Disentangling the effects of wetland loss and urban development on the quality of remaining wetlands

by

Theresa Patenaude

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Abstract

The relative effects of wetland loss and urbanization on the quality of remaining wetlands is poorly understood due to correlations between these landscape variables. My main objective was to determine the relative effects of wetland loss and urbanization on wetland quality. I accomplished this by selecting a set of wetlands for which amount of surrounding wetland cover and impervious cover were uncorrelated, at multiple spatial extents. Wetland quality was inferred through vegetation and benthic macroinvertebrate abundance and taxa richness. I found that wetland loss is more detrimental than urbanization to remaining wetland quality. My results indicate that policies aimed at reducing the impacts of urbanization surrounding wetlands will only partly be successful. Wetland management policies should also include wetland restoration in the landscape.

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Introduction

Although wetlands are highly productive and ecologically important systems, they are increasingly threatened by human disturbance. In southern Ontario, conversion of wetland to agriculture and urban areas has resulted in over 72% loss of wetlands, and they continue to be lost at an alarming rate (Ducks Unlimited Canada 2010). Remaining wetlands are becoming more isolated and are increasingly surrounded by urbanized lands. Thus, two common threats to wetlands are urbanization and wetland loss (Ducks Unlimited Canada 2010).

There are several mechanisms by which urban development and wetland loss impact remaining wetland quality. Urban development affects wetland quality through alteration of the natural hydrologic cycle. Water flows over impervious surfaces (e.g., roads, buildings) instead of being retained by soils and vegetation, which modifies the volume and quality of runoff (Scholes et al. 1998; Centre for Watershed Protection 2003). Urban stormwater runoff may contain trace metals (lead, zinc, copper, cadmium, nickel), de-icing salts, and nutrients which flow into nearby wetlands, changing wetland water and sediment chemistry (Scholes 1998; Revitt et al. 1999; Shutes et al. 1999; Centre for Watershed Protection 2003).

There are two mechanisms by which wetland loss is thought to impact wetland quality. When surrounding wetland habitat is lost, remaining wetland becomes more isolated. Isolation decreases the likelihood of species immigrating to the remaining wetland, thus decreasing its equilibrium species richness (MacArthur and Wilson 1967; Leibowitz 2003). Second, the presence of wetlands can play a role in pollution mitigation since wetlands can remove pollutants from stormwater runoff through

biofiltration and biological uptake (Revitt et al. 1999). Thus, the more wetland lost in an urban region, the lower the total wetland capacity to take up pollutants from stormwater runoff.

As stated by Yates and Bailey (2010), the relative effects of landscape disturbances to freshwater systems are poorly understood due to correlations between landscape variables. Wetland loss and urban development are often correlated since wetlands are frequently destroyed to allow for urban development. However, understanding the relative effects of wetland loss and urban development on the quality of remaining wetlands has important implications for management actions. For example, if the positive effect of adjacent wetland amount on wetland quality is larger than the negative effect of adjacent urban development, effective mitigation measures should include wetland preservation and restoration in the landscape. Currently, most mitigation decisions regarding wetland protection in North America follow a three-step sequence where wetland preservation and restoration is the last step considered. The first step is to avoid impacts, the second is to minimize unavoidable impacts and the third is to compensate for impacts through wetland restoration, creation, or protection (Clare et al. 2011). For instance, many municipalities in Ontario employ measures to protect wetlands from the impacts of urban development, but there are fewer actions aimed at restoring wetlands. Within Ontario, the Conservation Authorities Act (OMNR 1990) protects wetlands by regulating activities and development in and around wetlands with the objective of controlling floods, erosion, pollution, and the conservation of land. In addition, the Fisheries Act protects wetlands as fish habitats if they are known to

contribute to a fishery (Department of Justice Canada 2011). No strict wetland preservation goals or restoration policies exist under this Act.

Wetland quality refers to the health and integrity of ecosystem functions (e.g., decomposition and element/nutrient cycling) and is often measured through biological components which are responsive to environmental stress (Rader 2001). Ecosystem functions and biological components are strongly linked since ecosystem functions (e.g., element cycling) affect biota (e.g., vegetation), and in turn biota (e.g., invertebrates) affect ecosystem functions (e.g., decomposition; Rader 2001). Research in freshwater systems suggest that species assemblages respond earlier than measures of ecosystem function to environmental stress, making them more sensitive indicators of environmental change (Schindler 1987; Karr 1991; Yoder and Rankin 1998).

Two of the most common taxa used to infer wetland quality are plants and benthic macroinvertebrates (Helgen and Gernes 2001). These taxa are good indicators of wetland quality because they: 1) are sensitive to many chemical, physical, and ecological changes in the environment (nutrient enrichment, light availability, competition; Pinel-Alloul et al. 1996; Loughheed et al. 2001; Scheffer et al. 2001), 2) integrate elements from local runoff and sediment contamination and transfer them to higher trophic levels (Pinel-Alloul et al. 1996; O'Connor et al. 2000; Lopez et al. 2002), and 3) respond to environmental change relatively quickly (Helgen and Gernes 2001; Scheffer et al. 2001; Valley and Drake 2007; Beck et al. 2010). Landscape-scale studies have shown that wetland vegetation richness is negatively affected by urban development (Findlay and Houlihan 1997; Houlihan et al. 2006) and wetland isolation (Houlihan and Findlay 1997; Galatowitsch et al. 2000; Lopez et al. 2002; Gledhill et al. 2008). The effect of the

landscape on benthic macroinvertebrates is less clear. Richness has been observed to decline with urban development (Mensing et al. 1998; Hall et al. 2004) and wetland isolation (Mensing et al. 1998; Gledhill et al. 2008), but has also been observed to have no relationship with the surrounding landscape (Tangen et al. 2003; Alsfeld et al. 2010).

Although numerous studies have looked at both the effects of urban development and wetland loss (Houlahan and Findlay 1997; Mensing et al. 1998; Hall et al. 2004; Houlahan et al. 2006; Galatowitsch et al. 2000), their relative effects on the quality of remaining wetlands is largely unknown. In previous studies, survey wetlands were generally chosen to represent a gradient of disturbance from least to most impacted without controlling for collinearity between landscape predictors (Findlay and Houlahan 1997; Galatowitsch et al. 2000; Lopez et al. 2002; Hall et al. 2004; Houlahan et al. 2006; Gledhill et al. 2008), making it impossible to determine the independent effects of wetland loss and urban development. Mensing et al. (1998) report a low correlation between wetland cover and urban cover, but urban cover only represented a mean of 2-3% of their landscapes and only occurred in 40% of their landscapes, so the full potential effects of urban development were not measured in their study.

Therefore, the first objective of this study (objective 1) was to determine the relative effects of urbanization and wetland loss on the quality of remaining wetlands. I accomplished this by selecting a set of wetlands in which the amounts of surrounding wetland cover and urban development (measured as impervious cover) are uncorrelated, and I inferred wetland quality through wetland vegetation and benthic invertebrate abundance and taxa richness.

Since different landscape predictors influence wetlands through different mechanisms and these may operate at different spatial scales, a multi-scale approach should be used to evaluate the impact of the landscape on wetlands (Allan and Johnson 1997). Land-use impacts on wetland vegetation assemblages have been shown to occur at different scales (regional groundwater regime, local soil chemistry; Verhoeven et al. 1998), and benthic macroinvertebrates in streams were found to respond to both reach and watershed-scale features (Richards et al. 1997; Stephenson and Morin 2009). To appropriately assess wetland quality, the scale(s) at which vegetation and benthic macroinvertebrates are most sensitive to the landscape must be identified. Moreover, dispersal mode may affect the scale at which different types of vegetation and benthic invertebrates are affected by the landscape. For isolated water bodies such as wetlands, I predict that plants that employ aquatic dispersal will be more dispersal-limited and therefore respond to the landscape at smaller spatial scales than aerially dispersing vegetation. Likewise, invertebrates confined to aquatic dispersal are expected to have weaker dispersal capacities between isolated water bodies than invertebrates capable of flight (Leibowitz 2003; Petersen et al. 2004; Mykrä et al. 2007). Thus, invertebrates with aquatic dispersal will likely respond to the landscape at smaller spatial scales than those that fly.

Therefore, the second objective of this study (objective 2) was to determine the spatial scale(s) at which the landscape most strongly affects wetland quality, and to determine whether the spatial scale of effect varies with dispersal mode.

Methods

I used a focal patch design (Brennan et al. 2002) to study the independent effects of surrounding wetland amount and urban development on the quality of focal wetlands. Wetland amount was measured as the wetland cover and urban development was measured as impervious cover in the landscapes surrounding focal wetlands. Wetland quality was measured as the abundance and taxa richness of vegetation and benthic invertebrates in focal wetlands. The study was conducted in shallow open-water wetlands in eastern Ontario (Figure 1). This region has a flat topography (Thompson 2000) and is covered by about 9% urban areas and roads, 8% wetlands, 32% forest (mixed-wood and deciduous stand) and 51% agriculture (cropland and pasture; OMNR 1998; OMNR 2003).

Site selection

Wetland cover and impervious cover are generally negatively correlated across the region. A random selection of study sites would therefore not have allowed me to determine the independent effects of these two landcover types on wetland plants and invertebrates. Since this was my objective, I performed a systematic selection of focal wetlands, aimed at minimizing the correlation between wetland cover and impervious cover in the surrounding landscapes. My approach was to search for an equal number of focal wetlands in each of the four combinations of landscapes with low and high wetland and impervious cover (Figure 2). In particular, this meant searching for the rare wetlands that occur in landscapes with both high wetland cover and high impervious cover.

The site selection process was as follows. First, I identified all wetlands in eastern Ontario that had a perimeter between 100 and 900m, to minimize size differences among

focal wetlands (Figure 2). This resulted in 4048 candidate sites. Next, I determined landscape composition within .5, 1 and 1.5 km of each of these candidate wetlands. To eliminate potential confounding landscape variables, only focal wetlands with approximately equal amounts of forest and agriculture (cropland + pasture) in the landscape were considered potential survey sites. Neither forest nor agriculture could exceed 66% or fall below 33% of the total landcover occupied by these two landscape variables. This step reduced the number of candidate wetlands to 1111. The next step was to find a combination of these sites that minimized the correlation between wetland cover and impervious cover, while maximizing variation within each of these two variables (Figure 2). Based on this criterion, the candidate wetlands were reduced to those containing wetland cover in the range 0-10% of the surrounding landscape and impervious cover in the range 0-22% of the surrounding landscape (Figure 2). These steps reduced the number of candidate focal wetlands to 726. These 726 candidate wetlands were then divided into 4 combinations or quadrants, using the landscape data at the .5km scale: (i) high wetland cover, high impervious cover (22 sites); (ii) high wetland cover, low impervious cover (102 sites); (iii) low wetland cover, high impervious cover (76 sites); (iv) low wetland cover, low impervious cover (526 sites; Figures 2 and 3). Since the combination of high wetland cover and high impervious cover had the fewest possible sites, I mimicked the spread of these sites within that quadrant to sub-select 20-25 sites within each of the other three quadrants. By mimicking the spread within each quadrant I ensured there would be no correlation between wetland cover and impervious cover across the resulting set of candidate wetlands. This step reduced the candidate wetlands to 92. From these I determined the subset that remained uncorrelated when the

landscape variables were measured at the two larger spatial scales (1 and 1.5 km). Sites did not necessarily remain within the same quadrant at each spatial scale, but as a whole, wetland cover and impervious cover remained uncorrelated at each scale. Final candidate focal wetlands had non-overlapping 1.5km radius landscapes and were referenced against aerial photos (OMNR 2008) to ensure they contained standing water. A total of 40 candidate sites were available at this stage. Of these I chose 21 sites for sampling, after conducting site observations and obtaining permission for sampling from the landowners. In addition to these 21 sites, I selected one site with extreme (high) wetland cover and two sites with extreme (high) impervious cover for sampling. I did this to test whether the statistical relationships uncovered based on the 21 wetlands could be extrapolated beyond the ranges of the landscape values for these wetlands (Figure 4). The 24 focal wetlands are shown in Figures 1 and 4.

Forest cover, impervious cover, and wetland cover were based on the Ontario Geospatial Data (OMNR 2003), and agriculture cover was based on Ontario Classified LANDSAT data (OMNR 1998). All were quantified using ArcGIS10 (ESRI 2010).

Field surveys

The 24 focal wetlands were surveyed for plants and benthic macroinvertebrates during the summer of 2010. To avoid temporal bias in the wetland surveys, I used a randomized block design. Days of the week were randomly assigned to the quadrants (Figures 2 and 3): Mondays: high impervious, low wetland; Tuesdays: low impervious, high wetland; Wednesdays: low impervious, low wetland; Thursdays: high impervious, high wetland; Fridays: extreme sites. Next, focal wetlands were blocked into groups of four or five: one focal wetland from each quadrant was randomly chosen per block.

These blocks were then assigned to a week within each 5-week sampling round (see below).

Vegetation surveys

Vegetation sampling took place during two sampling rounds, where the surveys during the first round (7 June to 9 July) were more intensive than those during the second round (13 July to 13 August). During the first round I placed three 1x1m floating quadrats along ten transects perpendicular to the shore, dispersed at even intervals around the focal wetland (Figure 5). During the second round, the first transect was located midway between transects 10 and 1, between transects 3 and 4 and between transects 7 and 8 from the first round of sampling (Figure 5).

Along each transect, I placed quadrats where the water depth was approximately .25, .50, and 1m (Figure 5). In some instances the shoreline was steep and it was not possible to fit 3 quadrats along a transect, in which case only one or two quadrats were surveyed per transect. At other sites where the focal wetland did not reach a 1m depth, the quadrats were placed at equal distances from one another between the shoreline and 4m from the centre of the focal wetland. Since the number of quadrats varied between focal wetlands, I included it as a local predictor in my backwards stepwise regressions (see below). I recorded water depth at each quadrat location.

To estimate vegetation cover, the quadrat was subdivided into 25 sampling units using string. I then counted the number of sampling units in each quadrat in which floating, emergent, and submerged vegetation occurred. I also identified each vegetation type to the lowest taxonomic level possible (typically species but occasionally genus or family) and recorded its abundance in the quadrat based on the number of sampling units

it occupied. I counted and identified emergent and floating vegetation first, and then I passed a rake through each of the 25 sampling units to bring the submerged vegetation to the surface for enumeration and identification. When identification was not possible in the field, I took a sample back to the lab for further investigation. Crow and Hellquist (2000), and Newmaster et al. (1997) were used for identification.

Benthic macroinvertebrate surveys

Benthic macroinvertebrates were sampled from 13 July to 13 August along the same three transects as the vegetation sampling transects in round two (Figure 5). Invertebrates were sampled using a 500µm D-framed net. I waded into the wetland to approximately 1m depth and sampled using the kick-and-sweep method toward shore for approximately 1min. If the distance between 1m depth and the shore was too short to sample for 1 min, I moved 1m to the right and did another transect until 1min of sampling was complete.

Wetland kick-and-sweep samples contained a large amount of sediment, debris, and organic matter from which invertebrates had to be sorted. Invertebrates and debris were kept cool using ice, and were transported back to the lab live in large containers. Since the volume of debris and invertebrates was too great to sort in a timely manner, the kick-and-sweep sample was randomly subsampled. To do so, the initial volume of the entire kick-and-sweep sample was first recorded, then the entire sample was randomized by stirring, and then a 140ml subsample was removed using a beaker. The random subsample was poured into a white tray to aid with visual sorting. All benthic macroinvertebrates from the random subsample were removed from the debris and preserved in >70% ethanol for later identification. Random 140ml subsampling of the

original sample was repeated until 100 individuals had been removed from the entire kick-and-sweep sample. Note that all invertebrates from the subsample containing the 100th individual were removed (and later identified) in order to allow me to scale up the subsample estimates to an estimate of the number of invertebrates within the total volume sampled. Since three kick-and-sweep samples were taken at each focal wetland, 300+ individuals were identified per site. The total number of individuals identified from a site varied from 300 to 838 with an average of 372 individuals identified per focal wetland. The abundance of benthic macroinvertebrates in the subsamples and the combined volume of the subsamples were then used to estimate the total number of invertebrates in the volume of the entire 1min kick-and-sweep sample (Appendix A). Invertebrates were identified to the family level except for water mites (grouped as Hydracarina) and nematodes (grouped as Nematoda). Merritt and Cummins (2008), McCafferty (1998) and Pennak (1978) were used as references for identification.

