Diversity of freshwater mussel assemblages across Lake Ontario coastal wetlands in Canadian waters

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ABSTRACT

Reid, S.M., Kopf, V., Morris, T.J. 2018. Diversity of freshwater mussel assemblages across Lake Ontario coastal wetlands in Canadian waters. Can. Manuscr. Rep. Fish. Aquat. Sci. 3164: v + 21 p.

Laurentian Great Lakes coastal wetlands have become recognized as important habitats for the conservation of freshwater mussels, providing refuge from the impacts of invasive dreissenid (*Dreissena spp.*) mussels. Between 2011 and 2015, we sampled freshwater mussel assemblages at 40 coastal wetland sites along the north shore of Lake Ontario. Our study objectives included: developing species lists for each wetland; identifying wetlands that support mussel species at risk; comparing the composition of assemblages associated with different coastal wetland habitats (barrier beach, drowned river mouth and lacustrine); and documenting the degree of dreissenid mussel infestation. A total of 1640 live individuals (representing 11 mussel species) were collected using clam-rakes and visual-tactile sampling, with live individuals present in 83% of wetlands sampled. Between one and five species were detected at each wetland. Dominant species included Eastern Elliptio (*Elliptio complanata*), Fatmucket (*Lampsilis siliquoidea*) and Giant Floater (*Pyganodon grandis*). Giant Floater was the most widespread (collected from 73% of wetlands) and abundant species (60% of live individuals collected). Three mussel species at risk were detected: Eastern Pondmussel (*Ligumia nasuta*)(at seven wetlands), Lilliput (*Toxolasma parvum*)(at one wetland) and Mapleleaf (*Quadrula quadrula*)(at two wetlands). While species richness and assemblage structure did not vary among different wetland types, there were differences in the occurrence of invasive dreissenid mussels and degree of infestation. Compared to barrier beach and lacustrine wetlands, dreissenids were less frequently detected at drowned river mouth sites and the mass ratio of attached dreissenids to live mussels was lower. Mass-ratios were lowest for Giant Floater and greatest for Eastern Elliptio and Eastern Pondmussel.

RÉSUMÉ

Reid, S.M., Kopf, V., Morris, T.J. 2018. Diversité des assemblages de moules d'eau douce dans les terres humides côtières du lac Ontario dans les eaux canadiennes. Rapp. manus. can. sci. halieut. aquat. 3164: v + 21 p.

Les zones humides côtières des Grands Lacs laurentiens sont aujourd’hui connues comme des habitats importants pour les moules d’eau douce. En effet, elles constituent un refuge les protégeant des impacts des moules envahissantes de la famille des dressénidés (*Dreissena spp.*). Entre 2011 et 2015, des échantillons des communautés de moules d’eau douce ont été prélevés dans 40 sites des zones humides côtières le long de la rive nord du lac Ontario. Cette étude visait à dresser la liste des espèces de chaque zone humide, déterminer les zones humides dans lesquelles se trouvent des espèces de moules en péril, comparer la composition des communautés dans différents habitats des zones humides côtières (cordon littoral, embouchure submergée et milieux lacustres), ainsi qu’à documenter l’étendue de l’infestation de moules de la famille des dressénidés. Au total, 1 640 spécimens vivants (appartenant à 11 espèces de moules) ont été prélevés à l’aide de méthodes visuelles et tactiles, ainsi que de méthodes de ratissage. Des spécimens vivants étaient présents dans 83% des zones humides ayant fait l’objet de prélèvements. Entre une et quatre espèces de moules ont été observées dans chaque zone humide. Les espèces dominantes comprenaient l’elliptio de l’Est (*Elliptio complanata*), la lampsile siliquoïde (*Lampsilis siliquoidea*) et le pyganodon commun (*Pyganodon grandis*). Le pyganodon commun était l’espèce la plus répandue (échantillonnée dans 73% des zones humides) et la plus abondante (60% des spécimens vivants recueillis). Trois espèces de moules en péril ont été répertoriées : la ligumie pointue (*Ligumia nasuta*) (dans sept zones humides), le toxoplasme nain (*Toxolasma parvum*) (dans une zone humide), et la

mulette feuille d’érable (*Quadrula quadrula*) (dans deux zones humides). Aucune variation dans la diversité des espèces et la structure des communautés d’espèces n’a été constatée entre les différents types de zones humides, mais des différences ont été observées dans l’occurrence des moules envahissantes de la famille des dressénidés et dans le degré d’infestation. Les moules de la famille des dressénidés ont été moins fréquemment observées dans les sites d’embouchure submergée que dans les zones humides lacustres et de cordon littoral, et le rapport de masse des moules de la famille des dressénidés attachées à des moules vivantes y était également plus faible. Les rapports de masse pour le pyganodon commun étaient les plus faibles, et ceux de l’elliptio de l’Est et de la ligumie pointue les plus élevés.

INTRODUCTION

The invasion of the Laurentian Great Lakes basin by dreissenid mussels [Zebra Mussel, *Dreissena polymorpha* (Pallus, 1771) and Quagga Mussel *D. rostriformis bugensis* (Andrusov, 1897)] resulted in substantial and widespread declines in native mussel abundance and diversity (Schloesser and Nalepa 1994). By the early 1990's, native mussels were nearly extirpated from offshore waters of lakes Erie and St. Clair (Metcalfe-Smith et al. 2005). Further downstream, Quagga Mussel has become the dominant member of the nearshore benthic community in Lake Ontario (Wilson et al. 2006). Over the past 20 years, a number of studies have demonstrated the importance of Great Lakes coastal wetlands to freshwater mussel conservation. Remnant mussel assemblages have persisted in nearshore and coastal wetland areas of Lakes Erie, Huron and St. Clair (Nichols and Amberg 1997; Zanatta et al. 2002; Bowers and Szalay 2003; Crail et al. 2011; Sherman et al. 2013; Reid et al. 2016). Compared to adjacent open water habitats, wetlands are less suitable for dreissenid colonization and survival (Bowers and Szalay 2003; Sherman et al. 2013); thereby providing a refuge for native mussels. Given that dreissenid mussel removal may not be practical and brood-stock is required for native mussel reintroductions, recovery depends on identifying and protecting remnant native mussel assemblages.

While coastal wetlands are well recognized as important habitats for amphibians and reptiles, birds, fishes and mammals in the Laurentian Great Lakes basin (Sierzen et al. 2012), their value for native mussel conservation is not as well documented. Intensive, semi-quantitative inventories of coastal wetlands for freshwater mussels have recently occurred along the western and southern shores of Lake Erie (Zanatta et al. 2015), but similar extensive efforts have not been undertaken in Canadian waters. In the present study, we sampled the freshwater mussel assemblages in 40 Lake Ontario coastal wetlands. Study objectives included: (1) develop species lists for each wetland; (2) identify wetlands that support mussel species at risk; (3) compare the composition of assemblages associated with different coastal wetland habitat types; and (4) document the degree of dreissenid mussel infestation. For imperiled freshwater mussel taxa, these objectives address knowledge gaps related to distribution, population status, habitat requirements, and threat assessment, and support the establishment of a network of long-term population monitoring stations (Fisheries and Oceans Canada 2011a, 2011b, 2014, 2016).

