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Primay Research Paper

Relationship between riparian vegetation and stream benthic communities at three spatial scales

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Abstract

We examined the influence of riparian vegetation on macroinvertebrate community structure in streams of the Upper Thames River watershed in southwestern Ontario. Thirty-three μ-basins (129–1458 ha) were used to identify land cover variables that influenced stream macroinvertebrates. Micro-basins represented the entire drainage area of study streams and were similar in stream order (first, second) and land cover (agricultural or forest; no urban). We described the structure and composition of riparian vegetation and benthic macroinvertebrate communities at the outflow reach. The nature of the land cover was quantified for the stream network buffer (30 m) and the whole μ-basin. The objective of this study was to measure the magnitude and nature of the relationship between the riparian vegetation and benthic macroinvertebrate community at the outflow reach, stream network buffer, and whole μ-basin scales. Taxon richness (including total number of Ephemeroptera, Plecoptera, and Trichoptera taxa) and Simpson's diversity of the macroinvertebrate community all increased with increased tree cover in the riparian zone at the outflow reach scale. Simpson's equitability was lower with greater agricultural land cover in the stream network buffer. No relationship between the macroinvertebrate community and land cover was found at the whole μ-basin scale. Analysis of the influence of land cover on stream communities within a spatial hierarchy is important for understanding the interactions of stream ecosystems with their adjacent landscapes.

Introduction

Terrestrial and aquatic ecosystems are intimately linked through physical processes and fluxes of energy and nutrients across the riparian ecotone (Gregory et al., 1991; Verry et al., 2000). Riparian vegetation is of great importance to the maintenance of natural stream processes. The variety of wildlife and plants in riparian ecosystems provides inputs of organic matter, energy and nutrient to aquatic ecosystems (Rowe & Taylor, 1994; Bunn et al., 1999; Clausen et al., 2000). Riparian zones may buffer streams from adjacent lands by trapping sediment, nutrients and other contaminants (Carothers, 1977). Streamside vegetation provides shade necessary for natural temperature regimes and improves stream ecosystem health (Bunn et al., 1999). Because they are at the boundary of terrestrial and aquatic systems, riparian areas are powerful indicators of catchment quality (Richards et al., 1993).

The riparian landscape has been significantly degraded by human disturbances in North America such as urban development, industrial activity, logging, row crop agriculture, and grazing (Stevens & Cummins, 1999). These activities can result in streambank erosion, increased sedimentation, alteration of geomorphology of riparian habitats, loss of species diversity and assemblage composition of macroinvertebrates, and other detrimental effects (Osborne & Kovacic, 1993; Lenat & Crawford, 1994; Harriman et al., 1994; Barton & Farmer, 1997; Stevens & Cummins, 1999; Weigel et al., 2000). As a result of landscape alteration, many riparian areas no longer perform critical ecosystem functions (Carothers, 1977; Poff, 1997). Efforts to conserve biological communities require predictive models that describe the relationship between land use and the biological integrity of the aquatic community within a spatially hierarchy (Richards et al., 1993; Johnson & Gage, 1997; Wang et al., 2003).

Quantifying the relative role of catchment and reach scale environments for stream communities is important for understanding the interactions of stream ecosystems with their adjacent landscapes (Richards et al., 1996). The study of environmental factors at different spatial scales that influence stream communities increases the ability to detect anthropogenic effects, identify biological response signatures to human-induced stress and ultimately improve aquatic ecosystem health (Norris & Thoms, 1999; Weigel, 2003). Catchment-based assessment that addresses physical and biological components, are used to determine changes in stream biota exposed to stressors (Allan et al., 1997; Bailey et al., 2003).

This study used three spatial scales to investigate the effects of riparian vegetation on macroinvertebrate communities in streams of the Upper Thames River watershed in southern Ontario. We determined the magnitude and nature of the relationship between riparian vegetation and the structure of macroinvertebrate communities at the outflow reach, stream network buffer, and μ-basin scales.