Water chemistry

I sampled water chemistry once per sampling round at the deepest location along the last transect at each focal wetland. Temperature, pH, and conductivity were sampled using a hand-held meter (Hanna Instruments). I obtained a water column sample using an integrated tube sampler to measure water colour. At the lab, the water sample was .45µm filtered and water colour was measured spectrophotometrically as absorbance at 440nm. The absorption coefficient was then calculated according to Cuthbert and del Giorgio (1992). All water chemistry values were averaged between the two sampling rounds for input into the backwards-stepwise regressions (see statistical analyses below) except that only the temperature value for the second round of sampling was used to

determine the effects of temperature on benthic invertebrates (since invertebrates were only sampled in the second round).

Statistical analyses

Given the potential management implications of the study, I opted to use response variables in common use in wetland quality assessments. For vegetation the response variables were: species richness (U.S. EPA. 2002*b*; Mack 2007; Alsfeld et al. 2010) and percentage of the focal wetland covered by vegetation (U.S. EPA. 2002*b*; Mack 2007; Alsfeld et al. 2010). For benthic invertebrates the response variables were: family richness (Mensing et al. 1998; U.S. EPA. 2002*a*; McCormick et al. 2004; Alsfeld et al. 2010), abundance of individuals in a 1min kick-and-sweep sample (Mensing et al. 1998; McCormick et al. 2004; Stewart and Downing 2008), percentage of the individuals consisting of Ephemeroptera, Odonata, and Trichoptera (%EOT; U.S. EPA. 2002*a*; McCormick et al. 2004; Stewart and Downing 2008); and percentage of the individuals consisting of Amphipoda (%Amphipoda; U.S. EPA. 2002*a*; McCormick et al. 2004; Uzarski et al. 2004; Stewart and Downing 2008). These response variables are all expected to decrease with decreasing wetland quality. To ensure that these response variables were not spatially autocorrelated across the focal wetlands, I conducted Moran's *I* tests for each.

The following statistical analyses were conducted using data from the 21 focal wetlands that had been selected to avoid a correlation between wetland cover and impervious cover (see site selection; Figures 1 and 2). The spatial scale of effect of the landscape variables on focal wetland vegetation and invertebrates was unknown *a priori*. I first conducted simple linear regressions of each response variable against wetland

cover or impervious cover at multiple spatial scales (.2km-2.6km at .2km intervals) to determine the scale at which each landscape variable affected each response variable most strongly (objective 2; Houlahan et al. 2006; Eigenbrod et al. 2008; Ethier and Fahrig 2011), based on the absolute value of the regression coefficients (Smith et al. 2009). To assess whether dispersal ability affected the scale at which vegetation and invertebrates responded to the landscape (objective 2), I separated benthic invertebrate richness into families capable of flight at some stage in their life histories (aerial dispersal), and families which are confined to the aquatic environment (aquatic dispersal) and I separated wetland vegetation into species that have seeds above the surface of the water (aerial dispersal) and species whose seeds are found underwater (aquatic dispersal). I then conducted simple linear regressions to assess the scale of greatest effect of the landscape variables on each response variable in each of these categories separately (see above). To assess collinearity among landscape variables (wetland cover, impervious cover, forest cover, agricultural cover), I examined pairwise Pearson correlations at the scales of greatest effect for each response variable.

I tested all local, landscape, and response variables for normality using Kolmogorov-Smirnov tests and Q-Q plots. I was not able to control for local variables (wetland area, wetland perimeter, date, temperature, pH, conductivity, colour, maximum depth, number of quadrats) in the site selection, so I first conducted backwards-stepwise regressions (p -to-remove ≥ 0.05) to determine which local variables significantly affected the response variables. I retained any local variables that were significant ($p < 0.05$) in the last step of the stepwise regressions of any vegetation response variable in analyses of landscape predictors on vegetation responses (below). Likewise, I retained any local

variables that were significant ($p < .05$) in the last step of the stepwise regressions of any invertebrate response variable in analyses of landscape predictors on invertebrate responses (below).

Relative importance of wetland cover and impervious cover (objective 1) was assessed by conducting General Linear Models (GLM) of these landscape predictors at the scales of greatest effect determined for each response variable (see above). I conducted two GLMs for each response variable. The first included only the landscape predictors ("landscape only models"). The second included the landscape predictors plus the local predictors that were significant in the last step of the stepwise regressions (see above; "landscape+local models"). Relative importance of predictors was assessed using standardized regression coefficients (Smith et al. 2009).

Following these statistical analyses, I used the vegetation and invertebrate data from the three "extreme" sites in a post hoc test of the degree to which the model results based on the 21 sites (with uncorrelated wetland cover and impervious cover) could be extrapolated beyond the ranges of the landscape predictors in these 21 sites. Expected values of the response variables for each extreme site were obtained by inserting its landscape values in the statistical models (Appendix B). A range of expected values was obtained by determining the 95% confidence intervals of the residuals for each model and extending this range around the expected values for the extreme sites (Appendix B). The observed value of a response at an extreme site was then compared to its expected range, to determine whether the observed was within the expected range. This process was performed twice, first using the landscape only models and then using landscape+local models.

All statistical analyses were conducted using IBM SPSS Statistics 19 (2010) except for Moran's I , which was conducted in ArcMap 10 (ESRI 2010).

Results

Overall, I identified 92 taxa of vegetation and 67 taxa of benthic macroinvertebrates across all focal wetlands. The most commonly encountered vegetation taxa were *Chara* sp. (present at 18/24 sites), *Lythrum salicaria* (18/24), *Lemna minor* (16/24), *Potamogeton pussilus* (15/24), and *Typha* sp. (15/24). The most common invertebrate taxa encountered were Chironomidae (24/24), Coenagrionidae (23/24), Hydracarina (23/24), Planorbidae (22/24) and Dytiscidae (21/24). Correlations between the predictor variables are shown in Appendices C, D, and E. Correlations between wetland cover and impervious cover were low at all spatial scales (Pearson's $r \leq .3$; Appendix C). Impervious cover was significantly negatively correlated with forest and/or agriculture at some spatial scales (Appendix C). Among local variables, conductivity was significantly correlated with date and water colour was significantly correlated with water depth and pH (Appendix D). At the scales where wetland cover most strongly affected vegetation and invertebrates (see spatial scales of effect below), correlations between wetland cover and local variables were low (Pearson's $r \leq 0.282$; Appendix E). Impervious cover was correlated with conductivity at spatial scales $\leq 0.8\text{km}$ (Pearson's $r \geq 0.558$; Appendix E). None of the response variables showed significant autocorrelation (Moran's I from $-.131$ to $.045$, $p > .05$; Appendix F).

Spatial scales of effect (objective 2)

The scale at which the landscape most strongly affected the focal wetland varied depending on the landscape variable and response variable examined (Table 1, Figure 6). Wetland cover most strongly affected both vegetation and benthic invertebrates within about 1km of the focal wetlands (Table 1, Figure 6). Impervious cover affected

vegetation and benthic invertebrate richness most strongly within small areas (.4km and .2km from the wetlands respectively; Table 1, Figure 6). In contrast, vegetation cover and invertebrate abundance were most strongly affected by impervious cover at larger scales (1.8km and 1km respectively; Table 1, Figure 6).

The scale at which the landscape most strongly affected wetland vegetation species richness did not differ between the two vegetation dispersal modes (Table 1, Figure 7). Likewise, the scale of effect of wetland cover on invertebrate taxa richness did not differ between invertebrate dispersal modes (1km; Table 1, Figure 8). In contrast, taxa richness of aerially dispersing invertebrates was most strongly affected by impervious cover at a smaller scale (.2km) than taxa richness of aquatically dispersing invertebrates (1.2km; Table 1, Figure 8).

Relative importance of wetland cover and impervious cover (objective 1)

Wetland depth was a significant predictor of vegetation richness (Table 2). Conductivity, area, date, and pH were significant predictors of the benthic invertebrate response variables (Table 2).

When there was evidence for an effect of wetland cover on a wetland response variable, the effect was positive and the effect was always more important than the effect of impervious cover (Table 3). Specifically, wetland cover had a significant positive effect on vegetation richness ($\beta = .765$, $F = 5.408$, $df = 1, 18$, $p = .032$ at 1km), vegetation cover ($\beta = 1.745$, $F = 6.098$, $df = 1, 18$, $p = .024$ at 1km), and invertebrate richness ($\beta = .666$, $F = 6.173$, $df = 1, 18$, $p = .023$ at 1km). Wetland cover was 4.7, 1.8, and 2.2 times more important (based on beta-values) than impervious cover, for these three responses, respectively.

The effects of impervious cover were mixed across response variables (Table 3), with a significant positive effect on vegetation cover ($\beta = .970$, $F = 8.626$, $df = 1, 18$, $p = .009$ at 1.8km) but a significant negative effect on invertebrate richness ($\beta = -.307$, $F = 5.481$, $df = 1, 18$, $p = .031$ at .2km).

All results (significance, direction of effect, magnitude of relative importance) for the landscape+local models were consistent with the results for the landscape only models, except for the effect of impervious cover on invertebrate richness, which was no longer significant in the landscape+local model ($\beta = -.069$, $F = .164$, $df = 1, 18$, $p = .692$ at .2km; Table 3). In this model, conductivity ($\beta = -.011$, $F = 3.357$, $df = 1, 18$, $p = .088$) had the second highest explanatory power after wetland cover ($\beta = .691$, $F = 6.956$, $df = 1, 18$, $p = .020$).

"Extreme" focal wetlands

The observed response values at the site with extremely high wetland cover was either within (landscape only model for invertebrate richness) or below the expected range (all other models; Table 4).

The observed response values at the two sites with extremely high impervious cover were lower than the expected range when the direction of effect was positive (vegetation cover models; Table 4) and higher than the expected range when the direction of effect was negative (invertebrate richness models; Table 4).

Discussion

Relative importance of wetland cover and impervious cover (objective 1)

To my knowledge, this is the first study to examine the relative effects of urban development and wetland loss on the quality of remaining wetlands. I found that wetland cover and impervious cover have independent effects on wetland quality, with the effect of wetland cover generally stronger than the effect of impervious cover.

Wetland cover had a positive effect on vegetation richness, vegetation cover, and benthic invertebrate richness which is consistent with previous work (Findlay and Houlihan 1997; Mensing et al. 1998; Galatowitsch et al. 2000; Gledhill et al. 2008). The effect of wetland cover was about twice (or more) that of impervious cover. This suggests that the availability of colonist source patches, and the pollution uptake by other wetlands in the landscape have stronger positive effects on wetland quality than the negative effects associated with urbanization. Species richness of both vegetation and invertebrates declined with decreasing proportion of wetland cover in the landscape, which is the expected relationship if wetland loss reduces the availability of colonists (MacArthur and Wilson 1967; Gibbs 1993). However, there is debate as to the effect of wetland cover in the landscape on nutrients; some studies found improved water quality with proportion of wetland in the landscape (Detenbeck et al. 1993; Houlihan and Findlay 2004) and others found diminished water quality (Prepas et al. 2001). Houlihan and Findlay (2004) were unable to distinguish if water quality was improved by the presence of wetlands in the landscape or because the presence of wetlands was simply a proxy for the absence of agriculture. Since my study found a positive effect of wetland cover on wetland vegetation and benthic invertebrates, with a low correlation between

wetland cover and agricultural cover, this supports the suggestion that wetlands in the landscape act as sinks for nutrients and pollutants.

Impervious cover had a negative effect on benthic invertebrate richness which was also shown in previous studies (Mensing et al. 1998; Hall et al. 2004). When local variables were added to the model, however, impervious cover was no longer a significant predictor of invertebrate taxa richness. I hypothesize that the effect of impervious cover was masked by its positive correlation with conductivity in the model containing local variables. High levels of conductivity are negatively related to benthic invertebrate richness (Black et al. 2004; Ortiz and Puig 2007; Pond et al. 2008), and urban stream studies have found positive correlations between urbanization and conductivity (Wang and Yin 1997; Dow and Zampella 2000; Paul and Meyer 2001), suggesting that in these cases high conductivity is a result of urbanization (indexed here as impervious cover). Urban streams generally have high levels of ions originating from various pollutants that contain soluble salts (such as calcium, sodium, potassium, chloride, and magnesium; Rikard and Kunkle 1990; Wang and Yin 1997; Paul and Meyer 2001; Quina et al. 2011; McAlister et al. 2008), which increases conductivity of the water. Another mechanism that could cause the negative relationship between impervious cover and invertebrate richness is that urban development may act as a barrier to movement by invertebrates capable of flight (Seibert and Conover 1991; Rao and Girish 2007). In support of this, impervious cover has a statistically significant effect on aerially dispersing invertebrates but not on aquatic dispersers (Table 1). It is also possible that invasive species may be more likely to colonize wetlands near urban areas and may

exclude other species (Riley et al. 2005), which is not possible to test here, because identification was only done to the family level.

A surprising finding was that wetland vegetation cover was positively associated with impervious cover in the surrounding landscape. Since impervious cover was highly correlated with density of houses (Pearson's $r = 0.969$ at 1.8km, the scale of effect of impervious cover on vegetation cover), I hypothesize that the positive effect of impervious cover is due to nutrient enrichment by the human population in the landscape surrounding the focal wetland. Nutrients are beneficial for the productivity of aquatic vegetation until a point where the density of phytoplankton becomes high and blocks light from penetrating through the water, limiting vegetative productivity (Wetzel and Hough 1973). I expect that in the range of 0-22% impervious cover sampled (at .5km landscape scale), vegetation was not light-limited but at extremely high impervious cover levels the positive effect of nutrients on vegetation cover could decrease and eventually become negative. Our post hoc test using the extreme sites supported this view; a site with extremely high impervious cover had lower vegetation cover than expected based on our statistical model. An alternative mechanism generating the positive effect of impervious cover on vegetation cover is that the abundance of exotic species could increase with urbanization (Borgman and Rodewald 2005; Ehrenfeld 2008) due to increased disturbance and movement of seeds which facilitates invasion (Hobbs and Huenneke 1992; Trombulak and Frissell 2000). In support of this, a post-hoc analysis revealed that cover of exotic species significantly increased with impervious cover (linear regression, $\beta=2.177$, $R^2= .223$, $df=1, 19$, $F=5.444$, $p=.031$ at 1.8km), whereas cover of

native species did not (linear regression, $\beta=.632$, $R^2=.084$, $df= 1, 19$, $F=1.738$, $p=.203$ at 1.8km).

An additional unexpected finding was that, other than taxa richness, common benthic invertebrate indicators of water quality (invertebrate abundance, %EOT, %Amphipoda) were not significantly related to wetland cover or impervious cover. This is consistent with Tangen et al. (2003) who found no effect of the landscape on %EOT and %Amphipoda. It is possible that these response variables, which are based on their successful use in stream quality assessments, might not be good indicators of wetland quality (Rader 2001).

