long-term monitoring index stations in each watershed and collect baseline data to act as the foundation for the monitoring program. These data include indicators of unionid population status as outlined in DFO (2006). This document summarizes discussions that occurred over three meetings between 2005-2006 as part of an allowable harm analysis workshop for freshwater fishes and mussels. Only some of the indicators listed in DFO (2006) can be assessed using the data from these surveys (Table 2). The indicators discussed in this report to assess the status of a population include: 1) species distribution, 2) relative abundance, 3) size structure, 4) sex ratios, and 5) density. Density was included as an indicator even though it is not included as a criteria in DFO (2006) as it is an important population parameter and the collection of density data is one of the primary goals of the quantitative quadrat sampling technique that cannot be collected using qualitative methods (Metcalfe-Smith et al. 2007). Species richness (i.e., the presence of a rich or abundant mussel community) was also considered when discussing results at the watershed level (DFO 2006). The collection of these data will enable the detection of changes in the status of Ontario's riverine unionid communities and populations, specifically for Species at Risk (SAR).

Additionally, the establishment of index stations meets the objective outlined in many current recovery strategies for a long-term monitoring program for SAR populations; these data will aid in meeting short- and long-term recovery objectives (Dextrase et al. 2003; ARRT 2005; Morris 2006; DFO 2011; DFO 2013; DFO 2018; DFO 2019).

METHODS

SAMPLING METHODS

The quadrat survey technique was modified from Metcalfe-Smith et al. (2007). Sampling occurred in the most productive area of the site (highest number of mussels observed) as determined by previous timed-search surveys and was conducted by a minimum three person crew. A systematic sampling approach with three random starts was employed. Generally, the site was divided into 25 blocks (range=16–26 blocks; mean=22 blocks/site). Each block was 3 m in width by 5 m in length (15 m^2) and was subdivided into fifteen 1 m^2 quadrats (Figure 1). Within each block, three quadrats were chosen randomly to be excavated before the survey began and the same three quadrats were excavated in each block. The quadrats that were excavated varied between sites. Each quadrat was searched, beginning at the downstream end of the plot using three different techniques: 1) visual search with the naked eye, 2) visual search with a viewing box, and 3) excavation to a depth of 10–15 cm. Every mussel encountered was collected as searching continued. After each method was used, the mussels found were identified, sexed visually (if possible), and measured (maximum length) using Vernier calipers. Only sexually dimorphic species were sexed; additional sampling was not conducted to determine the sex of non-sexually dimorphic species. When the quadrat was fully excavated, the mussels were returned to the 1 m^2 area from which they were collected.

Environmental data was also collected at each site. Before a quadrat was excavated, water velocity (m/s) and depth (m) were measured using a flow meter and meter stick, respectively. After the excavation was complete, substrate composition (%), degree of siltation (high, medium, low), degree of algal growth (high, medium, low), shading (dense, partly open, open), and the presence or absence of aquatic macrophytes was visually estimated. Definitions of substrate sizes were modified from Wentworth (1922): boulder (>250 mm in diameter), cobble (60–250 mm), gravel (2–60 mm), sand (<2 mm), and “other” material (mud, muck, silt, and detritus).

SELECTION OF QUADRAT SITES

Each quadrat site was chosen based on the results of previous timed-searched surveys (Mackie 1996; Metcalfe-Smith et al. 1998b; Metcalfe-Smith et al. 1999; Metcalfe-Smith et al. 2000a; McGoldrick and Metcalfe-Smith 2004; Morris et al. 2007; Morris and

Edwards 2007; McNichols-O'Rourke et al. 2012; Morris et al. 2012a). Timed-search surveys at an effort of 4.5 person-hours are a suitable technique for detecting the presence of rare mussel species (Metcalfe-Smith et al. 2000b); therefore, the quadrat sites were generally chosen based on species richness, total unionid abundance, presence and abundance of SAR, and habitat type as observed during the initial timed-search surveys. While the objectives of these initial surveys were to determine the presence and distribution of mussels, including SAR, the objective of the quadrat surveys was to calculate densities and population estimates that can be monitored over time to detect any changes that have occurred. Between 2007 and 2018, 22 sites across five watersheds were surveyed using the intensive, quadrat method described above (Appendix A). All surveys were completed between the months of May and August.

Saugeen River

The Saugeen River is located in southwestern Ontario and the watershed drains 3,992 km^2 of land, used largely for agriculture, into Lake Huron (Martha Nicol, Saugeen Conservation 1078 Bruce Rd. 12 Box 150 Formosa, Ontario, N0G 1W0 personal communication). A total of eight sites were surveyed during a preliminary study of the Saugeen River in 2006 (Morris et al. 2007). In 2011, an additional nine sites, as well as three sites that had been surveyed in 2006, were sampled using the timed-search method (McNichols-O'Rourke et al. 2012). Based on the results at these 17 sites, four sites were selected as index stations in 2011 (Figure 2). Fourteen species of mussels (McNichols-O'Rourke et al. 2012) had been observed alive or as shells in the Saugeen River watershed before the current survey including *Cambarunio iris* (Rainbow) which is listed federally and provincially as Special Concern and *Truncilla donaciformis* (Fawnsfoot) which is listed federally and provincially as Endangered (Table 1).

Maitland River

The Maitland River watershed drains approximately 2,500 km^2 of land, which is used primarily for agriculture, into Lake Huron (McGoldrick and Metcalfe-Smith 2004). Between 1998 and 2004, a total of 21 sites were surveyed using the timed-search method (McGoldrick and Metcalfe-Smith 2004; DFO unpublished data). Based on these results, six sites were selected as index stations in 2008 (Figure 3). A total of 12 species were observed in the Maitland River watershed before the current survey (Epp et al. 2013; LGLUD 2020) including *C. iris* and *Lampsilis fasciola* (Wavyrayed Lampmussel), which has been designated as Special Concern federally and Threatened provincially (Table 1).

Bayfield River

The Bayfield River is under the management of the Ausable Bayfield Conservation Authority (ABCA) and is a relatively small basin draining 497 km^2 into Lake Huron

(Morris et al. 2012a). Land in this watershed is largely agricultural (ARRT 2005; Brock et al. 2010). In 2007, 18 sites were sampled in the Bayfield River watershed (Morris et al. 2012a) and based on the results of these surveys, a single site was selected as an index station in 2011 (Figure 4). A total of 16 species are known from the Bayfield River, including *C. iris* and *Quadrula quadrula* (Mapleleaf) which is listed federally (Great Lakes-Upper St. Lawrence population) and provincially as Special Concern (Table 1).

Grand River

The Grand River is Ontario's largest watershed. It covers approximately 6,800 km^2 of land before draining into Lake Erie (GRCA 2020a). Ninety-four sites were surveyed in 1995 and 1997–1998 (Mackie 1996; Metcalfe-Smith et al. 1998b; Metcalfe-Smith et al. 1999; Metcalfe-Smith et al. 2000a). Based on the results of these timed-search surveys, four sites were selected as index stations in 2007 and three more in 2010 for a total of seven index stations in the watershed (Figure 5). A total of 32 species had been recorded from the Grand River before the current survey, including 12 mussel SAR (Table 1).

Thames River

The Thames River is the second largest watershed in southwestern Ontario. It drains 5,285 km^2 of land into Lake St. Clair and land use is primarily agricultural (Morris 2006b). In 2004 and 2005, 37 sites were sampled in the Thames River during preliminary timed-search surveys (Morris and Edwards 2007). Based on the results of these surveys, five sites were selected as index stations in 2004, one in 2005, and six in 2010 (Figure 6). An additional four sites were selected as index stations in 2018; two of these were sites surveyed in the 2004–2005 timed-search surveys and two had been surveyed in 1998 (Metcalfe-Smith et al. 2000b). Ten of the 16 stations are located in the upper Thames River subwatershed and six are located in the lower Thames River subwatershed. In 2015–2017, the original twelve sites (established 2004-2010) were sampled for the second time marking the first monitoring event. A comparison of the two sampling events at these sites will be detailed in an upcoming report (DFO unpublished data); therefore, this report contains only the results of the four sites established in 2018. A total of 35 species of mussels have been observed in the Thames River over time (McNichols-O'Rourke et al. 2012), including 14 SAR (Table 1).

DATA ANALYSIS

To determine population estimates and status, the following data were analyzed: 1) species distribution, 2) relative abundance, 3) size structure, 4) sex ratios, and 5) density. All statistical analyses were completed in RStudio version 1.1.383 (RStudio Team 2016).

Species Distribution and Relative Abundance

The collection of species presence/absence, abundance, and distribution data provide insight into the status of unionid populations. These data were collected at each site so the following criteria for a healthy population could be assessed: 1) continuous, non-fragmented distribution, 2) relatively high abundance, and 3) occurring at multiple sites (DFO 2006). These data were analyzed by summarizing abundance data, calculating relative abundance for each species within a watershed (proportion of the total unionids observed), and calculating frequency of occurrence for each species within a watershed (percentage of sites a species was detected at). Species richness was calculated at the watershed level and spatial patterns across watersheds were also investigated to garner further insight into the status of Ontario's unionid populations.

Size Structure

Size structure was analyzed to investigate the following criteria from DFO (2006): 1) full length distribution and 2) recruitment. To evaluate the size structure of a population, length frequency distributions were generated using 10 mm size classes beginning at 0 mm and ending at the largest length observed during the survey. The first size class was adjusted to ensure that the following classes could be clearly separated into juvenile and adult (i.e., if the cut-off for juvenile length was 25 mm, the first class was 0–5 mm so the subsequent 10 mm classes would not include a class with both juveniles and adults). Length frequency distributions are presented for all SAR and any common species found in abundance of greater than 100 individuals. A Shapiro-Wilks test of normality was used to analyze the normality of the size distributions for populations found in abundance of greater than 100 individuals using the following equation (Aldridge 1999):

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n} (x_i - \overline{x})^2}$$

The proportion of individuals considered to be juveniles was calculated to investigate the status of recruitment within a population. Juveniles were classified as individuals under a specified length cut-off and this cut-off was determined differently among species depending on data availability. For sexually dimorphic species, juveniles were considered to be any individual below the smallest length at which a female could be sexed based on data from LGLUD (2020). Males and females of sexually dimorphic species become visually distinguishable once they reach sexual maturity (COSEWIC 2010a); before this time, all juveniles resemble adult males and sexes cannot be differentiated visually. The visual identification of a female indicates sexual maturity has been reached at that length (COSEWIC 2010a). The juvenile length cut-off for *L. fasciola* was determined to be 35 mm and for *Paetulunio fabalis* (Rayed Bean) to be 10 mm using this method. For non-sexually dimorphic species, the length cut-off for juveniles was taken from the COSEWIC status report if this information was available. The length cut-off of 50 mm was used for *Q. quadrula* as stated in COSEWIC (2016). If the length of maturity was not available for a non-sexually dimorphic species, the cut-off of 25 mm in length was used which represents individuals recruited into the population within the last 2-3 years (Haag and Warren 2007). This general cut-off was applied to all common species analyzed and to *Pleurobema sintoxia* (Round Pigtoe). The 25 mm cut-off was also used for *C. iris* as the age of maturity for this species in Ohio was determined to be three years of age which falls into the 2-3 year range encompassed by this cut-off (Haag and Warren 2007; Watters et al. 2009; COSEWIC 2015). As Ohio is in close geographic proximity to southwestern Ontario and shares a similar climate, the age at maturity should not vary greatly between the populations.

Sex-ratios

Observed sex-ratios of sexually dimorphic species were analyzed using a Chi-Square Goodness of Fit test with the following equation:

$$X^2 = \sum(O-E)^2/E$$

where O is the observed number and E is the expected number (McDonald 2009). Analysis was completed to determine if there was deviation from the balanced 1:1 sex-ratio expected in a population whose sex is determined genetically, as is the case with unionids (Morton 1991). A balanced sex ratio represents a criteria of healthy population status (DFO 2006). Sex-ratios were only analyzed for species found in abundance of greater than 50 individuals in a watershed but were presented for all SAR. *Cambarunio iris* is a sexually dimorphic species but it is very challenging to visually sex this species accurately. As such, sex ratios are not presented or analyzed for this species.

Density

Density was calculated using the following equation from Thompson (2012):

$$D = \tau / A$$

where τ is the total number of unionids in the study area and A is the total area sampled. Density for both individual species and at the site level was standardized per block (1 m^2). Density was calculated using the 15 m^2 block as the study area and the density from each block at a site was averaged to calculate an overall site density. Reporting data per quadrat (1 m^2) would cause pseudoreplication since quadrats are not independent. Mussel density was categorized as outlined in Metcalfe-Smith et al. (2007): very high (>10 mussels/m^2), high (>5–10 mussels/m^2), moderate (>1.5–5 mussels/m^2), and low (0–1.5 mussels/m^2). These categories were established specifically for the Sydenham River, which is the most mussel dense waterbody in Canada (DFO unpublished data), to evaluate whole unionid assemblage density. While using these categories for individual species in less dense watersheds is not a precise use of this qualitative assessment, it still provides a way to compare relative densities of species between watersheds. When discussing the results, it must be considered that species detected in “low density” are being categorized based on what is considered low in the Sydenham River. Standard error was calculated for average site and watershed densities by dividing the standard deviation by the square root of the number of samples (McDonald 2009); the number of samples refers to the number of blocks surveyed at a site.

RESULTS

For all sites surveyed, details on the geographic location, number of quadrats excavated, overall mean species richness, average density, water velocity, depth, and substrate composition can be found in Appendix B. Appendix C contains detailed information on abundance, relative abundance, density, and frequency of occurrence for each species at each site.

SAUGEEN RIVER

A total of 512 individuals representing six species were found at the four index stations surveyed in the Saugeen River watershed in 2011 (Table 3). Species richness ranged from one species at SG04a to four species at SG11 and SG08. Mean site density ranged from 0.40 (standard error (SE) ± 0.06) mussels/m^2 at SG04a to 2.83 (± 0.39) mussels/m^2 at SGR-SGR-05. Average density for the watershed was moderate at 1.69 (± 0.50) mussels/m^2. *Eurynia dilatata* (Spike) was the most abundant (442 individuals; 86.33% relative abundance) and widespread species, occurring at all four sites. *Cambarunio iris* was the second most abundant species observed in the watershed (46 individuals; 8.98% relative abundance). Lengths of *E. dilatata* ranged from 19.0-100.0 mm and represented a left skewed, non-normal distribution ($W=0.821$, $p=0.018$; Figure 7). Multiple size classes were represented but only 0.45% (two individuals) of the observed individuals had a shell length less than 25 mm. Three sexually dimorphic species were observed: *C. iris*, *Lampsilis cardium* (Plain Pocketbook), and *Lampsilis siliquoidea* (Fatmucket).

Cambarunio iris represents the only SAR observed at the Saugeen River watershed index stations. While it was the second most abundant species, its relative abundance was low. *Cambarunio iris* was detected at 50% of the sites being found in the North Saugeen River and the Teeswater River at the two most downstream index stations in the watershed. Density of *C. iris* at these two sites ranged from 0.23 (± 0.07) mussels/m^2 to 0.39 (± 0.09) mussels/m^2 with a low average watershed density of 0.31 (± 0.08) mussels/m^2. Lengths of *C. iris* ranged from 15.0–58.0 mm representing multiple size classes with 10.9% of individuals (five individuals) less than 25 mm in length (Figure 8).

MAITLAND RIVER

A total of 443 individuals representing 12 species were found at the six index stations surveyed in the Maitland River watershed (Table 4). Species richness ranged from five species at MR-01 to eight at MR-16 and MR-14. Mean site density ranged from 0.25 (± 0.07) mussels/m^2 at MR-01 to 2.78 (± 0.57) mussels/m^2 at MR-02. Average density for the watershed was low at 1.21 (± 0.41) mussels/m^2. There were no apparent trends in abundance, density, or species richness across the branches or upper/lower reaches of the Maitland River watershed. *Cambarunio iris* was the most abundant species (268 individuals; 60.5% relative abundance). *Cambarunio iris* and *L. cardium* were the most widespread species, both being found at all six sites. *Lasmigona costata* (Flutedshell) was the second most abundant species observed (51 individuals), although its relative abundance was low at 11.51%. Four sexually dimorphic species were found: *C. iris*, *L. cardium*, *L. fasciola* (11 males (M):13 females (F); 1 juvenile (JUV)), and *L. siliquoidea.*

Of the 443 unionids found, 66% were SAR representing two species: *C. iris* and *L. fasciola*. Densities of *C. iris* ranged from 0.07 (± 0.03) mussels/m^2 to 2.40 (± 0.57) mussels/m^2 with a low average density of 0.74 (± 0.40) mussels/m^2 across the watershed. The lengths of *C. iris* (10.54–71.0 mm) represented a normal distribution (W=0.877, p=0.177; Figure 9) represented by multiple size classes. Of the observed *C. iris,* 9.7% (26 individuals) had a shell length less than 25 mm representing juveniles. Twenty-five *L. fasciola* were detected at 67% (four of six) of the sites surveyed and was not found in the North Maitland River. The observed *L. fasciola* represented 5.64% of the total unionids found. Density of *L. fasciola* ranged from 0.03 (± 0.02) mussels/m^2 to 0.17 (± 0.07) mussels/m^2 with a low average density of 0.10 (± 0.03) mussels/m^2 across the watershed. Lengths of *L. fasciola* ranged from 29.0–79.4 mm (n=25) representing multiple size classes with 4% of individuals (one individual) with a shell length less than 35 mm (Figure 10). Lengths of male *L. fasciola* ranged from 37.4–79.4 mm (n=12) and lengths of female *L. fasciola* ranged from 39.5–77.5 mm (n=13). While *L. fasciola* sex ratios could not be statistically analysed due to the low sample size, males and females were found in similar abundance with 46% males and 54% females.

BAYFIELD RIVER

A total of 41 mussels representing seven species were found at the single index station surveyed in the Bayfield River (Table 5). Overall mean site density was low at 0.55 (± 0.11) mussels/m^2. *Cambarunio iris* was the most abundant species observed (21 individuals; 51.22% relative abundance) and *L. siliquoidea* was the second most abundant species (7 individuals; 17.07% relative abundance). A single *Actinonaias ligamentina* (Mucket) was found representing the first live record of this species in the Bayfield River. Two sexually dimorphic species were observed: *C. iris* and *L. siliquoidea*.

The only SAR found at the Bayfield River index station was *C. iris*. The relative abundance of C. iris was high, accounting for just over half of all observed unionids. Density of *C. iris* at the site was low at 0.28 (± 0.06) mussels/m^2. Lengths of *C. iris* ranged from 14.0–72.0 mm representing multiple size classes with 9.5% (two individuals) below the 25 mm length cut-off (Figure 11).

GRAND RIVER

A total of 401 mussels representing 21 species were found at the seven sites surveyed in the Grand River in 2007 and 2010 (Table 6). Species richness ranged from three species at GR-02 to 15 at GR-21. Mean site density ranged from 0.27 (± 0.07) mussels/m^2 at GR-01 to 2.25 (± 0.21) mussels/m^2 at GR-21. Average density for the watershed was low at 0.85 (± 0.28) mussels/m^2. *Lasmigona costata* was the most abundant species observed throughout the watershed (92 individuals; 22.94% relative abundance) and the most widespread species being found at 86% of sites (six of seven). *Lampsilis fasciola* was the second most abundant species (85 individuals; 21.20% relative abundance) and the only sexually dimorphic species observed (44 M:35 F; 3 JUV; 1 undetermined sex (UND)).

Of the total number of unionids found, 23% were SAR representing three species: *L. fasciola*, *P. sintoxia*, and *Q. quadrula*. *Lampsilis fasciola* was the most abundant and widespread SAR observed being found at 57% of sites (four of seven), all of which were in the upper Grand River. Density of *L. fasciola* ranged from 0.18 (± 0.05) mussels/m^2 to 0.73 (± 0.13) mussels/m^2 (Appendix C). Average density of *L. fasciola* across the sites was low at 0.34 (± 0.13) mussels/m^2. Lengths ranged over a full length distribution from 10.0–82.0 mm with 6.0% of individuals (four individuals) having a shell length less than 35 mm (Figure 12). The observed sex ratio of *L. fasciola* was 1.3:1 males to females; this represented a statistically equal proportion of the two sexes ($\chi^2_{0.05,1}$=1.025, p=0.311). Both *P. sintoxia* and *Q. quadrula* were found at a single site (GR-21), the most downstream index station in the Grand River watershed. Average density of *P. sintoxia* at the site was 0.08 (± 0.03) mussels/m^2 with lengths ranging within a narrow length distribution from 59.6–91.8 mm (n=6). No *P. sintoxia* individuals had a shell length of less than 25 mm (Figure 13). Average density of *Q. quadrula* at the site was 0.03 (± 0.02) mussels/m^2 with lengths ranging within a narrow distribution from 30.0–40.8 mm (n=2). Both of the *Q. quadrula* individuals found represent juveniles with a shell length less than 50 mm (Figure 14).

