EFFECTIVENESS OF RIPARIAN WETLANDS IN IMPROVING WATER QUALITY IN AN URBAN STREAM

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Ecological function in urban riparian systems has been relatively little studied and little is known about the potential of these riparian systems to buffer the kinds and levels of contamination associated with urban ecosystems. We studied two riparian wetlands along the Patroon Creek in Albany, New York, a tributary of the Hudson River that is heavily impacted by urban development and carries substantial contamination loads. Our study was designed to assist planning for restoration projects in the watershed. We hypothesized that the water chemistry, bacteria counts, and macroinvertebrate communities would indicate an improvement in water quality as the stream passes through riparian wetlands. We sought to demonstrate trends by using sequential samples. Water samples were collected from above, below and twice within two sections of wetlands (a total of eight sampling sites) from June to September 2007. Multi-plate samplers to collect aquatic invertebrates were placed at the same sites. We analyzed the concentrations of major dissolved ions and bacteria (total coliform, heterotrophic plate count or HPC, and *Escherichia coli*) counts in stream water samples and evaluated the invertebrate communities for richness and diversity. Despite substantial variation between sites, we detected a reduction in ammonia and sulfate after contact with the wetlands. The aquatic macroinvertebrate communities, although quite heterogeneous in composition, showed no spatial trend, indicating that they may be responding to unmeasured factors. Bacteria data provided some evidence of riparian wetland function. An apparent increase in total coliform from upstream to downstream within the wetland sections was accompanied by a drop (n.s.) in *E.coli*. The high level of impervious

surface and the numerous culverts and overland flow from commercial and industrial sites that bypass these buffers may limit function that is observable.

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INTRODUCTION

Only 2% of the river kilometers in the U.S. are free of human impact (Palmer et al. 2007). The extensiveness of the human impact on rivers and streams has led to a deluge of restoration activity, with expenditures estimated at over $1 billion per year (Palmer et al. 2007). Yet a synthesis of river and stream restoration practice found that the ecological effectiveness of restoration projects is inadequately documented and that scientific knowledge is poorly translated into restoration practice (Bernhardt et al. 2007). Our study in the Patroon Creek Watershed, Albany, NY was designed to assist in restoration planning that integrates ecological information and restoration goals at the earliest stages.

Urban stream ecosystems are typically degraded in both ecological function and biodiversity. Riparian buffer creation and maintenance is one of the most widespread activities in stream restoration and the most effective stream restoration programs have focused on improvements to stream banks and floodplains (Roy et al. 2006). The challenge of planning restoration for urban streams is compounded by the dearth of information on riparian buffer function in an urban context (Groffman et al. 2003).

Studies of riparian ecosystem function have concentrated on agricultural and forested watersheds (Groffman et al. 2003) and the impacts of urbanization on stream ecology have received less attention, although this is changing (Paul and Meyer 2001). In rural stream ecosystems it has been shown that riparian zones filter and transform a number of contaminants present in water thus enhancing water quality (Castelle et al. 1994, Clausen et al. 2000, Correll 2000). Riparian areas can serve as buffers by removing soluble nutrients and trapping or releasing suspended sediments (Correll 2000). Restoration projects have improved water quality and habitat in urban streams (for example, Charbonneau and Resh 1992). The lack of information on urban riparian buffers makes it difficult to set realistic ecological goals for restoring urban streams.

Proposals for a multi-use trail and potential restoration activities have been in progress for over a decade in the Patroon Creek watershed. Our objective was two-fold: to increase the understanding of remnant wetland function in an urban stream and to establish ecological information to assist in restoration planning. The focus on function in an urban stream and the connection to restoration planning sets this work apart from previous published work. Our results should be of interest to restoration planners in other watersheds as well as those studying urban stream ecosystems. We sought to evaluate the ecological function of remnant riparian wetlands along the Patroon Creek in Albany, NY. Evidence of improved water quality downstream of the wetlands would support restoration activities that enhance or expand remnant wetlands along the creek. We hypothesized that water quality would improve as water passes through the remnant wetlands. Specifically, after passing through the remnant wetland zones, measurable changes from upstream to downstream would be found in 1) biotic indicators (indices derived from benthic macroinvertebrate composition), 2) levels of total coliform (TC), *E.coli* and heterotrophic plate count (HPC), and 3) water chemistry (major dissolved ions), dissolved oxygen, and conductivity.

METHODS

Site description

A heavy influence of urbanization is evident in the Patroon Creek, which flows 10 km from its headwaters in the Albany Pine Bush to join the Hudson River through a culvert in Albany's Corning Preserve. For about one-third of its length, the creek drains an unconfined aquifer of fine, deep post-glacial dune sands (Landry and Rosenberg 1976). For much of the remainder, the creek is channelized, deeply incised or otherwise out of contact with its natural floodplain, riparian soils and vegetation. The stream channel was altered by the creation of reservoirs for drinking water in the 19th century and about one-third of the stream was moved and/or buried in culverts to make way for railroad and highway transportation routes in the 19th or 20th centuries.