Spatial scale of effect (objective 2)

The spatial scale of effect varied depending on the landscape predictor and response variables examined. Similar to previous work, vegetation (Houlahan et al. 2006) and benthic macroinvertebrates (Gledhill et al. 2008) were most strongly affected by wetland cover within about 1km of a sampled wetland. Both vegetation and benthic invertebrate taxa richness were most strongly affected by impervious cover between .2 and .4km of the focal wetland. This contrasts with previous studies which found larger scales of effect for vegetation richness (1km, Houlahan and Findlay 1997; .75km, Houlahan et al. 2006). This difference could be explained by the correlations between impervious cover and forest cover in these studies (Houlahan and Findlay 1997; Houlahan et al. 2006). Forest cover could be causing the effect or could have a stronger effect than impervious cover, which would mask the actual scale of effect of impervious cover and result in a larger apparent scale. In my study, impervious cover and forest cover have a low correlation at the scale where impervious cover most strongly affects

invertebrate richness (Pearson's $r = -0.380$ at .4km; Appendix C), eliminating the possibility that the observed scale of effect of impervious cover results from the effects of forest cover. Benthic invertebrate abundance and vegetation cover were most strongly affected by impervious cover at larger scales (1.8km and 1.0km, respectively) than the scales of effect for taxa richness. The scale of effect of impervious cover for benthic invertebrate abundance is consistent with previous research (Mensing et al. 1998). This is the first study to quantify the scale of effect for vegetation cover.

My results suggest that the scale of effect of the landscape does not differ between dispersal modes for wetland vegetation which suggests that aquatic and aerially dispersed vegetation may have similar dispersal distances. This is consistent with Flinn et al. (2010) where vegetation dispersed by water and wind both responded to the landscape at broad spatial scales.

In general, invertebrate dispersal mode (aerial vs. aquatic) did not influence the scale of effect of the landscape. My prediction that aerial dispersers would respond at large spatial scales because they are less dispersal-limited was not supported. Surprisingly, aerial dispersers were most strongly affected by impervious cover close to the wetland (0.2km). This might be due to traffic mortality of aerial dispersers as they are leaving the focal wetland, since the aerial stages of aquatic macroinvertebrates have commonly been found in road kill assessments (Seibert and Conover 1991; Rao and Girish 2007).

Implications and further research

My finding that wetland cover has a generally stronger effect than impervious cover on focal wetland quality confirms that policies aimed at mitigating the impacts of

urbanization on wetlands should include wetland restoration in the landscape. However, my result that impervious cover is not as important as wetland cover for focal wetland quality should be regarded with caution. Only a portion (0-22% at 0.5km) of the potential range (0-100%) of impervious cover was used in this study, and outside of this range, it is possible that the relative effects of impervious cover and wetland cover could change (Eigenbrod et al. 2011). Extrapolation of my results beyond this range should therefore be avoided.

This study has important implications for the spatial scales at which wetland management should take place. The landscape affected focal wetland biota most strongly at different scales depending on the landscape predictor and response variable used. This suggests that management should take place at different scales depending on the goal. For example, mitigation measures aimed at reducing the impacts of urban runoff to benthic invertebrates should take place within .2km from the focal wetland. In contrast, management aimed at restoring wetland habitat in the landscape to increase wetland vegetation richness should take place within about 1km of the focal wetland.

More generally, further research should be conducted on the responses of wetland biota to urbanization. Several studies have documented that the richness and abundance of exotic plant species is higher in urban forest patches than in non-urban forest patches (Borgman and Rodewald 2005; Ehrenfeld 2008; Duguay et al. 2007). There is a need for future research to document whether this pattern is also consistent for urban freshwater wetlands. Moreover, better indicator groups for wetland quality should be developed based on research documenting the sensitivities of wetland benthic invertebrates and vegetation to human land use and land cover change. Based on my results, benthic

macroinvertebrate and vegetation taxa richness are the best indicators of wetland quality. Vegetation cover should be avoided as an indicator of wetland quality since it was found to increase with impervious cover which is likely due to increasing nutrients and abundance of exotics.

Conclusions

This is a novel study examining the relative effects of wetland loss and urban development on the quality of remaining wetlands. While I found significant effects of both wetland loss and urban development, my study demonstrated that, within the sampled ranges of the predictor variables, wetland loss is more detrimental than urban development to the quality of remaining wetlands. This implies that wetland management policies should include wetland conservation and restoration. In Canada this is recognized in the Federal Policy on Wetland Conservation (Government of Canada 1991) which stipulates that there should be no net loss of wetlands on federal lands, and in Ontario the Provincial Policy on Natural Heritage (Ministry of Ontario 2005) which prevents the loss of provincially significant wetlands. These policies should be extended to include non-federal lands and all wetlands, regardless of their significance status. In addition, where the destruction of wetland habitat is inevitable, construction of artificial wetlands should take place.

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Tables

Table 1. Results of simple linear regressions of vegetation and benthic invertebrate response variables in 21 focal wetlands on wetland cover and impervious cover in the surrounding landscapes. "Scale" is the landscape size (radius) at which the landscape predictor had its largest effect on the response (see Figure 6). β = regression coefficient.

Response Variable	Wetland Cover					Impervious Cover				
	Scale (km)	R ²	β	F	p	Scale (km)	R ²	β	F	p
VEGETATION										
Richness	1.0	.220	.759	5.357	.032	.4	.034	-.156	.669	.424
%Cover	1.0	.269	2.169	7.004	.016	1.8	.304	1.136	9.731	.006
Aerial Richness	1.0	.289	.648	7.719	.012	.2	.024	.092	.473	.500
Aquatic Richness	.8	.054	.152	1.087	.310	.4	.147	-.169	4.448	.048
BENTHIC MACROINVERTEBRATES										
Richness	1.0	.187	.622	4.379	.05	.2	.163	-.285	3.71	.069
Abundance	1.4	.075	247.365	1.531	.231	1.0	.170	219.452	5.093	.036
%EOT	1.6	.075	-1.495	1.547	.229	.8	.103	.995	2.192	.155
%Amphipoda	.6	.207	1.054	4.967	.038	1.0	.109	.474	2.331	.143
Aerial Richness	1.0	.079	.207	1.627	.217	.2	.283	-.192	7.492	.013
Aquatic Richness	1.0	.171	.333	3.913	.063	1.2	.072	.1	1.475	.239

Table 2. Results of backward stepwise (p-to-remove > .05) regressions of focal wetland plant and invertebrate response variables on local variables (wetland area (m²), wetland perimeter (m), date, temperature (°C), pH, conductivity (μS/cm), water colour (absorption coefficient), maximum depth (m), number of quadrats). β = regression coefficient.

Response Variable	Local Variable	β	p
VEGETATION			
Richness	Depth	10.60	.036
%Cover	—	—	—
BENTHIC			
MACROINVERTEBRATES			
Richness	Conductivity	-.01	.028
Abundance	Area	.333	.004
	Date	-207.69	.008
%EOT	pH	18.48	.009
%Amphipoda	—	—	—

Table 3. Results of general linear models examining the effects of wetland and impervious cover in the surrounding landscapes on vegetation and benthic invertebrate response variables in focal wetlands. Local variables were included in the models in *b)* but not in *a)* (see Table 2). β = regression coefficient; bolded numbers indicate significance at $\alpha=.05$.

		Wetland Cover			Impervious Cover		
Response Variable	R ²	Scale (km)	β	p	Scale (km)	β	p
<i>a) Landscape Only Models</i>							
VEGETATION							
Richness	.175	1.0	.765	.032	.4	-.163	.355
%Cover	.451	1.0	1.745	.024	1.8	.97	.009
BENTHIC							
MACROINVERTEBRATES							
Richness	.308	1.0	0.666	.023	.2	-.307	.031
Abundance	.158	1.4	162.30	.406	1.0	200.32	.062
%EOT	.047	1.6	-1.12	.376	.8	-.831	.25
%Amphipoda	.156	.6	.896	.095	1.0	.28	.315
<i>b) Landscape+local models</i>							
VEGETATION							
Richness	.300	1.0	.753	.021	.4	-.073	.652
%Cover	.419	1.0	1.742	.028	1.8	.976	.011
BENTHIC							
MACROINVERTEBRATES							
Richness	.381	1.0	.691	.020	.2	-.069	.692
Abundance	.439	1.4	280.4	.116	1.0	94.67	.389
%EOT	.206	1.6	-1.047	.397	.8	.334	.709
%Amphipoda	.007	.6	.944	.112	.2	.017	.969

Table 4. Comparison of the wetland responses at three "extreme" wetland sites (one with extremely high wetland cover and two with extremely high impervious cover). Models were conducted at the scale where the landscape predictor had its largest effect on the response (see Table 1). Local variables were included in the models in *b*) but not in *a*) (see Table 2). *W* = wetland cover; *I* = impervious cover; Amount = % of the landscape; Expected range = 95% confidence intervals for the expected response value based on the models in Table 3; Observed = response value observed in the extreme wetland; Fit = whether the actual value is higher (↑), lower (↓), or within the expected range (–). For equations and confidence intervals, see Appendix B.

<i>a) Landscape Only</i>		<u>Extreme Wetland</u>				<u>Extreme Impervious</u>				
Response Variable	Amount (%)		Expected	Observed	Fit	Amount (%)		Expected	Observed	Fit
	<i>W</i>	<i>I</i>				<i>W</i>	<i>I</i>			
VEGETATION										
Richness	29.3	.8	32.5 – 36.9	33	–	1.7	32.5	6.1 – 10.6	7	–
% Cover	29.3	2.6	67.8 – 77.2	53.8	↓	9.6	37.7	67.5 – 76.9	58.6	↓
BENTHIC MACROINVERTEBRATES										
Richness	29.3	0	38.87 – 42.51	24	↓	1.7	61.5	1.6 – 5.2	24	↑
Abundance	25.6	2.3	5836.8 – 8530.2	1183	↓	6.8	29.5	8239.3 – 10932.7	1227.9	↓
%EOT	29.1	2.6	2.1 – 20.0	14.6	–	5.9	27.4	7.5 – 25.4	4.2	↓
%Amphipoda	49.2	2.3	40.2 – 48.3	0	↓	22.7	29.5	24.0 – 32.1	25.6	–

Table 4. (Continued)

<i>b) Landscape+local Models</i>			<u>Extreme Wetland</u>			<u>Extreme Impervious</u>				
Response Variable	Amount (%)		Expected	Observed	Fit	Amount (%)		Expected	Observed	Fit
	<i>W</i>	<i>I</i>				<i>W</i>	<i>I</i>			
VEGETATION										
Richness	29.3	.8	33.4 – 37.3	33	↓	1.7	32.4	12.2 – 16.2	7	↓
% Cover	29.3	2.6	67.9 – 77.3	53.8	↓	9.6	37.7	67.6 – 77.0	58.6	↓
BENTHIC MACROINVERTEBRATES										
Richness	29.3	0	38.7 – 41.7	24	↓	1.7	61.5	9.2 – 12.3	24	↑
Abundance	25.6	2.3	15771.8 – 17710.9	1183	↓	6.9	29.5	50827.1 – 52766.2	1227.9	↓
%EOT	29.1	2.6	15.0 – 29.5	14.6	↓	5.9	27.4	27.7 – 42.1	4.1	↓
%Amphipoda	49.2	2.3	44.2 – 52.0	0	↓	22.7	29.5	14.5 – 22.2	25.6	↑

Figures

Figure 1. Map of Eastern Ontario, Canada showing the 24 surveyed focal wetlands (•) and their surrounding landscapes within a 1.5km radius of the focal wetland. The dark grey areas represent urban cover, the light grey areas represent wetland cover, and the remaining areas are forest or agriculture. Landscapes are shown as categorized into five classes based on the amount of wetland cover and impervious cover in the landscape.

Figure 2. Illustration of the procedure used to obtain a set of focal wetland sites that minimized the correlation between wetland cover and impervious cover in the landscape. Crosses represent potential sites and grey squares represent final sites ($n=21$).

Figure 3. Landscapes surrounding four of the 21 focal wetlands (•) showing the independent gradients of wetland cover (dark grey) and impervious cover (black). a) high impervious cover, low wetland cover; b) high impervious cover, high wetland cover; c) low impervious cover, low wetland cover; d) low impervious cover, high wetland cover. Forest and agriculture are shown in white and open water is shown in light grey. Circular buffers are at .2km intervals.

Figure 4. Landscape composition of the final 21 wetlands (squares) and the 3 ‘extreme’ wetlands (circles). Landscape composition was determined within .5km, 1km, and 2km of the focal wetlands. The 3 ‘extreme’ wetlands are colour coded (black, grey, and white) so that their respective landscape compositions can be observed across scales.

Figure 5. Sampling design at each focal wetland. Round one of sampling is depicted in black and round two in grey. Squares represent 1x1m quadrats and lines represent transects. Quadrats for vegetation sampling were placed at approximately .25, .5, and 1m depths. Benthic invertebrates were sampled along the 3 transects of round two, beginning at about 1m depth and moving toward shore for 1min.

Figure 6. Scatterplots of regression coefficients from simple linear regressions of wetland response variables on wetland cover and impervious cover in the surrounding landscapes, at multiple spatial extents (nested circular areas surrounding the focal wetlands). Filled symbols indicate statistical significance at $\alpha=0.05$.

Figure 7. Scatterplots of regression coefficients from simple linear regressions of vegetation richness, subdivided by dispersal mode, on wetland cover and impervious cover in the surrounding landscapes, at multiple spatial extents (nested circular areas surrounding the focal wetlands). Filled symbols indicate statistical significance at $\alpha=0.05$.

Figure 8. Scatterplots of regression coefficients from simple linear regressions of invertebrate richness, subdivided by dispersal mode, on wetland cover and impervious cover in the surrounding landscapes, at multiple spatial extents (nested circular areas surrounding the focal wetlands). “Aerial” indicates that invertebrates are capable of flight at some stage in their life history; “aquatic” indicates that invertebrates are confined to the aquatic environment. Filled symbols indicate statistical significance at $\alpha=0.05$.

Appendices

Appendix A. Equation used to obtain the abundance of macroinvertebrates in a 1min kick-and-sweep sample and an example of the calculation for site W1. 180sec represents three 60 second kick-and-sweeps.

$$\begin{array}{ccc} \text{To determine the number of} & & \text{To standardize for sampling} \\ \text{individuals in the entire sample} & & \text{effort} \\ \downarrow & & \downarrow \\ \text{Abundance} = \# \text{ of individuals subsampled} \times \frac{\text{entire sample volume}}{\text{volume subsampled}} \times \frac{180 \text{ sec}}{\text{total kick - and - sweep duration}} \end{array}$$

Example for site W1:

$$\text{Abundance} = 305 \text{ individuals} \times \frac{15000\text{ml}}{1400\text{ml}} \times \frac{180\text{sec}}{82 \text{ sec}}$$

$$\text{Abundance} = 7173.34$$

Appendix B. Equations used to determine whether “extreme” wetland response values are within the expected range (see Table 4) based on the models in Table 3 and the confidence intervals of their residuals. The equations were used to determine the expected response value for “extreme” wetlands and the expected range was obtained by applying the 95% confidence interval of the residuals ($\pm$ value at the end of the equation) around the expected value. Models were conducted at the scale where the landscape predictor had its largest effect on the response (see Table 1, Figure 6). Local variables were included in the models in *b*) but not in *a*). *W* = wetland cover; *I* = impervious cover; *A* = wetland area; *P* = pH; *C* = conductivity; *D* = date; *MD* = maximum depth.

a) Landscape Only Models	b) Landscape+local Models
VEGETATION	
$Richness = 12.40 + .765(W) - .163(I) \pm 2.24$	$Richness = 1.32 + .753(W) - .073(I) + 9.997(MD) \pm 1.97$
$\%Cover = 18.87 + 1.745(W) + .97(I) \pm 4.71$	$\%Cover = 17.696 + 1.742(W) + .976(I) + 1.109(MD) \pm 4.72$
BENTHIC INVERTEBRATES	
$Richness = 21.17 + .666(W) - .307(I) \pm 1.82$	$Richness = 25.66 + .691(W) - .069(I) - 0(A) + .412(P) - .011(C) - .125(D) \pm 1.52$
$Abundance = 2565.13 + 162.30(W) + 200.32(I) \pm 1346.7$	$Abundance = - 564.17 + 280.4(W) + 94.67(I) + .361(A) + 1580.92(P) - .853(C) - 196.13(D) \pm 969.52$
$\%EOT = 45.77 - 1.12(W) - .831(I) \pm 8.96$	$\%EOT = - 68.57 - 1.047(W) + .334(I) + 0(A) + 15.59(P) + .02(C) - .112(D) \pm 7.22$
$\%Amphipoda = - .513 + .896(W) + .28(I) \pm 4.05$	$\%Amphipoda = 19.27 + 0.944(W) + .017(I) + 0(A) - 1.042(P) + .002(C) - .242(D) \pm 3.88$

Appendix C. Pairwise Pearson correlations (Pearson's r values) between the cover of four landscape predictors (wetland, impervious areas, agriculture, forest), measured at different spatial extents around 21 focal wetlands. Numbers in bold are significant at $\alpha=.05$ and starred (*) numbers are significant at $\alpha=.01$.