THAMES RIVER

A total of 905 live individuals representing 16 species were found across the four upper Thames River sites in 2018 (Table 7). Live species richness ranged from seven species at TR-16 to ten species at TR-15. Mean site density ranged by an order of magnitude from 0.69 (± 0.09) mussels/m^2 at TR-18 to 6.65 (± 0.58) mussels/m^2 at TR-36. Mean site density was lowest at the most upstream sites and highest at the most downstream site. Average density for the watershed was moderate at 3.02 (± 1.42) mussels/m^2. *Actinonaias ligamentina* was the most abundant species observed (459 individuals), representing half of the live individuals found (50.72% relative abundance). *Lasmigona costata* was the second most abundant species observed (115 individuals; 12.71% relative abundance) and the most widespread species being found at all sites. Lengths of *A. ligamentina* ranged over a full length distribution from 17.4–152.6 mm and represented a left-skewed and bimodal non-normal distribution (W=0.853, p=0.015, Figure 15). The lengths of *L. costata* ranged over a full length distribution from 17.6–122.5 mm representing a highly left-skewed and unimodal non-normal distribution (W=0.636, p=1.35^{-4}; Figure 16). Of the observed individuals, 0.44% (two individuals) of *A. ligamentina* and 0.85% (one individual) of *L. costata* had shell lengths less than 25 mm. Four sexually dimorphic species were observed: *C. iris*, *L. cardium*, *L. fasciola* (13 M:11 F; 3 UND), and *P. fabalis* (5 M:4 F; 2 UND).

Of the individuals found, 13% were SAR representing four species: *C. iris*, *L. fasciola*, *P. fabalis*, and *P. sintoxia*. *Cambarunio iris* was the most abundant SAR (78 individuals; 8.62% relative abundance) and was found at 75% of sites (three of four), occurring in the North and Middle Thames River. Density of *C. iris* ranged from 0.03 (± 0.02) mussels/m^2 to 0.97 (± 0.21) mussels/m^2 with a low average density of 0.35 (± 0.31) mussels/m^2 across the watershed. Lengths of *C. iris* ranged over a full distribution from 13.1–75.5 mm with 6.4% of individuals (five individuals) less than 25 mm in length (Figure 17). *Lampsilis fasciola* was also detected at 75% of sites and was found across all three branches of the upper Thames River. Density of *L. fasciola* ranged from 0.04 (± 0.03) mussels/m^2 to 0.17 (± 0.05) mussels/m^2 with a low average density of 0.12 (± 0.04) mussels/m^2 across the watershed. Lengths of *L. fasciola* ranged over a moderately narrow distribution from 40.8–80.2 mm (n=27) with no individuals below 35 mm in length (Figure 18). The observed sex ratios were not analyzed for *L. fasciola* but the abundance of males and females was similar with 54% male and 46% female. *Paetulunio fabalis* was detected at a single site in the North Thames River at a density of 0.15 (± 0.05) mussels/m^2. Length of *P. fabalis* ranged over a moderately full distribution from 12.5–31.4 mm (n=11) with no individuals having a length less than 10 mm (Figure 19). While analysis was not completed on the observed sex ratios of *P. fabalis*, the abundance of each sex was similar with 56% male and 44% female. *Pleurobema sintoxia* was detected at a single site in the Middle Thames River at a density of 0.04 (± 0.02) mussels/m^2. Lengths of *P. sintoxia* ranged over a narrow distribution from 68.1–98.0 mm (n=3) with no individuals below 25 mm in length (Figure 20).

SPATIAL PATTERNS ACROSS WATERSHEDS

A total of 2,302 live unionids representing 24 species were found during the initial survey of 22 index stations across five watersheds in southwestern Ontario. Species richness ranged widely from six species (Saugeen River) to 21 species (Grand River). Average watershed density was lowest in the Bayfield River at 0.55 mussels/m^2 and highest in the Thames River at 3.02 (± 1.42) mussels/m^2 (Table 8).

A total of 572 SAR individuals representing five species were found during the initial surveys of the index stations across five watersheds. Species richness ranged from one SAR in the Saugeen and Bayfield rivers to four species in the upper Thames River. *Cambarunio iris* was the most widely distributed SAR being found in four of five watersheds; Cambarunio iris was not detected in the Grand River although it is known to inhabit this watershed (Kidd 1973; Mackie 1996; Metcalfe-Smith et al. 2000a). Average SAR density was lowest in the Thames River at 0.20 (± 0.11) mussels/m^2 and highest in the Maitland River at 0.49 (± 0.25) mussels/m^2 (Table 8). A summary of the status criteria investigated is presented for each SAR across the watersheds (Table 9-13).

DISCUSSION

SAUGEEN RIVER

The Saugeen River watershed continues to support a unionid community that meets some criteria for critical health with low species richness, low abundance, and low density. The watershed had overall low species richness composed primarily of a single species (*E. dilatata*) with five other species found in low abundance and density. In both the 1993-1994 and 2006 surveys, *E. dilatata* was also the predominant species accounting for 51% and 67% of the observed unionids, respectively, and a similar assemblage of species was detected (Morris and Di Maio 1998-1999; Morris et al. 2007). Total site abundance and average site density decreased consistently across sites when moving into the upper reaches of the watershed; this trend was also observed by Morris et al. (2007). There are currently 52 dams across the Saugeen River watershed including several large structures which are known to impede the movement of fish species throughout the watershed, potentially limiting the distribution of hosts and, therefore, unionids in the upper reaches of the system (Smith 2002; Ontario Steelheaders 2020; SVCA 2020). Several of the large dams in the lower portion of the watershed (e.g., Denny's Dam in Southampton, Maple Hill Dam in Walkerton) do have fish ladders to facilitate salmon migration which may also assist host species in movement within the watershed (Ontario Steelheaders 2020). The paucity of recently recruited *E. dilatata* is one indicator of critical status for this population (DFO 2006). It is unlikely that a significant proportion of juveniles were missed during the surveys as the quadrat method is an effective technique for locating small, young mussels (Metcalfe-Smith et al. 2007; Reid and Morris 2017). Additionally, as *E. dilatata* is a slow growing species (Morris and Corkum 1999), it is unlikely that recent recruits exceed the 25 mm length cut-off, which is merely a general cut-off and is not specific to this species, and have been miscategorised in the recruitment estimation (Haag and Warren 2007; Metcalfe-Smith et al. 2007). Variation in recruitment year to year may account for why *E. dilatata* juveniles were not detected in the current survey (Haag 2012). Recruitment in unionids generally follows one of two patterns, low and constant recruitment or high and variable recruitment. Some *Elliptio* species (*Eurynia dilatata* was known as *Elliptio dilatata* at the time Haag (2012) was published) have been found to exhibit the high and variable recruitment pattern. Studies have found annual recruitment can range across years from no apparent recruitment to years where 50% of a population was represented by recruits (Haag 2012). The current surveys may have occurred during a year with no or very low recruitment in the *E. dilatata* population and are not an indication that the population is in a critical state due to low recruitment.

The Saugeen River watershed *C. iris* population meets criteria for critical population status with restricted non-continuous distribution, relatively low abundance, and low density as well as criteria of healthy status with a full length distribution and evidence of recruitment (DFO 2006). While the distribution of *C. iris* appears to be restricted to the lower reaches of the Saugeen River watershed based on the 2011 quadrat surveys, Morris et al. (2007) surveyed twice as many sites with a greater spread throughout the watershed and found a more extensive distribution of *C. iris* extending into the upper reaches of the Teeswater River, main channel Saugeen River, and Beatty Saugeen River where index stations were not established. A mere four index stations throughout the Saugeen River watershed make it difficult to determine complete species distributions; however, high resource requirements limit the number of index stations that can be established and surveyed (Reid and Morris 2017). Two of the index stations (SG04a and SG08) where no *C. iris* were detected were sites at which Morris et al. (2007) detected *C. iris*. This could suggest a reduction in distribution between the 2006 and 2011 surveys, however, the abundance of the *C. iris* at these sites in 2006 was low and this species is considered to be rare (<5% of unionid community) in the Saugeen River watershed (Morris et al. 2007; COSEWIC 2015). It is more likely that it is related to imperfect detection (Wisniewski et al. 2013) or the limitations associated with the detection of rare species using the quadrat survey technique (Reid and Morris 2017) rather than a decrease in the range of *C. iris*. Additionally, this was the first time that *C.*

iris was detected in the North Saugeen River as Morris et al. (2007) did not detect this species during 2006 surveys. While this could indicate an expansion in range within the North Saugeen River, the site surveyed by Morris et al. (2007) was over 30 km upstream of the index station and, as previously discussed, there is a decreasing trend of unionid abundance and density observed when moving upstream within the watershed. It is most likely that *C. iris* occurred in the downstream portion of North Saugeen River at the time of the Morris et al. (2007) surveys. While the abundance and density of *C. iris* in the watershed is low, it represents the second largest population of *C. iris* in Canada (COSEWIC 2015) which highlights the importance for continued monitoring of the Saugeen River watershed index stations.

MAITLAND RIVER

The Maitland River watershed unionid community meets criteria for critical status based on the low abundance and low density observed during the initial quadrat survey. Previous surveys also reported low abundance in the Maitland River watershed (McGoldrick and Metcalfe-Smith 2004; Epp et al. 2013); there are no previous density estimates to compare to the current survey. While low abundance is considered detrimental for a population (DFO 2006), the consistently low abundance of unionids in the Maitland River watershed indicates there has not been a recent decrease in population sizes which is a positive sign. The Huron County Clean Water Project was implemented by the County of Huron, Maitland Valley Conservation Authority (MVCA), and ABCA in 2005 to "provide financial and technical assistance to county residents to improve and protect water quality" (MVCA 2020). This program includes initiatives such as rural stormwater management plans, clean water diversion, and erosion control (ABCA 2020; MVCA 2020). The introduction of this program could be creating healthier environments for the Maitland River watershed unionid community contributing to the stability in abundances observed between the previous qualitative surveys and the current survey. The comparison of density over time when the first monitoring event is completed at the index stations will provide additional insight into the stability of the low abundance populations in the Maitland River watershed.

The Maitland River watershed *C. iris* population appears to be in a healthy state based on the widespread distribution, high relative abundance, evidence of recruitment, and full length distribution observed during the initial quadrat surveys. The complete distribution of *C. iris* across the index stations is a strong indication of healthy status but there are regions of the watershed that are not encompassed by the six index stations; conclusions about the distribution of *C. iris* throughout the watershed cannot be achieved based solely on the current surveys. The previous qualitative surveys do not provide additional distribution information within the watershed as the sites covered similar locations as the index stations. The high relative abundance of *C. iris* has been consistently observed during previous surveys of the Maitland River watershed indicating the ongoing persistence of this species which has most likely been positively impacted by the Huron County Clean Water Project (McGoldrick and Metcalfe-Smith 2004; Epp et al. 2013; ABCA 2020; MVCA 2020). The current survey found *C. iris* at twice the relative abundance of the previous qualitative surveys (21% from McGoldrick and Metcalfe-Smith 2004; 26% from Epp et al. 2013) which could be interpreted as an increase in the *C. iris* population; however, the index stations were established at sites where high abundances of SAR were recorded during previous surveys which likely resulted in the higher relative abundance that is not representative of the entire watershed. The full length distribution observed during the current survey included smaller individuals than found in the previous qualitative surveys. The observation of more juveniles can likely be attributed to the different survey techniques used as the quadrat survey method is more effective at detecting small individuals than the timed-search survey method (Reid and Morris 2017).

The *L. fasciola* population meets criteria for critical status with low relative abundance and little evidence of recruitment as well as criteria for healthy status with moderately widespread distribution, full length distribution, and a balanced sex ratio (DFO 2006). Similar to *C. iris*, *L. fasciola* has persisted in the Maitland River watershed in low abundance for many years and the relative abundance in the current survey was higher than in previous qualitative surveys (McGoldrick and Metcalfe-Smith 2004; Epp et al. 2013). The consistency in low abundance suggests over time there has not been a significant decrease in the population which may be attributed to increased efforts to maintain and improve the aquatic environments in the watershed through the Huron County Clean Water Project (ABCA 2020; MVCA 2020). The selection of index station locations to target SAR is likely the cause of the increased observed relative abundance. In contradiction to the limited recruitment detected during the current survey, the Maitland River watershed *L. fasciola* population is considered to be reproducing (COSEWIC 2010a). This discrepancy could be related to differences in the habitat requirements of juvenile and adult unionids (Strayer 2008); juvenile habitat may have unintentionally been excluded from the quadrat survey. Another explanation may be that index station location was not in the most reproductively successful areas of the watershed. Overall, the *L. fasciola* population in the Maitland River watershed appears to be healthy but persists in low abundance.

BAYFIELD RIVER

Based on the results from the single index station, the Bayfield River unionid community meets some criteria for critical status with incredibly low abundance and density observed. While no previous density estimates are available for the watershed, low abundances were observed during qualitative surveys throughout the Bayfield River watershed in 2007 (Morris et al. 2012a). A similar community assemblage was observed during the initial quadrat survey as compared to the previous qualitative surveys. It appears that the Bayfield River unionid community continues to persist in low abundance with the same species composition as previously recorded.

Based on the current survey, the Bayfield River *C. iris* population meets criteria for both critical status with low density and low abundance as well as healthy status with a full length distribution and evidence of recruitment (DFO 2006). While abundance of *C. iris* was low, the relative abundance of this species was high representing more than half of the observed unionids. Morris et al. (2012a) found *C. iris* in similar low abundances to the current survey but the relative abundance of *C. iris* was much lower during the previous survey compared to the current survey. The relative abundance of *C. iris* during the current survey was 51%, which represents both watershed wide and site relative abundance as only a single index station was sampled, while Morris et al. (2012a) found *C. iris* with a relative abundance of 2% across the entire watershed and 7% at the site that is now the index station. This could indicate an increase in *C. iris* abundance in the watershed; however, similar to the Maitland River, it is more likely due to the index site location as it was selected due to the higher abundance of *C. iris* found during the previous qualitative surveys. As the index stations were selected to target SAR, they generally provide a skewed relative abundance when compared to the widespread qualitative surveys. The establishment of a single index station in the Bayfield River does not allow inferences to be made regarding the distribution trends of *C. iris* in the watershed. Morris et al. (2012a) detected *C. iris* at five sites throughout the watershed including one site upstream and one site downstream of the index station as well as two sites in the Bannockburn River. Based on the previous qualitative surveys, C*. iris* is relatively widespread throughout the Bayfield River watershed and most likely remains as such. Establishing additional index stations in the Bayfield River watershed would provide more insight into the distribution of C*. iris* and facilitate a more complete understanding of the unionid community as a whole. Morris et al. (2012a) concluded that the Bayfield River *C. iris* population was experiencing ongoing reproduction and recruitment based on the size distribution observed; this paired with the current survey suggests that recruitment within this population has been occurring and continues to occur over time.

GRAND RIVER

The Grand River unionid community meets some criteria for critical status with low abundance and low density observed during the initial quadrat surveys. There was no evident trend in site abundance or average site density across the watershed when comparing the upper and lower Grand River as both parameters remained low throughout the watershed. Species richness was greatest at the most downstream index station suggesting many species in the watershed are restricted to the lower Grand River, including *P. sintoxia* and *Q. quadrula*. Kidd (1973) noted declines in abundance and species richness compared to historical watershed data but more recent qualitative surveys detected a rebound in the unionid community of the Grand River (Mackie 1996; Metcalfe-Smith et al. 2000a). The initial quadrat surveys found a unionid community more comparable to that of the Mackie (1996) and Metcalfe-Smith et al. (2000a) surveys with all finding over 20 species and highest richness in the downstream reaches of the watershed.

Lampsilis fasciola met criteria for both critical status with low abundance, low density, and restricted distribution as well as healthy status with evidence of recruitment, a full length distribution, and a balanced sex ratio (DFO 2006). Despite the indications of critical status, the Grand River supports the largest population of *L. fasciola* in Canada (COSEWIC 2010a) and the density in the Grand River was three times higher than the other watersheds where *L. fasciola* were detected during the current surveys. Additionally, low abundance and density were seen across all species in the Grand River during the current survey as well as the previous qualitative surveys (Mackie 1996; Metcalfe-Smith et al. 2000a) which suggests the low abundance and density observed in the current survey are not due to a recent reduction in *L. fasciola* population size. The Grand River *L. fasciola* population may be better categorized under a cautious status rather than critical based on its abundance and density. The distribution of *L. fasciola* also met the critical population status criteria as this species was restricted to sites in the upper Grand River and was not found in the lower reaches. This is likely due to changes in habitat over the course of the river, rather than a result of poor population health. *Lampsilis fasciola* inhabits clear waterbodies with sand or gravel substrate that is stabilized by cobble and boulder (COSEWIC 2010a; Metcalfe-Smith et al. 2005; Morris 2006) such as the upper Grand River. Water clarity decreases drastically in the lower Grand River and the substrate becomes dominated by sand and clay (Lake Erie Source Protection Region Technical Team 2008) resulting in unsuitable habitat for *L. fasciola* and contributing to the lack of occurrences in the lower reaches of the watershed. The presence of numerous, large dams across the Grand River may also be limiting the distribution of many species into the upper reaches of the watershed as host species movement is restricted. There is an extensive network of over 200 dams in the Grand River watershed including large structures in the lower reaches, such as in Dunnville and Caledonia (GRCA 2020b). While some dams, like the Dunnville Dam, have fishway structures to assist fish movement upstream of the dam, the presence of these barriers is likely altering the distribution of unionids within the watershed. Even with some criteria of critical/cautious health, the Grand River *L. fasciola* population appears to be in a healthy state.

Both the *P. sintoxia* and *Q. quadrula* populations meet numerous criteria for critical status including restricted distribution, low abundance, low density, narrow size distribution, and little to no evidence of recent recruitment (DFO 2006). Both species had very restricted distribution in the Grand River being found at only the most downstream index station but other qualitative surveys have found *P. sintoxia* and *Q. quadrula* as far upstream as Brantford and Caledonia, respectively, indicating the distribution of these two species is more extensive than what was captured by the index stations (Mackie 1996; LGLUD 2020). As discussed previously, all unionids were detected in low abundance and low density throughout the Grand River and while this is an indicator of critical status for *P. sintoxia* and *Q. quadrula*, it may be more accurate to interpret these results as an indication of cautious population status. *Pleurobema sintoxia* met additional criteria for critical status due to the paucity of juveniles and a narrow size distribution. In the LGLUD (2020), there is a single record of a *P. sintoxia* below the 25 mm juvenile cut-off with an individual of 9.5 mm found during the first monitoring event in 2018 at the GR-21 index station. The *P. sintoxia* population is known to be skewed towards older individuals and limited evidence of recruitment has been detected suggesting critical status (COSEWIC 2004; LGLUD 2020). *Quadrula quadrula* length was also found within a narrow size distribution which meets criteria for critical status; however, the observed individuals represented recent recruits which meets criteria for a healthy status. Based on the results of these surveys, it appears that neither the *P. sintoxia* or *Q*. *quadrula* population are considered healthy; however, the lack of recruitment for *P*. *sintoxia* suggests that this species has a more critical status than *Q. quadrula*. Establishing additional index stations in the lower reaches of the Grand River would provide more insight into the distribution and status of these SAR.

THAMES RIVER

Based on the current survey, the upper Thames River subwatershed supports a unionid community with relatively high density and a similar species assemblage to previous surveys (Morris and Edwards 2007). The Thames River is known to support a speciose and abundant unionid community although the watershed has experienced continuous declines in species richness over time (Morris and Edwards 2007). Previous studies have estimated that the Thames River has seen a 15-31% reduction in species richness compared to historical numbers (Metcalfe-Smith et al. 1998c); more recent surveys have detected only an ~8% reduction in richness with 30 of the 35 historical species still present (McNichols-O'Rourke et al. 2012). Along with a decrease in richness, previous surveys have detected a shift in the unionid community as members of the Anodontinae subfamily have become increasingly dominant over time representing as high as 60% of the total records in a survey (Metcalfe-Smith et al. 1998c; Morris and Edwards 2007). Of the total unionids detected in the Thames River during the current survey, 23% were Anodontinae marking a much lower proportion than observed in some previous surveys.