The watershed today is characterized by urban and suburban land use, with approximately 37% of the surface area occupied by impervious surfaces which are mainly roads, parking lots, and roofs (Audette 2004). Studies in other watersheds have shown alterations in a number of features with increasing impervious surface cover, including stream hydrology, biology, geomorphology (stream channel form) and physical characteristics (water temperature) (Paul and Meyer 2001). Significant sources of contamination in the Patroon Creek watershed include stormwater, leaking sanitation sewers, and an industrial zone that includes two federal Superfund sites. Earlier research indicates that concentrations of sodium and chloride are high year-round (Erickson 2004), and are higher relative to rural streams (Madden & Robinson 2004). The concentrations of these ions increase from upstream to downstream (Erickson 2004). However, the creek also passes through three nature preserves and a multi-use recreational trail running parallel to the creek has been proposed. In addition to concerns for wildlife and human health within the watershed, the creek pollutes the Hudson River Estuary without abatement.

We have assembled a 4.5 year record of background data on hydrology and water quality in the Patroon Creek watershed. Included are records from a stream gage installed by the US Geological Survey (USGS) in 2002, which makes real-time data available online (http://waterdata.usgs.gov/ny/nwis/current/?type=flow) and is maintained at one of our sampling sites on the creek. The Patroon Creek hydrograph is characterized by an extremely rapid rise in discharge at the onset of a storm event followed by a more gradual decrease (Figure 1). When road de-icing chemicals are applied during storms, there is a significant increase in specific conductance recorded at the gage (Arnason and Robinson 2006). In contrast, during storms when de-icing chemicals are not used (in warmer months) there is a significant decrease in conductance caused by dilution of base flow by precipitation. The inputs of surface runoff are significant flowing into the stream directly and through numerous culverts.

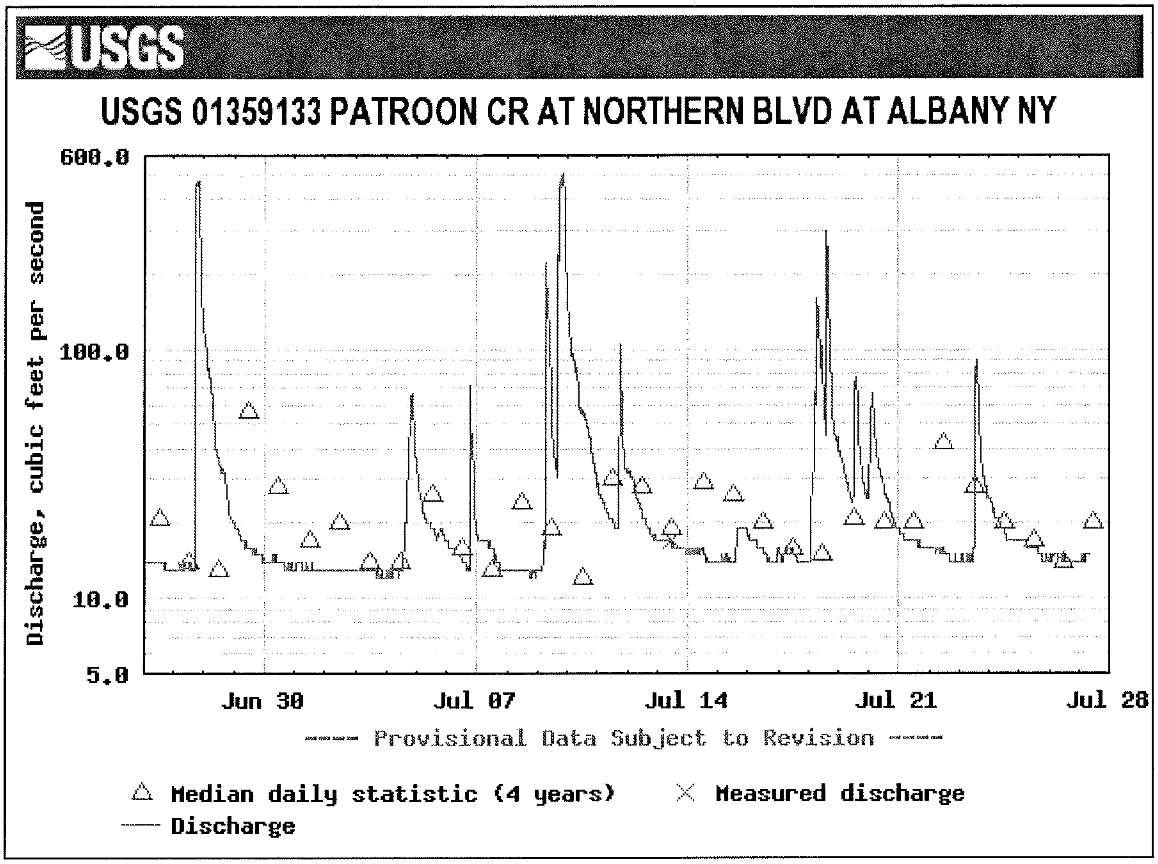

Figure 1. Patroon Creek discharge at the USGS stream gage, June-July 2007. Triangle symbols indicate means for four previous years.