		Impervious	Agriculture	Forest
0.2 km	Wetland	.300	-.321	-.343
	Impervious		-.271	-.204
	Agriculture			-.523
0.4 km	Wetland	.005	-.256	-.470
	Impervious		-.387	-.380
	Agriculture			-.281
0.6 km	Wetland	.270	-.388	-.319
	Impervious		-.483	-.676*
	Agriculture			-.031
0.8 km	Wetland	.121	-.364	-.151
	Impervious		-.471	-.659*
	Agriculture			-.088
1.0 km	Wetland	.200	-.408	-.072
	Impervious		-.518	-.620*
	Agriculture			-.121
1.2 km	Wetland	.160	-.313	-.143
	Impervious		-.501	-.596*
	Agriculture			-.139
1.4 km	Wetland	.106	-.193	-.236
	Impervious		-.443	-.559*
	Agriculture			-.17

Appendix C. (Continued)

		Impervious	Agriculture	Forest
1.6 km	Wetland	.020	-.109	-.232
	Impervious		-.392	-.503
	Agriculture			-.211
1.8 km	Wetland	-.038	-.126	-.174
	Impervious		-.354	-.440
	Agriculture			-.239
2.0 km	Wetland	-.133	-.136	-.106
	Impervious		-.327	-.404
	Agriculture			-.246
2.2 km	Wetland	-.182	-.192	-.084
	Impervious		-.287	-.394
	Agriculture			-.246
2.4 km	Wetland	-.216	-.208	-.05
	Impervious		-.279	-.377
	Agriculture			-.233
2.6 km	Wetland	-.253	-.211	-.015
	Impervious		-.259	-.368
	Agriculture			-.23

Appendix D. Pairwise Pearson correlations (Pearson's r values) between local variables: Depth = maximum sampling depth (m), Area = focal wetland area (m²), Perim = focal wetland perimeter (m), AVTemp= average water temperature rounds one and two (°C), Temp2= temperature (round two water temperature; °C), pH = water pH, Cond = water conductivity (μS/cm), Colour = water colour (absorption coefficient), and Quadrats = number of quadrats used to sample wetland plants. Numbers in bold are significant at $\alpha = .05$ and starred (*) numbers are significant at $\alpha = .01$.

	Area	Perim	AVTemp	Temp2	pH	Cond	Colour	Quadrats
Depth	.162	.249	.305	-.126	.396	-.058	-.673*	-.17
Area		.816*	.282	-.140	-.339	.572*	.024	-.745*
Perim			.182	-.184	-.349	.313	-.045	-.516
AVTemp				.611	.223	-.1	-.117	-.021
Temp2					.28	-.388	.072	.355
pH						-.339	-.618*	.034
Cond							.192	-.522
Colour								.032

Appendix E. Pairwise Pearson correlations between landscape predictors (wetland cover, impervious cover) and local variables (maximum sampling depth (m), focal wetland area (m²), focal wetland perimeter (m), average temperature between both sampling rounds (°C), round two temperature (°C), pH, conductivity (µS/cm), water colour (absorption coefficient)) at multiple spatial extents around 21 focal wetlands. Numbers in bold are significant at $\alpha = .05$ and starred (*) numbers are significant at $\alpha = .01$.

		Depth	Area	Perim	AVTemp	Temp2	pH	Cond	Colour
0.2 km	Wetland cover	-.108	.607*	.525	.017	-.035	-.366	.503	.24
	Impervious cover	.022	.336	.254	-.081	-.197	-.273	.660*	-.082
0.4km	Wetland cover	-.195	.32	.25	-.013	.011	-.236	.352	.156
	Impervious cover	-.245	.188	.064	-.165	-.318	-.363	.627*	.2
0.6 km	Wetland cover	-.033	.082	.126	.09	-.032	-.157	.21	.023
	Impervious cover	-.274	.428	.221	-.206	-.299	-.409	.633*	.121

Appendix E. (Continued)

		Depth	Area	Perim	AVTemp	Temp2	pH	Cond	Colour
0.8 km	Wetland cover	.115	-.023	.016	.231	.1	-.082	.147	-.08
	Impervious cover	-.287	.456	.268	-.236	-.281	-.421	.558*	.093
1.0 km	Wetland cover	.011	-.108	-.08	.109	.119	-.079	.055	-.134
	Impervious cover	-.209	.469	.32	-.199	-.257	-.37	.477	.044
1.2 km	Wetland cover	-.053	-.132	-.086	.028	.067	-.105	.086	-.078
	Impervious cover	-.141	.474	.315	-.175	-.254	-.297	.452	.007
1.4 km	Wetland cover	-.143	-.091	-.087	.022	.059	-.134	.218	.041
	Impervious cover	-.133	.424	.25	-.211	-.236	-.224	.436	-.027
1.6 km	Wetland cover	-.096	-.056	-.056	.081	.014	-.087	.282	-.001
	Impervious cover	-.143	.345	.176	-.267	-.23	-.188	.416	-.056
1.8 km	Wetland cover	-.028	-.046	-.02	.114	-.035	-.043	.259	-.08
	Impervious cover	-.154	.237	.099	-.331	-.227	-.169	.378	-.074

Appendix E. (Continued)

		Depth	Area	Perim	AVTemp	Temp2	pH	Cond	Colour
2.0 km	Wetland cover	.005	-.06	-.014	.137	-.043	-.011	.2	-.122
	Impervious cover	-.186	.155	.026	-.377	-.215	-.17	.35	-.007
2.2 km	Wetland cover	.041	-.04	.028	.145	-.048	-.008	.183	-.126
	Impervious cover	-.225	.096	-.024	-.425	-.228	-.19	.338	-.054
2.4 km	Wetland cover	.058	-.048	.016	.153	-.057	.025	.188	-.149
	Impervious cover	-.245	.059	-.055	-.438	-.223	-.193	.316	-.049
2.6 km	Wetland cover	.062	-.05	.004	.17	-.051	.048	.187	-.156
	Impervious cover	-.269	.024	-.089	-.447	-.214	-.191	0.93	-.037

Appendix F. Results of Moran's *I* tests for autocorrelation (clustering) in benthic invertebrate and wetland plant response variables across the study region.

Response Variable	Moran's <i>I</i>	z-score	p-value
VEGETATION			
Richness	.020	.767	.443
%Cover	.045	1.046	.295
BENTHIC MACROINVERTEBRATES			
Richness	-.131	-1.044	.297
Abundance	-.007	.435	.664
%EOT	-.012	.367	.713
%Amphipoda	-.097	-.672	.501

Appendix G. Values of response variables for benthic macroinvertebrates and vegetation at each of the 24 focal wetlands.

Site	Benthic macroinvertebrates				Vegetation	
	Taxa richness	Abundance	%EOT	%Amphipoda	Taxa richness	%Cover
W1	17	7173.34	1.31	.98	15	53.12
W2	15	7464.29	59.92	10.73	9	32.62
W3	20	9046.83	49.41	9.65	7	25.37
W4	21	1832.71	3.42	4.62	7	22.08
W5	21	2016.72	35.10	18.54	6	20.31
W6	31	7453.57	41.11	6.93	15	69.26
W7	17	4134.07	30.86	11.00	13	8.00
W8	28	3515.81	6.33	3.46	19	61.98
W9	19	12355.86	0.33	23.36	12	42.73
W10	24	3820.43	14.71	.30	11	40.51
W11	24	3906.89	33.75	6.83	15	41.47
W12	19	4720.28	23.79	.63	26	40.99
W13	30	11786.65	24.82	40.64	24	31.15
W14	25	5214.54	59.15	4.88	15	54.77
W15	27	11843.49	2.44	9.98	15	54.12
W16	25	4966.46	63.81	7.18	23	36.90
W17	20	3438.49	47.34	.00	21	33.88
W18	27	1690.15	53.92	1.25	21	35.76
W19	21	6671.73	38.72	22.78	16	31.17
W20	19	2533.19	7.27	.00	18	53.61
W21	11	1682.27	41.14	.00	11	36.34
W22	24	1183.03	14.62	.00	33	53.78
W23	24	9160.71	34.59	17.76	7	22.07
W24	29	1227.85	4.17	25.64	20	58.56

Appendix H. Dispersal mode (AE=aerial and AQ=aquatic) of benthic macroinvertebrate taxa based on presence of wings at some stage during that group's life history.

Taxonomic group	Family	Dispersal mode	Taxonomic group	Family	Dispersal mode
Anisoptera	Aeshnidae	AE	Coleoptera	Haliplidae	AE
	Cordulidae	AE		Hydrophilidae	AE
	Gomphidae	AE		Hadraenidae	AQ
	Libellulidae	AE		Chrysomelidae	AE
Zygoptera	Coenagrionidae	AE		Dytiscidae	AE
	Lestidae	AE		Elmidae	AE
Chironomidae	Chironomidae	AE		Gerissidae	AE
Amphipoda	Talitridae	AQ		Gyrinidae	AE
	Gammaridae	AQ		Noteridae	AQ
Isopoda	Asellidae	AQ		Scirtidae	AE
Ephemeroptera	Baetidae	AE	Trichoptera	Leptoceridae	AE
	Caenidae	AE		Phryganeidae	AE
	Heptogeniidae	AE		Polycentropodidae	AE
Hemiptera	Belostomatidae	AE		Psychomiidae	AE
	Corixidae	AQ	Ceratopogonidae	Ceratopogonidae	AE
	Geriidae	AE	Culicidae	Culicidae	AE
	Hebridae/Hebrinidae	AQ	Dixidae	Dixidae	AE
	Mesoveliidae	AQ	Muscidae	Muscidae	AE
	Nepidae	AQ	Tabanidae	Tabanidae	AE
	Notonectidae	AE	Tipulidae	Tipulidae	AE
	Pleidae	AQ	Miscellaneous	Chaoboridae	AE
	Veliidae	AQ	Diptera	Stratiomyidae	AE
Hydracarina		AQ		Pelecorhynchidae	AE
Oligochaeta	Aelosomatidae	AQ	Turbellaria	Planariidae	AQ
	Haplotaxidae	AQ	Bivalvia	Sphaeriidae	AQ
	Naididae	AQ		Unionidae	AQ
	Lumbriculidae	AQ	Hirudinea	Glossiphoniidae	AQ
Gastropoda	Ancylidae	AQ		Hirudinidae	AQ
	Hydrobiidae	AQ	Lepidoptera	Crambidae	AE
	Lymnaidae	AQ	Megaloptera	Corydalidae	AE
	Physidae	AQ		Sialidae	AE
	Planorbidae	AQ	Nematoda		AQ
	Valvatidae	AQ	Decapoda	Astacidae	AQ
	Viviparidae	AQ			

Appendix I. Dispersal mode (AE=aerial and AQ=aquatic based on whether seeds are above or below the surface of the water) and native status (N=native, E=exotic N/A=information not available or taxonomic resolution inappropriate) of wetland vegetation found at the 24 focal wetlands.

Taxa	Dispersal mode	Native status	Taxa	Dispersal mode	Native status	Taxa	Dispersal mode	Native status
<i>Alisma triviale</i>	AE	N	<i>Hydrocaris morsus-ranae</i>	AE	E	<i>Ranunculus sp.</i>	AE	N/A
<i>Betula pumila</i>	AE	N	<i>Impatiens capensis</i>	AE	N	<i>Riccia fluitans</i>	AQ	N
<i>Butomus umbellatus</i>	AE	E	<i>Impatiens pallida</i>	AE	N	<i>Rumex orbiculatus</i>	AE	N
<i>Asclepija incarnata</i>	AE	N	<i>Iris versicolor</i>	AE	N	<i>Sagittaria cuneata</i>	AE	N
<i>Calitriche hermaphroditica</i>	AQ	N	<i>Isoetes echinospora</i>	AQ	N	<i>Sagittaria graminea</i>	AE	N
<i>Calla palustris</i>	AE	N	<i>Juncus canadensis</i>	AE	N	<i>Sagittaria latifolia</i>	AE	N
<i>Carex (unknown)</i>	AE	N/A	<i>Lemna minor</i>	AQ	N	<i>Salix petiolaris</i>	AE	N
<i>Carex crinita</i>	AE	N	<i>Lemna trisulca</i>	AQ	N	<i>Scirpus acutus</i>	AE	N
<i>Carex diandra</i>	AE	N	<i>Lycopus uniflorus</i>	AE	N	<i>Scirpus cespitosus</i>	AE	N
<i>Carex intumescens</i>	AE	N	<i>Lythrum salicaria</i>	AE	E	<i>Scirpus cyperinus</i>	AE	N
<i>Carex lupulina</i>	AE	N	<i>Mentha sp.</i>	AE	N/A	<i>Scirpus subterminalis</i>	AE	N
<i>Carex pseudo-cyperus</i>	AE	N	<i>Moss</i>	AQ	N/A	<i>Scirpus validus</i>	AE	N
<i>Ceratophyllum demersum</i>	AQ	N	<i>Myriophyllum sibiricum</i>	AQ	N	<i>Scrophulariaceae sp.</i>	AE	N/A
<i>Chara sp.</i>	AQ	N/A	<i>Najas flexilis</i>	AQ	N	<i>Sium sp.</i>	AE	N
<i>Cicuta bulbifera</i>	AE	N	<i>Nitella sp.</i>	AQ	N/A	<i>Solanum dulcamara</i>	AE	E
<i>Cornus stolonifera</i>	AE	N	<i>Nuphar rubrodisca</i>	AE	N	<i>Sparganium americanum</i>	AE	N
<i>Cyperaceae</i>	AE	N/A	<i>Nuphar variegatum</i>	AE	N	<i>Sparganium androcladum</i>	AE	N
<i>Eichhornia crassipes</i>	AE	E	<i>Nymphaea odorata</i>	AQ	N	<i>Sparganium emersum</i>	AE	N
<i>Echinodorus tenellus</i>	AE	N	<i>Nyssa sylvatica</i>	AE	N	<i>Sparganium eurycarpum</i>	AE	N
<i>Eleocharis acicularis</i>	AE	N	<i>Onoclea sensibilis</i>	AE	N	<i>Sparganium fluctuans</i>	AE	N
<i>Eleocharis smallii</i>	AE	N	<i>Poaceae</i>	AE	N/A	<i>Spirea alba</i>	AE	N

Appendix I. (Continued)

Taxa	Dispersal mode	Native status	Taxa	Dispersal mode	Native status	Taxa	Dispersal mode	Native status
<i>Elodea canadensis</i>	AQ	N	<i>Polygonum amphibium</i>	AE	N	<i>Spirodella polyrhiza</i>	AQ	N
<i>Equisetum arvense</i>	AE	N	<i>Pontederia cordata</i>	AE	N	<i>Stuckenia filliformis</i>	AQ	N
<i>Equisetum fluviatile</i>	AE	N/A	<i>Potamogeton epihydrus</i>	AE	N	<i>Stuckenia pectinata</i>	AQ	N
<i>Equisetum palustre</i>	AE	N	<i>Potamogeton foliosis</i>	AQ	N	<i>Thelypteris palustris</i>	AE	N
<i>Equisetum pratense</i>	AE	N	<i>Potamogeton gramineus</i>	AE	N	<i>Typha sp.</i>	AE	N
<i>Equisetum variegatum</i>	AE	N	<i>Potamogeton natans</i>	AE	N	<i>Utricularia sp.</i>	AE	N/A
<i>Eupatorium perfoliatum</i>	AE	N	<i>Potamogeton nodosus</i>	AE	N	<i>Vallisneria americana</i>	AQ	N
<i>Galium trifidum</i>	AE	N	<i>Potamogeton pussillus</i>	AQ	N	<i>Wolffia arrhiza</i>	AQ	N
<i>Galium triflorum</i>	AE	N	<i>Potamogeton richardsonii</i>	AQ	N	<i>Zosterella dubia</i>	AQ	N
<i>Glyceria canadensis</i>	AE	N	<i>Potamogeton robinsii</i>	AE	N			
<i>Glyceria borealis</i>	AE	N	<i>Potamogeton zosteriformis</i>	AQ	N			

Appendix J. Values of local variables for each of the 24 focal wetlands. Area is the size of the focal wetland, perimeter is the circumference of the focal wetland, vegetation date is the sampling date for round one, vegetation temperature is the average temperature between both sampling rounds, invertebrate date is the sampling date for round two, invertebrate temperature is the water temperature during round two. pH, conductivity, water colour (absorption coefficient), number of quadrats used to sample vegetation, and maximum sampling depth of each focal wetland are also shown.