Despite the reduction in richness, the Thames River had the highest density of unionids compared to the other four watersheds in the current survey. The trend of increasing abundance and density when moving downstream in the watershed has also been detected in previous surveys (Morris and Edwards 2007) suggesting the lower Thames River supports a more robust unionid assemblage. The incredibly low level of recent recruitment detected for *A. ligamentina* and *L. costata* meets a criteria for critical status (DFO 2006). The bimodal length frequency distribution of *A. ligamentina* could be interpreted as indicating two distinct cohorts in the population as a result of variation in recruitment year to year as previously discussed. However, the genus *Actinonaias* is classified as an equilibrium strategist; this life history strategy is characterized by low and constant recruitment year to year making it unlikely that the bimodal distribution was a result of a strategic variation in recruitment (Haag 2012). The variation across time detected in the Thames River *A. ligamentina* population may just indicate a period of very low recruitment due to external factors.

While the Thames River had the highest overall density in the current surveys, it had the lowest density of SAR. All four SAR were found in low abundance and density during the current survey with *L. fasciola*, *P. fabalis*, and *P. sintoxia* classified as rare with a relative abundance less than 5%. Based on the current survey, *C. iris* is the healthiest SAR in the upper Thames River subwatershed and meets multiple criteria for healthy status with good distribution in the upper subwatershed, evidence of recent recruitment, and a full length distribution (DFO 2006). The upper Thames River subwatershed is known to support the majority of the *C. iris* population in the Thames River (COSEWIC 2015) and previous qualitative surveys recorded a healthy reproducing population (Morris and Edwards 2007). The size distribution of *C. iris* in the current survey was similar to the previous survey; however, based on the 25 mm juvenile length cut-off used in this report, Morris and Edwards (2007) did not detect any *C. iris* that represented juveniles as the smallest observed individual were 46-50 mm in length. This could indicate an increase in recruitment within the population, but it is more likely that juveniles were present during the 2004-2005 qualitative surveys and merely missed due to the limitations of the timed-search survey technique (Metcalfe-Smith et al. 2007; Reid and Morris 2017).

Lampsilis fasciola met criteria for critical status with low relative abundance, low density, and no evidence of recruitment as well as criteria for healthy status with widespread distribution across all three upper branches and a moderately full length distribution (DFO 2006). The lack of juveniles indicating that no recruitment is occurring in the Thames River *L. fasciola* population contradicts the findings of previous qualitative surveys (Morris and Edwards 2007; COSEWIC 2010a). Morris and Edwards (2007) concluded that the *L. fasciola* population, which was previously thought to be comprised of remnant individuals (COSEWIC 2010a), was healthy and reproducing based on the good representation of size classes observed during 2004-2005 qualitative surveys in the Thames River. Based on the 35 mm cut-off used in the current report to identify juveniles, however, Morris and Edwards (2007) did not detect juveniles as the smallest observed individuals were 46-50 mm in length providing no indication that the population was reproducing. While there was no support for evidence of reproduction based on the presence of juveniles, the previous qualitative surveys detected *L. fasciola* in greater abundance and distribution in the upper Thames River than was previously known to exist and suggested the population may be expanding within the watershed which would require reproduction to be occurring (Morris and Edwards 2007; COSEWIC 2010a). Juveniles may have been present during the 2004-2005 qualitative surveys and merely missed due to the limitations of the timed-search survey technique (Metcalfe-Smith et al. 2007; Reid and Morris 2017) or the 35 mm cut-off used in the current survey to classify juveniles may not be accurate. Continued monitoring of the Thames River index stations will provide further insight into the reproductive success and status of the *L. fasciola* population.

Paetulunio fabalis only met criteria for critical status with highly restricted distribution, low relative abundance, low density, and no evidence of recruitment based on the current surveys (DFO 2006). *Paetulunio fabalis* was historically known from both the North and South Thames River but the south branch population is now thought to be extirpated due to increased urban development and land use practices (COSEWIC 2010b). As found during the current survey, only the North Thames River population persists and expansion from this population to other areas of the Thames River is highly unlikely due to the presence of the large Fanshawe Dam at the downstream end of the north branch which prevents the movement of host fish between the north branch and other areas of the Thames River (COSEWIC 2010b). No evidence of recruitment was detected in the current surveys and while gravid females were observed in 2008 indicating reproduction is occurring, the 2008 surveys also did not detect any evidence of recruitment (COSEWIC 2010b). As the North Thames River population appears to be newly established (COSEWIC 2010b), it is unlikely that no reproduction is occurring. The incredibly small size of juvenile *P. fabalis* makes it challenging to detect these individuals even with the quadrat survey method (Haag 2012) and it is likely that juvenile individuals were present at the time of the surveys and merely remained undetected. Due to the highly restricted and isolated distribution and lack of detectable recruitment for many years, the Thames River *P. fabalis* population appears to be in critical status.

The upper Thames River *P. sintoxia* population only met criteria for critical status with restricted distribution, low relative abundance, narrow size distribution, and lack of recruitment (DFO 2006). *Pleurobema sintoxia* was historically rare yet widespread throughout the Thames River but has faced a drastic reduction in range being restricted to the Middle and South Thames River as found in the current surveys (COSEWIC 2004). The results of the initial survey at the four index stations in the upper Thames River subwatershed support the conclusions of other surveys that *P. sintoxia* is highly restricted in distribution and is an aged, relic population with little to no successful recruitment (COSEWIC 2004; Morris and Edwards 2007).

SPATIAL PATTERNS ACROSS WATERSHEDS

While the objective of the index stations is to track changes in unionid health over time within a watershed, comparing across the watersheds facilitates a more complete understanding of the status of unionid communities and SAR populations in Ontario. Unionid density was low throughout all of the watersheds. This trend was also seen in SAR density which is expected as SAR are often inherently rare and occur at low densities (OMNRF 2018). The lack of a consistent trend in density indicates that this population demographic is not linked to geographic region (e.g., northwestern region versus central region of southwestern Ontario). There was a notable trend of increased richness in common and at-risk species in the two most southern and largest watersheds (Grand and Thames) compared to the more northern, smaller watersheds during the current surveys. This trend may be attributed to the large scale distribution patterns of unionids across North America. Many Canadian species are distributed extensively in the United States, with the highest richness seen in the Great Plains province in central United States; however, these species have a restricted distribution in Canada as this area represents the northern extent of their range (Haag 2012). Additionally, unionid species colonized the Great Lakes via different sources (e.g., Atlantic and Mississipian regions) following the Pleistocene glaciation which led to differences in unionid assemblages across the five Great Lakes. After colonization, the Lake Erie and Lake St. Clair drainage basins had the highest species richness and this likely contributes to the higher species richness observed in the Grand and Thames rivers compared to other watersheds in the Lake Huron drainage basin (Haag 2012). This trend is also seen in the Sydenham River (Lake St. Clair drainage) which supports the most species rich unionid community in Canada and is also a southern river (Clarke 1992; Metcalfe-Smith et al. 2003).

It is challenging to draw conclusions about which watershed supports the healthiest unionid communities as the trend between richness and average density were not consistent. The Grand and Thames rivers support the most rich species assemblages of both common species and SAR. Evidence of recent recruitment was low or missing in SAR populations in the Maitland, Grand, and Thames rivers which could indicate a declining trajectory (DFO 2006). It must be considered that while the quadrat survey technique increases likelihood of detecting juveniles (Reid and Morris 2017), if juvenile unionids occupy different habitats than adults they may not be occurring in the selected survey area. This would result in a skewed estimation of recruitment as recent recruits would not be detected during the survey. Juveniles have been found to be more sensitive than adults to low oxygen levels, toxin levels in the substrate, calcium levels, and sheer stress resulting in differing habitat requirements (Strayer 2008). However, Neves and Widlak (1987) found that older juveniles of 2-3 years in age occupied habitats similar to adults. While different habitat requirements between juvenile and adult unionids is a consideration when interpreting the recruitment data, it is not likely that it would significantly impact the accuracy of the observed levels of recruitment.

CONCLUSION

Fisheries and Oceans Canada established 22 long-term monitoring index stations across five waterbodies between 2007 and 2018. During the initial surveys at these sites, a total of 2,302 live individuals representing 24 species were observed, including 572 SAR representing five species. These surveys met the outlined objectives by:

- establishing index stations to provide a location for long-term monitoring of unionid communities and SAR populations;
- collecting baseline data to form the foundation of the monitoring program and facilitate comparison to future sampling events; and,
- collecting data to investigate indicators of unionid population status including 1) species distribution, 2) relative abundance, 3) size structure, 4) sex ratios, and 5) density.

Species at Risk populations that met only criteria for critical status and appear to be in the worst state of health include: *P. sintoxia* in the Grand River, *P. fabalis* in the Thames River, and *P. sintoxia* in the Thames River. While other SAR populations met criteria for healthy status most also met at least one criteria for critical status. Indicators of critical status in almost all SAR populations highlights the importance of continued monitoring of all of the established index stations to detect changes in these populations of concern over time by providing insight into changes in status and trends. As SAR populations have declined in many areas in Canada it is important to monitor their remaining populations. Establishing more accurate and species specific length cut-offs for juveniles will assist in estimating and assessing recruitment over time.

In light of the findings of Reid and Morris (2017), the index station sampling design may need to be adjusted for future monitoring events to increase the efficacy of detecting changes in SAR and density. With a 20% area surveyed, this technique cannot reliably detect rare species (densities < 0.1 m^2) or small changes in density (Reid and Morris 2017). In order to detect all species at a site as well as small changes in density, the sampling effort would have to be increased substantially to 80% excavation of an area

(Reid and Morris 2017). This greater effort is required to meet the objectives of the monitoring program and provide accurate insight into trends of SAR populations. Consideration of the increase in resources necessary to complete this greater effort is required (Reid and Morris 2017).

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Table 1. Species at Risk in Ontario and their current federal (Government of Canada 2020) and provincial (OMNRF 2020) designation status as of June 2020. Historic (H; prior to 1999) and current (C; after 1998) observations of live (Y) or shell (SH) SAR in the surveyed waterbodies are presented. Nomenclature here and throughout follows Williams et al. (2017), Watters (2018), and Smith et al. (2020).

Scientific Name	Common Name	SARA (Federal)	ESA (Provincial)	Saugeen		Maitland		Bayfield		Grand		Thames	
				H	C	H	C	H	C	H	C	H	C
[1]*Cambarunio iris*	Rainbow	Special Concern	Special Concern	Y	Y	Y	Y	-	Y	Y	Y	Y	Y
Epioblasma rangiana	Northern Riffleshell	Endangered	Endangered	-	-	-	SH	-	-	-	-	SH	-
Epioblasma triquetra	Snuffbox	Endangered	Endangered	-	-	-	-	-	-	SH	-	SH	-
Lampsilis fasciola	Wavyrayed Lampmussel	Special Concern	Threatened	-	-	Y	Y	-	-	Y	Y	Y	Y
Obliquaria reflexa	Threehorn Wartyback	Threatened	Threatened	-	-	-	-	-	-	SH	Y	Y	Y
Obovaria olivaria	Hickorynut	Endangered	Endangered	-	-	-	-	-	-	SH	-	SH	-
Obovaria subrotunda	Round Hickorynut	Endangered	Endangered	-	-	-	-	-	-	SH	-	SH	-
[2]*Paetulunio fabalis*	Rayed Bean	Endangered	Endangered	-	-	-	-	-	-	-	-	SH	Y
Pleurobema sintoxia	Round Pigtoe	Endangered	Endangered	-	-	-	-	-	-	SH	Y	Y	Y
Ptychobranchus fasciolaris	Kidneyshell	Endangered	Endangered	-	-	-	-	-	-	SH	SH	SH	SH
Quadrula quadrula	Mapleleaf	[4]Special Concern	Special Concern	-	-	-	-	-	Y	Y	Y	Y	Y
[3]*Sagittunio nasutus*	Eastern Pondmussel	Special Concern	Special Concern	-	-	-	-	-	-	SH	-	-	-
Simpsonaias ambigua	Salamander Mussel	Endangered	Endangered	-	-	-	-	-	-	-	-	-	SH
Toxolasma parvum	Lilliput	Endangered	Threatened	-	-	-	-	-	-	SH	Y	Y	Y
Truncilla donaciformis	Fawnsfoot	Endangered	Endangered	-	Y	-	-	-	-	SH	Y	-	Y

Species currently listed under SARA and formerly known as:
[1]*Villosa iris*
[2]*Villosa fabalis*
[3]*Ligumia nasuta*

[4]Great Lakes - Upper St. Lawrence population

Table 2. Criteria for assessing mussel population status taken from DFO (2006). Criteria able to be assessed from the data collected during the surveys outlined in this report are highlighted.

Critical	Cautious	Healthy
• narrow size/age distribution (particularly if skewed towards large old individuals) • no recruitment • no hosts • severely skewed sex ratio (particularly towards males) • fragmented distribution • relatively low abundance • occupies a single/few sites • no live animals (only shells) • degraded habitat (quality, area, extent) • demonstrated effects of Aquatic Invasive Species (AIS)	• naturally small population (area or abundance) • naturally fragmented • AIS present but no demonstrated effects	• full length distribution • balanced sex ratio • recruitment • continuous non fragmented distribution • relatively high abundance • occurs at multiple sites • good habitat (quality, area, extent) • contiguous sites • occupies historical range • healthy host population (diversity and abundance) • no evidence of AIS, pathogens, pathogens, parasites, hybridization • high genetic variability • rich or abundant mussel community

Table 3. Species information for each site surveyed in the Saugeen River watershed by Fisheries and Oceans Canada in 2011. Sites are presented in downstream to upstream order. Species at Risk are highlighted.

Species	SGR-SGR-05	SG11	SG08	SG04a	Totals	Relative Abundance (%)	Frequency of Occurrence (%)
Alasmidonta marginata	13	2	-	-	15	2.93	50.00
Alasmidonta viridis	-	1	1	-	2	0.39	50.00
Cambarunio iris	29	17	-	-	46	8.98	50.00
Eurynia dilatata	170	128	114	30	442	86.33	100.00
Lampsilis cardium	-	-	5	-	5	0.98	25.00
Lampsilis siliquoidea	-	-	2	-	2	0.39	25.00
Total abundance	212	148	122	30	**512**		
Total SAR abundance	29	17	0	0	**46**		
Live species richness	3	4	4	1	**6**		
Total species richness	3	4	4	1	**6**		

Table 4. Species information for each site surveyed in the Maitland River by Fisheries and Oceans Canada in 2008. Sites are presented in downstream to upstream order. Species at Risk are highlighted. Unknown individuals are included in abundance totals but not in species richness totals.

Species	MR-09	MR-01	MR-16	MR-02	MR-14	MR-21	Totals	Relative Abundance (%)	Frequency of Occurrence (%)
Actinonaias ligamentina	3	-	3	-	-	-	6	1.35	33.33
Alasmidonta marginata	3	2	4	2	2	-	13	2.93	83.33
Alasmidonta viridis	10	1	-	6	-	2	19	4.29	66.67
Anodontoides ferussacianus	-	-	-	-	1	-	1	0.23	16.67
Cambarunio iris	89	4	12	144	7	12	268	60.50	100.00
Lampsilis cardium	7	2	3	7	12	3	34	7.67	100.00
Lampsilis fasciola	9	5	9	-	2	-	25	5.64	66.67
Lampsilis siliquoidea	-	-	1	-	-	-	1	0.23	16.67
Lasmigona compressa	-	-	1	-	3	1	5	1.13	50.00
Lasmigona costata	3	-	11	6	25	6	51	11.51	83.33
Pyganodon grandis	-	-	-	2	-	2	4	0.90	33.33
Strophitus undulatus	-	-	-	-	12	-	12	2.71	16.67
Unknown	2	1	1	-	-	-	4	0.90	50.00
Total abundance	126	15	45	167	64	26	**443**		
Total SAR abundance	98	9	21	144	9	12	**293**		
Live species richness	7	5	8	6	8	6	**12**		
Total species richness	7	5	8	6	8	6	**12**		

Table 5. Species information for the single site surveyed in the Bayfield River by Fisheries and Oceans Canada in 2011. Species at Risk are highlighted.

Species	Total Abundance	Relative Abundance (%)
Actinonaias ligamentina	1	2.44
Alasmidonta viridis	4	9.76
Cambarunio iris	21	51.22
Lampsilis siliquoidea	7	17.07
Lasmigona compressa	1	2.44
Lasmigona costata	1	2.44
Pyganodon grandis	6	14.63
Total abundance	**41**	
Total SAR abundance	**21**	
Live species richness	**7**	
Total species richness	**7**	

Table 6. Species information for the seven sites surveyed in the Grand River by Fisheries and Oceans Canada in 2007 and 2010. Sites are presented in downstream to upstream order. Species at Risk are highlighted.

Species	GR-21	GR-01	GR-02	GR-03	GR-33	GR-31	GR-13	Totals	Relative Abundance (%)	Frequency of Occurrence (%)
Actinonaias ligamentina	53	10	-	-	-	-	-	63	15.71	28.57
Alasmidonta marginata	22	-	7	15	3	-	-	47	11.72	57.14
Alasmidonta viridis	-	-	-	-	-	-	1	1	0.25	14.29
Anodontoides ferussacianus	1	-	-	-	-	-	-	1	0.25	14.29
Cyclonaias pustulosa	4	-	-	-	-	-	-	4	1.00	14.29
Eurynia dilatata	-	-	-	-	31	-	1	32	8.00	28.57
Fusconaia flava	3	-	-	-	-	-	-	3	0.75	14.29
Lampsilis cardium	1	4	-	-	-	-	-	5	1.25	28.57
Lampsilis fasciola	-	-	18	46	11	10	-	85	21.20	57.14
Lampsilis siliquoidea	-	3	-	3	-	-	-	6	1.50	28.57
Lasmigona compressa	-	-	-	-	-	1	-	1	0.25	14.28
Lasmigona costata	52	-	10	22	4	2	2	92	22.94	85.71
Ligumia recta	13	-	-	-	-	-	-	13	3.24	14.28
Pleurobema sintoxia	6	-	-	-	-	-	-	6	1.50	14.28
Potamilus alatus	1	-	-	-	-	-	-	1	0.25	14.28
Potamilus fragilis	2	-	-	-	-	-	-	2	0.50	14.28
Pyganodon grandis	-	3	-	-	-	1	-	4	1.00	28.57
Quadrula quadrula	2	-	-	-	-	-	-	2	0.50	14.28
Strophitus undulatus	5	-	-	3	1	6	14	29	7.23	71.43
Truncilla truncata	3	-	-	-	-	-	-	3	0.75	14.28
Utterbackia imbecillis	1	-	-	-	-	-	-	1	0.25	14.28
Total abundance	169	20	35	89	50	20	18	**401**		
Total SAR abundance	8	0	18	46	11	10	0	**93**		
Live species richness	15	4	3	5	5	5	4	**21**		
Total species richness	15	4	3	5	5	5	4	**21**		

Table 7. Species information for the four sites surveyed in the upper Thames River subwatershed by Fisheries and Oceans Canada in 2018. Sites are presented in downstream to upstream order. Species at Risk are highlighted. S(#) represents the number of shells of a species observed. V(#) represents the number of valves of a species observed. Unknown individuals are included in abundance totals but not in species richness totals.

Species	TR-36	TR-18	TR-15	TR-16	Totals	Relative abundance (%)	Frequency of occurrence (%)
Actinonaias ligamentina	454	5	-	-	459	50.72	50.00
Alasmidonta marginata	8	2	5	-	15	1.66	75.00
Alasmidonta viridis	V(2)	-	17	15	32	3.54	50.00
Cambarunio iris	-	3	73	2	78	8.62	75.00
Cyclonaias tuberculata	5	7	-	-	12	1.33	50.00
Eurynia dilatata	V(3)	2	78	S(2),V(4)	80	8.84	50.00
Fusconaia flava	1	-	5	1	7	0.77	75.00
Lampsilis cardium	1	9	-	-	10	1.10	50.00
Lampsilis fasciola	3	11	13	-	27	2.98	75.00
Lasmigona complanata	7	-	-	-	7	0.77	25.00
Lasmigona compressa	-	-	8	10	18	1.99	50.00
Lasmigona costata	16	2	74	23	115	12.71	100.00
Paetulunio fabalis	-	11	-	-	11	1.22	25.00
Pleurobema sintoxia	-	-	3	S(1)	3	0.33	25.00
Pyganodon grandis	-	-	V(3)	4	4	0.44	25.00
Strophitus undulatus	3	-	18	5	26	2.87	75.00
Unknown	1	-	-	-	1	0.11	25.00
Total abundance	499	52	294	60	**905**		
Total SAR abundance	3	25	89	2	**119**		
Live species richness	9	9	10	7	**16**		
Total species richness	11	9	11	9	**16**		

Table 8. Average density (± standard error) and density category in each watershed for all unionids detected and SAR detected during the initial surveys in 2007–2018. Density category is taken from Metcalfe-Smith et al. (2007). Standard error could not be calculated in the Bayfield River as only one site was surveyed.