METHODS

STUDY AREA

During the summer months of 2011, 2012, 2013, and 2015, 40 coastal wetlands along the Canadian (Ontario) shoreline of Lake Ontario were sampled. Sites were located between the city of St. Catherines (western end) to Thousand Islands archipelago of the St. Lawrence River (eastern end) (Figure 1). Wetlands represented three hydrogeomorphic classes: barrier beach (n=12), drowned river-mouth (n=14) and lacustrine (n=14) (Figure 2). These classes are based on geomorphic position, dominant hydrologic source and connectivity to Lake Ontario (Albert et al. 2005). Barrier beach wetlands are separated from coastal processes by a barrier beach or other barrier feature, but may still be directly connected to Lake Ontario via a channel. Water levels are maintained by lake levels when connected or maintained by groundwater and inflowing watercourses when isolated. Drowned river-mouth wetlands occur along lower reaches of watercourses that flow into Lake Ontario, are affected by the back flooding of lake waters, and are protected from wave action by bars and channel morphology. Lacustrine wetlands are directly influenced by lake-level fluctuations, nearshore currents, and ice scour. Geomorphic features along the shoreline (e.g. “sand-spit”) may provide some protection from wave action. Wetlands were classified using satellite imagery (e.g. “Google Earth”) and the Ontario Great Lakes Coastal Wetland Atlas (Environment Canada and Ontario Ministry of Natural Resources 2003).

Wetlands were 13 to 2093 (median: 116) hectares in size (Environment Canada and Ontario Ministry of Natural Resources 2003). Across these wetlands, aquatic macrophyte coverage ranged from absent to extensive, and water clarity (as measured with a transparency tube, Anderson and Davic 2004) was poor (<0.1 m) to excellent (>1.2 m). Wetland sediments (based on texture and visual assessment) were a variable mix of clay (mean = 21.4%), silt and organic material (mean = 49.7%), and sand and fine gravel (mean = 28.6%).

MUSSEL SAMPLING

From anywhere in the open-water habitat of each wetland, 12 sampling points were randomly selected. At each sampling point, one hour of search effort by visual/tactile methods and one hour of search effort by clam-rake was completed concurrently (Reid et al. 2014). Sampling was limited to within a 50 m radius of the start point, and areas sampled by either method did not overlap. Based on past results, most species are expected to be detected during the first 10 points (Reid et al. 2014, 2017). Visual/tactile searching involved either floating on air mattresses and hand searching the sediment for mussels (on the surface and probing through sediment for burrowed mussels), or searching for mussels with an underwater viewer (Plastimo® Round Underwater Viewer, 0.33 m diameter) or polarized lenses. In wetlands with clear water, mussels could be visually detected by spotting siphons or small clusters of dreissenids. It is estimated that tactile searches of soft sediments sampled up to a depth of 0.1 m. For the clam-rake method, an Eagle Claw® Clam Rake (0.84 m long handle, with a 0.26 x 0.15 m metal basket and ten 0.15 m long steel teeth) was dragged through the sediment and wetland vegetation. Spacing of wire mesh within the basket was 2.5 cm x 5 cm. Water depths sampled ranged 0.05 to 1.5 m.

Live individuals and shells (whole and valves) were identified to species based on shell characteristics (Metcalfe-Smith et al. 2005). Mussel collection data were archived in the Lower Great Lakes Unionid Database (Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada). Research underway (Porto-Hannes 2017) indicates that a hybrid zone between Fatmucket (*Lampsilis siliquoidea*) and Eastern Lampmussel (*Lampsilis radiata*) exists in the eastern areas of this study. Morphological and genetic intermediate forms exist. Species identifications in this study were only based on shell characteristics, without corresponding genetic analysis. Therefore, Fatmucket and Eastern Lampmussel records should be viewed with some caution. Live mussels and the total mass of attached dreissenids were weighed separately (±0.1 g). The presence of byssal threads on live individuals was also recorded. After processing and removal of dreissenids, live mussels were returned to the sediment close to their area of collection.

At each sampling point, substrate composition, soft substrate depth, and aquatic macrophyte cover were characterized. Percent composition of three substrate size classes (clay, silt and organic material, and, sand and gravel) was assessed using visual and tactile observations. Several soft substrate depth measurements were taken within each point using a metre stick, and a single representative value was recorded. Aquatic macrophyte (combined emergent, floating and submergent vegetation) cover was visually assessed using the following categories: none, low (1-25%), moderate (26-50%), and heavy (>50%).

DATA ANALYSIS

Mussel collection data associated with each sampling method were pooled (for each sampling point) prior to analysis. When based on only live individuals, significantly more species (+150%) were detected from each wetland by visual-tactile sampling than clam-raking (Wilcoxon paired-sample test: W = 270, p = 0.002). There was no significant difference when live individuals and fresh shells were used to create species lists (W = 209, p = 0.09).

Based on total relative abundance of live individuals and percent frequency of occurrence, each mussel species was classified as Dominant, Common, Occasional or Rare. Classification was based on the Olmstead-Tukey's test (Sokal and Rohlf 1995), where each category is represented by quadrants of a scatter plot divided by two axes that identify median frequency of occurrence and median relative abundance. Dominant species are encountered at a high frequency and are abundant. Common species are frequently encountered but at low abundances. Occasional species are infrequently encountered but show relative high abundance. Lastly, rare species occur at a low frequency of detection and abundance. Shell length distributions were used to assess population status for each species. The presence of small individuals and multiple length classes were interpreted as evidence of recent and ongoing recruitment (Cudmore et al. 2006; Haag 2012; Zanatta et al. 2015).

Mussel collections from each wetland were characterized based on: (1) number of live individuals; (2) number of sampling points where live individuals were collected; and (3) number of species detected. The degree of fouling by dreissenid mussels was characterized based on the percent of live individuals infested by dreissenids, and the ratio of attached dreissenid mass to live mussel mass (Ricciardi 2003; Lucy et al. 2013). The number of species detected (*i.e.* non-rarefied species richness estimate) was calculated using two datasets: live individuals only, and live individuals plus fresh shells. For each measure, statistical differences among the three wetland types were tested with the Kruskal-Wallis test and Mann-Whitney multiple comparisons. Differences in species richness among wetland types were also assessed using individual- and sample-based rarefaction curves (Colwell et al. 2004). Curves were computed using the estimator Mao's τ and the software EstimateS version 9.1.0 (Colwell 2013). The relationship between number of live individuals collected and number of species detected was tested using the Spearman Rank correlation. Similarities among the mussel assemblages were also visualized using non-metric dimensional scaling (nMDS) based on Bray-Curtis dissimilarity matrices of site by species count data. Significant differences among wetland types were tested using one-way analysis of similarity (ANOSIM) with up to 999 permutations. Species detected at only one wetland (i.e. "<5% of sites"), and sites without live individuals were removed from the dataset prior to analysis. Univariate and multivariate analyses were done using the software PAST version 1.94 (Hammer et al. 2001).