For four years samples have been collected at seven sites along the Patroon Creek for coliform analysis [total coliform (TC), *E. coli*, and heterotrophic plate count (HPC) conducted by the laboratory of the Albany County Department of Health]. Although quite variable in time, there is a general trend toward higher values downstream (Figure 2). Means and maxima appear to be diminishing, but remain quite high (2005 TC mean plate counts = 18,000, maximum = 116,000; 2005 *E. coli* mean plate counts = 2,300, maximum = 2,000). At these levels, the creek may represent a public health hazard for community residents when in contact with the water.

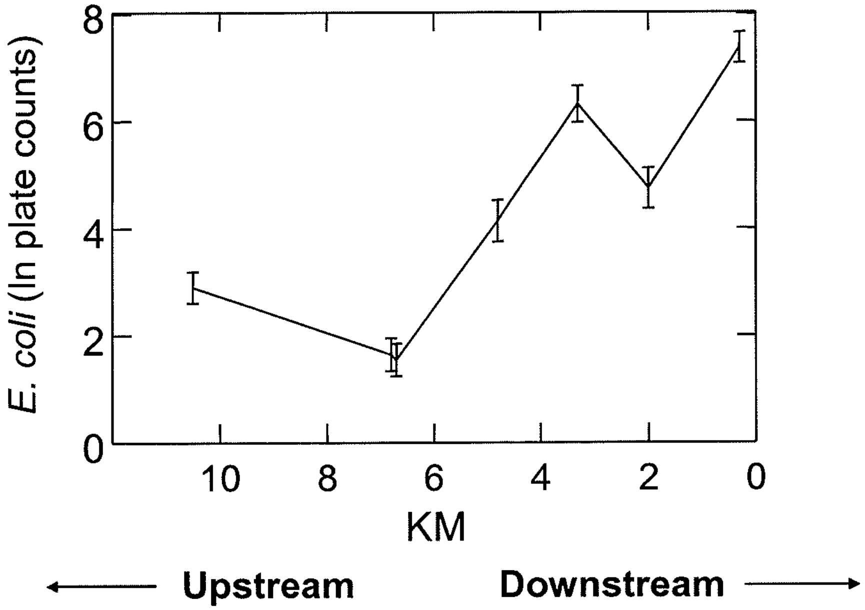

Figure 2. Counts of *E.coli*, means of monthly water samples taken from 2002-07.

The aquatic macrocinvertebrate community is an important indicator of stream water quality. Aquatic macroinvertebrate communities have been studied more than other communities in urban systems (Paul and Meyer 2001). The reduced diversity and abundance seen in urban systems has been correlated with the level of impervious surface and other features of urbanization (Moore and Palmer 2005, studies summarized in Paul and Meyer 2001). Previous biological assessments by Audette (2004) of the Patroon Creek using benthic macroinvertebrates have categorized the water quality as moderately to severely impacted, matching or exceeding those of 1994 New York State Department of Environmental Conservation studies (Bode et al. 2002). However, when comparing sites above and below remnant riparian zones, the indices showed increases in water quality. In addition, when plotted against the amount of upstream impervious surface, the biotic indicators rose indicating substantially "cleaner" water (Audette 2004).

The present study was prompted by previous research (Audette 2004) regarding two remnant wetland areas around Patroon Creek which extend more than 1 km along the stream channel. This earlier work focused on sites above and below the remnant wetland areas. Chemical assessments had shown that mean concentrations of major ions are typical of urban streams, with moderate nutrient levels and high concentrations of sodium and chloride. All major ions were lower downstream of the two remnant riparian areas. Significant reductions were found in concentrations of nitrate, sodium, calcium and potassium. Controls (samples taken at each end of an underground culvert flow) showed no changes in concentrations (Audette 2004).