	All unionids		**SAR**	
	Average density (±SE) (mussels/m^2)	**Density category**	**Average density (±SE) (mussels/m^2)**	**Density category**
Saugeen River	1.69 (± 0.50)	Moderate	0.31 (± 0.08)	Low
Maitland River	1.21 (± 0.41)	Low	0.49 (± 0.25)	Low
Bayfield River	0.55	Low	0.28	Low
Grand River	0.85 (± 0.28)	Low	0.25 (± 0.10)	Low
Thames River	3.02 (± 1.42)	Moderate	0.20 (± 0.11)	Low

Table 9. Status criteria for *Cambarunio iris* (Rainbow) in each of the five watersheds surveyed by Fisheries and Oceans Canada. NA represents instances where data was collected for this criterion but it was not analyzed due to low sample size. Distribution is based on presence at the index stations in the current surveys. Density category is taken from Metcalfe-Smith et al. (2007).

	Distribution	Relative abundance (%)	Density (±SE) (mussels/m^2)	Density category	Length distribution	Proportion recent recruits (%)	Sex ratios
Saugeen River	Continuous	8.98	0.31 (± 0.08)	Low	NA	10.9	NA
Maitland River	Continuous	60.50	0.74 (± 0.40)	Low	Normal	9.7	NA
Bayfield River	Continuous	51.22	0.28 (± 0.06)	Low	NA	9.5	NA
Grand River	-	-	-	-	-	-	-
Thames River	Continuous	8.62	0.35 (± 0.31)	Low	NA	6.4	NA

Table 10. Status criteria for *Lampsilis fasciola* (Wavyrayed Lampmussel) in each of the five watersheds surveyed by Fisheries and Oceans Canada. NA represents instances where data was collected for this criterion but it was not analyzed due to low sample size. Distribution is based on presence at the index stations in the current surveys. Density category is taken from Metcalfe-Smith et al. (2007).

	Distribution	Relative abundance (%)	Density (±SE) (mussels/m^2)	Density category	Length distribution	Proportion recent recruits (%)	Sex ratios
Saugeen River	-	-	-	-	-	-	-
Maitland River	Continuous	5.64	0.10 (± 0.03)	Low	NA	0.00	NA
Bayfield River	-	-	-	-	-	-	-
Grand River	Restricted	21.20	0.34 (± 0.13)	Low	NA	6.00	Equal
Thames River	Continuous	2.98	0.12 (± 0.04)	Low	NA	0.00	NA

Table 11. Status criteria for *Paetulunio fabalis* (Rayed Bean) in each of the five watersheds surveyed by Fisheries and Oceans Canada. NA represents instances where data was collected for this criterion but it was not analyzed due to low sample size. Distribution is based on presence at the index stations in the current surveys. Density category is taken from Metcalfe-Smith et al. (2007).

	Distribution	Relative abundance (%)	Density (±SE) (mussels/m^2)	Density category	Length distribution	Proportion recent recruits (%)	Sex ratios
Saugeen River	-	-	-	-	-	-	-
Maitland River	-	-	-	-	-	-	-
Bayfield River	-	-	-	-	-	-	-
Grand River	-	-	-	-	-	-	-
Thames River	Restricted	1.22	0.15 (± 0.05)	Low	NA	18.2	NA

Table 12. Status criteria for *Pleurobema sintoxia* (Round Pigtoe) in each of the five watersheds surveyed by Fisheries and Oceans Canada. NA represents instances where data was collected for this criterion but it was not analyzed due to low sample size. Distribution is based on presence at the index stations in the current surveys. Density category is taken from Metcalfe-Smith et al. (2007).

	Distribution	Relative abundance (%)	Density (±SE) (mussels/m^2)	Density category	Length distribution	Proportion recent recruits (%)	Sex ratios
Saugeen River	-	-	-	-	-	-	-
Maitland River	-	-	-	-	-	-	-
Bayfield River	-	-	-	-	-	-	-
Grand River	Restricted	1.50	0.08 (± 0.03)	Low	NA	0.00	NA
Thames River	Restricted	0.33	0.04 (± 0.02)	Low	NA	0.00	NA

Table 13. Status criteria for *Quadrula quadrula* (Mapleleaf) in each of the five watersheds surveyed by Fisheries and Oceans Canada. NA represents instances where data was collected for this criterion but it was not analyzed due to low sample size. Distribution is based on presence at the index stations in the current surveys. Density category is taken from Metcalfe-Smith et al. (2007).

	Distribution	Relative abundance (%)	Density (±SE) (mussels/m^2)	Density category	Length distribution	Proportion recent recruits (%)	Sex ratios
Saugeen River	-	-	-	-	-	-	-
Maitland River	-	-	-	-	-	-	-
Bayfield River	-	-	-	-	-	-	-
Grand River	Restricted	0.50	0.03 (± 0.02)	Low	NA	100.00	NA
Thames River	-	-	-	-	-	-	-

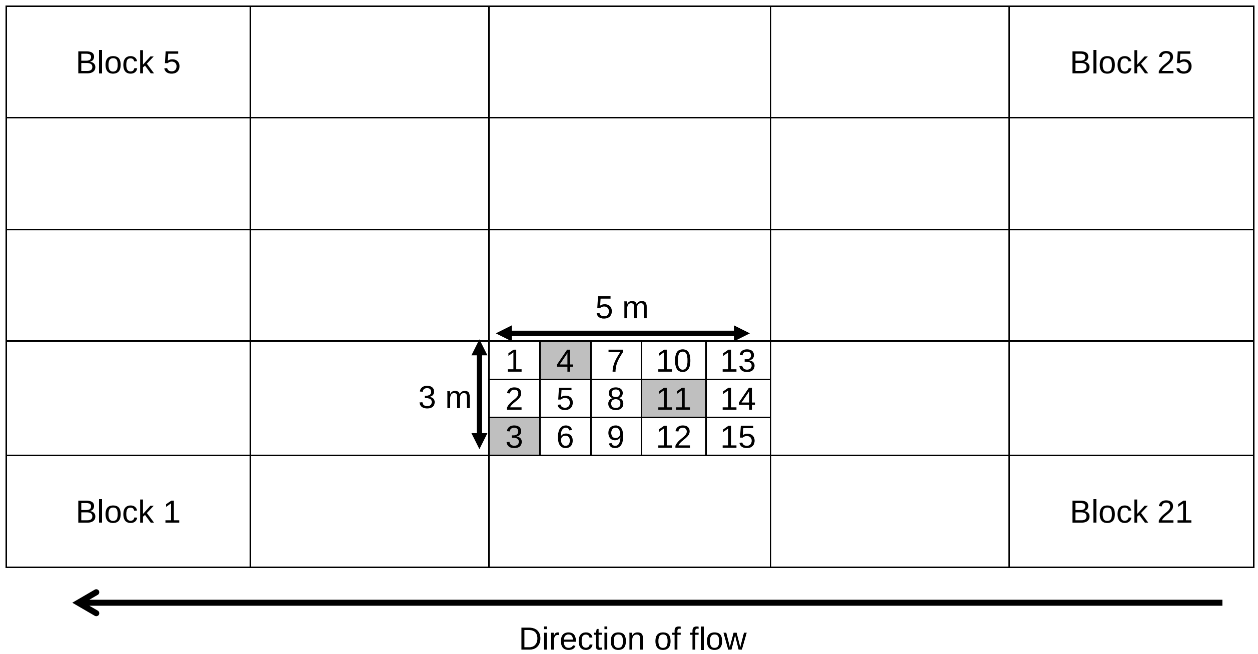


Figure 1. Systematic sampling design (Metcalfe-Smith et al. 2007) implemented at sites between 2007 and 2018 using 1 m^2 quadrats in a block setup. The shaded boxes mark the location of the randomly selected quadrats that would be sampled in each block.

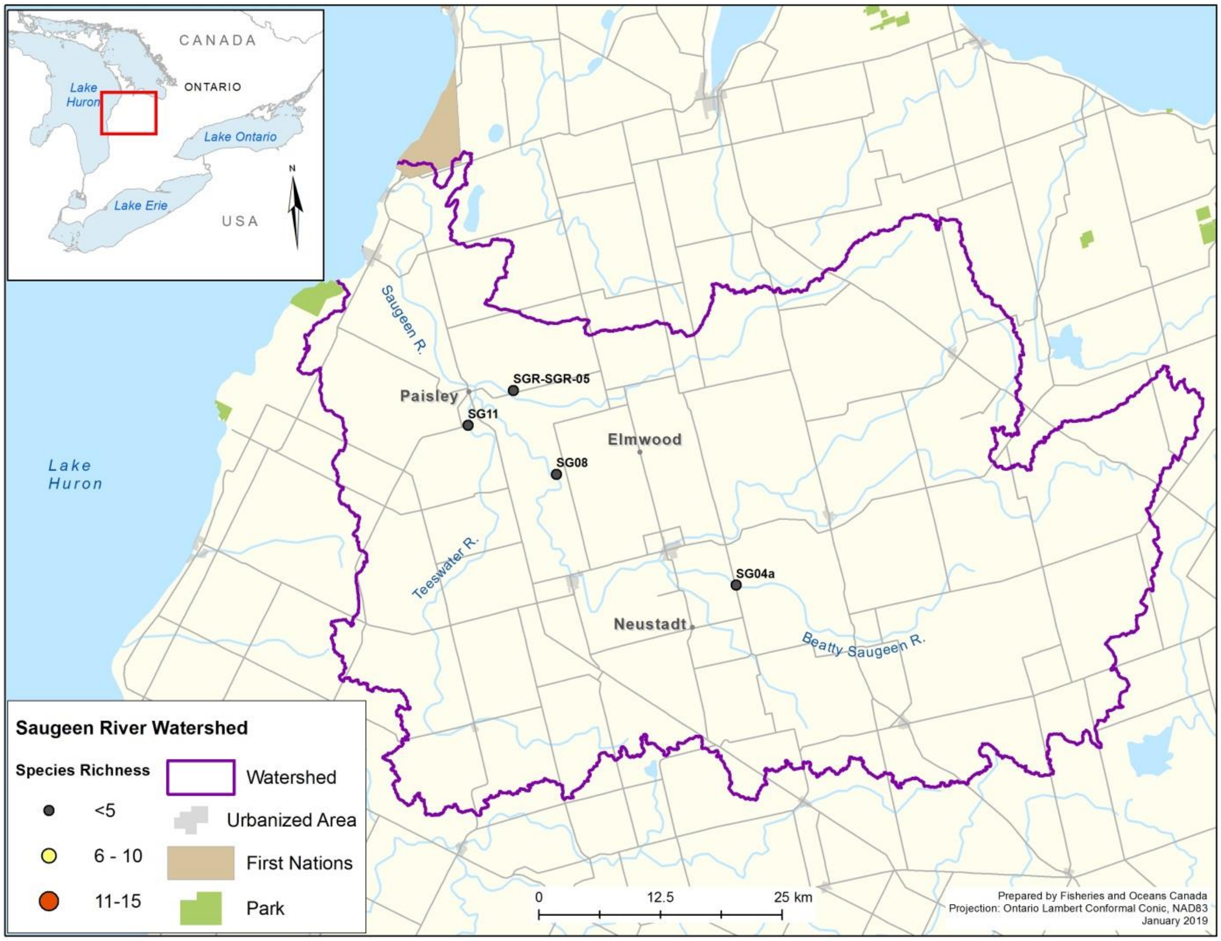


Figure 2. Four Saugeen River watershed monitoring stations surveyed using the quadrat technique in 2011 by Fisheries and Oceans Canada. The Saugeen River watershed is outlined in purple. Site number corresponds to numbers in Table 2 and Appendix A – C.

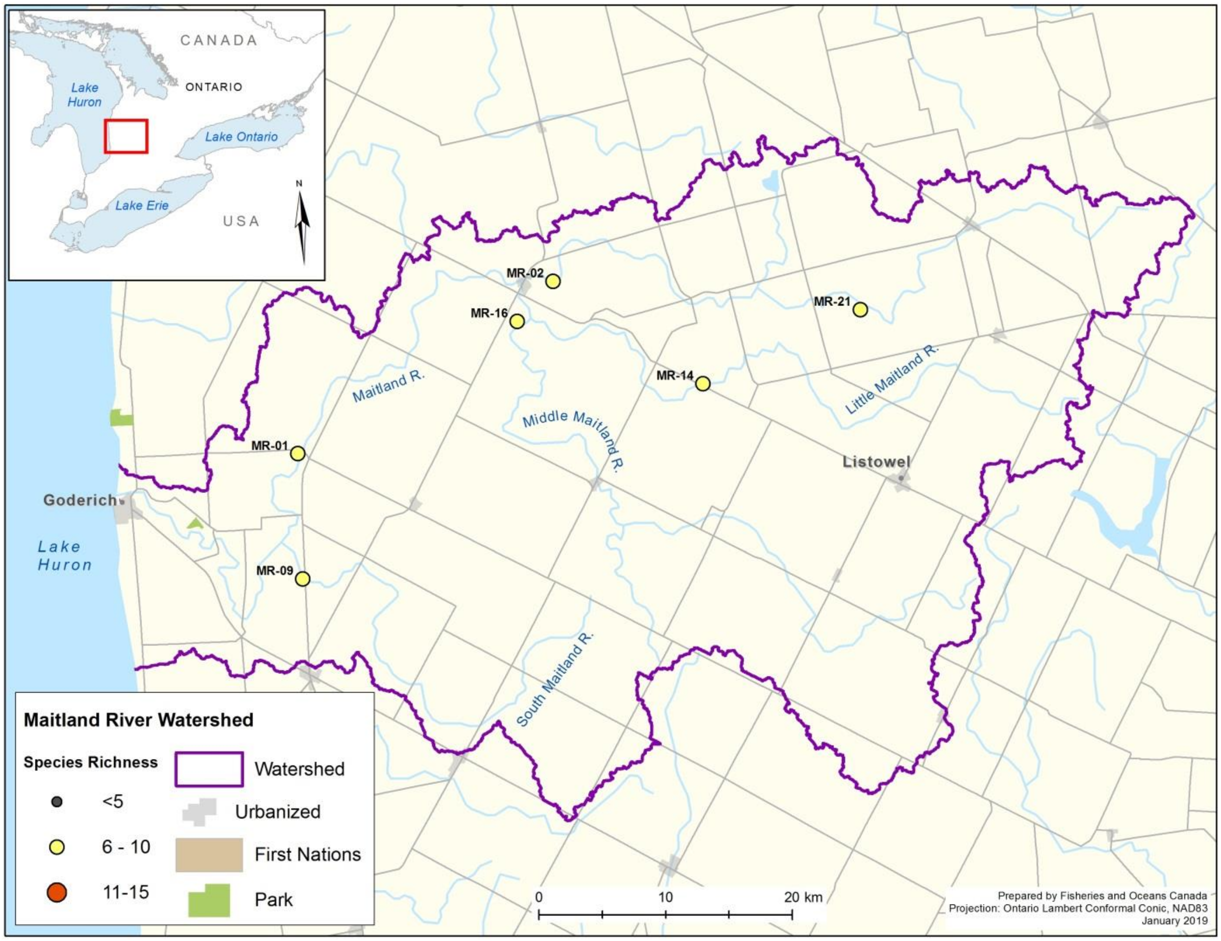


Figure 3. Six Maitland River watershed monitoring stations surveyed using the quadrat technique in 2008 by Fisheries and Oceans Canada. The Maitland River watershed is outlined in purple. Site numbers correspond to numbers presented in Table 3 and Appendix A – C.

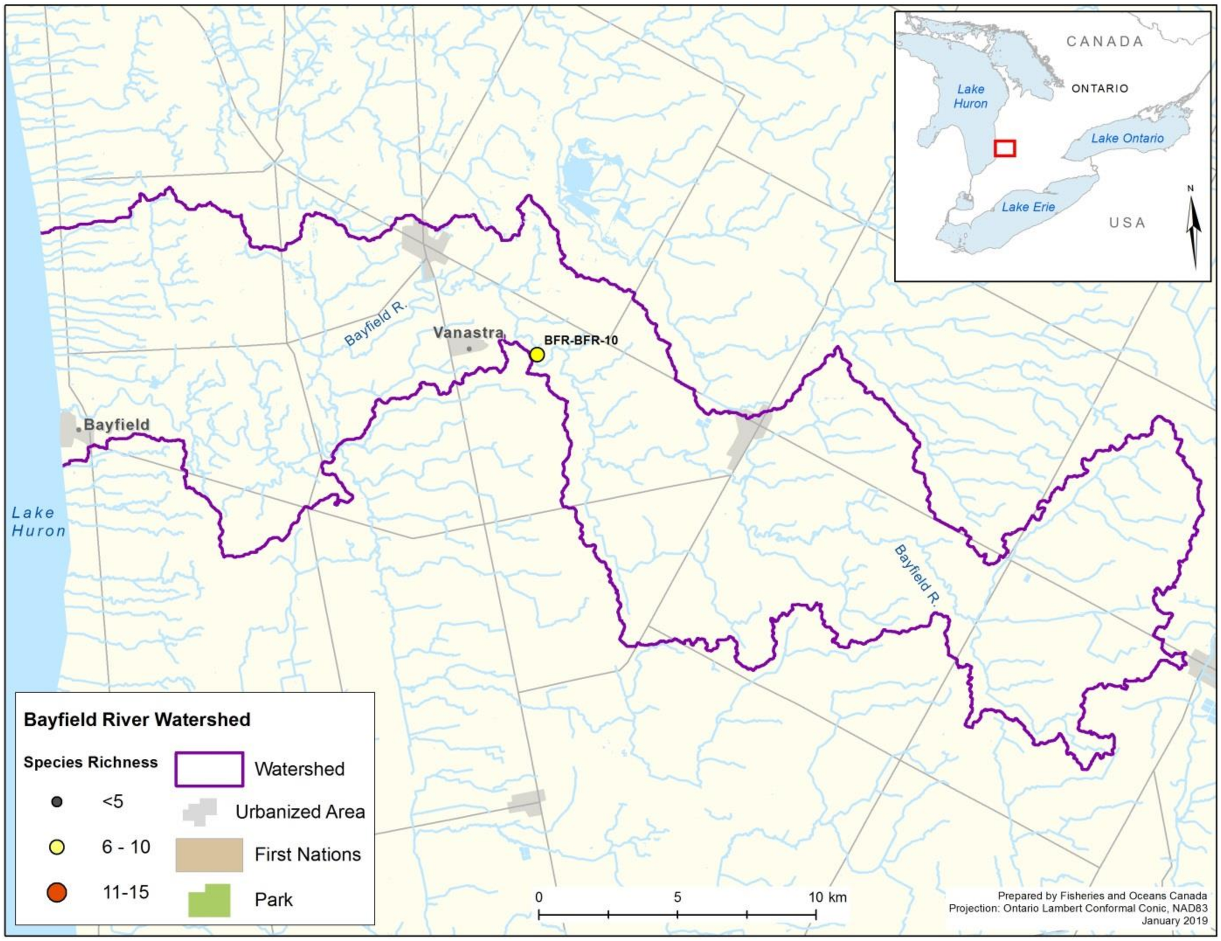


Figure 4. The single Bayfield River monitoring station surveyed using the quadrat technique in 2011 by Fisheries and Oceans Canada. The Bayfield River watershed is outlined in purple. Site number corresponds to numbers presented in Table 4 and Appendix A – C.