Methods

The study area spanned the 3500 km^2 of the Upper Thames River Catchment in southwestern Ontario, Canada (Fig. 1). The topography in the watershed is flat to gently undulating, with some long gentle slopes at elevations of 260–278 m. Much of the Upper Thames River watershed is particularly subject to enhanced channelization, agricultural drain systems, subsurface drainage, runoff, spills, and bank alterations, among other stressors (UTRCA, 2001). Riparian habitats and hydrology of the Thames River's tributary stream network have been highly modified at local and regional scales by years of aggregated mining, grazing, timber harvesting, and agricultural practices (Abell et al., 2000). Woody vegetation is largely absent from many riparian areas because of livestock grazing, and removal of vegetation along the floodplain for agricultural use or urban development. Forests have also been substantially reduced and changed by introduced species and over-logging, which have altered the original species composition of the riparian vegetation where it still occurs.

A total of 33 sites on first- and second- order streams were sampled. The watersheds of these sites were delineated from a 10 × 10 m resolution Digital Elevation Model using Rivertools 2.4 (Rivex LLC 2001) and ArcGIS 8 (ESRI 2000). Each stream was characterized in a hierarchical framework of three spatial scales; the *outflow reach* (a stream length 10× the width of the stream channel; Parsons & Norris, 1996), a 30 m *buffer* on each side of the stream network within the reach's watershed, and the whole *μ-basin* (Fig. 2).

At the *outflow reach* scale, a visual estimate of aerial cover of riparian vegetation along a 30 m buffer on either side of the stream through the length of the site was quantified and classified as ground (grasses and herbs), shrubs, sub-canopy trees (<10 m in height) and canopy trees (>10 m in height). Percent shading of the stream by riparian vegetation was also visually estimated by standing midstream at the middle of the site. Macroinvertebrates were sampled using a 250 μm mesh-size D-net (Hauer & Lamberti, 1996) with a three-minute travelling side-by-side kick sample (Reynoldson et al., 1997). Each macroinvertebrate sample was rinsed with tap water in a 250 μm sieve and the invertebrates were preserved in 70% ethanol. Sub-samples were taken from random cells until 300 organisms or more were picked (Marchant, 1989). All specimens were identified to family level, with the exception of Oligochaeta, Acariformes and Nematoda. Community descriptors (richness = number of taxa = S; Simpson's diversity = $D = 1/\sum p_i^2$; Simpson's equitability = S/D) were calculated for each μ-basin to describe variation in macroinvertebrate

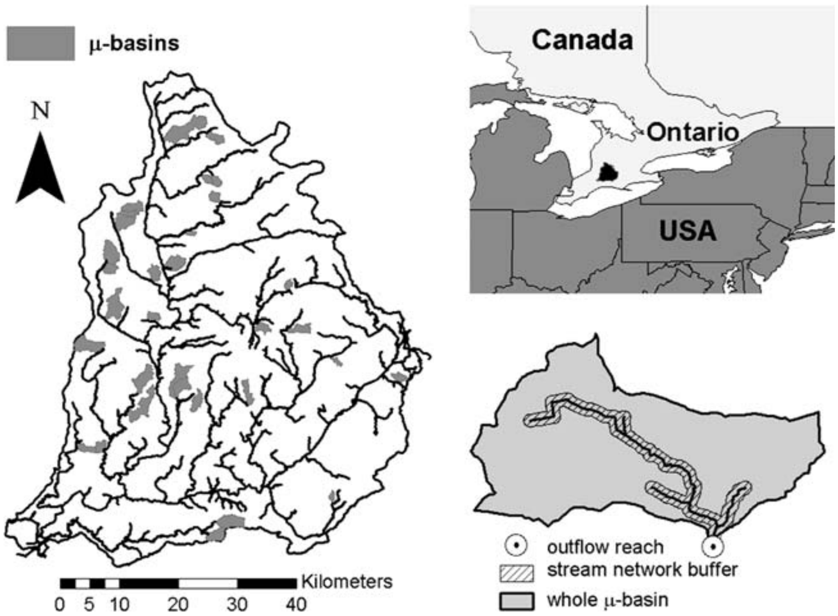

Figure 1. The Upper Thames River Watershed in southwestern Ontario, Canada (top right), the 33 agricultural μ-basins of this study (left), and the three spatial scales used in the study (bottom right).