RESULTS

A total of 1640 live individuals (representing 11 mussel species, Table 1) were collected. Live individuals were collected from 83% of wetlands sampled, and, on average (median), from 25% of points sampled within each wetland. In most cases (77%), 10 or fewer individuals of any species were collected from each wetland. Overall, the median number of live individuals collected from each wetland was 3.5 (range: 0 to 560). At the 66% of wetlands where live individuals were present, the spatial distribution of individuals was clumped (variance-mean ratio (Krebs 1989) median = 2.4, range = 0.8 to 70.2).

Between one and five species were detected from each wetland where live individuals were present. The greatest numbers of species were detected from Jordan Harbour (five species), which is located just west of St. Catherines, and three eastern Lake Ontario wetlands located in Prince Edward County (four species from each of Lake Consecon, East Lake and Pleasant Bay). Species richness and the number of individuals collected were strongly correlated (r_s = 0.89, p <0.0001). In total, 399 shells (either halves or whole) were collected. Shells of nine species were found. At half of the wetlands, some species (range: one to three species) were only detected through the collection of fresh shells (Table 2). At four wetlands, the presence of shells was the only indicator of the occurrence of Eastern Elliptio, Fragile Papershell and Paper Pondshell. Shells were also the only evidence of Eastern Pondmussel from Presqu'ile Bay. Sixty-nine percent of live individuals were collected using visual-tactile methods while 31% were collected with the clam-rake.

Dominant species included Eastern Elliptio, Fatmucket and Giant Floater (Table 2). Giant Floater was the most widespread (collected from 73% of wetlands) and abundant species (60% of live individuals collected). Other species were encountered at five or fewer wetlands, and typically represented <10% of the total number of live individuals. Three at-risk mussel species were collected: Eastern Pondmussel (36 collected from seven wetlands), Lilliput (nine collected from one wetland) and Mapleleaf (100 collected from two wetlands). Evidence of recent recruitment was found for five species. For common and dominant species, multiple size-classes were detected at 13 to 71% of wetlands where the species was found (Table 3).

There were habitat differences among sampling points with mussel species at risk and sampling points where more common species were collected (Figures 3-5). Mussel species at risk were frequently collected from areas with softer substrates comprised largely of clay, silt and organic material, and limited aquatic macrophyte cover (<25% cover). Alternatively, common species were more frequently collected from areas with firmer sand and gravel substrates, and greater aquatic macrophyte cover.

Some habitat differences existed among wetland types. Water clarity was significantly greater at lacustrine wetlands (median = 95.4 cm) than barrier beach (median = 26.5 cm) and drowned river wetlands (median = 30.6 cm) (Kruskal-Wallis test: H = 14.7, p = 0.0007; Mann-Whitney pairwise comparisons: p < 0.001). There was significantly less clay substrate at sampling points in lacustrine wetlands (median = 0.4%) than barrier beach (median = 17.7%) and drowned river wetlands (median = 36.3%) (Kruskal-Wallis test: H = 15.32, p = 0.0005; Mann-Whitney pairwise comparisons: p < 0.003). Soft substrate depths were similar among wetland types (range of median values: 16.8 to 20.0 cm). The number of sampling points with limited aquatic macrophyte cover (<25%) was greater at barrier beach (median = 8) and drowned river wetlands (median = 8) than lacustrine wetlands (median = 2.5) (Kruskal-Wallis test: H = 8.7, p = 0.01; Mann-Whitney pairwise comparisons: p < 0.02).

Individual-based rarefaction curves indicate that mussel species were more rapidly detected (as individuals were collected) from barrier beach wetlands than from other wetland types (Figure 6). However, both sample-based rarefaction curves (Figure 6) and univariate comparisons did not indicate any significant differences in species richness among wetland types (Kruskal-Wallis test: live individuals only: H = 0.75, p = 0.69; live individuals and fresh shells: H = 0.78; p = 0.68) (Table 4). The bi-plot of non-metric dimensional scaling (nMDS) site-scores indicated a large degree of overlap in mussel assemblage structure among wetland types in multivariate space (Figure 7). Variation along the first axis represented differences in the numbers of Giant Floater collected, while the second axis separated sites along a gradient of increasing counts of other species and greater species richness. Based on the Bray-Curtis dissimilarity measure, there were no significant differences among wetland types (ANOSIM: R= 0.08, p = 0.07).

Dreissenid mussels were detected at 43% of drowned river mouth wetlands, 57% of barrier beach wetlands, and 83% of lacustrine wetlands. Attached byssal threads or attached live dreissenids were found on live mussels at 14% of drowned river mouth wetlands, 33% of barrier beach wetlands, and 43% of lacustrine wetlands. Up to 243.6 g (mean = 10.8 g) of dreissenids were removed from individual live mussels (n = 758). There were significant differences in the mass ratio of attached dreissenids to live mussels among wetland types (Kruskal-Wallis test: H = 770.6, p <0.0001); with the lowest ratios associated with drowned river mouth wetlands (Mann-Whitney test: p < 0.017). Alternatively, there was no significant difference in the percentage of live individuals with either attached byssal threads or attached live dreissenids (H = 0.49, p = 0.83). Across all wetlands sampled, the mass-ratios of attached dreissenids to live mussels were lowest for Giant Floater and greatest for Eastern Elliptio and Eastern Pondmussel (Figure 8).

DISCUSSION

Results from the semi-quantitative survey support the importance of Lake Ontario coastal wetlands for the conservation of freshwater mussel biodiversity in the lower Great Lakes basin, and provide a baseline dataset for future status assessments of mussel species at risk. Live individuals from two-thirds of the species known historically from the nearshore Canadian waters of Lake Ontario were collected. Our survey identified a similar number of species as recently detected from 34 nearshore Lake Ontario sites in the United States (Bossenbroek et al. 2018). Mussel assemblages were more diverse than those recently sampled in Lake Huron and Lake Michigan (Sherman et al. 2013) but less diverse than Lake St. Clair (Zanatta et al. 2002) and Lake Erie wetlands (Bowers and Szalay 2003, Crail et al. 2011, Zannata et al. 2015, Reid et al. 2016). As seen in other studies (Bossenbroek et al. 2018), mussel collections were numerically dominated by a small number of species (Eastern Elliptio, Fatmucket, and Giant Floater). While species richness and assemblage structure did not vary among different wetland types, there were differences in the occurrence of invasive dreissenid mussels and degree of infestation.

Targeted sampling of lower Great Lakes coastal wetlands to confirm the distribution and population status of imperiled mussel species has been identified as a priority recovery action (Fisheries and Oceans Canada 2014, 2016). This study supported the recovery action for three species. Eastern Pondmussel was formerly considered one of the most common species of the lower Great Lakes (Metcalfe et al. 1998).The species was subsequently believed extirpated from the Canadian waters of Lake Ontario (COSEWIC 2007). We detected Eastern Pondmussel at seven wetland sites; although only one or two live individuals were collected from three of the wetlands. Recently, single live individuals were also collected during intensive sampling of north shore Lake Erie coastal wetlands (Rondeau Bay and Lake Pond in Point Pelee National Park) (Reid et al. 2016, COSEWIC 2017). However, the viability of such small and isolated lower Great Lakes basin subpopulations is uncertain. Targeted sampling of western Lake Ontario wetlands also resulted in the discovery of previously undocumented populations of two mussel species-at-risk (Mapleleaf and Lilliput) (this study, Minke-Martin et al. 2015). The lack of prior knowledge of these species from the Canadian waters of Lake Ontario may reflect the focus of past mussel inventories on sampling southern Ontario rivers. A small number of Eastern Pondmussel and Lilliput were also recently collected from nearshore Lake Ontario sites in waters of the United States (Bossenbroek et al. 2018).