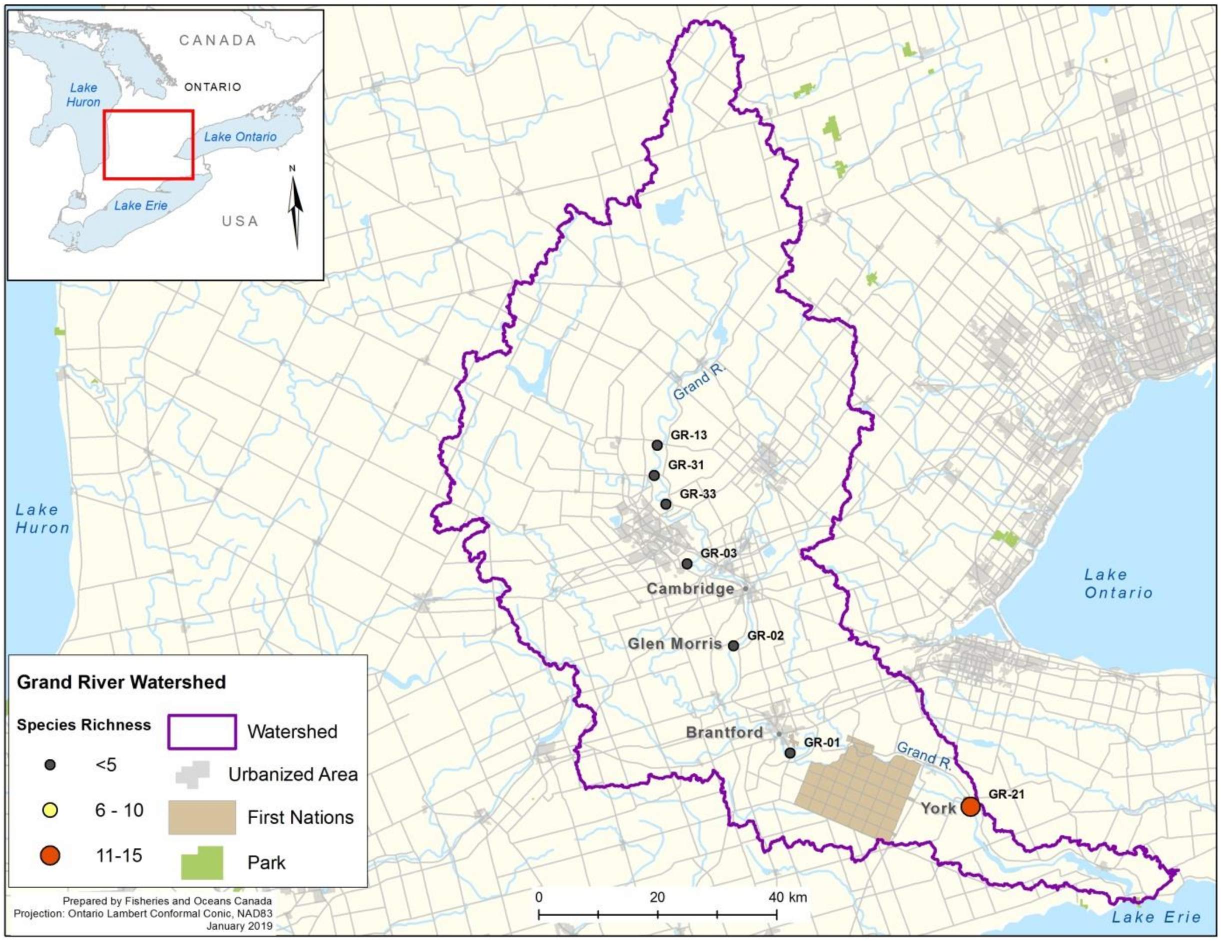


Figure 5. Seven Grand River monitoring stations surveyed using the quadrat technique in 2007 and 2010 by Fisheries and Oceans Canada. The Grand River watershed is outlined in purple. Site numbers correspond to numbers presented in Table 5 and Appendix A – C.

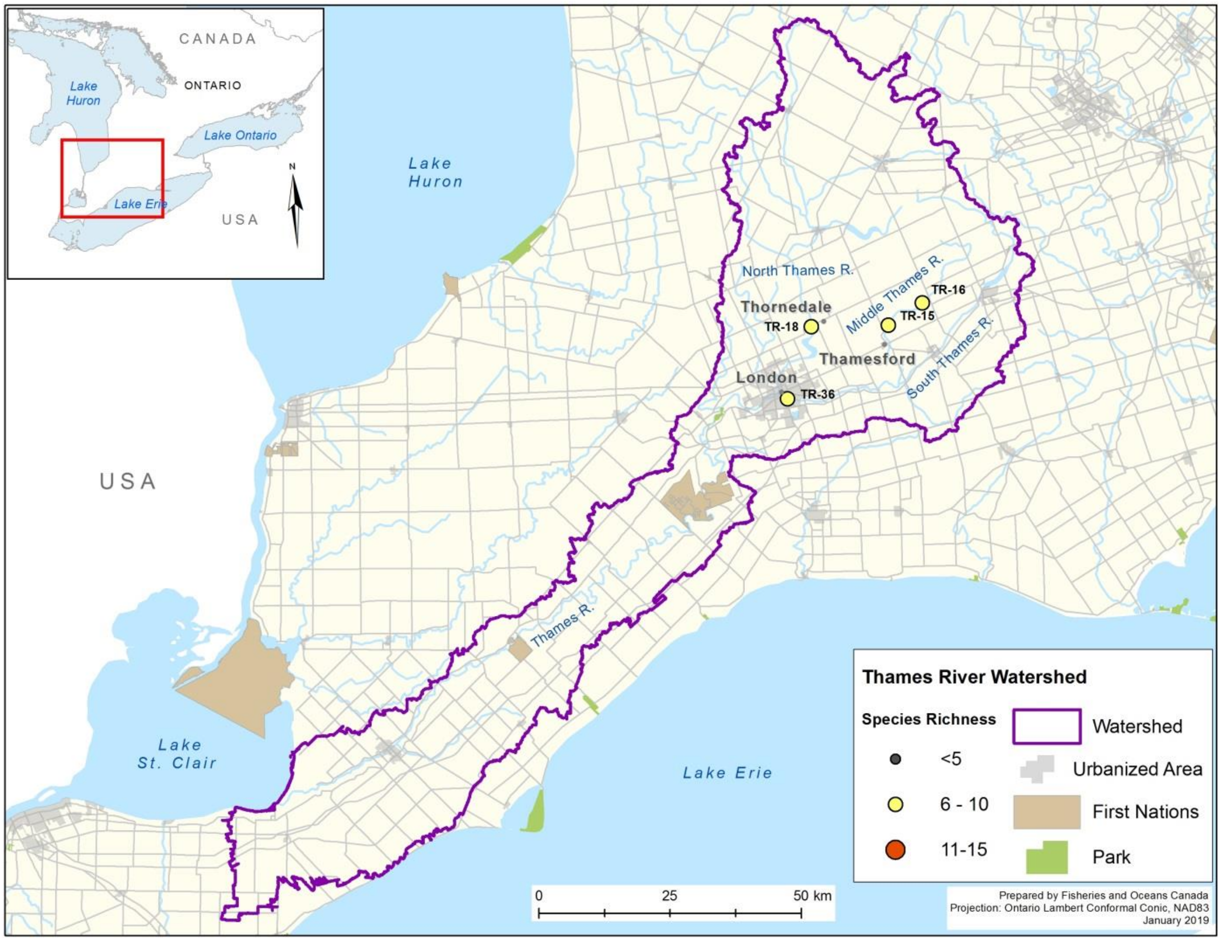


Figure 6. Four Thames River monitoring stations surveyed using the quadrat technique in 2018 by Fisheries and Oceans Canada. The Thames River watershed is outlined in purple. Site numbers correspond to the numbers presented in Table 6 and Appendix A – C.

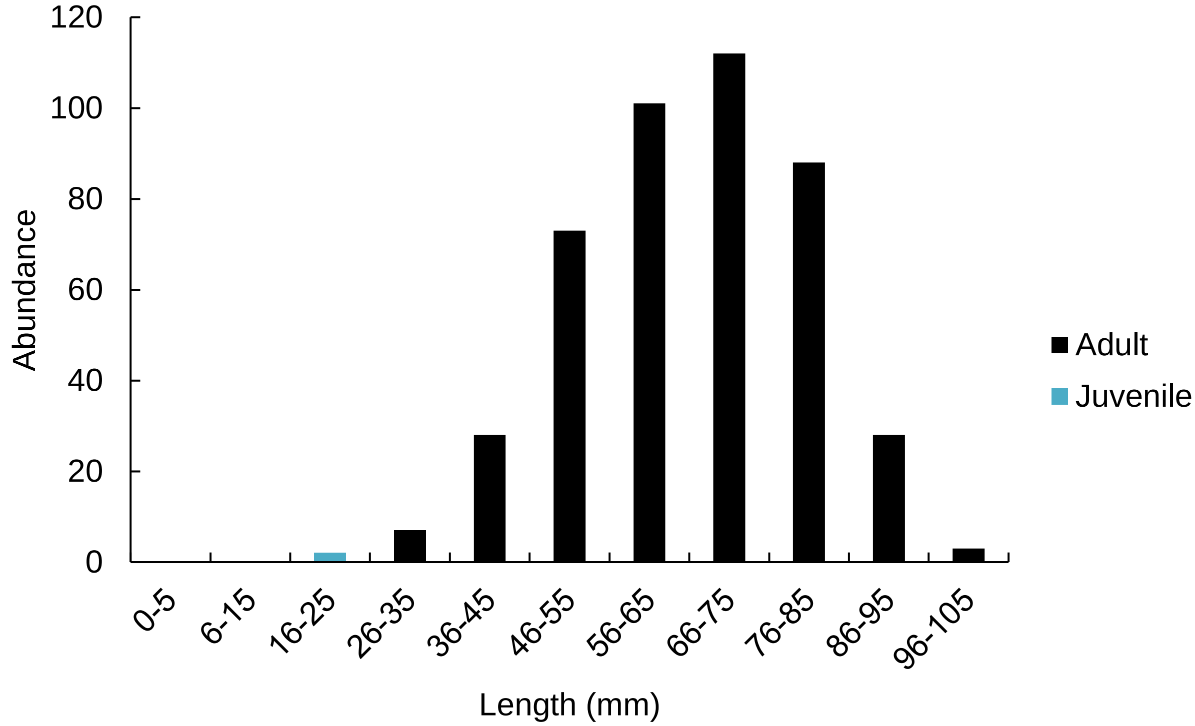


Figure 7. Length frequency distribution of *Eurynia dilatata* (Spike) found in the Saugeen River (n=442) by Fisheries and Oceans Canada in 2011.

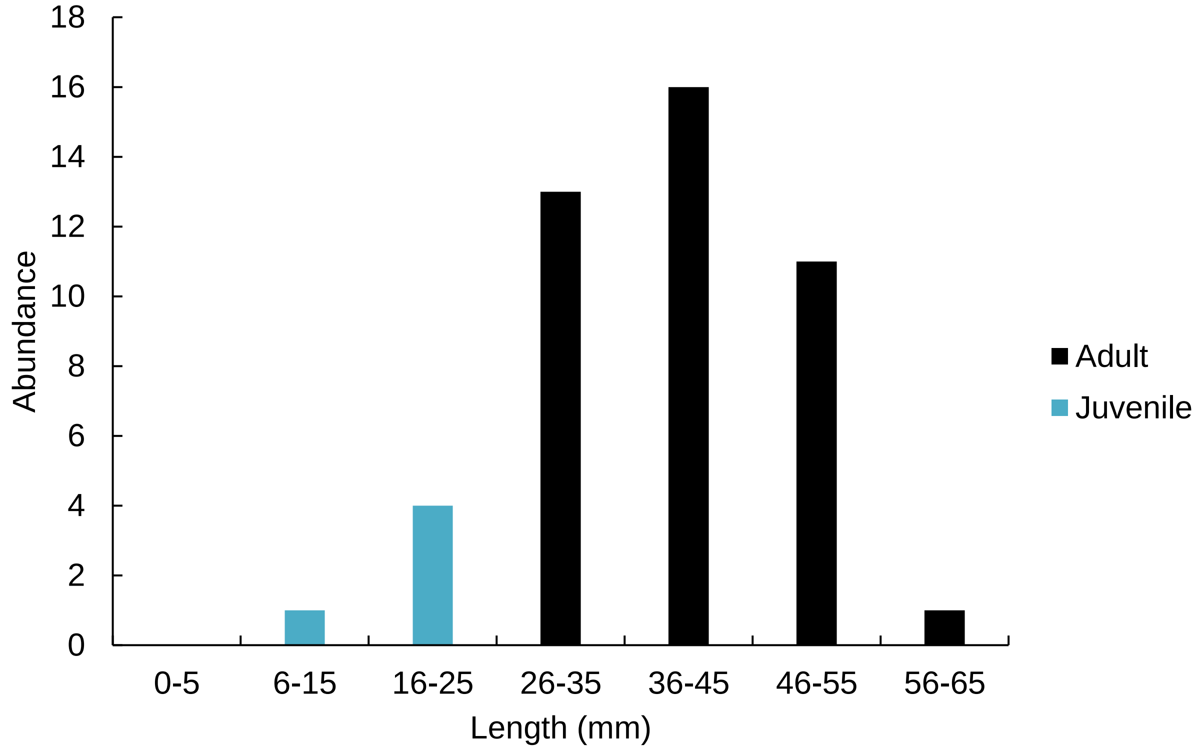


Figure 8. Length frequency distribution of *Cambarunio iris* (Rainbow) found in the Saugeen River watershed (n=46) by Fisheries and Oceans Canada in 2011.

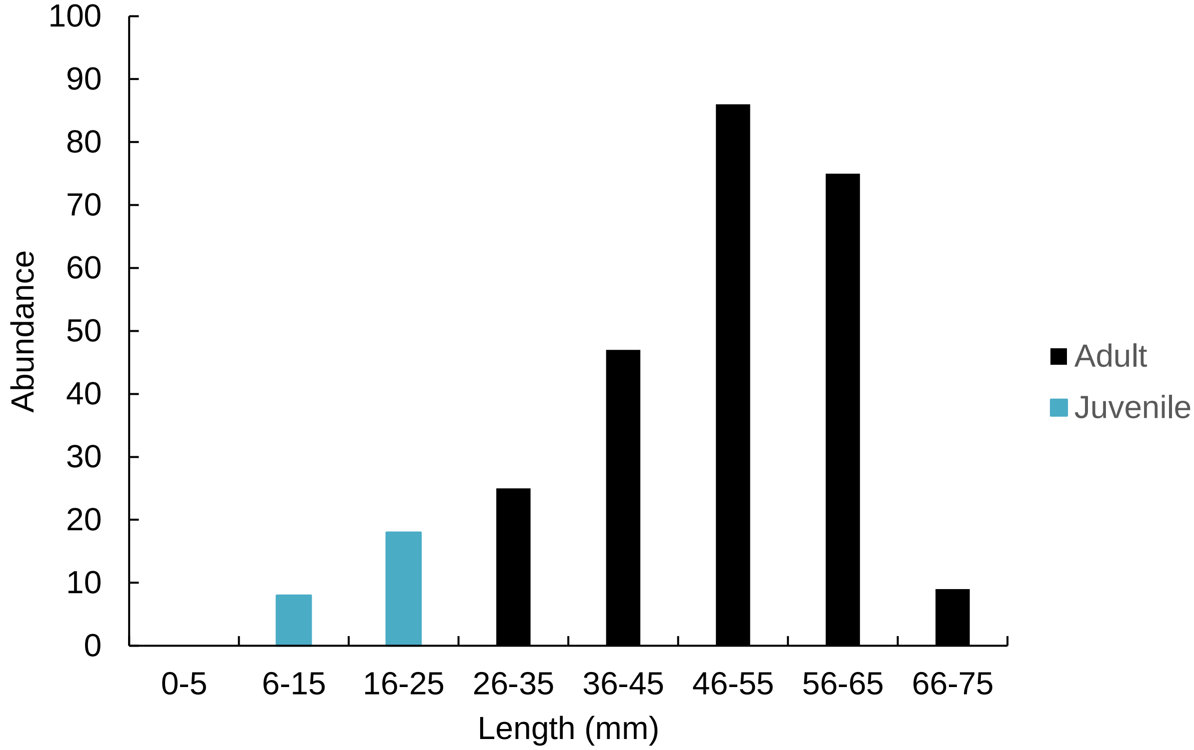


Figure 9. Length frequency distribution of *Cambarunio iris* (Rainbow) found in the Maitland River watershed (n=268) by Fisheries and Oceans Canada in 2008.

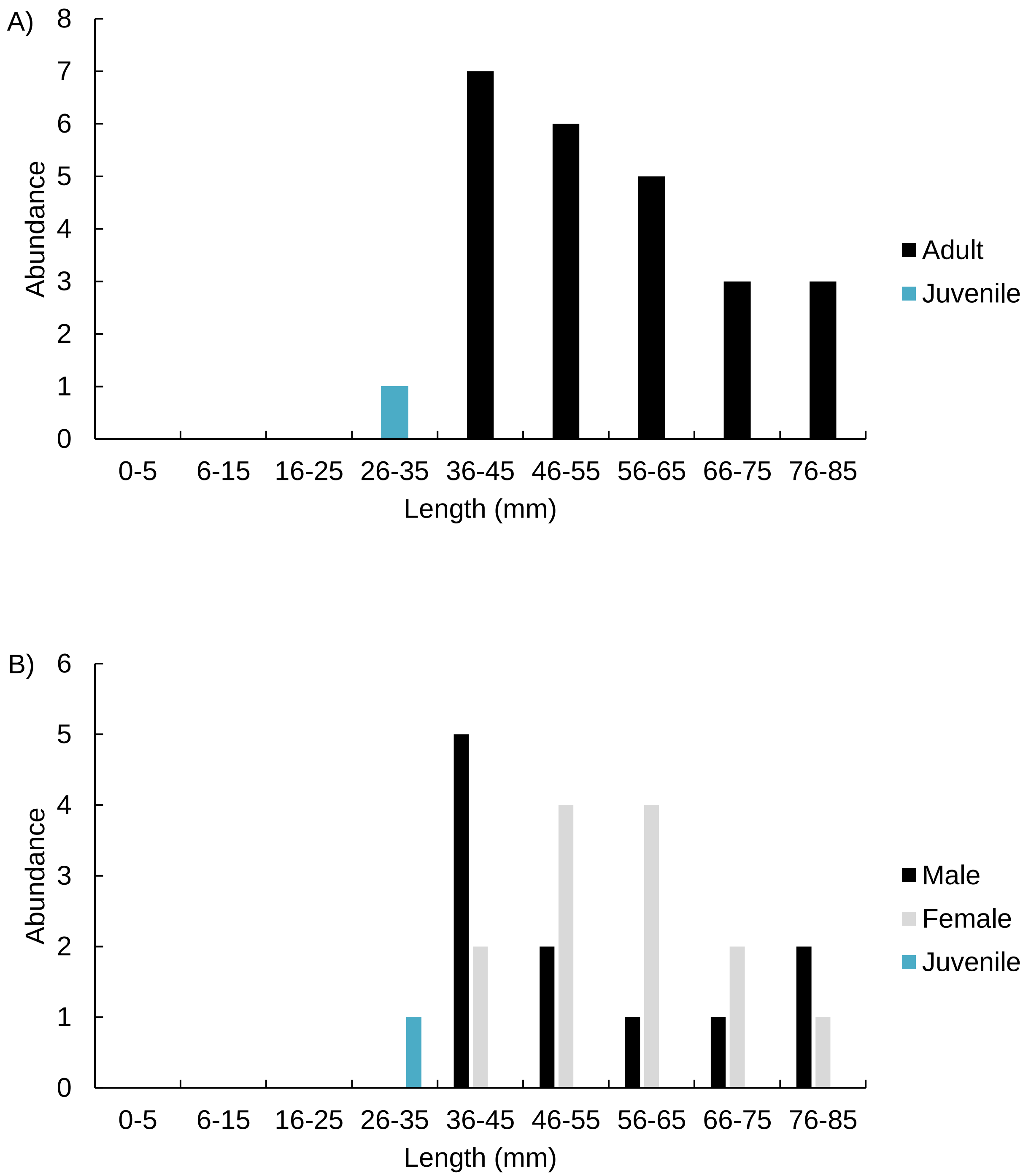


Figure 10. Length frequency distribution of *Lampsilis fasciola* (Wavyrayed Lampmussel) with A) all individuals combined and B) sexes separated found in the Maitland River watershed (n=25) by Fisheries and Oceans Canada in 2008.