Site	Area (m ²)	Perimeter (m)	Vegetation		Invertebrate		pH	Conductivity (μS/cm)	Absorption coefficient	Quadrats (#)	Maximum depth (m)
			Date (Julian)	Temp (°C)	Date (Julian)	Temp (°C)					
W1	3651.21	287.9	25	23.0	60	25.6	7.28	669.0	10.36	38	0.65
W2	2309.99	191.4	10	22.2	46	24.5	8.30	274.0	2.30	39	0.82
W3	704.56	109.4	2	23.3	38	25.0	7.85	421.5	4.03	38	1.00
W4	892.54	130.2	17	20.1	52	18.4	8.00	444.5	4.03	32	1.30
W5	515.50	119.9	1	21.7	37	24.1	6.84	285.5	13.82	39	0.40
W6	2933.56	227.7	9	25.8	45	25.3	8.56	283.5	4.03	39	1.18
W7	5997.27	377.4	31	27.4	66	24.6	8.21	307.5	2.30	38	1.10
W8	3535.48	843.3	11	21.6	47	20.7	6.76	306.0	4.61	39	1.10
W9	31715.76	1150.7	32	24.2	67	20.2	6.79	1082.0	5.76	21	1.01
W10	1807.06	200.7	29	25.7	64	22.6	7.99	585.5	2.30	39	0.95
W11	8222.41	440.2	18	22.7	51	25.4	7.75	645.5	4.61	39	1.10
W12	10540.98	615.9	16	23.8	53	22.4	7.49	441.0	1.73	39	1.36
W13	6506.75	354.9	3	26.6	39	30.5	8.12	233.5	2.88	36	1.00
W14	2095.73	186.3	8	22.0	44	24.5	7.82	448.5	4.03	39	0.89

Appendix J. (Continued)

Site	Area (m ²)	Perimeter (m)	Vegetation		Invertebrate		pH	Conductivity (μS/cm)	Absorption coefficient	Quadrats (#)	Maximum depth (m)
			Date (Julian)	Temp (°C)	Date (Julian)	Temp (°C)					
W15	859.03	109.7	4	20.1	40	23.5	7.28	494.0	5.76	39	0.55
W16	3028.08	221.6	19	25.3	54	25.3	7.99	208.5	3.45	37	1.36
W17	3346.22	286.8	23	25.0	58	24.9	9.30	629.5	2.88	32	1.20
W18	4222.95	340.9	22	26.9	57	27.9	7.80	176.5	4.61	39	1.17
W19	8836.21	882.5	24	23.7	59	25.0	7.98	413.5	4.61	37	1.10
W20	10019.22	405.1	30	28.4	65	26.3	6.77	828.0	9.21	39	1.02
W21	333.48	90.9	26	19.8	61	20.8	7.56	803.5	3.45	39	1.13
W22	18401.07	866.6	5	23.9	43	25.4	7.57	314.0	3.45	36	1.20
W23	5956.84	298.5	12	23.8	50	25.1	8.53	824.0	4.03	36	1.40
W24	140684.1	4642.5	33	25.3	68	23.7	6.58	237.5	3.45	39	1.00

Appendix K. Measures of landscape composition for all 24 focal wetlands at multiple scales.

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
Scale: 0.2km	W1	35.98	16.18	28.36	13.81	5.67	10
	W2	3.05	8.30	37.29	47.55	3.82	1
	W3	4.54	8.97	45.21	41.31	0.00	5
	W4	10.10	0.00	47.53	39.11	3.26	0
	W5	4.33	1.61	11.42	80.27	2.37	0
	W6	24.09	0.00	35.27	39.41	1.22	0
	W7	4.43	4.77	71.81	15.53	3.46	1
	W8	26.73	9.23	27.77	30.16	6.12	3
	W9	45.50	20.14	11.94	14.26	8.17	8
	W10	6.20	20.29	36.13	36.81	0.57	7
	W11	34.76	17.23	21.81	26.18	0.00	0
	W12	13.49	14.30	36.48	4.95	30.78	0
	W13	22.22	3.78	15.24	44.41	14.35	3
	W14	22.89	19.61	27.25	26.49	3.76	1
	W15	14.79	3.27	36.17	17.92	27.86	0
	W16	1.83	3.51	55.16	21.00	18.50	2
	W17	11.32	8.01	71.02	9.64	0.00	3
	W18	5.20	11.52	52.94	24.60	5.74	2
	W19	6.81	9.41	19.79	59.54	4.45	3
	W20	20.31	12.50	19.90	47.35	0.00	0
	W21	1.41	23.75	16.86	49.46	8.52	5
	W22	78.02	0.00	8.58	2.63	10.78	0
	W23	2.42	61.47	3.24	33.57	0.00	9
	W24	72.33	3.49	6.89	12.41	4.88	0
Scale: 0.4km	W1	13.18	14.81	45.14	22.89	3.98	40
	W2	0.76	5.16	41.79	50.12	2.17	6
	W3	13.35	5.78	31.55	48.30	1.02	8
	W4	4.91	1.35	47.34	44.71	1.70	0
	W5	3.94	15.11	28.53	49.87	2.55	21
	W6	13.62	6.84	35.18	43.64	0.72	8
	W7	10.81	3.57	56.91	26.90	1.80	4
	W8	10.60	9.67	43.13	29.14	7.45	22
	W9	16.36	19.90	22.91	9.58	31.26	24
	W10	4.22	25.41	28.15	40.82	1.40	40

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
Scale: 0.4km	W11	16.71	11.55	46.52	22.52	2.71	0
	W12	7.88	11.73	23.52	48.40	8.47	1
	W13	6.29	3.58	28.36	49.98	11.79	8
	W14	24.06	12.83	31.67	27.24	4.20	2
	W15	13.68	9.35	29.74	43.70	3.53	19
	W16	0.51	3.79	56.86	37.92	0.92	7
	W17	6.41	10.30	55.97	26.31	1.01	16
	W18	1.30	10.96	41.37	43.55	2.82	8
	W19	8.15	5.91	33.95	49.43	2.57	5
	W20	13.56	11.11	32.41	41.57	1.35	3
	W21	0.35	26.03	38.76	32.30	2.56	23
	W22	69.86	0.75	14.35	11.62	3.42	0
	W23	2.73	32.47	18.52	45.28	1.00	19
	W24	41.11	14.38	7.35	27.29	9.87	16
Scale: 0.6km	W1	9.29	10.35	45.02	30.37	4.97	71
	W2	0.34	3.90	43.30	50.77	1.69	14
	W3	6.40	11.42	35.55	45.46	1.16	47
	W4	4.44	2.52	38.40	52.63	2.01	7
	W5	1.75	9.34	56.16	30.97	1.78	31
	W6	9.44	10.48	36.81	40.76	2.51	25
	W7	7.56	2.18	45.10	42.71	2.45	5
	W8	12.59	10.82	35.29	30.35	10.95	48
	W9	7.72	28.15	19.24	4.98	39.91	81
	W10	9.35	18.25	33.95	37.21	1.24	66
	W11	9.72	13.78	43.46	30.91	2.13	3
	W12	6.33	8.46	25.17	53.23	6.81	5
	W13	4.64	5.00	27.13	53.17	10.06	14
	W14	17.58	15.74	25.93	31.15	9.60	34
	W15	11.01	19.59	22.02	45.07	2.30	62
	W16	8.49	4.02	46.66	39.42	1.41	10
	W17	7.86	8.81	52.42	29.17	1.75	21
	W18	0.58	12.67	49.92	34.18	2.65	8
	W19	4.24	4.08	35.66	53.87	2.15	8
	W20	12.04	8.67	38.63	39.33	1.33	8
	W21	0.33	16.68	39.08	42.00	1.91	33
	W22	36.43	2.60	23.94	33.08	3.95	3

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
	W23	2.03	13.81	33.91	48.68	1.58	27
	W24	14.31	27.44	5.62	15.30	37.34	142
Scale: 0.8km	W1	7.27	8.50	43.94	34.54	5.75	108
	W2	0.19	3.02	39.85	55.27	1.67	17
	W3	6.07	10.94	35.78	45.40	1.81	76
	W4	3.41	2.24	40.37	52.60	1.38	17
	W5	1.03	6.90	62.52	27.09	2.46	40
	W6	6.44	10.44	39.26	40.99	2.87	68
	W7	5.40	2.63	39.70	49.92	2.35	14
	W8	11.45	11.46	31.54	27.92	17.64	98
	W9	4.67	29.30	15.60	4.54	45.89	296
	W10	9.74	13.70	47.74	27.57	1.25	96
	W11	6.05	12.64	37.03	41.88	2.40	7
	W12	6.78	6.60	26.32	54.51	5.79	7
	W13	8.56	5.39	24.12	52.41	9.52	18
	W14	14.35	16.22	22.96	30.62	15.85	128
	W15	7.94	22.94	19.72	47.29	2.11	81
	W16	11.09	2.75	42.03	42.26	1.86	11
	W17	8.88	6.38	51.23	31.81	1.70	26
	W18	0.40	11.99	52.75	31.96	2.90	26
	W19	2.58	3.74	30.82	60.59	2.26	11
	W20	13.04	6.81	31.96	46.82	1.37	12
	W21	2.97	13.98	38.85	42.54	1.66	43
	W22	36.43	2.60	23.94	33.08	3.95	5
	W23	2.03	13.81	33.91	48.68	1.58	49
	W24	14.31	27.44	5.62	15.30	37.34	323
Scale: 1.0km	W1	5.60	7.57	43.32	34.66	8.85	148
	W2	1.07	3.43	33.75	59.92	1.83	24
	W3	5.78	11.47	35.29	45.01	2.45	122
	W4	2.36	2.23	47.42	46.90	1.09	29
	W5	1.29	4.95	67.40	24.07	2.29	46
	W6	4.97	14.59	36.41	40.87	3.15	164
	W7	3.61	2.82	35.40	55.70	2.47	16
	W8	9.79	12.64	26.91	25.14	25.52	181
	W9	3.73	30.36	12.56	4.33	49.02	625
	W10	8.92	10.77	55.65	23.39	1.27	118

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
Scale: 1.0km	W11	4.72	9.88	37.71	45.43	2.26	25
	W12	6.87	5.69	25.55	56.52	5.37	9
	W13	8.68	5.11	20.90	48.68	16.63	25
	W14	11.57	19.73	20.19	29.66	18.85	266
	W15	11.44	21.16	17.30	47.59	2.51	132
	W16	10.59	3.03	42.62	41.08	2.67	22
	W17	7.83	5.08	45.48	38.28	3.33	28
	W18	1.31	12.93	50.66	28.67	6.44	101
	W19	1.82	6.26	32.87	56.30	2.74	26
	W20	9.53	6.53	29.38	52.67	1.89	17
	W21	3.16	13.48	38.46	42.78	2.13	80
	W22	29.31	2.31	27.34	37.27	3.76	6
	W23	1.67	13.84	35.72	47.52	1.25	102
	W24	9.59	29.51	4.15	11.40	45.36	530
Scale: 1.2km	W1	7.71	6.90	43.29	33.51	8.59	176
	W2	0.80	4.19	26.52	66.58	1.91	30
	W3	7.77	10.19	37.12	42.47	2.45	154
	W4	2.03	3.05	51.66	42.31	0.95	50
	W5	1.78	4.11	68.87	23.03	2.20	50
	W6	4.20	20.33	36.37	36.22	2.88	425
	W7	3.18	2.57	32.57	59.56	2.12	24
	W8	10.01	11.96	23.51	24.01	30.51	233
	W9	3.94	32.13	10.58	6.45	46.91	1095
	W10	8.86	10.10	57.71	22.03	1.30	150
	W11	4.28	10.47	39.33	43.52	2.39	67
	W12	7.81	5.47	24.47	57.06	5.19	9
	W13	7.07	5.36	20.00	46.41	21.16	32
	W14	10.56	21.55	18.33	28.70	20.85	371
	W15	12.07	20.33	21.56	43.27	2.76	211
	W16	10.06	3.68	42.79	40.39	3.08	31
	W17	8.79	4.42	38.76	44.20	3.83	32
	W18	1.71	11.85	46.75	28.02	11.67	163
	W19	1.68	7.27	37.93	50.53	2.59	57
	W20	8.09	6.69	29.00	53.85	2.37	20
	W21	2.95	14.56	34.84	45.08	2.56	134
	W22	25.71	2.44	27.35	41.21	3.29	11

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
	W23	1.17	13.10	38.20	46.37	1.16	152
	W24	7.52	32.03	3.87	9.13	47.45	708
Scale: 1.4km	W1	12.29	6.16	42.92	30.71	7.93	198
	W2	0.99	5.21	22.84	69.04	1.92	38
	W3	10.47	9.28	38.23	39.71	2.30	187
	W4	2.01	3.69	51.47	41.69	1.14	89
	W5	1.83	3.77	69.19	22.98	2.23	62
	W6	3.84	22.91	37.51	32.87	2.88	709
	W7	2.89	2.35	31.05	61.89	1.82	28
	W8	9.53	10.22	21.55	24.59	34.11	270
	W9	5.30	30.84	10.79	7.90	45.17	1427
	W10	9.98	8.90	57.05	22.77	1.30	179
	W11	4.52	11.59	40.18	41.38	2.34	113
	W12	7.46	5.72	24.48	57.33	5.01	15
	W13	6.33	6.36	18.91	43.47	24.93	39
	W14	9.63	21.33	18.14	28.87	22.03	511
	W15	11.33	22.45	26.66	36.53	3.02	517
	W16	9.39	3.56	42.27	41.71	3.07	45
	W17	9.56	5.37	33.13	48.58	3.36	63
	W18	1.78	10.66	44.02	27.97	15.57	186
	W19	1.51	7.70	39.04	48.26	3.48	102
	W20	8.15	6.30	27.23	53.79	4.53	23
	W21	2.99	16.52	33.52	44.06	2.91	272
	W22	25.60	2.35	26.12	43.12	2.80	14
	W23	1.39	12.79	43.03	41.62	1.17	195
	W24	6.84	34.19	3.65	7.73	47.59	1180
Scale: 1.6km	W1	12.55	5.76	46.90	27.58	7.21	215
	W2	1.47	6.36	22.39	67.74	2.05	50
	W3	11.27	8.21	40.76	37.55	2.21	208
	W4	1.99	3.70	49.45	43.47	1.39	142
	W5	1.61	3.79	72.10	20.54	1.97	72
	W6	3.61	23.49	38.08	32.04	2.78	1009
	W7	2.69	2.79	32.22	60.36	1.94	45
	W8	9.47	9.95	21.03	23.90	35.65	340
	W9	5.94	27.71	12.40	9.52	44.44	1535
	W10	12.78	8.42	53.92	23.62	1.26	245