Dressenid mussels were first detected in Lake Ontario in 1989, and subsequently nearshore habitats have been heavily impacted by the extensive coverage and high biomass of dreissenids (Wilson et al. 2006; Pennuto et al. 2012). Dreissenid fouling has subsequently been a major threat to the persistence of native freshwater mussels. Currently, Quagga Mussel is the numerically dominant dreissenid species, with only a small percentage of the biomass represented by the Zebra Mussel (Wilson et al. 2006; Burlakova et al. 2014). In this study, dreissenids were detected at 60% of the coastal wetlands sampled; either as dead shells, or live individuals attached to aquatic macrophytes, native mussel shells and live individuals. Evidence of dreissenid infestation was detected at a similar frequency (44% of live individuals collected) as nearshore and wetland habitats along Lake Erie and Lake Ontario in the United States (Burlakova et al. 2014), but at a much lower frequency than nearby eastern Ontario inland lakes (>75%) (Reid et al. 2017). For all mussel species, mean dreissenid to live mussels mass ratios were well below the threshold (≥1.0) associated with large mortality events (Ricciardi 2003). The overall ratio (mean across all species = 0.066, SE = 0.004) was also equal to that reported for Lake Erie and other Lake Ontario nearshore habitats (Burlakova et al. 2014).

In this study, dreissenid fouling differed among wetland types and among native mussel species. Compared to barrier beach and lacustrine wetlands, dreissenids were less frequently detected at drowned river mouth sites and the mass ratio of attached dreissenids to live mussels was lower. Variation in dreissenid abundance among Great Lakes wetlands has been previously related to a diversity of factors including: water level fluctuation, water flow and retention, water chemistry (conductivity and turbidity), soft substrates that permit native mussels to burrow and remove attached dreissenids, the presence of dense aquatic vegetation, and remoteness of source of veligers (Nichols and Wilcox 1997; Bodamer and Bossenbroek 2008; McGoldrick et al. 2009; Sherman et al. 2013; Zannata et al. 2015). In this study, differences in water clarity, clay substrate and aquatic macrophyte cover were measured between drowned river and lacustrine wetlands (but not barrier beach wetlands), and may explain some of the variation in dreissenid abundance. Additionally, lacustrine wetlands were either directly connected to Lake Ontario or located within large closed embayments; exposing live native mussels to a constant source of veligers.

Mass-ratios of attached dreissenids to live mussels were lowest for Giant Floater and greatest for Eastern Pondmussel; indicating this mussel species at risk is most vulnerable to dreissenid fouling. Unpublished research from Lake St. Clair on the impacts of zebra mussels has shown Eastern Pondmussel to have a low rate of survival (30%) and carry heavy loads of attached zebra mussels (Hunter pers. comm. 2004, cited in COSEWIC 2007). The comparatively low level of infestation on Giant Floater is consistent with that reported for other Lake Erie and Lake Ontario habitats in US waters (Burlakova et al. 2014). In some cases, differences in dreissenid fouling reflected where the species was collected. Almost all live Eastern Elliptio and Fatmucket were collected from lacustrine and barrier beach wetlands, while 41% of live Giant Floater was collected from drowned river mouths. Therefore, it is not clear whether differences are due to species-specific differences such as burrowing behaviour or shell morphology, or reflect small-scale habitat characteristics.

Given the catastrophic losses of freshwater mussel diversity across the Great Lakes, the detection, inventory and continued monitoring of remnant populations in coastal wetlands are important recovery actions. Knowledge of species' distributions, habitat preferences and the relative severity of threats posed by invasive species such as dreissenid mussels is essential to the ongoing management of these imperiled species.The effective implementation of priority recovery actions such as the identification of critical habitat and the targeting of mitigation and remediation activities, depends upon the availability of high quality, temporally relevant data. Ongoing efforts to evaluate these coastal wetland assemblages will be essential to the long term survival and recovery of many of these freshwater mussel species at risk.

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Table 1. Scientific and common names of freshwater mussels collected from Lake Ontario coastal wetlands (follows Williams et al. 2017).

Scientific Name	**Common Name**
Subfamily Ambleminae	
Tribe Lampsilini	
Lampsilis cardium (Rafinesque, 1820)	Plain Pocketbook
Lampsilis radiata (Gmelin, 1791)	Eastern Lampmussel
Lampsilis siliquoidea (Barnes, 1823)	Fatmucket
Leptodea fragilis (Rafinesque, 1820)	Fragile Papershell
Ligumia nasuta (Say, 1817)	Eastern Pondmussel*
Potamilus alatus (Say, 1817)	Pink Heelsplitter
Toxolasma parvum (Barnes, 1823)	Lilliput*
Tribe Pleurobemini	
Elliptio complanata (Lightfoot, 1786)	Eastern Elliptio
Tribe Quadrulini	
Quadrula quadrula (Rafinesque, 1820)	Mapleleaf*
Subfamily Anodontinae	
Tribe Anodontini	
Pyganodon grandis (Say, 1829)	Giant Floater
Utterbackia imbecillis (Say, 1829)	Paper Pondshell

**species at risk*

Table 2. Comparison of the relative abundance (RA) and frequency of occurrence (FO) of freshwater mussels collected from three Lake Ontario coastal wetland types. FO was calculated separately using species lists for live individuals and for fresh shells (whole or single valves).

		Barrier Beach (n=12)			Drowned River (n=14)			Lacustrine (n=14)		
Common Name	**Class[1]**	**RA**	**FO-live**	**FO-shells**	**RA**	**FO-live**	**FO-shells**	**RA**	**FO-live**	**FO-shells**
Eastern Elliptio	D	11.0	16.7	33.3	0.4	7.1	14.3	59.6	21.4	50.0
Eastern Lampmussel	R	0.1	8	0	0	0	0	0	0	0
Eastern Pondmussel	C	1.1	16.7	0	3.5	21.4	14.3	3.9	14.3	28.6
Fatmucket	D	23.3	25.0	41.7	0	0	7.1	15.2	50.0	50.0
Fragile Papershell	R	0	0	8.3	1.5	7.1	21.4	0	0	14.3
Giant Floater	D	59.2	83.3	75.0	73.4	64.3	64.3	19.1	71.4	35.7
Lilliput	R	0	0	0	1.7	7.1	0	0	0	0
Mapleleaf	R	0	0	0	18.5	14.3	14.3	0	0	0
Paper Pondshell	C	1.2	33.3	41.7	0.9	21.4	28.6	0.6	7.1	21.4
Pink Heelsplitter	R	0	0	0	0	0	0	1.1	7.1	7.1
Plain Pocketbook	R	4.1	8	8	0.2	7.1	0	0.6	7.1	0

1: D = dominant; C = common; R = rare

Table 3. Variation in median (range) shell length across nine freshwater mussel species collected from 40 Lake Ontario coastal wetlands. Recent Recruits are the numbers of wetlands where individuals < 40 mm shell length were collected. Multiple Length Classes are the numbers of wetlands where both short and long shells were collected.