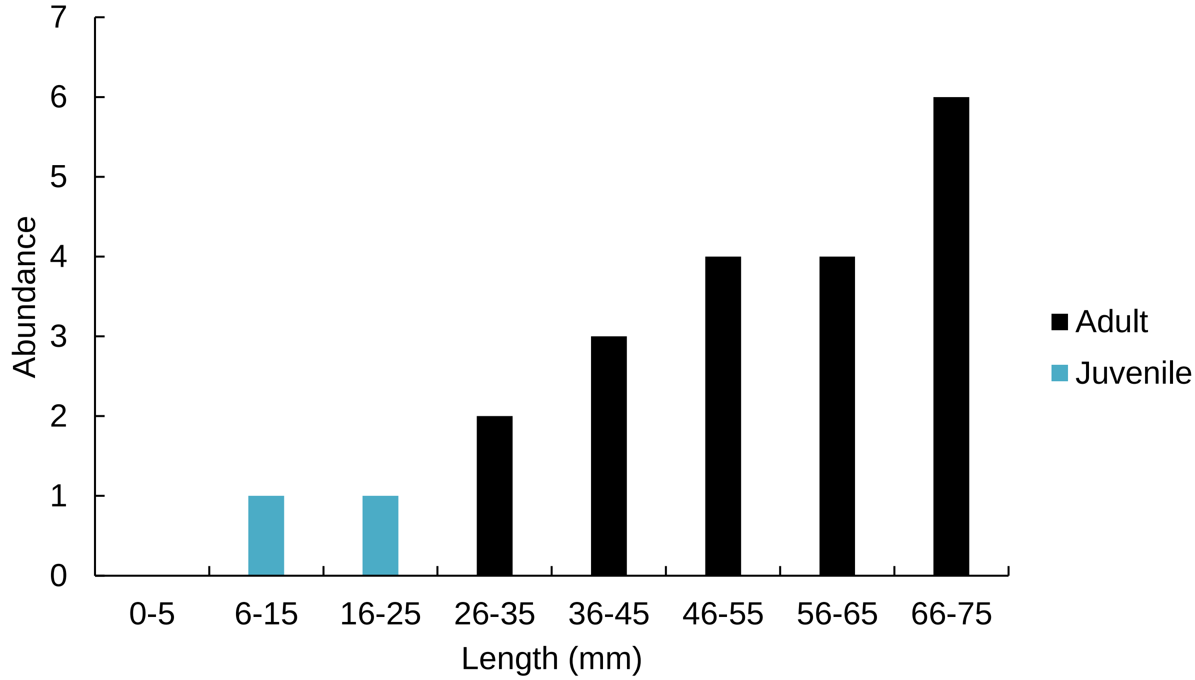


Figure 11. Length frequency distribution of *Cambarunio iris* (Rainbow) found in the Bayfield River (n=21) by Fisheries and Oceans Canada in 2011.

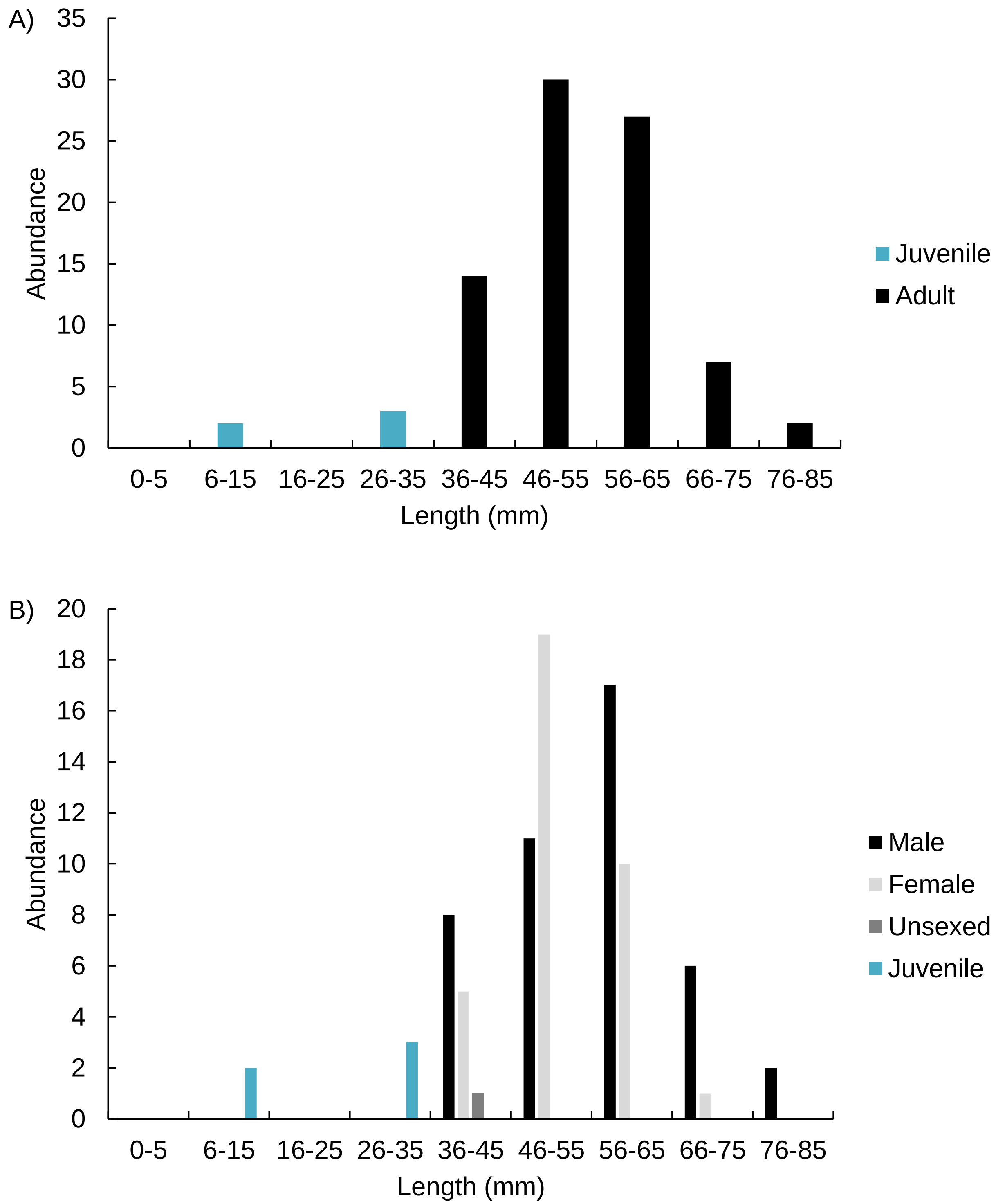


Figure 12. Length frequency distribution of *Lampsilis fasciola* (Wavyrayed Lampmussel) with A) all individuals combined and B) sexes separated found in the Grand River (n=85) by Fisheries and Oceans Canada in 2007 and 2010.

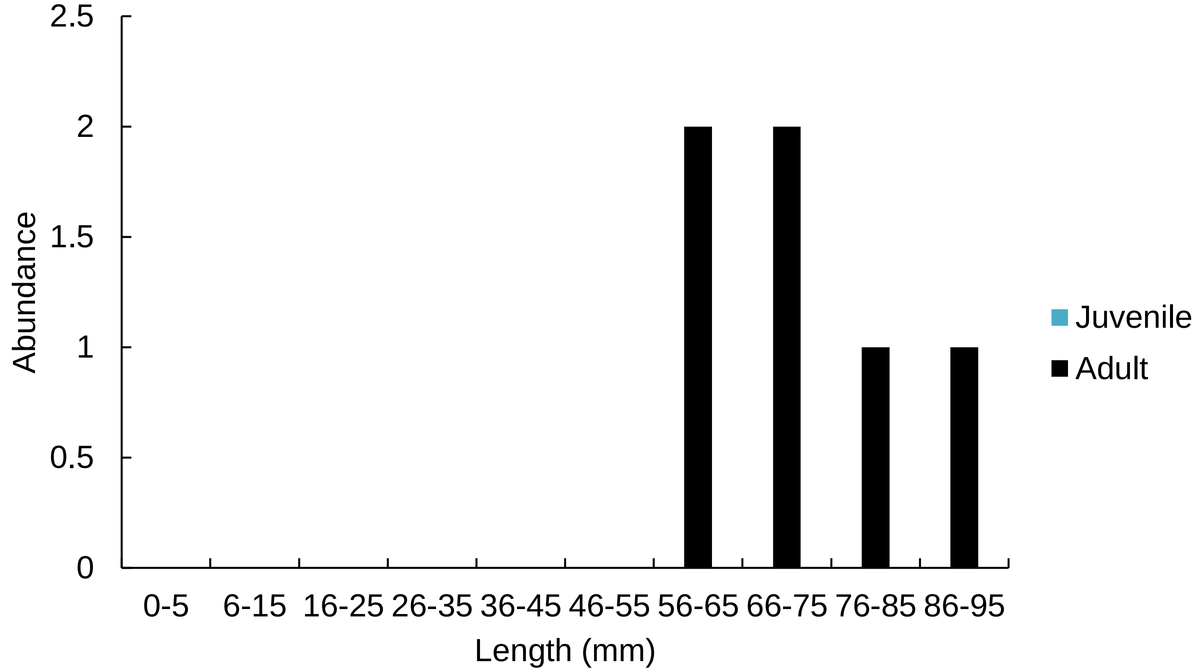


Figure 13. Length frequency distribution of *Pleurobema sintoxia* (Round Pigtoe) found in the Grand River (n=6) by Fisheries and Oceans Canada in 2010.

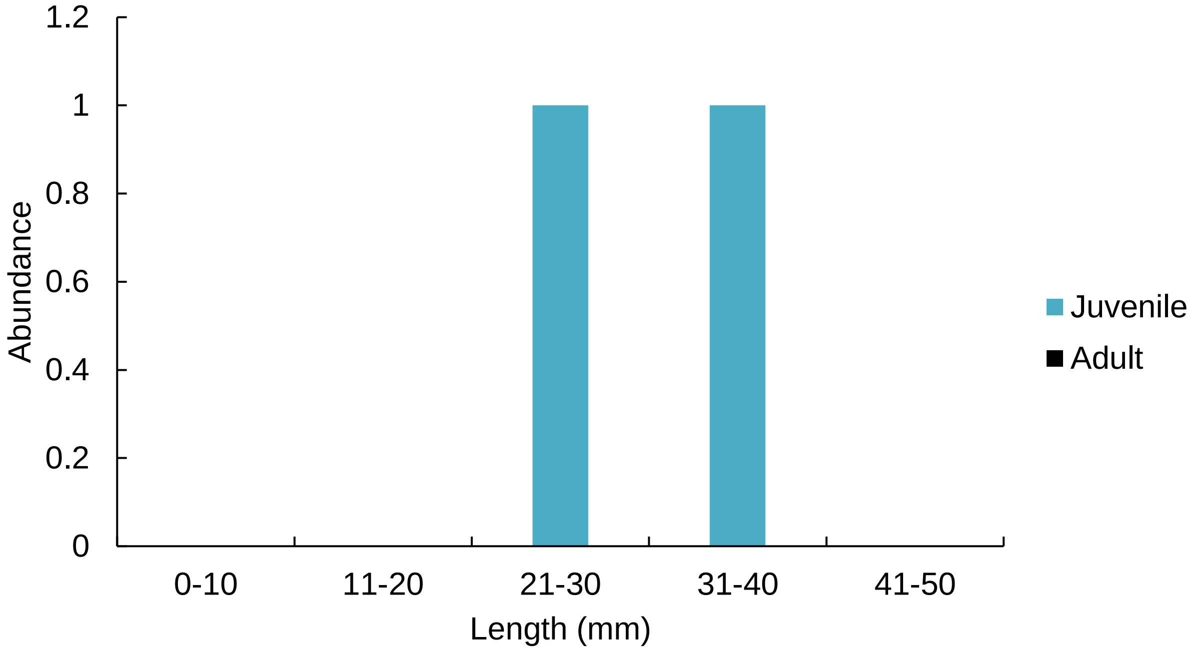


Figure 14. Length frequency distribution of *Quadrula quadrula* (Mapleleaf) found in the Grand River (n=2) by Fisheries and Oceans Canada in 2010.

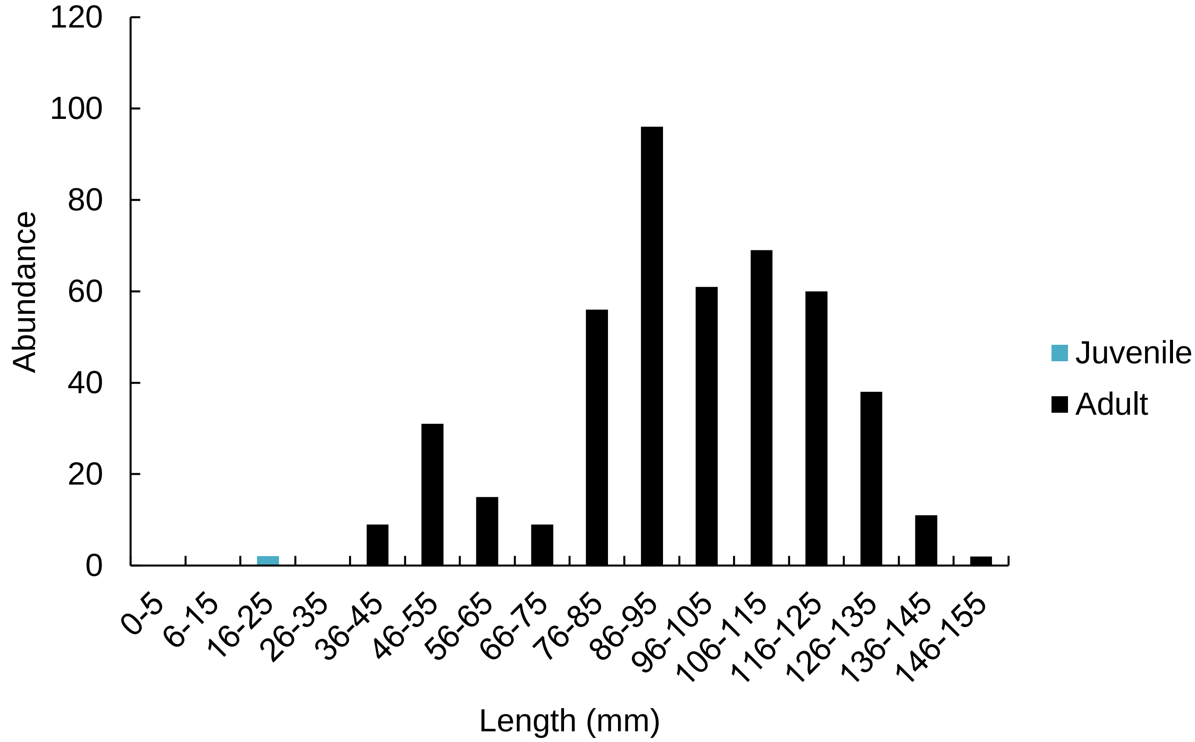


Figure 15. Length frequency distribution of *Actinonaias ligamentina* (Mucket) found in the Thames River (n=459) by Fisheries and Oceans Canada in 2018.

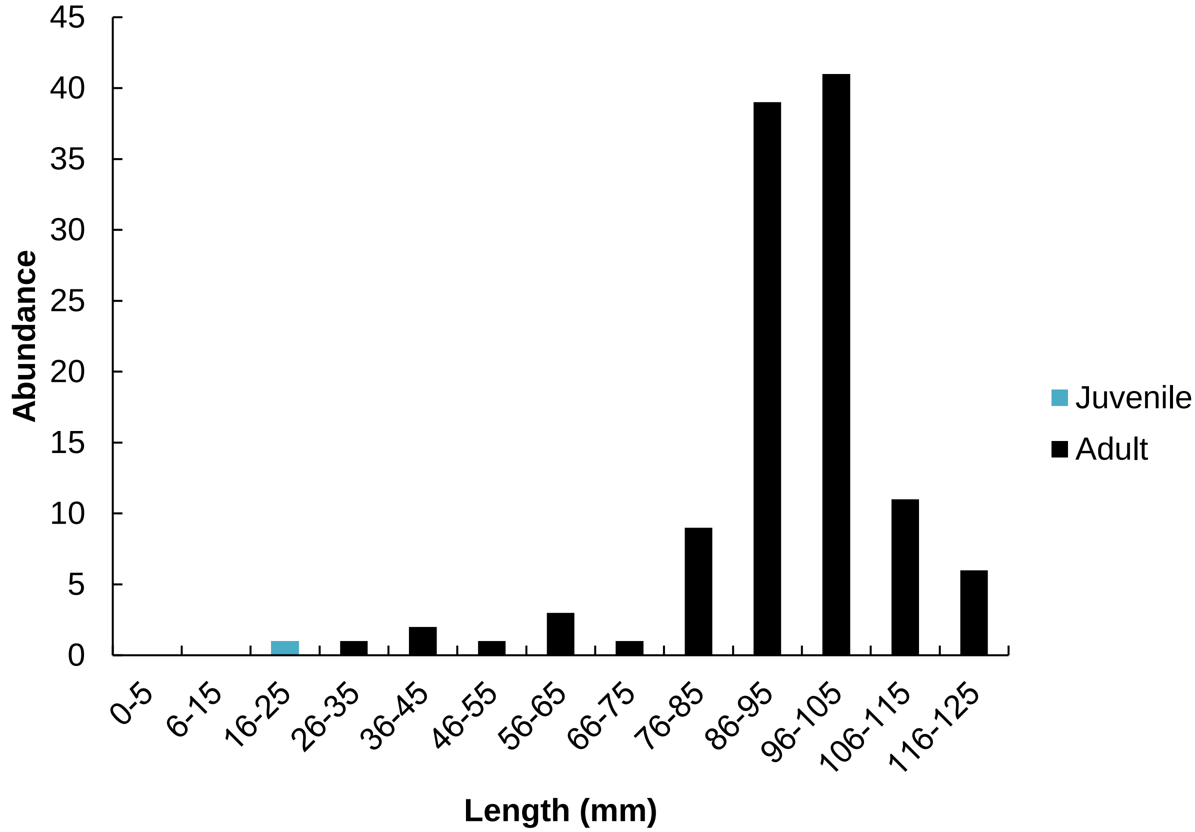


Figure 16. Length frequency distribution of *Lasmigona costata* (Flutedshell) found in the Thames River (n=115) by Fisheries and Oceans Canada in 2018.