Water chemistry and bacteria study

In this study, we sought to repeat previous tests, adding intermediate sampling points within the riparian zones in an attempt to establish rates of change. Sampling was conducted at eight sites. Sites were established above and below the remnant wetland sections plus two sites within each section. Sampling sites U1-U4 are located in section 1, and D1-D4 are in section 2, moving from Upstream to Downstream in the creek. Two of the sampling sites (numbers D1 and D4) were at locations that had been sampled previously (Audette 2004), while the other four were newly selected for this study. A water sample was collected at each site for analysis of major dissolved anions and cations. A separate sample for bacteria analysis was collected at four of the sites, those above and below each remnant wetland zone. The bacteria analysis was conducted for this project by the Albany County Health Department under contract with the City of Albany. Because the number of sampling sites is limited by the sampling agreement between the County and the University we were precluded from sampling bacteria at all eight sites. Dissolved oxygen, temperature, specific conductance and pH were measured in the stream at each sample site when the water samples were collected.

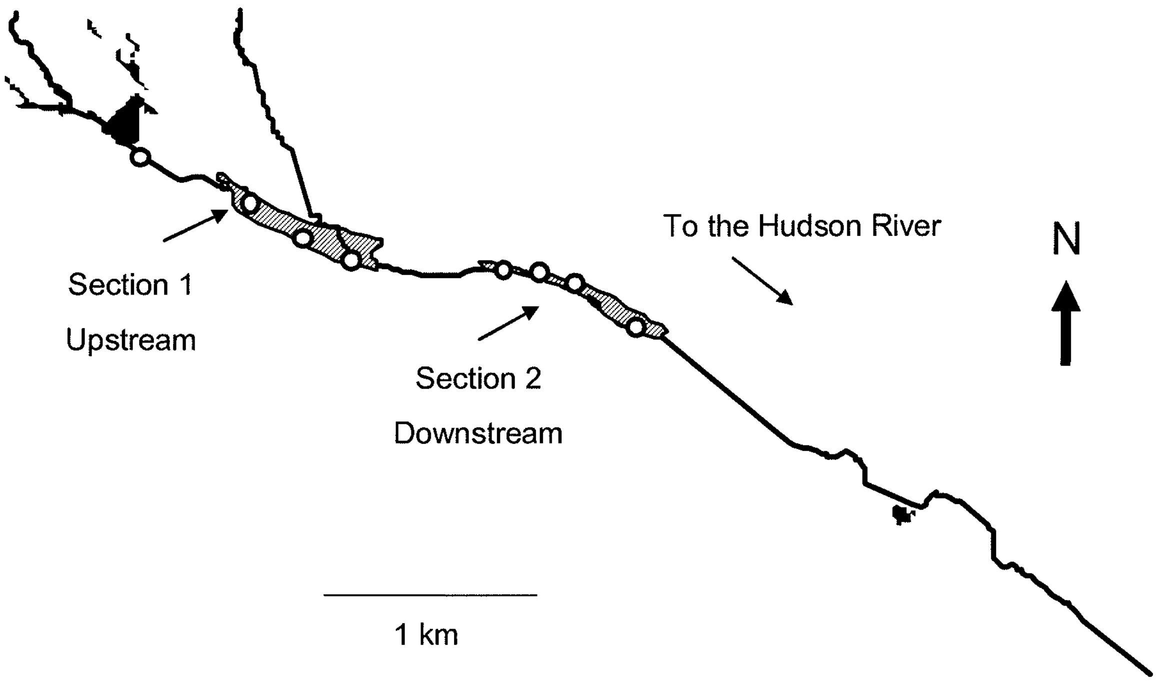

Figure 3. Study sections and eight sampling sites reported in this study along Patroon Creek.

Each site was sampled monthly from May to September 2007 during the second week of the month. Grab samples were taken in sterile Nalgene bottles, stored in a cooler during transportation to the lab, and refrigerated until analyzed. Five milliliters of each sample was filtered and analyzed in an ion chromatograph (Dionex DX-120 and ICS- 90 systems run with Chromeleon™ software) for anion (Cl^-, NO_3^-, Fl^-, and SO_3^-) and cation (Na^+, Ca^{++}, Mg^{++}, and NH_4^+) concentrations.

Quality control for IC data

The level of detection (LOD) and level of quantification (LOQ) were calculated for each ion using the quantities detected in samples of deionized water and known standards (6 cation standard, 5 anion standard, 5 ion standard) that were analyzed along with the water samples. For fluoride, phosphate, and sulfate, values from previous runs with the same machines were used because these ions were either not detected or were seldom detected in the deionized water (DI) in our runs. The LOD and LOQ were calculated using the mean and standard deviations across the six different analysis runs. The water sample ion data were adjusted using these LOD and LOQ. Other protocols followed US EPA Method 300.1.