community structure. The Family Biotic Index (FBI) was calculated using values assigned to organisms based on their family tolerance to organic pollution (Hilsenhoff, 1988). The total number of taxa of commonly intolerant taxa (Ephemeroptera, Plecoptera and Trichoptera: EPT) was used as an indicator of sensitivity to organic pollution (Lenat & Crawford, 1994).

For the *buffer* and *whole μ-basin* scales, land cover data were extracted from an existing GIS land cover layer created by the Upper Thames River Conservation Authority (UTRCA) in 1983 and updated with aerial photography taken by Ontario Ministry of Natural Resources in 2001. Proportions of agriculture and forest within each stream buffer and each μ-basin (exclusive of the buffer) were the only land cover categories used for this study.

Variation and co-variation of the macroinvertebrate community descriptors and their multi-scale environment were analyzed in Systat 9.0 (Systat© 2002 by SPSS Inc.). Principal Component Analyses (PCAs) of the covariance matrices were used to determine the major gradients of variability for the macroinvertebrate community at the outflow reach and the land cover at the outflow reach, buffer, and whole μ-basin scales. Pearson correlations of community descriptors and land cover gradients measured the strength and nature of the relationships between assemblage structure of macroinvertebrates and the riparian vegetation at the three spatial scales.

Results

At the outflow reach scale, field surveys described riparian zones that ranged from mostly herbaceous vegetation to complete coverage of trees (canopy forest) on a 30 m wide-corridor either side of streams (Table 1, Fig. 2). Herbaceous vegetation coverage varied between 80 and 100% with a median of 100%, and shrubs ranged between 0 and 60% (median = 10%). Total contribution of forest coverage including high and low trees ranged from 0 to 90% with a median of 10% each. Shade varied between 5 and 100% with a median of 38%.

The riparian vegetation in the outflow reach varied substantially in composition among the μ-basins. A variety of deciduous trees represented the canopy development and provided necessary shade to the macroinvertebrate communities. The most regularly recorded woody species were willow (*Salix* spp.), hawthorn (*Crataegus* spp.),