Common Name	Shell Length (mm)	Recent Recruits	Multiple Length Classes
Eastern Elliptio	66 (29-151)	1	4
Eastern Pondmussel	104 (47-126)	0	5
Fatmucket	83 (39-185)	1	3
Fragile Papershell	104 (82-162)	0	1
Giant Floater	103 (26-229)	5	12
Lilliput	37 (26-72)	0	1
Mapleleaf	99.5 (38-133)	1	2
Paper Pondshell	77 (38-207)	1	1
Plain Pocketbook	81 (60-119)	0	1

Table 4. Abundance, species richness, and evidence of dreissenid infestation for freshwater mussel assemblages sampled in three Lake Ontario coastal wetland habitat types. Wetland type codes: BB = barrier beach; DR: drowned river mouth; and, LA= lacustrine.

	Median (minimum, maximum)		
Parameter	**BB (n=12)**	**DR (n=14)**	**LA (n=14)**
Live individuals (count)	3.5 (0, 560)	6 (0, 200)	2 (0, 102)
Sampling points with live mussels	3 (0, 12)	3 (0, 11)	2 (0, 10)
Species Richness[1]	1.5 (0, 4)	1.5 (0, 5)	1 (0, 4)
Species Richness[2]	2 (0, 4)	1.5 (0, 5)	1 (0, 4)
Live individuals with evidence of dressenids (%)	0 (0, 100)	0 (0, 100)	25 (0, 100)

1: live individuals only; 2: live individuals and fresh shells

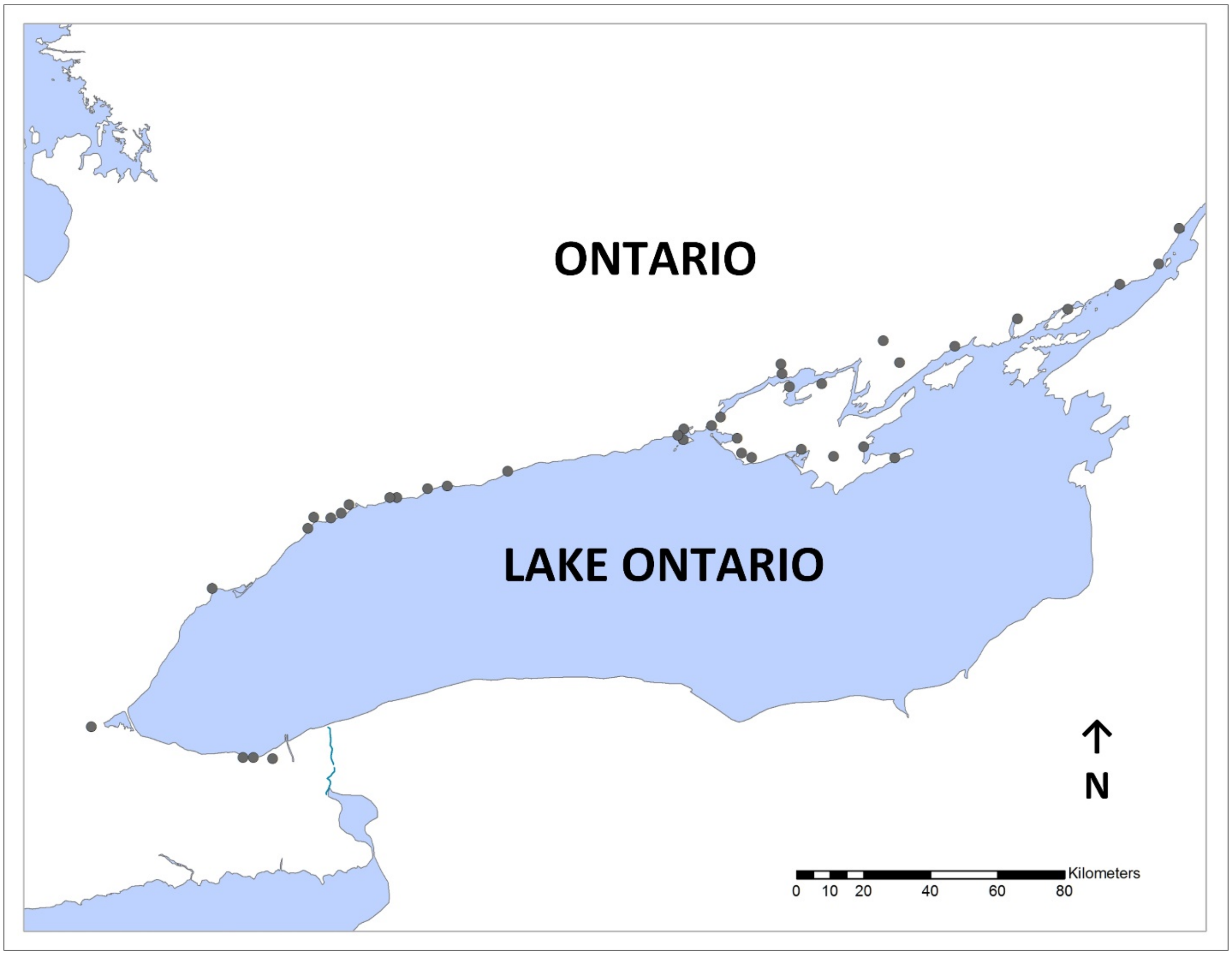

Figure 1. Distribution of 40 Lake Ontario coastal wetland sites sampled from 2011 to 2015.

Figure 2. Lake Ontario examples of the three hydrogeomorphic coastal wetland classes sampled 2011 to 2015. Upper panel: barrier beach - Oshawa Second Marsh; middle panel: drowned river-mouth - 16 and 17 Mile Creek; and lower panel: lacustrine - Presqu'ile Bay.