Macroinvertebrate analysis

Samples were collected on multi-plates at each of the locations identified above. Multi-plates were used instead of kick sampling due to the nature of the substrate in the creek. The substrate is generally soft, mostly a mix of Pine Bush sand and clay to the west, changing to primarily clay bottom to the east, mixed with organic sediment and other sedimentary materials, natural and anthropogenic. Rocky substrate occurs in some locations, probably of artificial origin except where the creek has deeply incised and lost contact with older floodplains. The plates installed in August and were left in the water for five weeks or more. The last plates to be collected were retrieved eight weeks later (September 22). The samples were removed from the plates and processed following the guidelines in Bode et al. 2002. For each sampling site, half of the sample was analyzed, rather than one-quarter as called for by Bode et al. (2002). This was due to the relatively few organisms observed in the quarter samples at all locations. Because of this modified approach to the analysis, our results should not be used to directly compare the Patroon Creek to data reported for other streams.

For each sampling location, following Bode et al. (2002), the sample with the larger amount of sediment was analyzed, with one exception. The smaller sample for position 1 in the upstream section was analyzed, because the larger sample had to be discarded. The quantity of material analyzed was similar to the amounts for other sampling locations. Position 4 in the downstream section was over-sampled: one-fifth extra material was reviewed, so the data were adjusted for this sample by randomly eliminating one-fifth of the organisms.

For the few organisms that we were unable to identify beyond order, we grouped the organisms as "other" within the order. The "other" categories likely contain organisms from more than one taxon within an order. Rather than distinguish among them, we left them grouped, for example, as "other Ephemeroptera." This conservative approach underestimates the diversity of organisms.

Invertebrates were identified to Family using the pictorial key published by the New York State Department of Environmental Conservation and *A Guide to the Study of Fresh-water Biology* by Needham and Needham (1962) with assistance from staff in the DEC Stream Biomonitoring Unit. Family richness and Ephemeroptera, Plecoptera and Trichoptera (EPT) richness were calculated for each site (Bode et al. 2002). Invertebrate diversity among sample sites was compared using the Jaccard Index of similarity (based on presence-absence of the 14 taxa) and the Curtis-Bray Index (based on both shared composition and abundance) (Magurran 2004). In addition, we calculated site diversity scores using the Simpson Index (Magurran 2004). Matrices of Jaccard and Curtis-Bray similarity were also used to construct cluster diagrams (hierarchical clustering; SYSTAT 11$^{©}$). The results of cluster analysis using the Curtis-Bray Index were virtually identical to those using the Jaccard Index, thus we report only the Jaccard results.

Statistical analyses

Analysis of variance (ANOVA) was used to test for statistically significant differences between mean values of all water chemistry and coliform measurements for pooled upstream and downstream sites for each of the two zones at $\alpha=0.05$. For those zones with internal samples, regression was used to test for trends (linear or nonlinear, according to data shape). Because an earlier study (Erickson 2004) indicated that concentrations of chloride and sodium increase in the creek from upstream to downstream, both one-way and two-way tests were used. The two-way analysis was used to test the effect of the upstream versus downstream position of the wetland as well as the effect of site position within a section. The two factors for the two-way analysis were position reported in the tables as POS (within a wetland section, ranging from 1-4) and section reported as SEC (the upstream or downstream section).

RESULTS

Water quality analysis results

Two samples taken during September had nitrate values that were in excess of any previously reported values; these were treated as outliers and they are excluded from analyses in this report. Chloride varied significantly in time and space (Figure 4). Chloride was found to be highly correlated with specific conductance and sodium. The ratios of sodium to chloride and specific conductance to chloride are shown in Figure 5 and indicate that the primary source is sodium chloride (NaCl). The analysis of variance for chloride, by month and by section (section one is the remnant wetland located upstream and section two is further downstream) showed that chloride varied significantly between the two sections and among the months ($p < 0.001$). The dip in the value for July corresponds to high rainfall levels (Figure 1), which appear to contribute substantial variability to much of our data.

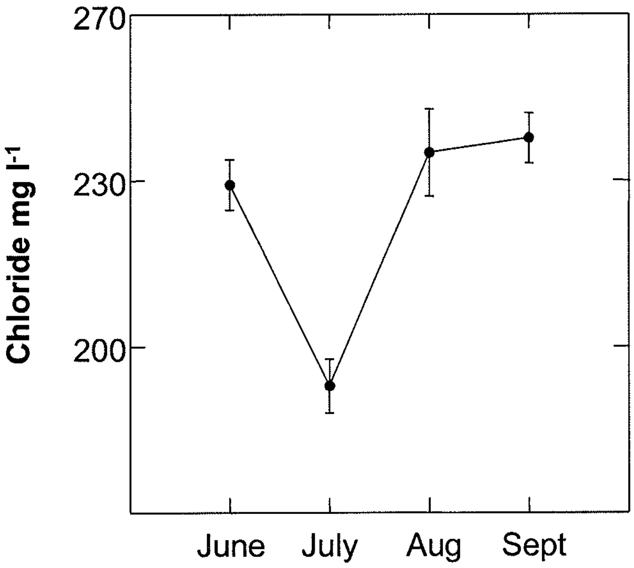

Figure 4. Chloride concentration, averages of eight sample sites, June – September.