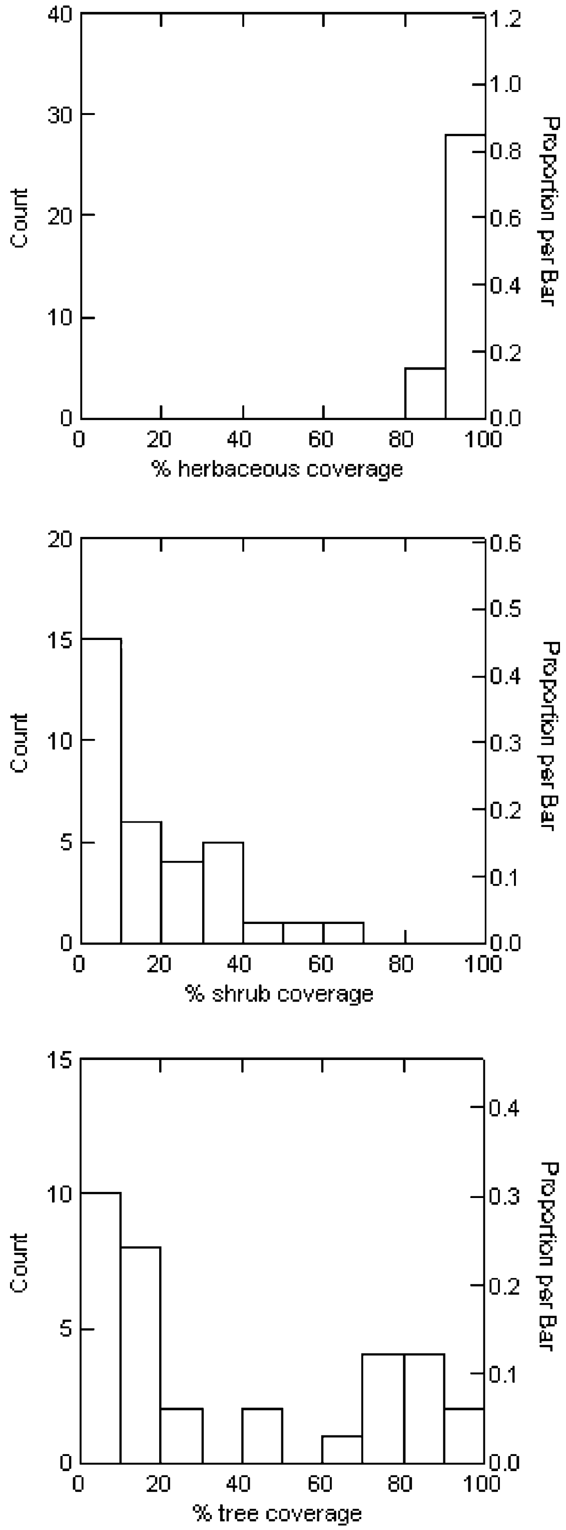

Figure 2. Histogram of tree, shrub and herbaceous coverage measured at the outflow reach scale.

Manitoba maple (*Acer negundo*), dogwood (*Cornus stolonifera*), and cherry (*Prunus serotina*). Understory vegetation in the forest sites was mainly shrubs and herbs, whereas the mixed and pasture sites were dominated by grasses, and vines. Several herbaceous species occurred in all study sites but the most common were jewelweed (*Impatiens capensis*), goldenrod (*Solidago* spp.), horsetail (*Equisetum arvense*), watercress (*Nasturtium officinale*), mustard (*Brassica nigra*) and *Phalaris arundinaceae*. Results of principal component analysis of vegetation cover at the outflow reach described a gradient that explained 71% of the total variation in riparian vegetation across μ-basins. Herbaceous sites were located at the negative end of the gradient, while forested sites were at the positive extreme of the gradient (Table 1).

The most commonly found benthic macroinvertebrate taxa in the outflow reach were Chironomidae, making up 47% of the total organisms, followed by Oligochaeta and Dytiscidae, which made up 9 and 7% respectively. Cyclopoida, Isopoda (Asellidae), Coleoptera (Elmidae), Hemiptera (Corixidae), Pulmonata, Bivalvia were also common and in combination made up 26% among all organisms collected. Total taxa richness ranged from 9 to 21 taxa, and Simpson's diversity index from 1.4 to 7. Equitability varied between 0.1 and 0.6 ($s = 0.2$). Estimates of the FBI ranged greatly from a low score of 4.6 to a high of 7.7, and the contribution of sensitive taxa of organic pollution, EPT, was low (0–6). Principal component analysis of the macroinvertebrate indices showed one important axis, accounting for 50% of the total variance explained across μ-basins, which was interpreted as a gradient from pollution-tolerant to very tolerant communities (Table 1).

At the stream network buffer and whole μ-basin scales, agricultural land ranged between 1 and 100% with a median of 91%. Forest cover was observed, and its extent varied between 0 and 99% with a median of 9%. At the buffer and whole μ-basin scales, the land cover gradient was calculated based upon the proportions of forest and agriculture explained over 90% of the total variation in land cover across μ-basins (Table 1).