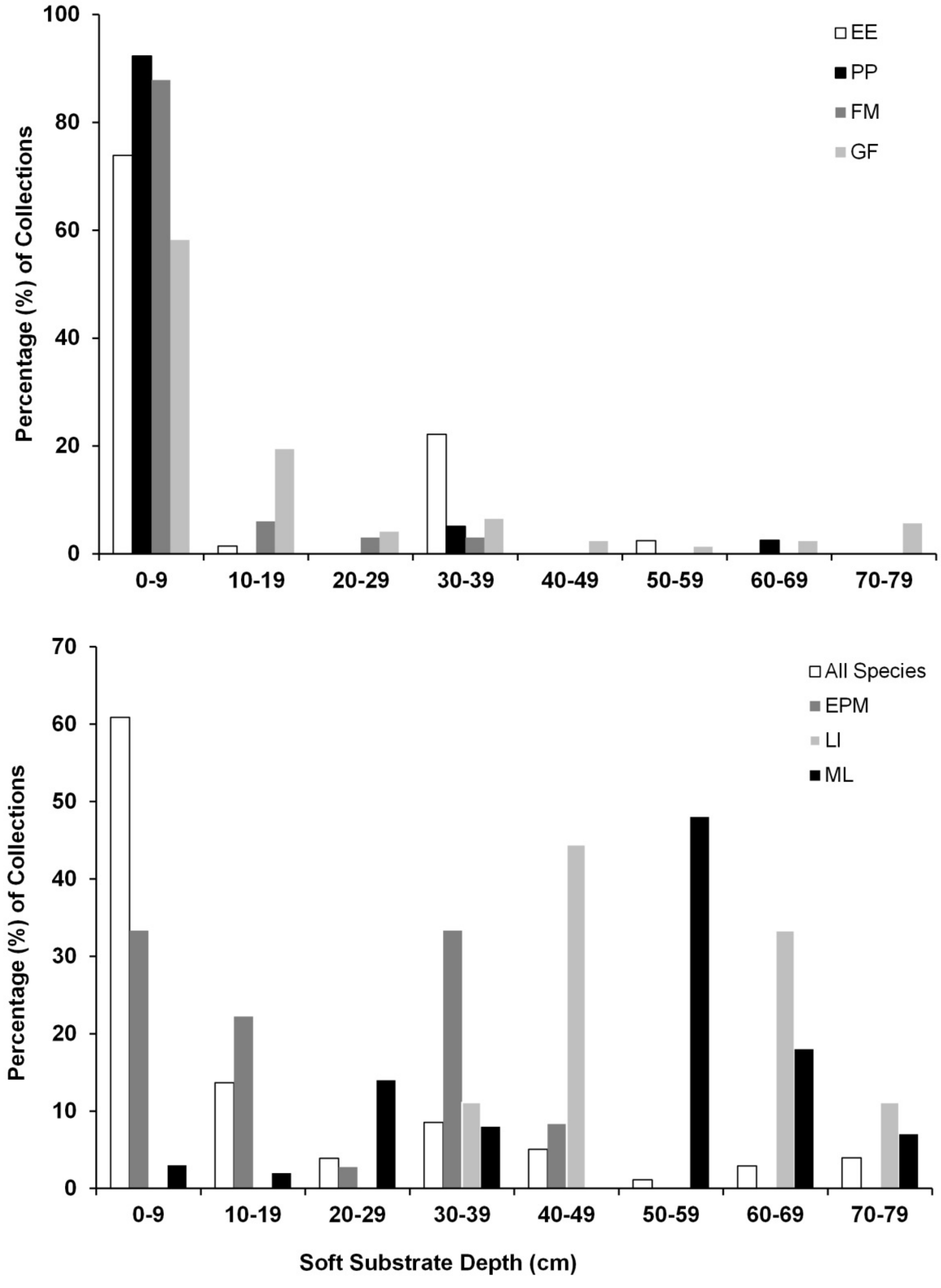

Figure 3. Variation in soft substrate depth across Lake Ontario wetland sampling points where seven freshwater mussel species were collected. Species codes: EE= Eastern Elliptio; FM = Fatmucket; EPM = Eastern Pondmussel, GF = Giant Floater; LI = Lilliput; ML = Mapleleaf; PP = Plain Pocketbook.

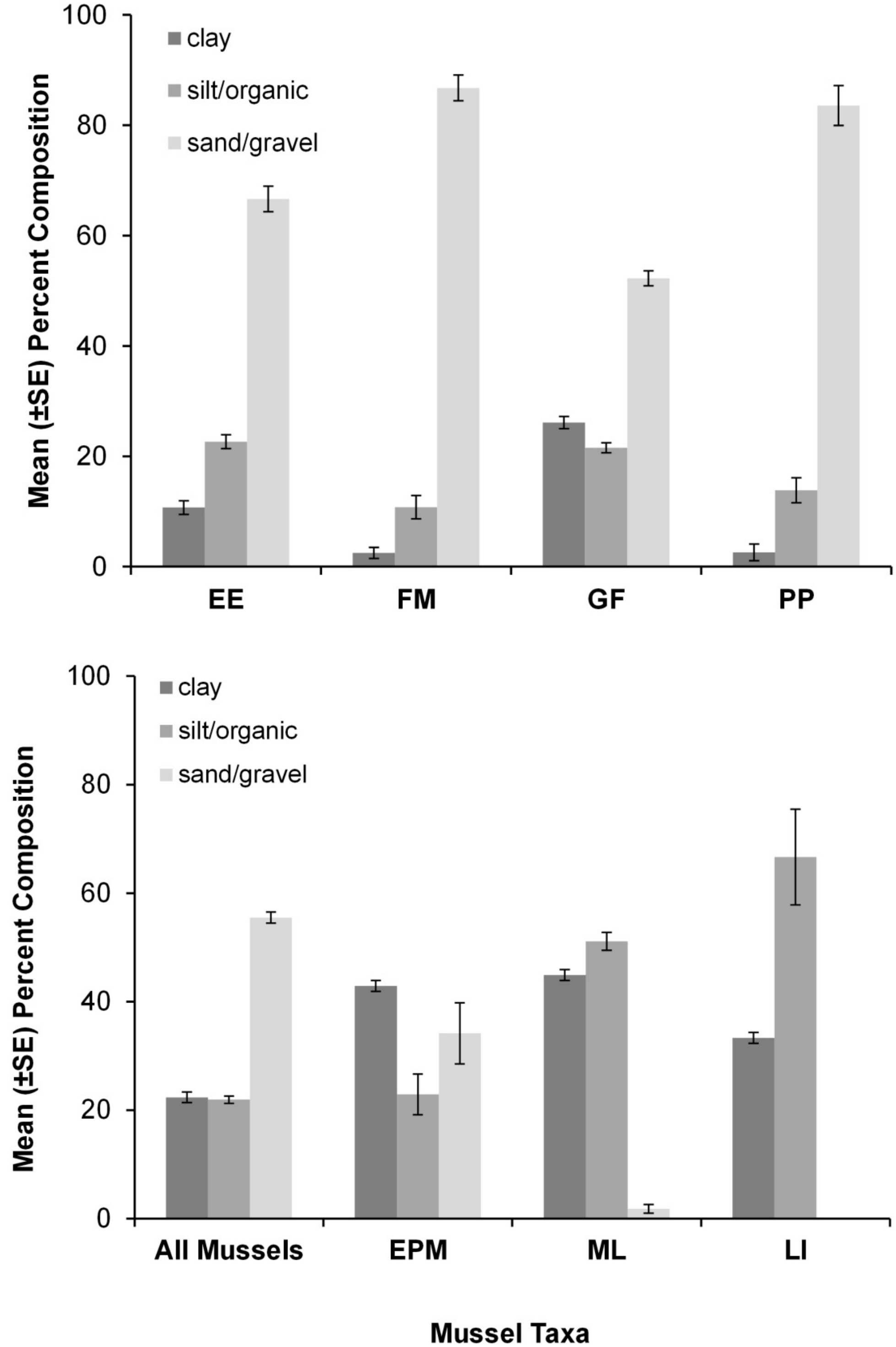

Figure 4. Variation in substrate composition across Lake Ontario wetland sampling points where seven freshwater mussel species were collected. Species codes: EE= Eastern Elliptio; FM = Fatmucket; EPM = Eastern Pondmussel, GF = Giant Floater; LI = Lilliput; ML = Mapleleaf; PP = Plain Pocketbook.