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
Scale: 1.6km	W11	4.70	13.15	40.63	39.33	2.20	261
	W12	7.80	6.03	24.72	56.25	5.20	30
	W13	5.78	7.24	19.70	39.36	27.92	51
	W14	8.22	20.66	19.03	29.48	22.60	671
	W15	9.60	24.05	32.00	31.21	3.14	971
	W16	8.83	3.61	40.39	44.25	2.92	54
	W17	10.68	5.57	30.00	50.18	3.57	81
	W18	1.64	9.10	42.43	27.93	18.91	216
	W19	1.54	7.25	39.66	45.99	5.56	133
	W20	8.34	6.03	26.01	54.26	5.35	28
	W21	3.01	18.97	33.08	42.10	2.83	551
	W22	29.12	2.43	23.14	42.85	2.47	14
	W23	1.95	12.01	45.55	39.30	1.18	226
	W24	5.86	36.51	3.39	7.09	47.15	1815
Scale: 1.8km	W1	11.85	5.30	49.07	27.29	6.49	232
	W2	2.33	6.52	22.24	67.10	1.82	62
	W3	11.80	7.00	42.46	36.68	2.06	226
	W4	1.71	3.70	46.28	46.54	1.77	167
	W5	1.38	3.55	73.66	19.45	1.96	82
	W6	3.85	23.17	37.24	32.83	2.91	1286
	W7	2.51	2.88	33.85	58.63	2.13	55
	W8	10.24	10.61	20.21	22.77	36.16	437
	W9	6.17	23.56	12.99	13.56	43.73	1562
	W10	14.97	7.71	51.70	24.11	1.51	304
	W11	3.75	14.05	40.73	39.29	2.18	437
	W12	9.06	6.07	24.71	54.98	5.18	41
	W13	5.38	7.49	21.12	34.94	31.08	90
	W14	7.95	19.53	19.07	29.16	24.29	801
	W15	8.37	26.37	33.22	29.21	2.82	1453
	W16	9.19	3.77	38.27	46.10	2.67	67
	W17	11.37	5.67	26.93	51.55	4.48	100
	W18	1.37	7.83	41.61	27.41	21.78	221
	W19	1.96	7.10	40.22	42.30	8.42	162
	W20	8.29	5.92	24.51	55.49	5.79	32
	W21	3.08	21.07	33.40	39.58	2.87	843
	W22	31.83	2.56	20.54	42.82	2.26	16

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
	W23	2.52	11.37	47.44	37.38	1.29	318
	W24	5.50	37.71	3.28	7.43	46.08	2472
Scale: 2.0km	W1	12.83	5.21	49.13	26.52	6.31	—
	W2	3.29	5.91	23.07	66.03	1.70	—
	W3	14.15	6.06	41.62	36.15	2.02	—
	W4	1.42	3.45	45.86	47.21	2.05	—
	W5	1.36	3.52	74.83	18.18	2.11	—
	W6	4.01	21.42	35.96	33.62	4.99	—
	W7	3.00	3.15	33.35	58.22	2.28	—
	W8	11.16	9.99	19.65	21.96	37.24	—
	W9	6.05	20.85	13.44	16.15	43.50	—
	W10	17.14	7.01	49.78	24.43	1.64	—
	W11	3.04	13.58	42.24	38.90	2.23	—
	W12	10.92	5.98	25.28	52.19	5.63	—
	W13	5.47	7.55	21.22	32.73	33.02	—
	W14	7.40	20.46	17.52	27.74	26.88	—
	W15	7.19	28.80	32.54	28.92	2.55	—
	W16	9.58	3.97	36.24	47.65	2.56	—
	W17	11.81	5.28	24.81	52.00	6.11	—
	W18	1.14	7.36	41.68	25.82	23.99	—
	W19	2.09	6.78	41.17	38.75	11.21	—
	W20	7.97	5.72	24.76	55.48	6.07	—
	W21	2.81	22.74	34.99	36.55	2.91	—
	W22	33.00	2.52	19.92	42.09	2.47	—
	W23	2.63	10.89	50.28	34.81	1.38	—
	W24	5.91	38.46	3.33	7.59	44.71	—
Scale: 2.2km	W1	14.93	6.04	49.86	25.37	3.80	—
	W2	3.06	5.35	24.91	65.70	0.99	—
	W3	18.09	5.75	39.75	36.46	0.00	—
	W4	1.32	3.79	47.46	45.51	1.92	—
	W5	1.28	3.67	76.60	18.00	0.45	—
	W6	4.66	21.32	36.21	34.01	3.81	—
	W7	3.22	3.68	32.48	59.59	1.03	—
	W8	13.72	10.50	20.02	21.19	34.57	—
	W9	7.05	21.92	14.10	17.59	39.34	—
	W10	19.04	7.17	47.35	25.96	0.47	—

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
Scale: 2.2km	W11	2.85	13.76	45.73	38.19	0.00	—
	W12	13.11	6.40	26.31	49.40	4.78	—
	W13	6.32	7.66	21.49	32.36	32.17	—
	W14	6.79	24.64	16.62	26.61	25.34	—
	W15	6.33	36.20	30.41	26.78	0.00	—
	W16	9.73	4.07	35.69	49.12	1.39	—
	W17	13.73	5.15	22.89	52.47	5.77	—
	W18	1.28	7.75	43.27	23.65	24.05	—
	W19	2.14	7.29	42.63	35.29	12.65	—
	W20	8.17	5.65	25.57	52.95	7.66	—
	W21	2.82	27.69	36.37	33.26	0.00	—
	W22	34.36	2.39	20.44	42.21	0.00	—
	W23	2.47	11.82	53.63	32.13	0.00	—
	W24	5.79	49.59	6.50	8.43	36.19	—
Scale: 2.4km	W1	15.42	5.66	48.28	24.95	5.69	—
	W2	2.88	4.97	26.06	65.19	0.91	—
	W3	19.62	5.04	38.32	36.94	0.08	—
	W4	1.14	3.81	48.91	44.21	1.93	—
	W5	1.29	3.48	77.07	17.76	0.40	—
	W6	4.48	19.69	36.08	33.57	6.18	—
	W7	3.77	3.77	31.83	59.52	1.11	—
	W8	13.72	9.78	20.39	19.99	36.12	—
	W9	7.02	20.22	14.50	18.67	39.59	—
	W10	20.99	6.65	44.74	26.90	0.72	—
	W11	2.81	12.12	47.61	37.14	0.32	—
	W12	14.08	6.46	27.69	46.01	5.76	—
	W13	6.43	7.26	21.11	32.10	33.10	—
	W14	5.83	25.70	15.61	25.59	27.27	—
	W15	5.38	37.96	30.45	26.32	0.00	—
	W16	9.18	3.92	35.32	50.22	1.36	—
	W17	14.90	4.68	21.73	51.88	6.81	—
	W18	1.26	7.27	43.71	22.76	25.01	—
	W19	1.92	7.25	43.55	31.98	15.31	—
	W20	7.69	5.78	25.50	50.08	10.95	—
	W21	3.59	27.63	36.87	32.00	0.00	—
	W22	34.54	2.30	21.65	40.86	0.00	—

Appendix K. (Continued)

	Site	Wetland cover (%)	Impervious cover (%)	Agriculture cover (%)	Forest cover (%)	Lakes and rivers (%)	Houses (#)
	W23	2.54	12.02	55.54	29.90	0.00	—
	W24	5.05	50.59	5.62	9.05	35.31	—
Scale: 2.6km	W1	16.43	5.41	46.16	24.19	7.81	—
	W2	2.87	4.83	27.15	64.20	0.95	—
	W3	20.79	4.45	37.43	36.95	0.38	—
	W4	0.98	3.79	49.63	43.69	1.91	—
	W5	1.20	3.54	76.51	18.07	0.68	—
	W6	4.08	18.88	36.49	32.41	8.14	—
	W7	5.03	3.75	30.80	59.16	1.26	—
	W8	13.23	8.95	21.17	19.99	36.66	—
	W9	7.08	18.72	15.36	19.58	39.26	—
	W10	22.05	6.17	43.44	27.57	0.78	—
	W11	2.71	11.37	48.02	36.00	1.90	—
	W12	14.34	6.33	29.01	42.44	7.88	—
	W13	6.33	6.71	20.77	32.23	33.96	—
	W14	5.10	26.06	15.61	24.60	28.63	—
	W15	4.61	40.52	29.91	25.30	0.00	—
	W16	9.05	3.70	34.73	51.01	1.50	—
	W17	15.47	4.39	21.13	51.44	7.57	—
	W18	1.52	6.87	44.54	21.29	25.78	—
	W19	1.79	6.99	43.81	29.82	17.59	—
	W20	7.23	5.81	25.83	46.84	14.28	—
	W21	3.96	27.38	37.30	31.42	0.00	—
	W22	34.56	2.21	22.77	39.52	0.95	—
	W23	2.80	12.16	57.35	27.75	0.00	—
	W24	4.39	52.07	4.99	9.11	34.43	—

Appendix L. The date that each wetland was visited during rounds one and two of sampling.

Site	Date (round 1)	Date (round 2)
W1	1-Jul-10	5-Aug-10
W2	16-Jun-10	22-Jul-10
W3	8-Jun-10	14-Jul-10
W4	23-Jun-10	28-Jul-10
W5	7-Jun-10	13-Jul-10
W6	15-Jun-10	21-Jul-10
W7	7-Jul-10	11-Aug-10
W8	17-Jun-10	23-Jul-10
W9	8-Jul-10	12-Aug-10
W10	5-Jul-10	9-Aug-10
W11	24-Jun-10	27-Jul-10
W12	22-Jun-10	29-Jul-10
W13	9-Jun-10	15-Jul-10
W14	14-Jun-10	20-Jul-10
W15	10-Jun-10	16-Jul-10
W16	25-Jun-10	30-Jul-10
W17	29-Jun-10	3-Aug-10
W18	28-Jun-10	2-Aug-10
W19	30-Jun-10	4-Aug-10
W20	6-Jul-10	10-Aug-10
W21	2-Jul-10	6-Aug-10
W22	11-Jun-10	19-Jul-10
W23	18-Jun-10	26-Jul-10
W24	9-Jul-10	13-Aug-10

Appendix M. Number of individuals of each benthic macroinvertebrate taxa sampled from all 24 focal wetlands.

Taxonomic group	Family	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Anisoptera	Aeshnidae	0	0	1	0	0	0	0	0	0	1	0	0
	Cordulidae	0	6	4	2	0	1	0	0	0	4	0	2
	Gomphidae	0	0	0	0	0	0	0	0	0	0	1	1
	Libellulidae	3	14	4	0	0	4	0	4	0	12	10	0
Zygoptera	Coenagrionidae	1	36	25	0	1	29	11	5	1	18	10	6
	Lestidae	0	0	0	0	22	0	0	0	0	0	1	0
Chironomidae	Chironomidae	38	61	74	77	35	25	176	104	4	119	42	95
Amphipoda	Talitridae	3	53	41	15	0	30	36	11	7	1	22	2
	Gammaridae	0	0	0	0	56	0	10	0	64	0	0	0
Isopoda	Asellidae	0	0	0	0	49	8	0	0	12	0	12	0
Ephemeroptera	Baetidae	0	142	137	6	83	7	35	1	0	2	18	0
	Caenidae	0	64	36	3	0	72	72	9	0	8	60	62
	Heptogeniidae	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Belostomatidae	0	0	0	0	0	0	0	0	0	0	0	0
	Corixidae	0	6	2	37	0	0	0	3	0	1	0	3
	Geriidae	0	0	0	0	0	0	0	1	0	0	0	0
	Hebridae/Hebrinidae	0	0	0	0	0	0	0	0	0	1	0	0
	Mesoveliidae	0	0	0	0	0	0	0	0	0	0	0	0
	Nepidae	1	0	0	0	0	0	0	0	0	0	0	0
	Notonectidae	0	0	1	0	0	1	0	0	0	0	0	0
	Pleidae	0	0	0	0	0	39	8	48	0	0	1	14
	Veliidae	0	0	0	0	0	1	0	0	0	0	0	0

Appendix M. (Continued)

Taxonomic group	Family	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24
Anisoptera	Aeshnidae	0	1	2	3	2	0	0	0	0	0	0	0
	Cordulidae	12	0	0	0	8	1	2	1	0	0	2	0
	Gomphidae	2	0	0	0	2	0	0	0	0	0	1	0
	Libellulidae	14	26	0	12	1	2	0	10	2	9	1	5
Zygoptera	Coenagrionidae	106	38	2	141	33	3	67	4	2	2	6	1
	Lestidae	0	0	0	4	0	0	0	0	0	0	0	0
Chironomidae	Chironomidae	47	37	24	39	59	52	48	168	150	72	69	20
Amphipoda	Talitridae	341	16	4	26	0	2	96	0	0	0	81	79
	Gammaridae	0	0	41	0	0	2	4	0	0	0	0	1
Isopoda	Asellidae	73	0	0	0	0	1	4	0	0	0	0	2
Ephemeroptera	Baetidae	9	5	6	34	36	6	3	0	92	0	26	0
	Caenidae	22	123	1	34	69	158	95	0	34	30	81	1
	Heptogeniidae	0	0	0	0	0	0	1	0	0	0	0	0
Hemiptera	Belostomatidae	0	1	1	1	0	1	0	0	0	0	0	2
	Corixidae	5	1	0	1	5	2	3	4	0	6	0	2
	Geriidae	0	0	0	0	0	0	0	0	0	0	0	0
	Hebridae/Hebrinidae	0	1	0	0	0	0	0	0	0	1	0	0
	Mesoveliidae	0	0	0	0	0	0	0	0	0	0	1	0
	Nepidae	0	0	0	0	0	0	0	0	0	0	0	0
	Notonectidae	0	0	0	11	0	0	0	0	0	0	0	2
	Pleidae	13	30	0	2	2	8	0	5	0	2	33	94
	Veliidae	0	0	0	4	0	0	1	0	0	0	1	1

Appendix M. (Continued)

Taxonomic group	Family	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Hydracarina		7	65	1	124	1	59	17	30	1	53	104	64
Oligochaeta	Aelosomatidae	0	0	0	3	0	0	0	3	0	0	2	0
	Haplotaxidae	0	0	0	2	0	5	0	3	99	0	3	0
	Naididae	114	8	22	0	0	18	5	17	4	19	0	7
	Lumbriculidae	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	Ancylidae	0	0	0	0	0	0	0	0	0	1	0	0
	Hydrobiidae	0	0	0	0	0	0	0	0	0	0	0	0
	Lymnaidae	24	0	0	5	0	3	0	1	19	0	3	1
	Physidae	17	0	0	2	6	1	1	12	34	5	1	5
	Planorbidae	63	1	43	6	4	9	0	13	25	12	10	35
	Valvatidae	2	0	0	0	0	30	0	0	8	0	0	0
	Viviparidae	0	0	0	0	0	9	0	0	15	0	4	0
Coleoptera	Haliplidae	1	1	4	12	0	2	2	0	0	3	1	1
	Hydrophilidae	1	0	0	2	2	0	0	1	1	2	0	0
	Hadraenidae	0	0	1	0	2	0	0	0	0	1	0	0
	Chrysomelidae	3	0	0	0	0	0	0	0	0	0	1	0
	Dytiscidae	18	1	4	5	12	2	2	8	2	2	2	1
	Elmidae	0	0	0	0	0	2	2	0	0	0	0	0
	Gerissidae	0	0	0	0	0	1	0	0	0	0	0	0
	Gyrinidae	0	0	0	0	0	0	0	0	0	0	0	0
	Noteridae	0	0	0	0	0	0	0	15	0	0	0	0
	Scirtidae	0	0	0	0	0	0	0	1	2	0	0	0