The correlation between land cover and macroinvertebrate structure differed across scales (Table 2). At the outflow reach scale, vegetation

Table 1. Descriptive statistics and principal component coefficients for environmental and biological descriptors at multiple spatial scales ($n = 33$)

Environmental Characteristics	Median	Minimum	Maximum	PC1
Outflow reach scale				
Bank Riparian width (m)	24.00	3.50	30.00	–
Riparian vegetation shade (%)	38.00	0.00	100.00	–
Riparian high tree cover (%)	10.00	0.00	90.00	0.81
Riparian low tree cover (%)	10.00	0.00	75.00	0.54
Riparian shrub cover (%)	10.00	0.00	60.00	0.23
Riparian herbaceous cover (%)	100.00	80.00	100.00	−0.07
Biological characteristics				
FBI	5.70	4.60	7.70	–
BMIPC1	−0.10	−1.60	2.50	–
EPT	1.00	0.00	6.00	–
Richness (S)	15.00	9.00	21.00	–
Diversity (D)	3.30	1.40	6.70	–
Equitability (E)	0.20	0.10	0.60	–
Stream network buffer scale				
Stream length (m)	4226.00	1319.0	17657.00	–
Buffer Agriculture (%)	94.00	1.00	100.00	−0.22
Buffer Forest (%)	6.00	0.00	99.00	0.22
Whole μ-basin scale				
Area (ha)	439.00	129.00	1548.00	–
Perimeter (m)	11174.00	5406.00	25936.00	–
Basin Agriculture (%)	91.00	55.00	100.00	−0.01
Basin Forest (%)	9.00	0.00	44.00	0.01

PC1, role of variable in defining the major gradient among the sites.

Table 2. Pearson correlations between selected environmental/ biological characteristics and principal component scores at the multiple spatial scales (reach-riparian, buffer and basin)

Environmental characteristics (%)	Outflow reach PC1	BMI PC1	EPT	FBI	Buffer PC1	Basin PC1
Riparian vegetation shade	**0.83****	0.12	**0.62****	−0.22	−0.13	−0.07
Riparian tree cover	**0.97****	0.21	**0.66****	−0.1	0.10	0.20
Riparian shrub cover	**0.50****	0.04	0.25	−0.26	**0.50****	**0.50****
Riparian herbaceous cover	−0.36*	−0.28	−0.25	**0.38***	0.22	**0.38***
Biological characteristics						
FBI	−0.13	**−0.34***	−0.11	–	−0.19	−0.10
BMIPC1	0.16	–	0.13	–	−0.14	−0.16
EPT	**0.65****	0.13	–	–	0.13	0.06
Richness (S)	**0.55****	0.18	**0.64****	−0.21	0.17	0.10
Diversity (D)	**0.38***	**0.85****	**0.31***	−0.29	−0.19	−0.26
Equitability (E)	0.10	**0.80****	−0.02	−0.22	**−0.41***	−0.27

Basin, Buffer and Riparian PC1s represent the gradients derived from a PCA for land cover at basin, buffer and reach scales respectively. BMIPC1: based on PCA for relative abundance of macroinvertebrate taxa.*$p < 0.05$, **$p < 0.001$.

cover and shade were positively associated with EPT, total richness and Simpson's diversity. More diverse and sensitive communities were found at outflow reaches with more forest vegetation. At the stream network buffer scale, Simpson's equitability was lower in μ-basins with more agricultural land cover in the buffer. There was no relationship between land cover at the whole μ-basin scale and the outflow reach macroinvertebrate community.

Discussion

Patterns of the macroinvertebrate assemblage structure in streams are in large part a function of the riparian environments that exist across different spatial scales. This approach leads to the understanding of environmental stressors which may be a major factor driving the benthic community structure, and provides ecological connection among different spatial boundaries of environmental conditions (Allan et al., 1997; Sponseller et al., 2001). In this study, we assessed the relative influence of riparian vegetation on the structure of macroinvertebrates operating at multiple scales (reach, buffer and basin). Within the range of riparian environments encountered, our results indicate that the structure of macroinvertebrates was influenced by both local and regional features. However, the local scale was more important in determining assemblage structure patterns. Results of this study reinforce assertions that riparian-reach variables influence macroinvertebrate structure and function more than land use-catchment variables (Stewart et al., 2000; Sponseller et al., 2001).