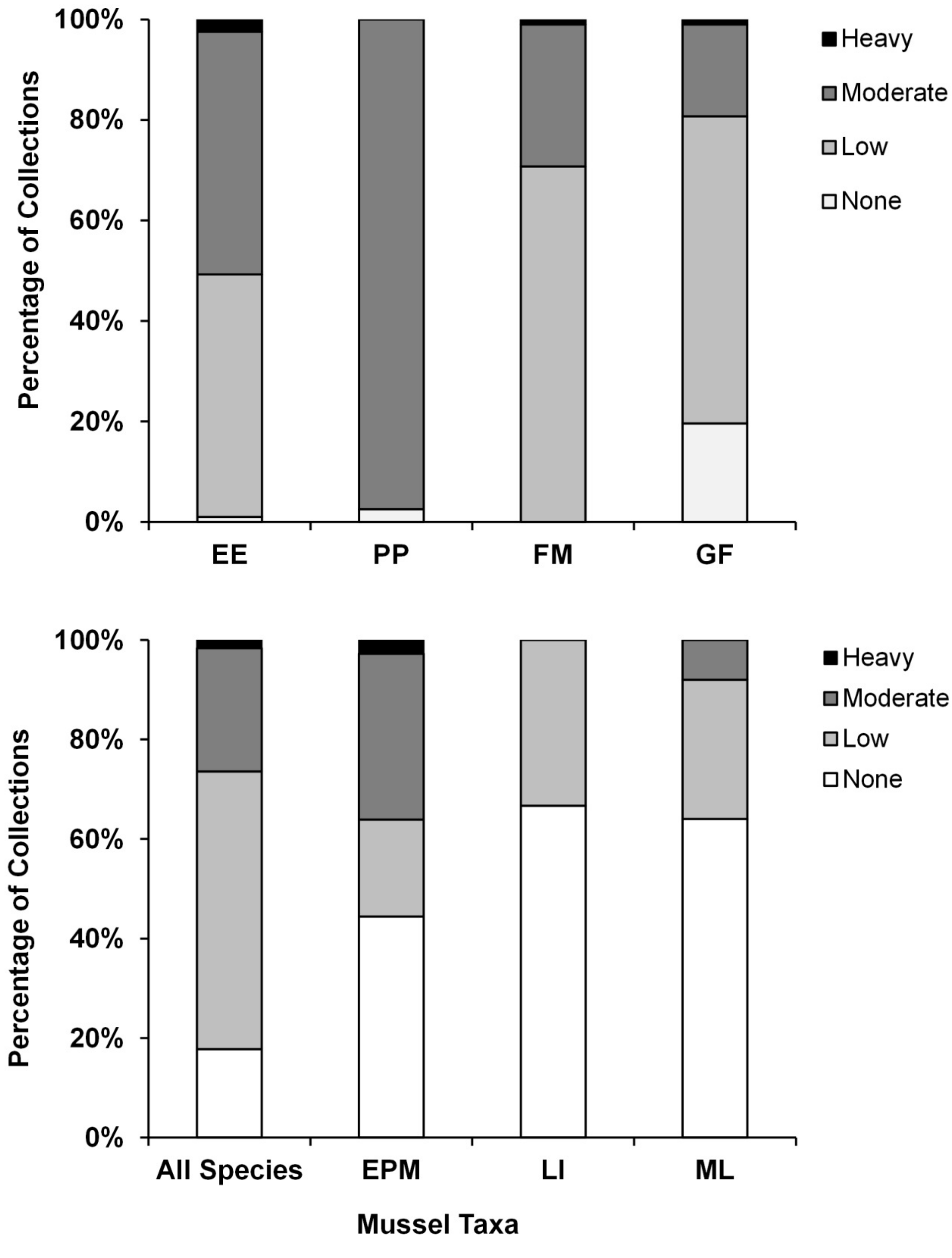

Figure 5. Variation in aquatic macrophyte coverage across Lake Ontario wetland sampling points where seven freshwater mussel species were collected. Macrophyte coverage categories: low (1-25%), moderate (26-50%), and heavy (>50%). Species codes: EE= Eastern Elliptio; FM = Fatmucket; EPM = Eastern Pondmussel, GF = Giant Floater; LI = Lilliput; ML = Mapleleaf; PP = Plain Pocketbook.