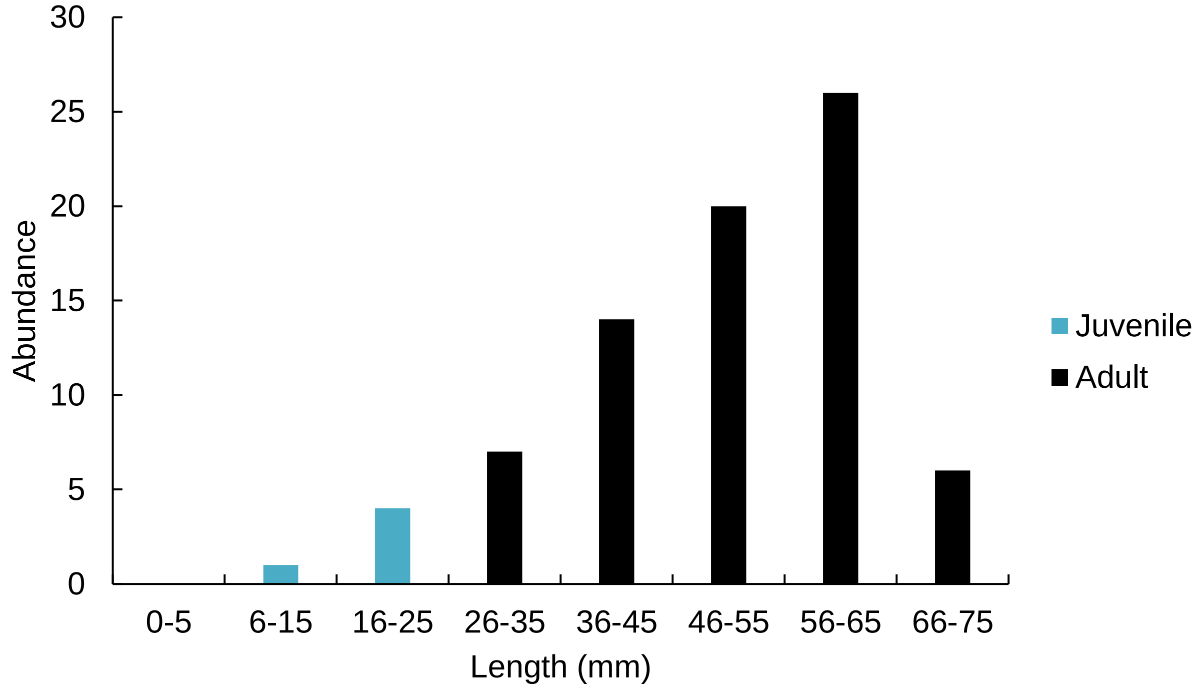
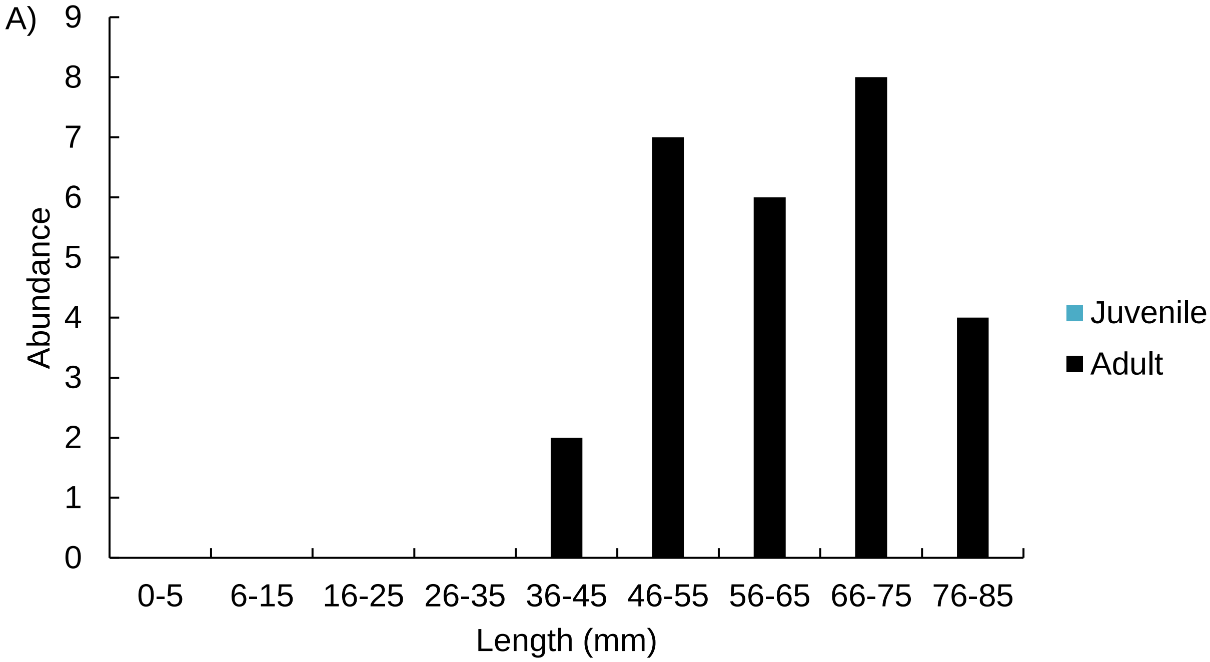


Figure 17. Length frequency distribution of *Cambarunio iris* (Rainbow) found in the Thames River (n=78) by Fisheries and Oceans Canada in 2018.



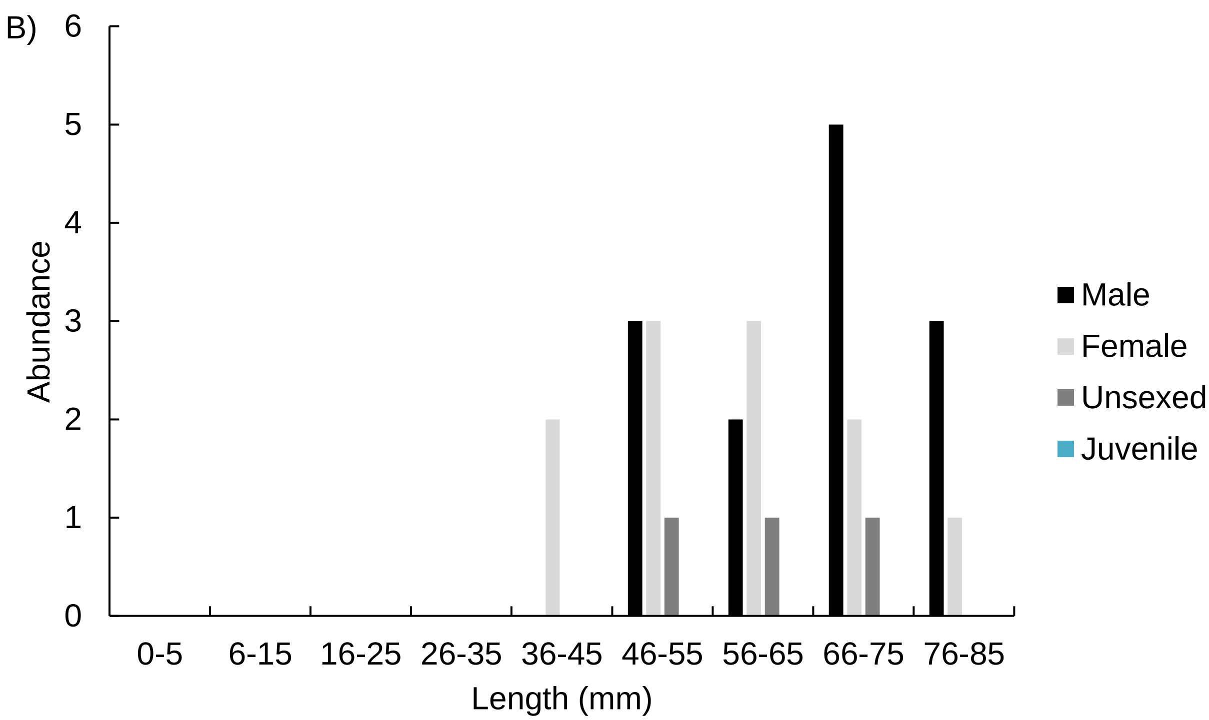
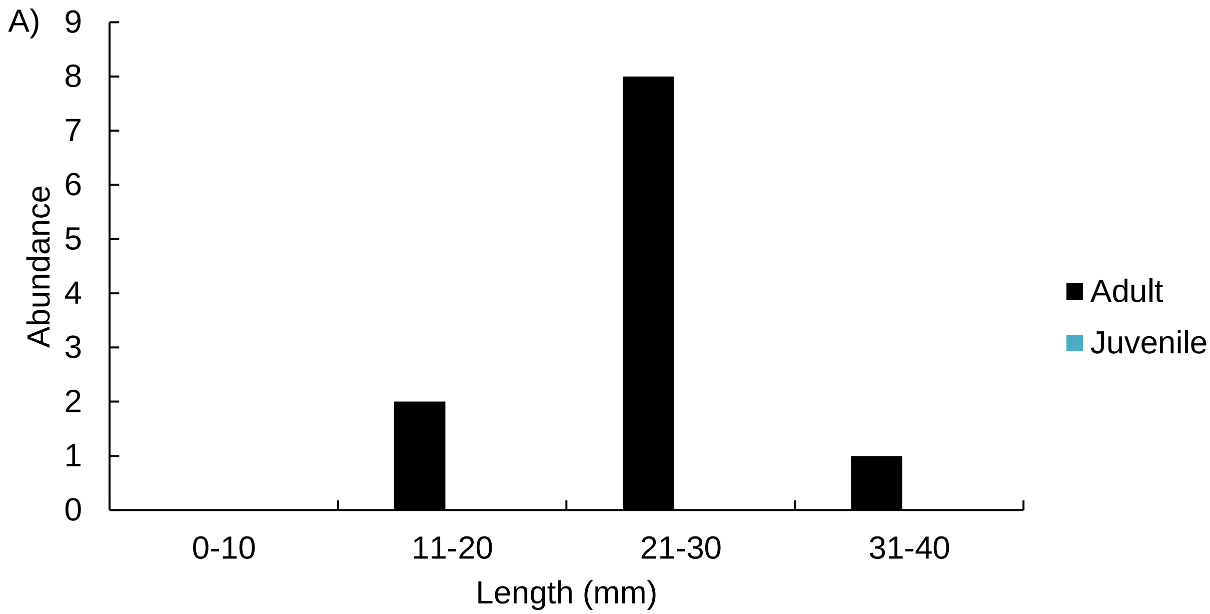


Figure 18. Length frequency distribution of *Lampsilis fasciola* (Wavyrayed Lampmussel) with A) all individuals combined and B) sexes separated found in the Thames River (n=27) by Fisheries and Oceans Canada in 2018.



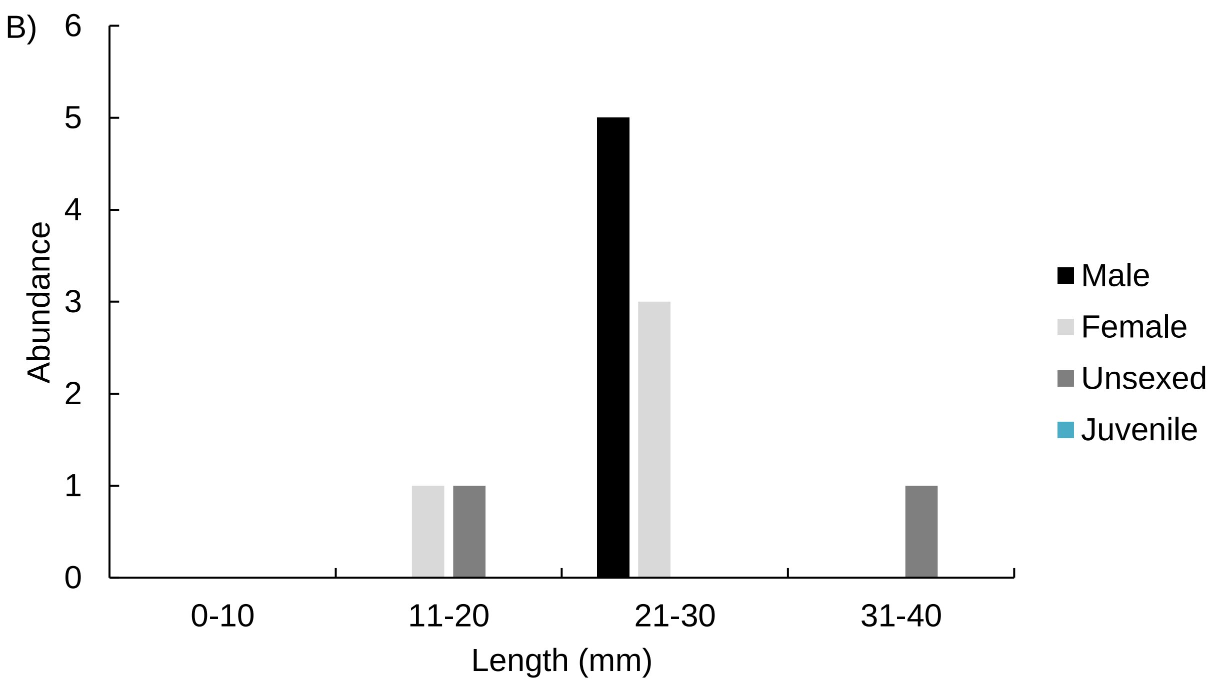


Figure 19. Length frequency distribution of *Paetulunio fabalis* (Rayed Bean) with A) all individuals combined and B) sexes separated found in the Thames River (n=11) by Fisheries and Oceans Canada in 2018.

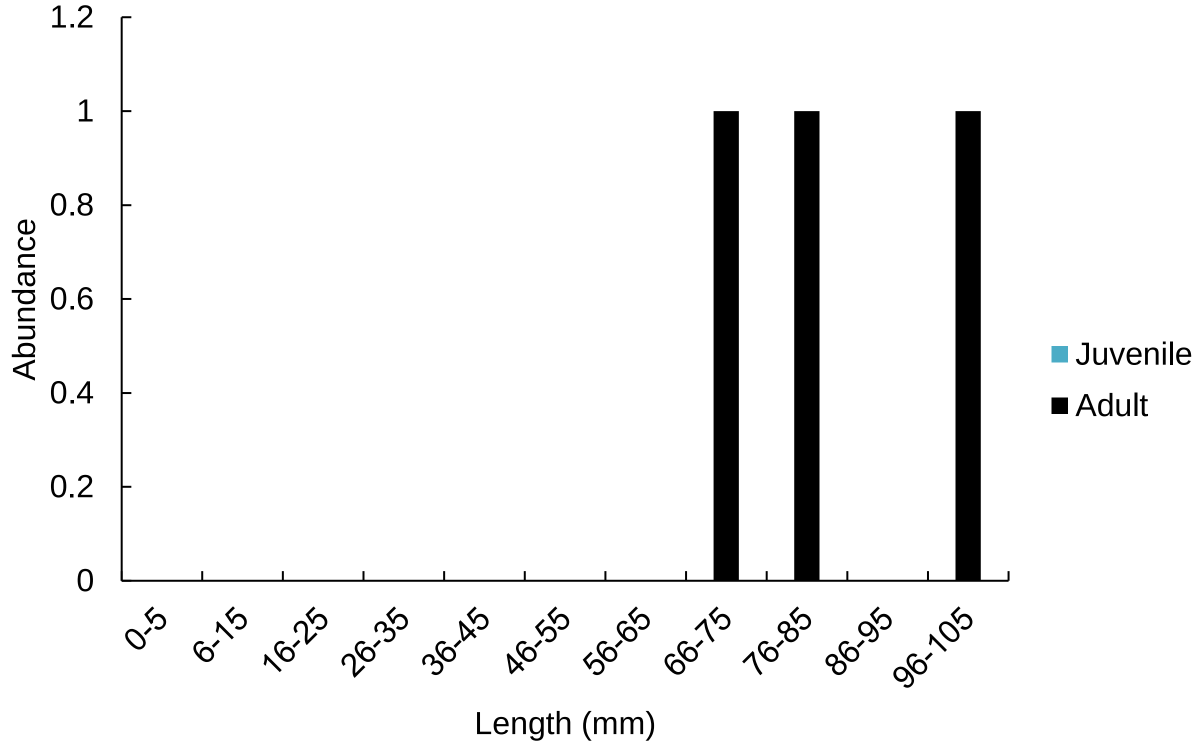


Figure 20. Length frequency distribution of *Pleurobema sintoxia* (Round Pigtoe) found in the Thames River (n=3) by Fisheries and Oceans Canada in 2018.

Appendix A. Site specific details for the index stations surveyed between 2007 and 2018 by Fisheries and Oceans Canada. Sites are presented in downstream to upstream order within each watershed. Some sites have been previously reported under a different site code; where applicable, the original site code is provided.

Site Code (Original Site Code)	Date Sampled	Latitude	Longitude	Watershed	Waterbody	Local Description
SGR-SGR-05 (DM11[1])	29-Jun-11	44.3045	-81.2155	Saugeen River	North Saugeen River	County Rd. 11 bridge crossing; East of Paisley
SG11	27-Jun-11	44.2762	-81.2763	Saugeen River	Teeswater River	Concession Rd. 20 bridge crossing
SG08 (SG8[2])	25-Jul-11	44.2269	-81.1655	Saugeen River	Main Saugeen River	Concession 10 bridge crossing; West of Elmwood
SG04a (SG04[1], SG4[2])	27-Jul-11	44.1159	-80.9423	Saugeen River	Beatty Saugeen River	~300 m upstream of Grey Road 3 bridge crossing; near Neustadt.
MR-09	31-Jul-08	43.6846	-81.5410	Maitland River	South Maitland River	County Rd. 8 bridge crossing; in Summerhill
MR-01	30-Jul-08	43.7736	-81.5402	Maitland River	Lower Maitland River	Auburn (HWY 25) bridge crossing
MR-16	12-Aug-08	43.8599	-81.3194	Maitland River	Middle Maitland River	Jamestown Rd. bridge crossing
MR-02	17-Jul-08	43.8872	-81.2824	Maitland River	North Maitland River	B-Line Road bridge crossing
MR-14	22-Jul-08	43.8093	-81.1405	Maitland River	Little Maitland River	Johnston Line bridge crossing; East of Jamestown
MR-21	16-Jul-08	43.8560	-80.9827	Maitland River	North Maitland River	Spencetown Line bridge crossing; West of Newbridge
BFR-BFR-10 (BF3-2[3])	13-Jun-11	43.5793	-81.4903	Bayfield River	Bayfield River	At Sanctuary Line bridge crossing; 2km East of Vanastra
GR-21	06-Jul-10	43.0111	-79.8806	Grand River	Grand River	1.5 km downstream of York on west shore (near Mount Healey)

GR-01	02-Jun-10	43.1097	-80.2444	Grand River	Grand River	Downstream of Erie Ave. bridge crossing; downstream of Brantford
GR-02	31-May-10	43.2764	-80.3472	Grand River	Grand River	At canoe launch area downstream of bridge in Glen Morris
GR-03	26-Jul-07	43.4047	-80.4333	Grand River	Grand River	2 km upstream of the Kitchener Sewage Treatment Plant in Doon Heritage Crossroads Corner Area
GR-33	22-Aug-07	43.4963	-80.4693	Grand River	Grand River	Downstream from Kiwanis Park
GR-31	04-Jul-07	43.5410	-80.4903	Grand River	Grand River	Along Sawmill Road; just above the confluence of the Conestogo River
GR-13	29-Aug-07	43.5859	-80.4806	Grand River	Grand River	At the covered bridge in West Montrose
TR-36 (TM04-20[4])	03-Jul-18	42.9737	-81.2320	Thames River	South Thames River	Upstream of Wellington Rd. in Watson Park
TR-18 (TM04-2[4])	04-Jun-18	43.0954	-81.1684	Thames River	North Thames River	Downstream of Thorndale Rd. bridge crossing
TR-15	18-Jul-18	43.0909	-80.9884	Thames River	Middle Thames River	North of Thamesford; downstream of Rd 74 bridge crossing
TR-16	13-Aug-18	43.1257	-80.9068	Thames River	Middle Thames River	Downstream of 35th Line bridge crossing

[1]Original site code from McNichols-O'Rourke et al. (2012).
[2]Original site code from Morris et al. (2007).
[3]Original site code from Morris et al. (2012a).
[4]Original site code from Morris and Edwards (2007).

Appendix B. Number of blocks, number of quadrats, total abundance, overall species richness, mean site density (± standard error), mean site richness (± standard error), and physical characteristics (± standard error) of the habitat at each site that was surveyed between 2007 and 2018 by Fisheries and Oceans Canada. Sites are presented in downstream to upstream order.