Table 1. Two-way ANOVA table comparing chloride ion concentrations in laboratory water samples (Fig. 4). Starred results were significant at $p<0.05$.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
POS	482.320	3	160.773	0.145	0.932
SEC	6658.621	1	6658.621	5.992	0.024*
POS*SEC	1552.311	3	517.437	0.466	0.710
Error	21113.084	19	1111.215		

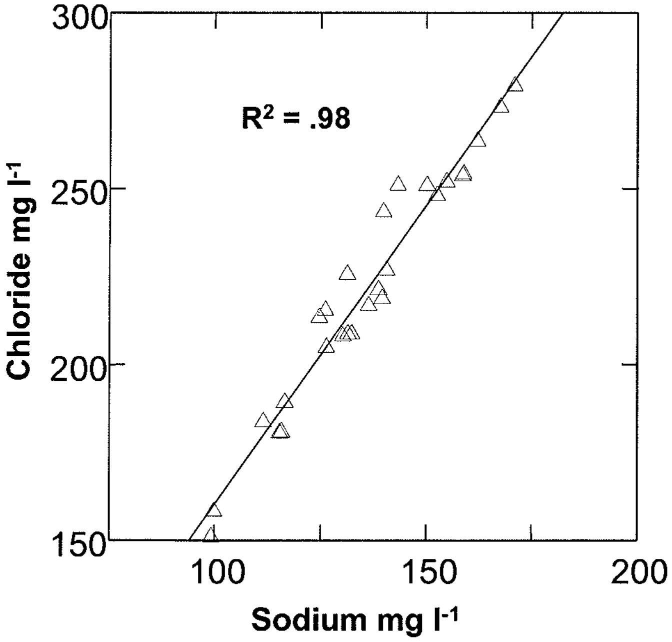

Figure 5. Ratio of concentration of chloride to sodium, averaging the monthly samples taken at the eight sampling sites.

Table 2. Pearson correlation matrix for major ions at all sample locations (N = 18). Starred values indicate significant Bonferroni probabilities (p< .05)

	FL	CL	NO3	SO3	NA	NH4	K	MG	CA
Fl	1.000								
Cl	0.327	1.000							
NO_3	0.107	0.222	1.000						
SO_3	0.465	-0.052	0.696*	1.000					
NA	0.277	0.990*	0.274	-0.015	1.000				
NH_4	0.109	-0.497	-0.139	0.238	-0.486	1.000			
K	0.003	0.256	0.454	0.160	0.282	0.245	1.000		
Mg	0.461	0.858*	0.319	0.273	0.865*	-0.238	0.206	1.000	
Ca	0.462	0.876*	0.234	0.204	0.885*	-0.274	0.146	0.939*	1.000

Specific conductance and chloride levels in the creek (averaged for the May to August samples) increase somewhat moving downstream, although the error bars are larger around the higher values (Figure 6).

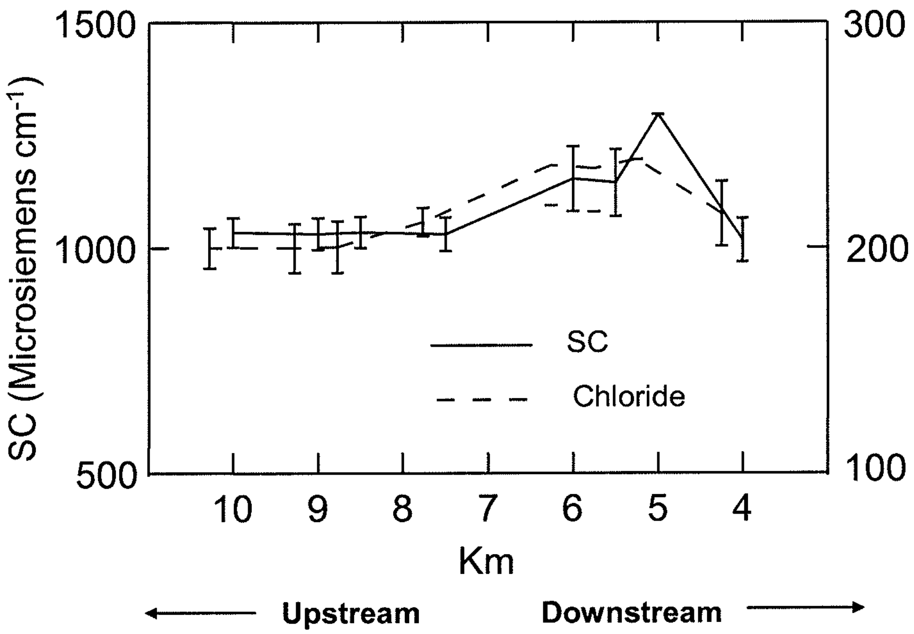

Figure 6. Specific conductance and chloride concentrations in Patroon Creek. Means of monthly samples taken at eight sites from May to August 2007.