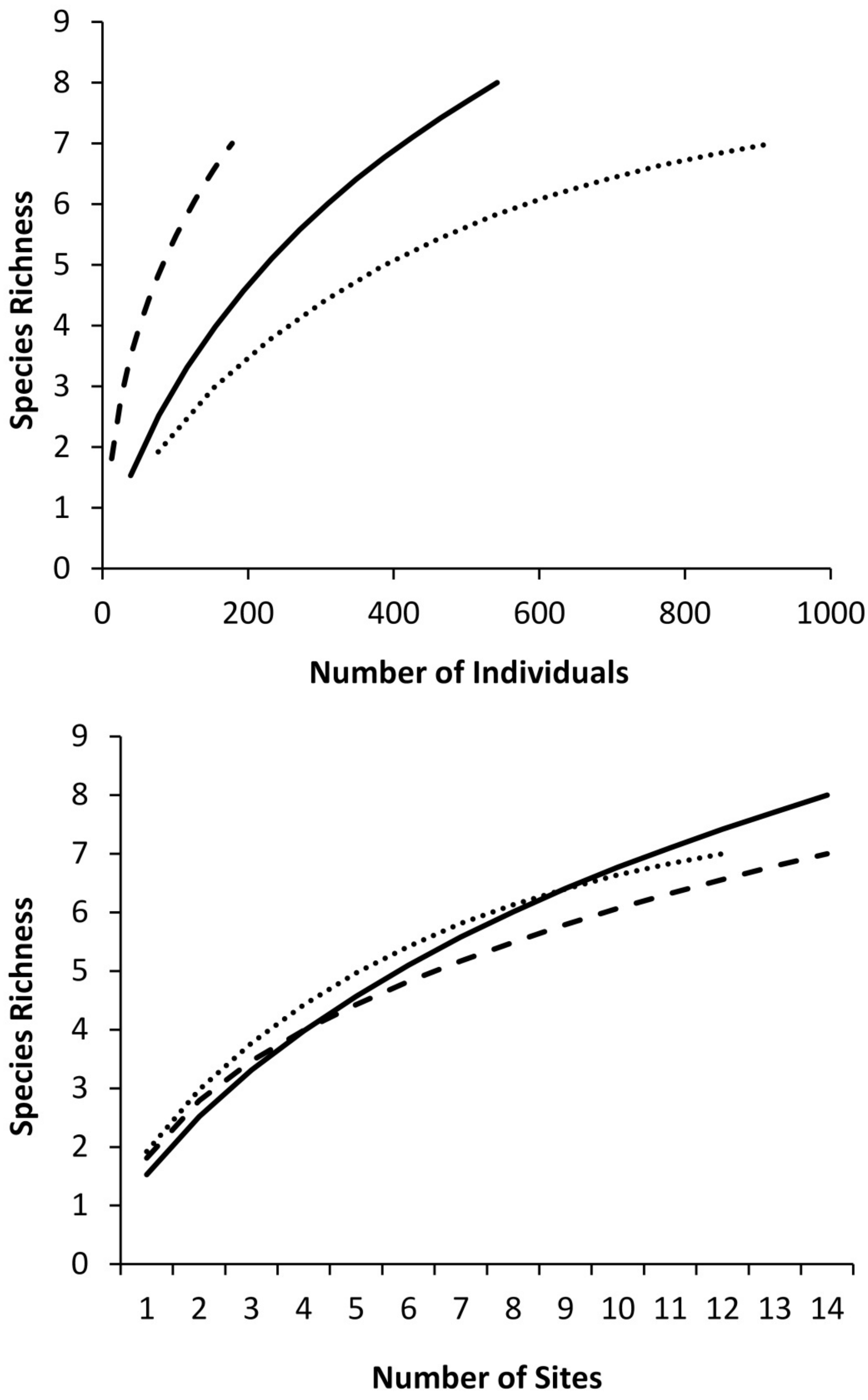

Figure 6. Individual- (upper panel) and sample-based (lower panel) species accumulation curves for freshwater mussel assemblages associated with three Lake Ontario coastal wetland types: barrier beach (••••), drowned river mouth (---) and lacustrine (▬). Richness was estimated using Mao's τ.

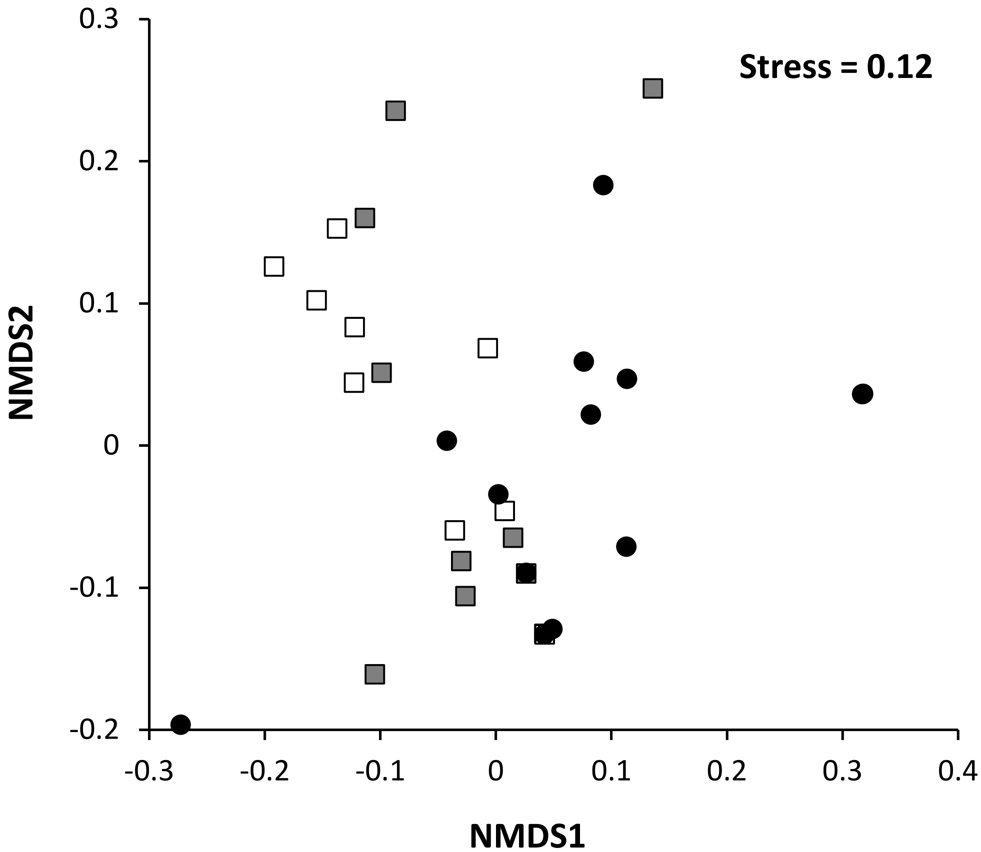

Figure 7. nMDS ordination of freshwater mussel assemblages from three Lake Ontario coastal wetland types: barrier beach (■), drowned river mouth (□) and lacustrine (●). Ordination was based on species counts and the Bray-Curtis dissimilarity measure.

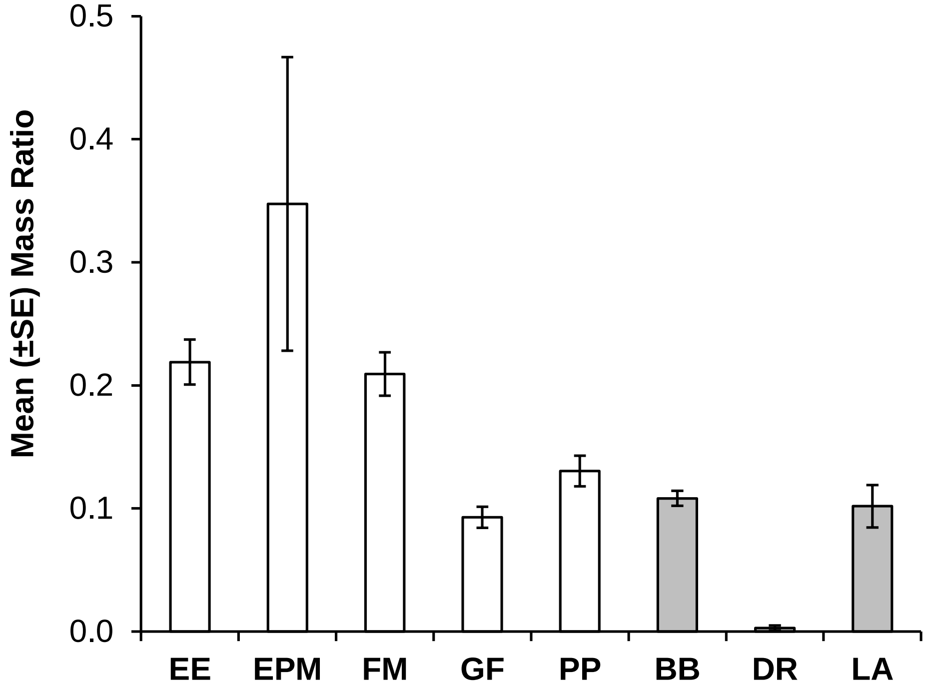

Figure 8. Comparison of the mass (g) ratios of attached dreissenids to live individuals among freshwater mussel species, and Lake Ontario wetland types. Species codes: EE = Eastern Elliptio, EPM = Eastern Pondmussel; FM = Fatmucket; GF = Giant Floater; and, PP = Plain Pocketbook. Wetland type codes: BB = barrier beach; DR: drowned river mouth; and, LA= lacustrine.