Appendix M. (Continued)

Taxonomic group	Family	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24
Hydracarina		48	4	14	19	76	30	35	36	0	85	4	2
Oligochaeta	Aelosomatidae	0	0	0	0	0	0	0	0	0	0	4	0
	Haplotaxidae	0	0	8	0	0	0	0	0	16	1	0	1
	Naididae	6	6	6	5	7	25	14	17	0	22	0	60
	Lumbriculidae	0	0	0	1	0	0	0	0	0	0	0	0
Gastropoda	Ancylidae	0	0	0	3	0	0	0	0	0	0	0	0
	Hydrobiidae	0	0	0	0	0	0	0	0	0	4	0	0
	Lymnaidae	1	9	159	3	1	0	0	0	1	5	2	2
	Physidae	6	0	4	0	0	1	2	9	0	6	0	2
	Planorbidae	1	10	101	3	4	2	0	44	2	21	3	3
	Valvatidae	57	3	1	0	0	1	14	0	0	0	8	2
	Viviparidae	0	0	0	0	0	0	0	0	0	0	9	7
Coleoptera	Haliplidae	0	2	1	4	1	1	2	1	2	4	1	1
	Hydrophilidae	0	0	3	0	0	1	0	0	0	0	0	0
	Hadraenidae	0	0	0	0	0	0	0	0	0	0	0	0
	Chrysomelidae	1	1	0	0	0	0	0	0	0	2	0	0
	Dytiscidae	1	4	36	1	0	3	0	0	4	2	2	1
	Elmidae	6	1	3	0	0	0	4	0	0	0	0	0
	Gerissidae	0	0	0	0	0	0	0	0	0	0	0	0
	Gyrinidae	1	0	0	3	0	0	0	0	0	0	0	0
	Noteridae	0	1	1	0	0	0	0	1	0	0	0	0
	Scirtidae	0	0	14	0	0	1	0	0	0	0	0	0

Appendix M. (Continued)

Taxonomic group	Family	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Trichoptera	Leptoceridae	0	34	0	0	0	60	11	0	0	0	8	3
	Phryganeidae	0	0	3	0	0	1	0	0	0	4	0	0
	Polycentropodidae	0	0	0	0	0	4	0	0	0	0	0	0
	Psychomiidae	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	Ceratopogonidae	0	2	3	18	0	4	0	8	2	3	4	8
Culicidae	Culicidae	0	0	0	1	15	0	0	0	1	0	0	0
Dixidae	Dixidae	0	0	0	0	1	0	0	0	0	0	0	0
Muscidae	Muscidae	0	0	0	0	1	0	0	0	0	0	0	0
Tabanidae	Tabanidae	0	0	0	1	1	0	0	0	0	0	0	0
Tipulidae	Tipulidae	0	0	0	1	1	0	0	0	0	0	0	0
Miscellaneous	Chaoboridae	0	0	16	0	1	0	0	1	0	0	0	0
Diptera	Stratiomyidae	1	0	0	0	0	1	0	1	0	0	0	0
	Pelecorhynchidae	0	0	0	0	0	0	0	0	0	0	0	0
Turbellaria	Planariidae	0	0	0	0	0	3	0	0	0	0	0	1
Bivalvia	Sphaeriidae	8	0	0	2	5	0	19	12	0	57	1	4
	Unionidae	0	0	0	0	0	0	0	0	0	0	0	0
Hirudinea	Glossiphoniidae	0	0	3	1	3	1	9	1	0	0	1	0
	Hirudinidae	0	0	0	0	1	0	0	1	0	3	0	0
Lepidoptera	Crambidae	0	0	0	0	0	1	0	2	3	0	0	0
Megaloptera	Corydalidae	0	0	0	0	0	0	0	2	0	0	0	0
	Sialidae	0	0	0	0	0	0	0	0	0	0	0	0
Nematoda		0	0	0	0	0	0	2	0	0	1	0	0
Decapoda	Astacidae	0	0	0	0	0	0	0	0	0	0	0	0
Totals:		305	494	425	322	302	433	418	300	304	333	320	311

Appendix M. (Continued)

Taxonomic group	Family	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24
Trichoptera	Leptoceridae	39	0	0	0	0	0	1	0	0	3	2	6
	Phryganeidae	0	1	0	3	0	2	0	8	0	0	0	0
	Polycentropodidae	0	0	0	0	0	0	1	1	0	0	0	0
	Psychomiidae	4	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	Ceratopogonidae	5	2	1	3	4	5	34	10	0	12	6	1
Culicidae	Culicidae	0	0	0	0	1	0	0	0	0	0	0	0
Dixidae	Dixidae	0	0	0	0	0	0	0	0	0	0	0	0
Muscidae	Muscidae	0	0	0	0	0	0	0	0	0	0	0	0
Tabanidae	Tabanidae	0	0	0	0	0	0	0	0	0	0	0	1
Tipulidae	Tipulidae	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous	Chaoboridae	0	0	1	0	0	1	0	1	11	2	0	0
Diptera	Stratiomyidae	0	0	1	0	0	0	0	0	0	0	0	0
	Pelecorhynchidae	1	0	0	0	0	0	0	0	0	0	0	0
Turbellaria	Planariidae	12	0	0	2	0	0	8	0	0	0	1	1
Bivalvia	Sphaeriidae	3	2	6	0	5	2	0	7	0	5	106	9
	Unionidae	0	0	0	0	1	0	0	0	0	0	0	0
Hirudinea	Glossiphoniidae	0	3	7	0	2	5	0	0	0	3	6	1
	Hirudinidae	0	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera	Crambidae	0	0	0	0	0	0	0	2	0	1	0	2
Megaloptera	Corydalidae	0	0	3	0	0	0	0	0	0	0	0	0
	Sialidae	1	0	0	0	0	0	0	0	0	0	0	0
Nematoda		1	0	0	0	0	1	0	1	0	1	0	0
Decapoda	Astacidae	1	0	0	0	0	0	0	0	0	0	0	0
Totals:		838	328	451	362	319	319	439	330	316	301	344	312

Appendix N. Total number of quadrats, total number of sampling units, number of sampling units containing floating, emergent, or submerged vegetation, and number of sampling units containing each taxa of vegetation at all 24 focal wetlands.

	W1	W2	W3	W4	W5	W6	W7	W8
# quadrats	38	39	38	32	39	39	38	39
# subsampling units	950	975	950	800	975	975	950	975
Floating	706	4	14	6	0	683	1	868
Emergent	637	11	37	1	594	656	42	188
Submerged	171	939	672	523	0	687	185	757
<i>Alisma triviale</i>	1	0	0	0	0	0	0	0
<i>Asclepia incarnata</i>	0	0	0	0	0	0	0	0
<i>Betula pumila</i>	0	0	0	0	0	0	0	0
<i>Butomus umbellatus</i>	0	0	0	0	0	631	0	0
<i>Calitriche hermaphroditica</i>	0	0	0	1	0	0	0	0
<i>Calla palustris</i>	0	0	0	0	0	0	0	0
<i>Carex</i> (unknown)	0	0	0	0	5	0	0	0
<i>Carex crinita</i>	0	0	0	0	0	0	0	0
<i>Carex diandra</i>	0	0	0	0	0	0	0	0
<i>Carex intumescens</i>	0	0	0	0	0	0	0	0
<i>Carex lupulina</i>	4	0	0	0	0	0	0	0
<i>Carex pseudo-cyperus</i>	0	0	0	0	0	0	0	0
<i>Ceratophyllum demersum</i>	0	0	0	0	0	128	15	0
<i>Chara sp.</i>	0	910	279	520	0	0	9	673
<i>Cicuta bulbifera</i>	0	0	0	0	0	1	0	0
<i>Cornus stolonifera</i>	0	0	0	0	0	0	0	0
Cyperaceae	35	0	0	0	0	0	0	0
<i>Eichhornia crassipes</i>	0	0	0	0	0	0	0	0
<i>Echinodorus tenellus</i>	0	0	0	0	0	0	0	0
<i>Eleocharis acicularis</i>	0	0	0	0	0	0	8	6
<i>Eleocharis smallii</i>	3	11	0	0	5	0	9	0
<i>Elodea canadensis</i>	0	0	0	0	0	68	0	0
<i>Equisetum arvense</i>	0	0	0	0	0	0	0	0
<i>Equisetum fluviale</i>	0	0	0	0	0	0	0	0
<i>Equisetum palustre</i>	0	0	0	0	0	0	0	0
<i>Equisetum pratense</i>	23	0	0	1	0	0	0	0

Appendix N. (Continued)

	W9	W10	W11	W12	W13	W14	W15	W16
# quadrats	21	39	39	39	36	39	39	37
# subsampling units	525	975	975	975	900	975	975	925
Floating	515	189	336	414	209	80	97	134
Emergent	71	99	178	109	135	605	656	367
Submerged	87	897	699	676	497	917	830	523
<i>Alisma triviale</i>	0	0	0	0	0	0	0	0
<i>Asclepia incarnata</i>	0	0	0	0	2	0	0	0
<i>Betula pumila</i>	0	0	0	0	0	0	0	0
<i>Butomus umbellatus</i>	0	0	0	0	0	0	0	0
<i>Calitriche hermaphrodita</i>	0	0	0	0	0	0	0	0
<i>Calla palustris</i>	0	0	0	0	0	0	0	0
<i>Carex (unknown)</i>	0	0	0	0	0	0	0	0
<i>Carex crinita</i>	0	0	3	2	0	0	0	0
<i>Carex diandra</i>	0	0	0	0	0	0	0	0
<i>Carex intumescens</i>	0	0	0	0	0	0	0	0
<i>Carex lupulina</i>	0	0	0	0	0	0	0	0
<i>Carex pseudo-cyperus</i>	0	0	0	0	0	0	341	0
<i>Ceratophyllum demersum</i>	76	0	0	188	0	0	0	0
<i>Chara sp.</i>	0	886	486	447	109	887	0	266
<i>Cicuta bulbifera</i>	21	0	1	5	0	0	0	0
<i>Cornus stolonifera</i>	0	0	0	3	0	0	0	17
Cyperaceae	0	0	0	0	0	0	0	0
<i>Eichhornia crassipes</i>	0	0	0	0	0	0	0	0
<i>Echinodorus tenellus</i>	0	0	0	0	0	0	8	0
<i>Eleocharis acicularis</i>	0	38	12	22	19	13	0	0
<i>Eleocharis smallii</i>	0	6	8	4	13	450	0	23
<i>Elodea canadensis</i>	0	0	0	0	367	0	0	0
<i>Equisetum arvense</i>	0	7	0	2	1	0	0	0
<i>Equisetum fluviale</i>	0	0	0	20	0	0	0	0
<i>Equisetum palustre</i>	0	0	0	0	0	0	0	0
<i>Equisetum pratense</i>	0	0	0	0	0	0	0	0

Appendix N. (Continued)

	W17	W18	W19	W20	W21	W22	W23	W24
Floating	43	249	344	720	188	231	29	953
Emergent	127	95	9	230	22	447	4	31
Submerged	643	702	512	618	853	774	563	729
# quadrats	32	39	37	39	39	36	36	39
# subsampling units	800	975	925	975	975	900	900	975
<i>Alisma triviale</i>	0	0	0	0	0	0	0	0
<i>Asclepias incarnata</i>	0	0	0	0	0	11	0	0
<i>Betula pumila</i>	0	0	0	0	0	2	0	0
<i>Butomus umbellatus</i>	0	0	0	0	0	0	0	0
<i>Calitriche hermaphrodita</i>	0	0	2	0	0	0	0	0
<i>Calla palustris</i>	0	0	0	8	0	0	0	0
<i>Carex (unknown)</i>	0	0	0	9	0	32	0	0
<i>Carex crinita</i>	0	0	0	0	0	0	0	0
<i>Carex diandra</i>	0	0	0	0	0	1	0	0
<i>Carex intumescens</i>	0	0	0	0	2	0	0	0
<i>Carex lupulina</i>	0	0	0	0	0	0	0	0
<i>Carex pseudo-cyperus</i>	0	0	0	0	0	99	0	0
<i>Ceratophyllum demersum</i>	26	0	389	81	0	127	0	265
<i>Chara sp.</i>	510	591	6	112	663	106	529	0
<i>Cicuta bulbifera</i>	4	0	0	12	0	0	0	0
<i>Cornus stolonifera</i>	0	0	0	0	0	0	0	0
Cyperaceae	0	0	0	0	0	0	0	0
<i>Eichhornia crassipes</i>	0	0	1	0	0	0	0	0
<i>Echinodorus tenellus</i>	0	0	0	0	0	0	0	0
<i>Eleocharis acicularis</i>	54	2	0	0	0	0	0	0
<i>Eleocharis smallii</i>	7	0	0	0	0	109	0	0
<i>Elodea canadensis</i>	180	10	0	0	0	0	0	431
<i>Equisetum arvense</i>	5	4	0	0	0	0	0	0
<i>Equisetum fluviale</i>	0	0	0	0	0	0	0	0
<i>Equisetum palustre</i>	0	0	0	0	0	42	0	0
<i>Equisetum pratense</i>	0	17	0	0	17	0	0	0

Appendix N. (Continued)

	W1	W2	W3	W4	W5	W6	W7	W8
<i>Equisetum variegatum</i>	0	0	0	0	0	0	0	0
<i>Eupatorium perfoliatum</i>	0	0	0	0	0	0	0	0
<i>Galium trifidum</i>	0	0	0	0	0	0	0	0
<i>Galium triflorum</i>	0	0	0	0	0	0	0	0
<i>Glyceria canadensis</i>	0	0	0	0	0	0	0	0
<i>Glyceria borealis</i>	0	0	0	0	0	0	0	4
<i>Hydrocaris morsus-ranae</i>	17	0	0	0	0	602	0	707
<i>Impatiens capensis</i>	0	0	0	0	0	0	0	0
<i>Impatiens pallida</i>	0	0	0	0	0	0	0	0
<i>Iris versicolor</i>	0	0	0	0	0	0	0	0
<i>Isoetes echinospora</i>	0	0	0	0	0	0	0	0
<i>Juncus canadensis</i>	0	0	0	0	0	0	0	0
<i>Lemna minor</i>	702	0	0	5	0	280	1	0
<i>Lemna trisulca</i>	0	0	0	1	0	8	0	6
<i>Lycopus uniflorus</i>	0	0	0	0	0	0	0	0
<i>Lythrum salicaria</i>	140	3	0	0	7	1	0	4
<i>Mentha sp.</i>	0	0	16	0	0	0	0	0
Moss	0	4	581	0	0	0	98	119
<i>Myriophyllum sibiricum</i>	0	0	0	0	0	0	0	0
<i>Najas flexilis</i>	0	0	0	0	0	0	17	0
<i>Nitella sp.</i>	0	0	0	0	0	0	0	0
<i>Nuphar rubrodisca</i>	0	0	0	0	0	0	0	0
<i>Nuphar variegatum</i>	0	0	1	0	0	0	0	66
<i>Nymphaea odorata</i>	0	0	13	0	0	0	0	0
<i>Nyssa sylvatica</i>	0	0	0	0	0	0	0	0
<i>Onoclea sensibilis</i>	0	0	0	0	0	0	0	0
Poaceae	179	0	23	0	0	0	37	88
<i>Polygonum amphibium</i>	16	4	0	0	0	0	0	22
<i>Pontederia cordata</i>	0	0	0	0	0	0	0	0
<i>Potamogeton epihydrus</i>	0	0	0	2	0	6	0	0
<i>Potamogeton foliosus</i>	0	0	0	0	0	539	0	0
<i>Potamogeton gramineus</i>	0	33	0	0	0	0	0	0
<i>Potamogeton natans</i>	0	0	0	0	0	0	0	62
<i>Potamogeton nodosus</i>	0	0	0	0	0	0	0	0
<i>Potamogeton pussillus</i>	145	0	0	5	0	65	36	34
<i>Potamogeton richardsonii</i>	0	0	0	0	0	0	0	0
<i>Potamogeton robinsii</i>	0	0	0	0	0	0	0	0