At the outflow reach scale, significant relationships between riparian vegetation and the macroinvertebrate community indicate that forest canopy strongly influenced the structure of macroinvertebrate communities across μ-basins. Forest shade and coverage appeared to increase EPT, total richness and diversity taxa. Riparian forests in stream corridors further increase the value of large numbers of sensitive macroinvertebrates and may support greater terrestrial invertebrate abundances than adjacent habitats (Naiman et al., 1993; Tate & Heinly, 1995).

The weaker relationships found between land cover at the stream network buffer and whole μ-basin scales are consistent with the findings of other multiscale studies that most variation in macroinvertebrate assemblage structure can be accounted for by smaller local-scale factors (Richards et al., 1996; Hawkins & Vinson, 2000). Likewise, community structure may be more sensitive to local land-use disturbances than ecosystem processes that incorporate both biotic and abiotic components at broader spatial scales (Sponseller et al., 2001). There is a simpler hypothesis for the weaker relationships, however, that cannot be rejected until more detailed land cover data (including species composition and cover) are collected at the larger spatial scales. The description of the riparian vegetation at the outflow reach scale was much more detailed than the larger scales. Similarly, previous studies did not find convincing relationships between catchment variables based upon land cover and macroinvertebrate assemblage structure in streams (Sandin & Johnson, 2000; Heino et al., 2002). However, this finding does not imply that basin land use has little effect on streams. Other studies comparing macroinvertebrate assemblages among basins characterized by different land-use practices (e.g., native forest vs. pasture) have documented predictive ability at the catchment-scale (Lenat & Crawford 1994; Richards et al., 1996; Roth et al., 1996; Wang et al., 1997). Future analyses of the influence of basin land use characteristics (e.g., deforestation, percentage of land managed with conservation-tillage or the use of Riparian Best Management Practices) may provide insight into the patterns observed here.

Forest buffers examined in this study were highly fragmented and reduced to small woodlots, defining a land cover gradient that varied from long agricultural buffers to reduced corridors with more woody vegetation. This confirms the high intensity of agricultural development and removal of streamside vegetation in the study area reported in previous studies (Bucher et al., 1997; Abell et al., 2000). Macroinvertebrate communities have been continuously exposed to a gradient of human disturbance for many decades in the Upper Thames River Watershed. Patterns of macroinvertebrate distribution patterns could be related to the ability of macroinvertebrate taxa to tolerate environmental conditions associated with agricultural land use, rather than the ability of taxa to tolerate naturally occurring environmental factors. Richards et al. (1996) suggested that tolerant macroinvertebrate communities are capable to respond to in-stream disturbances with a large proportion of depositional taxa. Previous studies that have examined the correspondence between different scale environmental factors and macroinvertebrate structure suggest that buffer scale factors are important determinants of assemblage structure (Allan et al., 1997; Collinge & Forman, 1998). The high sustained anthropogenic disturbance in the Upper Thames River Watershed, may profoundly alter the effects of buffer environments on the macroinvertebrate communities.

The study demonstrated that within a hierarchy of spatial scales that range from the basin to the small reach scale, stream macroinvertebrate structure was influenced by factors operating at both local and regional scales in landscapes that have significantly been modified by human activities. Strong relationships between the riparian vegetation and macroinvertebrate structure at the within-reach scale can be related to local landuse factors. The study found that tolerant taxa occur commonly throughout the area and are associated with the agricultural development in the study area; whereas more diverse communities with pollution-sensitive taxa are related to remaining patches of forests.

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