Ammonium was not significantly different between zones (Table 3). Although higher mean ammonium values were returned for the most upstream position in the wetlands compared to the sampling point located furthest downstream (Figure 7). Sulfate declined with position and the difference between sections was statistically significant (Table 4).

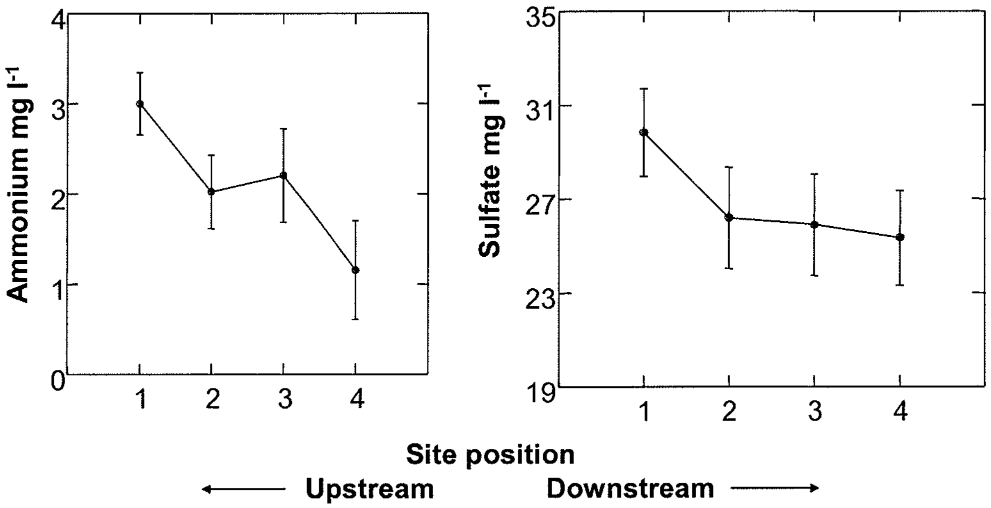

Figure 7. Variations in major ions, ammonium and sulfate, averaged for each wetland position (1-4) across the Upstream and Downstream sections.

Table 3. Two-way ANOVA table comparing ammonium ion concentrations in laboratory water samples (Fig. 7).

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
POS	7.250	3	2.417	3.012	0.076
SEC	2.411	1	2.411	3.004	0.111
POS*SEC	2.683	3	0.894	1.115	0.385
Error	8.827	11	0.802		

Table 4. Two-way ANOVA table comparing sulfate ion concentrations in laboratory water samples (Fig. 7). Starred results were significant at $p<0.05$.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
POS	94.303	3	31.434	1.125	0.364
SEC	188.848	1	188.848	6.756	0.018*
POS*SEC	49.158	3	16.386	0.586	0.631
Error	531.124	19	27.954		

Dissolved oxygen, pooled among the two sections, varied with position, showing a decline and then an increase at the most downstream sampling site (Figure 8). Mean dissolved oxygen was significantly different among positions (Table 5).

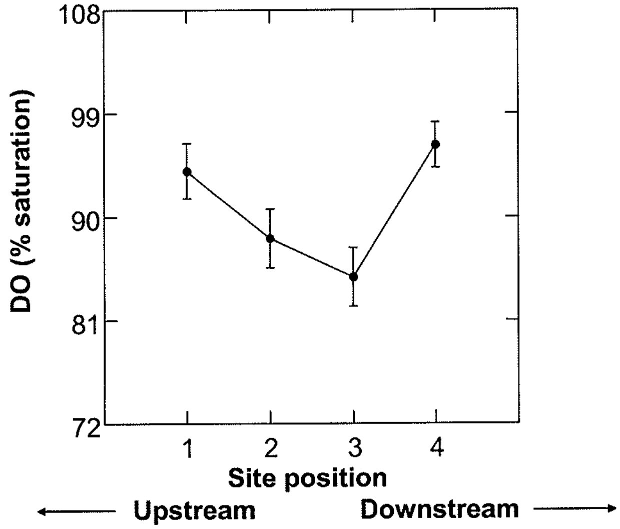

Figure 8. Variation in dissolved oxygen, values averaged for each position (1-4) in each of the two wetland sections pooled.

Table 5. Two-way ANOVA table comparing dissolved oxygen concentrations in field water samples (Fig. 8). Starred results were significant at $p<0.05$.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
POS	605.165	3	201.722	5.138	0.008*
SEC	90.484	1	90.484	2.305	0.144
POS*SEC	241.820	3	80.607	2.053	0.137
Error	824.508	21	39.262		

Macroinvertebrate analysis

The total number of organisms found at a sampling site ranged from 23 to 118. The number of families of aquatic macroinvertebrates found at each site varied from 2 to 9. No Plecoptera (stoneflies) were found at any site. Ephemeroptera and Trichoptera were found at six of the eight sites (U1-4, D1, D4). Few species of Ephemeroptera or Trichoptera were found; the highest EPT richness found was 3. A list of taxa is included in Table 5.