Appendix N. (Continued)

	W9	W10	W11	W12	W13	W14	W15	W16
<i>Equisetum variegatum</i>	0	0	0	0	0	0	0	3
<i>Eupatorium perfoliatum</i>	0	0	0	0	0	0	0	0
<i>Galium trifidum</i>	5	0	1	0	0	0	0	0
<i>Galium triflorum</i>	6	0	0	0	0	0	0	0
<i>Glyceria canadensis</i>	0	0	0	0	0	0	0	0
<i>Glyceria borealis</i>	0	0	0	0	0	0	0	0
<i>Hydrocaris morsus-ranae</i>	374	0	80	27	0	0	0	0
<i>Impatiens capensis</i>	3	0	0	0	0	0	0	0
<i>Impatiens pallida</i>	8	0	0	9	0	0	0	0
<i>Iris versicolor</i>	0	0	1	0	4	0	0	0
<i>Isoetes echinospora</i>	0	0	0	0	0	0	0	0
<i>Juncus canadensis</i>	0	0	0	0	0	110	0	0
<i>Lemna minor</i>	515	0	60	0	44	2	62	97
<i>Lemna trisulca</i>	141	0	0	0	2	0	0	5
<i>Lycopus uniflorus</i>	0	0	0	11	2	0	0	0
<i>Lythrum salicaria</i>	6	0	15	41	13	21	232	1
<i>Mentha sp.</i>	0	0	0	0	0	0	0	0
Moss	0	0	0	142	45	29	719	9
<i>Myriophyllum sibiricum</i>	0	0	0	0	0	0	0	0
<i>Najas flexilis</i>	0	79	92	0	34	0	0	277
<i>Nitella sp.</i>	0	0	0	0	0	0	0	0
<i>Nuphar rubrodisca</i>	0	0	0	2	0	0	0	0
<i>Nuphar variegatum</i>	0	0	0	0	0	0	0	0
<i>Nymphaea odorata</i>	0	0	0	0	0	0	0	0
<i>Nyssa sylvatica</i>	0	0	0	0	0	0	0	0
<i>Onoclea sensibilis</i>	0	0	0	1	0	0	0	0
Poaceae	0	0	0	34	27	23	110	136
<i>Polygonum amphibium</i>	0	0	0	0	0	0	0	0
<i>Pontederia cordata</i>	0	0	0	0	0	0	0	0
<i>Potamogeton epihydrus</i>	0	0	0	0	0	0	0	0
<i>Potamogeton foliosis</i>	0	0	0	0	0	0	0	0
<i>Potamogeton gramineus</i>	0	216	0	0	0	0	0	46
<i>Potamogeton natans</i>	0	87	221	225	168	0	0	0
<i>Potamogeton nodosus</i>	0	0	0	0	0	0	0	0
<i>Potamogeton pussillus</i>	0	18	206	194	0	0	0	19
<i>Potamogeton richardsonii</i>	0	0	0	0	0	0	0	0
<i>Potamogeton robinsii</i>	0	0	0	0	0	0	0	0

Appendix N. (Continued)

	W17	W18	W19	W20	W21	W22	W23	W24
<i>Equisetum variegatum</i>	0	0	0	0	0	0	0	0
<i>Eupatorium perfoliatum</i>	0	0	0	0	0	3	0	0
<i>Galium trifidum</i>	1	0	0	5	0	36	0	0
<i>Galium triflorum</i>	0	0	0	1	0	0	0	0
<i>Glyceria canadensis</i>	0	0	0	0	0	50	0	0
<i>Glyceria borealis</i>	0	0	0	0	0	0	0	0
<i>Hydrocaris morsus-ranae</i>	0	0	178	650	0	185	0	4
<i>Impatiens capensis</i>	0	0	0	0	0	0	0	0
<i>Impatiens pallida</i>	0	0	0	0	0	0	0	0
<i>Iris versicolor</i>	0	0	0	0	0	1	0	0
<i>Isoetes echinospora</i>	23	0	0	0	0	0	0	0
<i>Juncus canadensis</i>	0	0	0	0	0	0	0	0
<i>Lemna minor</i>	7	44	159	460	5	54	0	0
<i>Lemna trisulca</i>	0	0	0	0	0	0	0	881
<i>Lycopus uniflorus</i>	0	0	0	0	0	0	0	0
<i>Lythrum salicaria</i>	5	3	0	1	2	77	1	0
<i>Mentha sp.</i>	0	0	0	0	0	0	0	0
Moss	4	2	8	63	201	558	0	0
<i>Myriophyllum sibiricum</i>	0	0	0	0	0	0	0	18
<i>Najas flexilis</i>	27	90	0	0	0	0	38	81
<i>Nitella sp.</i>	0	0	0	0	0	0	0	2
<i>Nuphar rubrodisca</i>	0	125	0	0	0	0	0	0
<i>Nuphar variegatum</i>	0	0	0	0	0	0	0	20
<i>Nymphaea odorata</i>	0	0	1	0	154	0	24	50
<i>Nyssa sylvatica</i>	0	0	0	0	0	3	0	0
<i>Onoclea sensibilis</i>	0	0	0	0	3	0	0	0
Poaceae	43	54	14	9	6	225	1	0
<i>Polygonum amphibium</i>	0	0	0	0	0	2	0	0
<i>Pontederia cordata</i>	0	0	0	0	0	0	0	11
<i>Potamogeton epihydrus</i>	0	0	95	0	0	0	0	0
<i>Potamogeton foliosis</i>	0	0	0	0	0	0	0	0
<i>Potamogeton gramineus</i>	50	131	0	0	0	0	0	0
<i>Potamogeton natans</i>	0	4	0	0	0	22	0	0
<i>Potamogeton nodosus</i>	0	0	43	0	0	0	0	0
<i>Potamogeton pussillus</i>	60	93	64	339	0	85	0	161
<i>Potamogeton richardsonii</i>	0	0	0	0	0	0	20	0
<i>Potamogeton robinsii</i>	0	0	0	0	0	0	0	114

Appendix N. (Continued)

	W1	W2	W3	W4	W5	W6	W7	W8
<i>Potamogeton zosteriformis</i>	0	0	0	0	0	0	0	13
<i>Ranunculus sp.</i>	0	0	0	0	0	0	0	0
<i>Riccia fluitans</i>	0	0	0	0	0	0	0	9
<i>Rumex orbiculatus</i>	0	0	0	0	0	0	0	0
<i>Sagittaria cuneata</i>	123	0	0	0	0	0	0	122
<i>Sagittaria graminea</i>	0	0	0	0	0	0	0	0
<i>Sagittaria latifolia</i>	0	0	0	0	0	37	1	29
<i>Salix petiolaris</i>	0	0	0	0	0	0	0	0
<i>Scirpus acutus</i>	144	0	0	0	7	0	0	0
<i>Scirpus cespitosus</i>	0	0	0	0	0	0	0	0
<i>Scirpus cyperinus</i>	0	0	0	0	0	0	0	0
<i>Scirpus subterminalis</i>	0	1	0	0	0	0	0	0
<i>Scirpus validus</i>	0	0	0	0	28	0	0	0
<i>Scrophulariaceae sp.</i>	0	0	0	0	0	0	0	0
<i>Sium sp.</i>	0	0	0	0	0	0	0	0
<i>Solanum dulcamara</i>	0	0	0	0	0	0	0	53
<i>Sparganium americanum</i>	0	0	0	0	0	0	0	0
<i>Sparganium androcladum</i>	0	0	0	0	0	0	0	0
<i>Sparganium emersum</i>	0	0	0	0	0	0	0	0
<i>Sparganium eurycarpum</i>	403	0	0	0	0	0	0	0
<i>Sparganium fluctuans</i>	0	0	0	0	0	0	0	0
<i>Spirea alba</i>	0	0	0	0	0	0	0	0
<i>Spirodella polyrhiza</i>	0	0	0	0	0	188	0	489
<i>Stuckenia filliformis</i>	0	0	0	0	0	0	9	0
<i>Stuckenia pectinata</i>	14	150	0	0	0	76	19	7
<i>Thelypteris palustris</i>	0	0	0	0	0	0	0	0
<i>Typha sp.</i>	0	0	20	0	701	2	0	0
<i>Utricularia sp.</i>	0	28	0	0	0	0	0	0
<i>Vallisneria americana</i>	0	0	0	0	0	0	3	0
<i>Wolffia arrhiza</i>	0	0	0	0	0	0	0	0
<i>Zosterella dubia</i>	0	0	0	0	0	0	0	0

Appendix N. (Continued)

	W9	W10	W11	W12	W13	W14	W15	W16
<i>Potamogeton zosteriformis</i>	0	0	0	0	3	0	0	104
<i>Ranunculus sp.</i>	0	0	0	0	0	0	1	0
<i>Riccia fluitans</i>	0	0	0	0	0	0	0	32
<i>Rumex orbiculatus</i>	0	0	0	0	0	0	0	0
<i>Sagittaria cuneata</i>	0	0	0	0	0	0	0	15
<i>Sagittaria graminea</i>	0	0	0	0	0	0	145	0
<i>Sagittaria latifolia</i>	0	0	0	0	0	1	44	1
<i>Salix petiolaris</i>	0	0	0	0	0	0	18	2
<i>Scirpus acutus</i>	0	0	0	0	0	0	0	133
<i>Scirpus cespitosus</i>	0	0	0	0	0	0	0	3
<i>Scirpus cyperinus</i>	0	0	0	0	4	0	0	0
<i>Scirpus subterminalis</i>	0	0	0	0	0	0	45	0
<i>Scirpus validus</i>	0	3	0	0	46	0	18	0
<i>Scrophulariaceae sp.</i>	0	0	0	3	0	0	0	0
<i>Sium sp.</i>	0	0	0	0	0	0	0	0
<i>Solanum dulcamara</i>	0	0	0	2	0	0	0	44
<i>Sparganium americanum</i>	0	0	0	0	0	30	0	0
<i>Sparganium androcladum</i>	0	0	0	0	0	0	0	55
<i>Sparganium emersum</i>	0	0	0	0	0	0	0	0
<i>Sparganium eurycarpum</i>	0	0	0	0	0	94	0	0
<i>Sparganium fluctuans</i>	0	0	0	0	0	14	0	0
<i>Spiraea alba</i>	0	0	0	0	0	0	0	0
<i>Spirodella polyrhiza</i>	116	0	0	340	0	0	0	0
<i>Stuckenia filliformis</i>	0	0	0	0	0	0	0	0
<i>Stuckenia pectinata</i>	0	105	0	2	1	133	0	0
<i>Thelypteris palustris</i>	0	0	0	0	0	0	0	0
<i>Typha sp.</i>	54	69	148	96	71	0	14	39
<i>Utricularia sp.</i>	0	0	4	45	73	22	0	0
<i>Vallisneria americana</i>	0	0	0	0	1	0	1	0
<i>Wolffia arrhiza</i>	0	0	0	0	0	0	0	0
<i>Zosterella dubia</i>	0	0	0	22	0	0	0	0

Appendix N. (Continued)

	W17	W18	W19	W20	W21	W22	W23	W24
<i>Potamogeton zosteriformis</i>	0	0	24	0	0	0	0	266
<i>Ranunculus sp.</i>	0	0	0	0	0	3	0	0
<i>Riccia fluitans</i>	0	0	0	35	0	0	0	0
<i>Rumex orbiculatus</i>	0	0	0	0	0	0	0	18
<i>Sagittaria cuneata</i>	0	5	0	0	0	0	0	0
<i>Sagittaria graminea</i>	0	0	0	0	0	0	0	0
<i>Sagittaria latifolia</i>	0	0	3	0	0	0	0	5
<i>Salix petiolaris</i>	0	0	0	0	0	2	0	0
<i>Scirpus acutus</i>	2	0	0	4	7	0	0	0
<i>Scirpus cespitosus</i>	0	0	0	0	0	0	0	0
<i>Scirpus cyperinus</i>	0	0	0	0	0	0	0	0
<i>Scirpus subterminalis</i>	0	0	0	0	0	7	0	0
<i>Scirpus validus</i>	0	0	0	0	0	0	0	0
<i>Scrophulariaceae sp.</i>	0	0	0	0	0	0	0	0
<i>Sium sp.</i>	0	0	0	0	0	5	0	0
<i>Solanum dulcamara</i>	0	4	0	0	3	0	0	0
<i>Sparganium americanum</i>	24	0	0	0	0	0	0	0
<i>Sparganium androcladum</i>	0	0	0	0	0	0	0	0
<i>Sparganium emersum</i>	0	0	16	2	0	4	0	0
<i>Sparganium eurycarpum</i>	0	0	2	0	0	0	0	2
<i>Sparganium fluctuans</i>	0	0	0	0	0	18	0	0
<i>Spiraea alba</i>	0	0	0	0	0	2	0	0
<i>Spirodella polyrhiza</i>	0	0	0	0	0	0	0	911
<i>Stuckenia filliformis</i>	0	0	0	0	0	0	0	0
<i>Stuckenia pectinata</i>	159	5	0	0	0	0	0	0
<i>Thelypteris palustris</i>	0	2	0	0	0	0	0	0
<i>Typha sp.</i>	21	1	0	167	0	3	2	0
<i>Utricularia sp.</i>	0	0	0	212	0	4	0	17
<i>Vallisneria americana</i>	0	1	0	0	0	0	0	56
<i>Wolffia arrhiza</i>	0	0	0	0	0	0	0	944
<i>Zosterella dubia</i>	0	0	0	0	0	3	0	0

Appendix O. The combined duration (in seconds) of the three kick-and-weep samples, the combined volume of all three kick-and-sweep samples, the number of subsamples removed to obtain a minimum of 300 individuals (100 individuals per kick-and-sweep sample), and the total volume subsampled to obtain a minimum of 300 individuals.

Site #	Total kick-and-sweep duration (sec)	Entire sample volume (ml)	Number of 140ml Subsamples	Volume subsampled (ml)
W1	82	15000	10	1400
W2	195	13750	6	840
W3	151	15000	6	840
W4	190	10000	12	1680
W5	152	15000	19	2660
W6	158	13750	6.5	910
W7	175	8750	6.5	910
W8	82	13750	19.5	2730
W9	73	15000	6.5	910
W10	123	11250	10.25	1435
W11	187	15000	8.5	1190
W12	143	15000	9	1260
W13	176	12500	6.5	910
W14	139	13750	8	1120
W15	102	12500	6	840
W16	164	10500	6	840
W17	142	12500	10.5	1470
W18	126	6750	13	1820
W19	141	15000	9	1260
W20	98	13750	23.5	3290
W21	143	11250	19	2660
W22	173	13750	26	3640
W23	160	8750	3.5	490
W24	128	15000	11.5	5360