	SAUGEEN RIVER			
	SGR-SGR-05	**SG11**	**SG08**	**SG04a**
# of blocks	25	25	26	25
# of quadrats	75	75	78	75
Total abundance	212	148	122	30
Total live species richness	3	4	4	1
Mean unionid density (/m^2)	2.83 (± 0.39)	1.97 (± 0.25)	1.56 (± 0.88)	0.40 (± 0.06)
Mean species richness (/m^2)	0.64 (± 0.05)	0.51 (± 0.05)	0.28 (± 0.05)	0.24 (± 0.03)
Depth (m)	0.29 (± 0.01)	0.47 (± 0.01)	0.32 (± 0.01)	0.37 (± 0.01)
Water velocity (m/s)	0.56 (± 0.02)	0.35 (± 0.01)	0.12 (± 0.02)	0.25 (± 0.01)
Bedrock (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Boulder (%)	15.15 (± 1.56)	16.38 (± 1.70)	0.00 (± 0.00)	12.08 (± 1.90)
Cobble (%)	39.63 (± 1.72)	47.77 (± 2.21)	1.41 (± 0.47)	45.69 (± 1.79)
Gravel (%)	23.36 (± 1.10)	21.31 (± 1.46)	22.44 (± 2.60)	26.11 (± 1.26)
Sand (%)	16.42 (± 1.39)	12.77 (± 1.12)	43.85 (± 2.87)	13.26 (± 0.79)
Silt (%)	4.63 (± 0.90)	1.38 (± 0.43)	14.81 (± 1.55)	2.01 (± 0.60)
Clay (%)	0.00 (± 0.00)	0.15 (± 0.15)	0.06 (± 0.06)	0.14 (± 0.14)
Muck (%)	0.00 (± 0.00)	0.00 (± 0.00)	15.58 (± 2.22)	0.00 (± 0.00)
Marl (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Detritus (%)	0.82 (± 0.31)	0.23 (± 0.13)	1.86 (± 0.65)	0.69 (± 0.35)

	MAITLAND RIVER					
	MR-09	MR-01	MR-16	MR-02	MR-14	MR-21
# of blocks	21	20	21	20	20	20
# of quadrats	63	60	63	60	60	60
Total abundance	126	15	45	167	64	26
Total live species richness	7	5	8	6	8	6
Mean unionid density (/m^2)	2.03 (± 0.27)	0.25 (± 0.07)	0.71 (± 0.16)	2.78 (± 0.57)	1.07 (± 0.23)	0.43 (± 0.12)
Mean species richness (/m^2)	0.70 (± 0.06)	0.23 (± 0.07)	0.57 (± 0.11)	0.62 (± 0.07)	0.67 (± 0.11)	0.33 (± 0.10)
Depth (m)	0.45 (± 0.01)	0.19 (± 0.01)	0.31 (± 0.01)	0.34 (± 0.01)	0.39 (± 0.02)	0.45 (± 0.01)
Water velocity (m/s)	0.37 (± 0.02)	0.23 (± 0.02)	0.24 (± 0.02)	0.12 (± 0.01)	0.57 (± 0.03)	0.06 (± 0.01)
Bedrock (%)	0.40 (± 0.28)	0.00 (± 0.00)	3.14 (± 1.39)	0.00 (± 0.00)	0.00 (± 0.00)	5.87 (± 1.74)
Boulder (%)	31.75 (± 1.99)	3.79 (± 0.75)	15.00 (± 2.24)	4.31 (± 0.86)	0.5 (± 0.42)	10.09 (± 1.57)
Cobble (%)	31.11 (± 1.14)	45.86 (± 0.93)	28.31 (± 1.46)	43.88 (± 1.13)	6.92 (± 1.22)	32.35 (± 1.08)
Gravel (%)	20.48 (± 0.73)	26.72 (± 0.60)	33.56 (± 1.80)	29.74 (± 0.84)	65.92 (± 3.05)	26.89 (± 0.79)
Sand (%)	14.05 (± 0.72)	22.07 (± 0.58)	15.68 (± 0.97)	14.35 (± 0.80)	22.92 (± 2.73)	19.76 (± 0.88)
Silt (%)	2.14 (± 0.56)	1.55 (± 0.31)	2.80 (± 0.64)	7.11 (± 0.55)	1.83 (± 0.31)	5.04 (± 0.04)
Clay (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Muck (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.17 (± 0.17)	0.09 (± 0.09)	1.00 (± 0.41)	0.00 (± 0.00)
Marl (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.17 (± 0.17)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Detritus (%)	0.08 (± 0.08)	0.00 (± 0.00)	1.19 (± 0.57)	0.52 (± 0.36)	0.92 (± 0.65)	0.00 (± 0.00)

BAYFIELD RIVER	
	BFR-BFR-10
# of blocks	25
# of quadrats	75
Total abundance	41
Total live species richness	7
Mean unionid density (/m^2)	0.55 (± 0.11)
Mean species richness (/m^2)	0.41 (± 0.07)
Depth (m)	0.32 (± 0.01)
Water velocity (m/s)	0.22 (± 0.01)
Bedrock (%)	0.00 (± 0.00)
Boulder (%)	12.13 (± 1.80)
Cobble (%)	45.07 (± 1.84)
Gravel (%)	26.27 (± 1.29)
Sand (%)	14.07 (± 1.11)
Silt (%)	1.47 (± 0.40)
Clay (%)	0.73 (± 0.34)
Muck (%)	0.00 (± 0.00)
Marl (%)	0.00 (± 0.00)
Detritus (%)	0.27 (± 0.16)

	GRAND RIVER						
	GR-21	GR-01	GR-02	GR-03	GR-33	GR-31	GR-13
# of blocks	25	25	25	21	20	16	21
# of quadrats	75	75	75	63	60	48	63
Total abundance	169	20	35	89	50	20	18
Total live species richness	15	4	3	5	5	5	4
Mean unionid density (/m^2)	2.25 (± 0.21)	0.27 (± 0.07)	0.47 (± 0.09)	1.41 (± 0.19)	0.83 (± 0.12)	0.42 (± 0.08)	0.29 (± 0.12)
Mean species richness (/m^2)	1.33 (± 0.12)	0.20 (± 0.05)	0.37 (± 0.07)	0.78 (± 0.09)	0.50 (± 0.05)	0.35 (± 0.07)	0.19 (± 0.05)
Depth (m)	0.27 (± 0.01)	0.47 (± 0.02)	0.32 (± 0.01)	0.35 (± 0.01)	0.28 (± 0.01)	0.27 (± 0.02)	0.26 (± 0.01)
Water velocity (m/s)	0.56 (± 0.02)	0.03 (± 0.01)	0.41 (± 0.01)	0.36 (± 0.01)	0.45 (± 0.01)	0.49 (± 0.03)	0.32 (± 0.01)
Bedrock (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Boulder (%)	0.00 (± 0.00)	0.00 (± 0.00)	5.60 (± 1.43)	6.36 (± 1.02)	0.28 (± 0.16)	3.72 (± 1.01)	0.71 (± 0.41)
Cobble (%)	55.73 (± 1.28)	20.74 (± 2.27)	53.13 (± 0.99)	45.26 (± 1.18)	43.33 (± 0.42)	49.68 (± 1.31)	15.95 (± 0.55)
Gravel (%)	30.00 (± 0.65)	30.14 (± 1.78)	31.13 (± 0.84)	40.49 (± 1.01)	50.09 (± 0.34)	40.96 (± 1.37)	77.78 (± 0.74)
Sand (%)	12.47 (± 0.61)	38.45 (± 2.45)	10.13 (± 0.42)	7.10 (± 0.66)	5.46 (± 0.20)	5.43 (± 0.26)	5.08 (± 0.08)
Silt (%)	1.27 (± 0.38)	9.46 (± 1.89)	0.00 (± 0.00)	0.63 (± 0.29)	0.83 (± 0.26)	0.21 (± 0.15)	0.48 (± 0.25)
Clay (%)	0.53 (± 0.18)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Muck (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Marl (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Detritus (%)	0.00 (± 0.00)	1.22 (± 0.60)	0.00 (± 0.00)	0.16 (± 0.16)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)

THAMES RIVER				
	TR-36	**TR-18**	**TR-15**	**TR-16**
# of blocks	25	25	25	25
# of quadrats	75	75	75	75
Total abundance	499	52	294	60
Total live species richness	9	9	10	7
Mean unionid density (/m^2)	6.65 (± 0.58)	0.69 (± 0.09)	3.92 (± 0.70)	0.80 (± 0.17)
Mean species richness (/m^2)	0.83 (± 0.07)	0.53 (± 0.07)	1.36 (± 0.13)	0.49 (± 0.09)
Depth (m)	0.34 (± 0.01)	0.42 (± 0.01)	0.37 (± 0.01)	0.44 (± 0.01)
Water velocity (m/s)	0.35 (± 0.01)	0.32 (± 0.01)	0.16 (± 0.01)	0.09 (± 0.01)
Bedrock (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Boulder (%)	3.80 (± 0.76)	13.27 (± 1.37)	11.09 (± 1.25)	0.12 (± 0.08)
Cobble (%)	32.60 (± 1.20)	45.23 (± 1.52)	32.89 (± 2.32)	22.71 (± 1.62)
Gravel (%)	36.84 (± 0.90)	32.64 (± 1.22)	33.13 (± 1.78)	40.71 (± 1.62)
Sand (%)	26.40 (± 1.13)	8.87 (± 0.74)	20.67 (± 1.87)	29.33 (± 1.65)
Silt (%)	0.33 (± 0.14)	0.00 (± 0.00)	2.13 (± 0.50)	2.00 (± 0.68)
Clay (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.40 (± 0.25)
Muck (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	3.67 (± 1.31)
Marl (%)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)
Detritus (%)	0.03 (± 0.03)	0.00 (± 0.00)	0.08 (± 0.07)	1.07 (± 0.49)

Appendix C. Composition of the mussel community at each site surveyed between 2007 and 2018 by Fisheries and Oceans Canada. Species at Risk are highlighted. All species known (historical and current) from the watershed are listed. Sites are presented in downstream to upstream order.

SGR-SGR-05
North Saugeen River

Species	Abundance	Relative Abundance (%)	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	13	6.13	0.17	16.00
Alasmidonta viridis	-	-	-	-
Cambarunio iris	29	13.68	0.39	26.67
Eurynia dilatata	170	80.19	2.27	81.33
Lampsilis cardium	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Potamilus alatus	-	-	-	-
Pyganodon grandis	-	-	-	-
Strophitus undulatus	-	-	-	-
Truncilla donaciformis	-	-	-	-

SG11
Teeswater River

Species	Abundance	Relative Abundance (%)	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	2	1.35	0.03	2.67
Alasmidonta viridis	1	0.68	0.01	1.33
Cambarunio iris	17	11.49	0.23	18.67
Eurynia dilatata	128	86.49	1.71	76.00
Lampsilis cardium	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Potamilus alatus	-	-	-	-
Pyganodon grandis	-	-	-	-
Strophitus undulatus	-	-	-	-
Truncilla donaciformis	-	-	-	-

SG08 Main Saugeen River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels/m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	1	0.82	0.01	1.28
Cambarunio iris	-	-	-	-
Eurynia dilatata	114	93.44	1.46	34.62
Lampsilis cardium	5	4.10	0.06	6.41
Lampsilis siliquoidea	2	1.64	0.03	2.56
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Potamilus alatus	-	-	-	-
Pyganodon grandis	-	-	-	-
Strophitus undulatus	-	-	-	-
Truncilla donaciformis	-	-	-	-

SG04a Beatty Saugeen River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels/m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Cambarunio iris	-	-	-	-
Eurynia dilatata	30	100.00	0.40	28.00
Lampsilis cardium	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Potamilus alatus	-	-	-	-
Pyganodon grandis	-	-	-	-
Strophitus undulatus	-	-	-	-
Truncilla donaciformis	-	-	-	-

MR-09 South Maitland River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels/m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	3	2.38	0.05	3.17
Alasmidonta marginata	3	2.38	0.05	4.76
Alasmidonta viridis	10	7.94	0.14	11.11
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	89	70.63	1.46	63.49
Eurynia dilatata	-	-	-	-
Lampsilis cardium	7	5.56	0.08	11.11
Lampsilis fasciola	9	7.14	0.17	11.11
Lampsilis siliquoidea	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	3	2.38	0.05	4.76
Pyganodon grandis	-	-	-	-
Strophitus undulatus	-	-	-	-
Unknown	2	1.59	0.03	1.59

MR-01 Lower Maitland River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels/m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	2	13.33	0.03	3.33
Alasmidonta viridis	1	6.67	0.02	1.67
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	4	26.67	0.07	6.67
Eurynia dilatata	-	-	-	-
Lampsilis cardium	2	13.33	0.03	3.33
Lampsilis fasciola	5	33.33	0.08	8.33
Lampsilis siliquoidea	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Pyganodon grandis	-	-	-	-
Strophitus undulatus	-	-	-	-
Unknown	1	6.67	0.02	1.67

MR-16 Middle Maitland River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	3	6.67	0.05	4.76
Alasmidonta marginata	4	8.89	0.06	6.35
Alasmidonta viridis	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	12	26.67	0.19	15.87
Eurynia dilatata	-	-	-	-
Lampsilis cardium	3	6.67	0.05	4.76
Lampsilis fasciola	9	20.00	0.14	14.29
Lampsilis siliquoidea	1	2.22	0.02	1.59
Lasmigona compressa	1	2.22	0.02	1.59
Lasmigona costata	11	24.44	0.17	15.87
Pyganodon grandis	-	-	-	-
Strophitus undulatus	-	-	-	-
Unknown	1	2.22	0.02	1.59

MR-02 North Maitland River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	2	1.20	0.03	3.33
Alasmidonta viridis	6	3.59	0.10	10.00
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	144	86.23	2.40	70.00
Eurynia dilatata	-	-	-	-
Lampsilis cardium	7	4.19	0.12	11.67
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	6	3.59	0.10	8.33
Pyganodon grandis	2	1.20	0.03	3.33
Strophitus undulatus	-	-	-	-

MR-14 Little Maitland River				
Species	Abundance	Relative Abundance (%)	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	2	3.13	0.03	3.33
Alasmidonta viridis	-	-	-	-
Anodontoides ferussacianus	1	1.56	0.02	1.67
Cambarunio iris	7	10.94	0.12	10.00
Eurynia dilatata	-	-	-	-
Lampsilis cardium	12	18.75	0.20	20.00
Lampsilis fasciola	2	3.13	0.03	3.33
Lampsilis siliquoidea	-	-	-	-
Lasmigona compressa	3	4.69	0.05	5.00
Lasmigona costata	25	39.06	0.42	25.00
Pyganodon grandis	-	-	-	-
Strophitus undulatus	12	18.75	0.20	15.00

MR-21 North Maitland River				
Species	Abundance	Relative Abundance (%)	Density (mussels/m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	2	7.69	0.03	3.33
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	12	46.15	0.20	18.33
Eurynia dilatata	-	-	-	-
Lampsilis cardium	3	11.54	0.05	3.33
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona compressa	1	3.85	0.02	1.67
Lasmigona costata	6	23.08	0.10	10.00
Pyganodon grandis	2	7.69	0.03	3.33
Strophitus undulatus	-	-	-	-

BFR-BFR-10 Bayfield River				
Species	**Abundance**	**Relative Abundance (%)**	**Mean Density (mussels/m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	1	2.44	0.01	1.33
Alasmidonta viridis	4	9.76	0.05	5.33
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	21	51.22	0.28	22.67
Lampsilis cardium	-	-	-	-
Lampsilis siliquoidea	7	17.07	0.09	9.33
Lasmigona complanata	-	-	-	-
Lasmigona compressa	1	2.44	0.01	1.33
Lasmigona costata	1	2.44	0.01	1.33
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Pyganodon grandis	6	14.63	0.08	6.67
Quadrula quadrula	-	-	-	-
Strophitus undulatus	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

GR-21 Grand River				
Species	Abundance	Relative Abundance (%)	Density (mussels /m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	53	31.36	0.71	48.00
Alasmidonta marginata	22	13.02	0.29	24.00
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	1	0.59	0.01	1.33
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	4	2.37	0.05	5.33
Eurynia dilatata	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	3	1.78	0.04	4.00
Lampsilis cardium	1	0.59	0.01	1.33
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	52	30.77	0.69	52.00
Ligumia recta	13	7.69	0.17	17.33
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	6	3.55	0.08	8.00
Potamilus alatus	1	0.59	0.01	1.33
Potamilus fragilis	2	1.18	0.03	2.67
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	2	1.18	0.03	2.67
Sagittunio nasutus	-	-	-	-
Strophitus undulatus	5	2.96	0.07	6.67
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	3	1.78	0.04	4.00
Utterbackia imbecillis	1	0.59	0.01	1.33

GR-01 Grand River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	10	50.00	0.13	10.67
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	-	-	-	-
Eurynia dilatata	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	4	20.00	0.05	5.33
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	3	15.00	0.04	4.00
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	-	-	-	-
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	3	15.00	0.04	4.00
Quadrula quadrula	-	-	-	-
Sagittunio nasutus	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

GR-02 Grand River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	7	20.00	0.09	9.33
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	-	-	-	-
Eurynia dilatata	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	18	51.43	0.24	18.67
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	10	28.57	0.13	12.00
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	-	-	-	-
Sagittunio nasutus	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

GR-03 Grand River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	15	16.85	0.24	20.63
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	-	-	-	-
Eurynia dilatata	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	46	51.69	0.73	47.62
Lampsilis siliquoidea	3	3.37	0.05	3.17
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	22	24.72	0.35	25.40
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	-	-	-	-
Sagittunio nasutus	-	-	-	-
Strophitus undulatus	3	3.37	0.05	4.76
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

GR-33 Grand River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	3	6.00	0.05	5.00
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	-	-	-	-
Eurynia dilatata	31	62.00	0.52	35.00
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	11	22.00	0.18	18.33
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	4	8.00	0.07	6.67
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	-	-	-	-
Sagittunio nasutus	-	-	-	-
Strophitus undulatus	1	2.00	0.02	1.67
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

GR-31 Grand River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	-	-	-	-
Eurynia dilatata	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	10	50.00	0.21	18.75
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	1	5.00	0.02	2.08
Lasmigona costata	2	10.00	0.04	4.17
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	1	5.00	0.02	2.08
Quadrula quadrula	-	-	-	-
Sagittunio nasutus	-	-	-	-
Strophitus undulatus	6	30.00	0.13	10.42
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

GR-13 Grand River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	1	5.56	0.02	1.59
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	-	-	-	-
Eurynia dilatata	1	5.56	0.02	1.59
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	2	11.11	0.03	3.17
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	-	-	-	-
Sagittunio nasutus	-	-	-	-
Strophitus undulatus	14	77.78	0.22	17.46
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

TR-36 South Thames River				
Species	Abundance	Relative Abundance (%)	Density (mussels /m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	454	90.98	6.05	98.67
Alasmidonta marginata	8	1.60	0.11	10.67
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	-	-	-	-
Cyclonaias pustulosa	-	-	-	-
Cyclonaias tuberculata	5	1.00	0.07	6.67
Eurynia dilatata	-	-	-	-
Epioblasma rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	1	0.20	0.01	1.33
Lampsilis cardium	1	0.20	0.01	1.33
Lampsilis fasciola	3	0.60	0.04	2.67
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	7	1.40	0.09	8.00
Lasmigona compressa	-	-	-	-
Lasmigona costata	16	3.21	0.21	16.00
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Paetulunio fabalis	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	3	0.60	0.04	4.00
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-
Unknown	1	0.20	0.01	1.33

TR-18 North Thames River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m^2)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	5	9.62	0.07	6.67
Alasmidonta marginata	2	3.85	0.03	2.67
Alasmidonta viridis	-	-	-	-
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	3	5.77	0.04	4.00
Cyclonaias pustulosa	-	-	-	-
Cyclonaias tuberculata	7	13.46	0.09	8.00
Eurynia dilatata	2	3.85	0.03	2.67
Epioblasma rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	-	-	-	-
Lampsilis cardium	9	17.31	0.12	10.67
Lampsilis fasciola	11	21.15	0.15	14.67
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	-	-	-	-
Lasmigona costata	2	3.85	0.03	2.67
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Paetulunio fabalis	11	21.15	0.15	12.00
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	-	-	-	-
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

TR-15 Middle Thames River				
Species	**Abundance**	**Relative Abundance (%)**	**Density (mussels /m²)**	**Occurrence (% of quadrats)**
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	5	1.70	0.07	5.33
Alasmidonta viridis	17	5.78	0.23	13.33
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	73	24.83	0.97	52.00
Cyclonaias pustulosa	-	-	-	-
Cyclonaias tuberculata	-	-	-	-
Eurynia dilatata	78	26.53	1.04	53.33
Epioblasma rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	5	1.70	0.07	4.00
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	13	4.42	0.17	16.00
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	8	2.72	0.11	10.67
Lasmigona costata	74	25.17	0.99	49.33
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Paetulunio fabalis	-	-	-	-
Pleurobema sintoxia	3	1.02	0.04	4.00
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	-	-	-	-
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	18	6.12	0.24	20.00
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-

TR-16
Middle Thames River

Species	Abundance	Relative Abundance (%)	Density (mussels /m^2)	Occurrence (% of quadrats)
Actinonaias ligamentina	-	-	-	-
Alasmidonta marginata	-	-	-	-
Alasmidonta viridis	15	25.00	0.20	18.67
Amblema plicata	-	-	-	-
Anodontoides ferussacianus	-	-	-	-
Cambarunio iris	2	3.33	0.03	2.67
Cyclonaias pustulosa	-	-	-	-
Cyclonaias tuberculata	-	-	-	-
Eurynia dilatata	-	-	-	-
Epioblasma rangiana	-	-	-	-
Epioblasma triquetra	-	-	-	-
Fusconaia flava	1	1.67	0.01	1.33
Lampsilis cardium	-	-	-	-
Lampsilis fasciola	-	-	-	-
Lampsilis siliquoidea	-	-	-	-
Lasmigona complanata	-	-	-	-
Lasmigona compressa	10	16.67	0.13	10.67
Lasmigona costata	23	38.33	0.31	20.00
Ligumia recta	-	-	-	-
Obliquaria reflexa	-	-	-	-
Obovaria olivaria	-	-	-	-
Obovaria subrotunda	-	-	-	-
Paetulunio fabalis	-	-	-	-
Pleurobema sintoxia	-	-	-	-
Potamilus alatus	-	-	-	-
Potamilus fragilis	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	-
Pyganodon grandis	4	6.67	0.05	4.00
Quadrula quadrula	-	-	-	-
Simpsonaias ambigua	-	-	-	-
Strophitus undulatus	5	8.33	0.07	6.67
Toxolasma parvum	-	-	-	-
Truncilla donaciformis	-	-	-	-
Truncilla truncata	-	-	-	-
Utterbackia imbecillis	-	-	-	-