Family and EPT richness were greater in the upstream wetland than the downstream wetland. Moving downstream within the two wetland sections showed different patterns (Figures 9, 10). In the upstream section, the family richness was similar through positions 1-3, whereas it dropped slightly in position 4. In the downstream section, family richness dropped considerably moving to positions 2 and 3, and then increased by position 4. EPT richness showed the same pattern, none of these taxa were found in position 2 and 3 of section 2.

Table 6. Taxa of aquatic macroinvertebrates in multiplate samples, Aug-Sept 2007. Taxa marked with an asterisk were also found by Audette (2004).

Class	Order	Family	Genus
Crustacea	Isopoda*		
	Amphipoda*		
Insecta	Ephemeroptera	Baetidae	
		Unidentified	
	Diptera	Simuliidae* (black flies)	
		Chironomidae* (true midges)	
		Empididae (dance flies)	Hemerodromia
	Trichoptera	Hydropsychidae*	
	Coleoptera	Elmidae (riffle beetle)*	
Other Phyla	Gastropoda (snails)*		
	Annelida		
	Nemertea		
	Platyhelminthes		

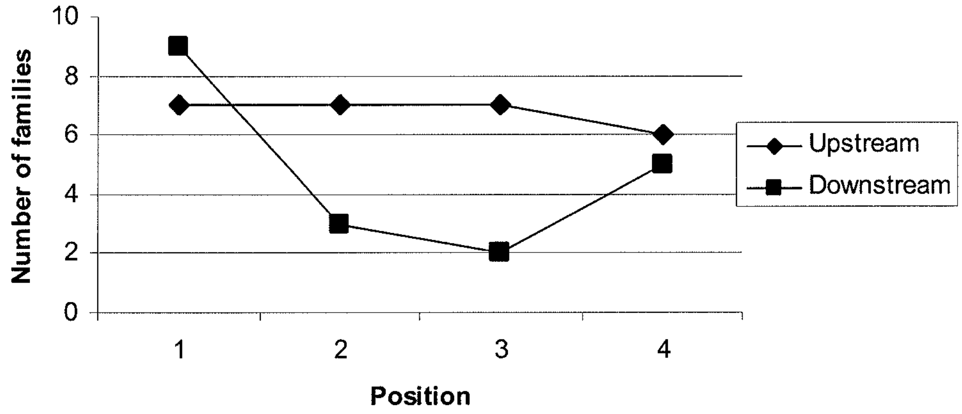

Figure 9: Family richness of aquatic macroinvertebrates for positions in the Upstream and Downstream wetland sections, moving from upstream to downstream (1-4).

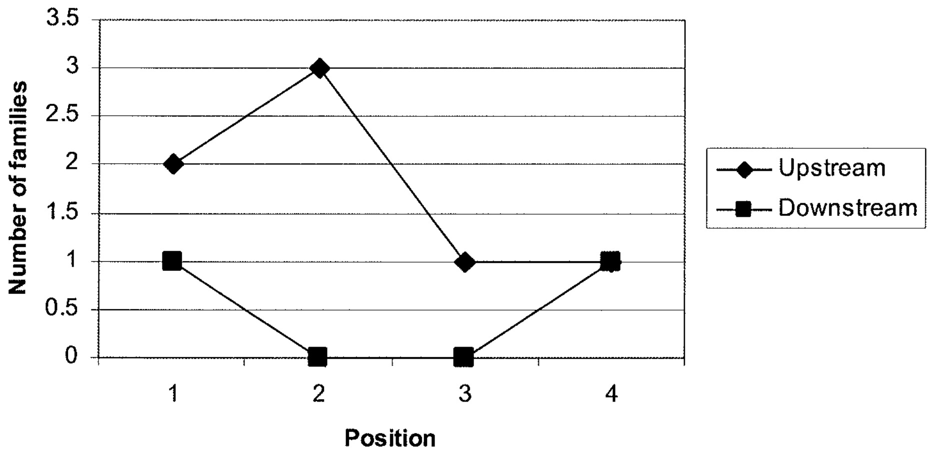

Figure 10: EPT richness for each wetland position in the Upstream and Downstream wetland sections, moving from upstream to downstream (1-4) within the sections.

The Simpson Index shows that the upstream wetland has a higher diversity than most locations within the downstream wetland (Figure 11). The diversity within the downstream section is lower within the wetland than at the entrance or furthest downstream point. Interestingly, the positions with the highest diversity are the most downstream point in the upstream section and the most upstream point in the downstream section.

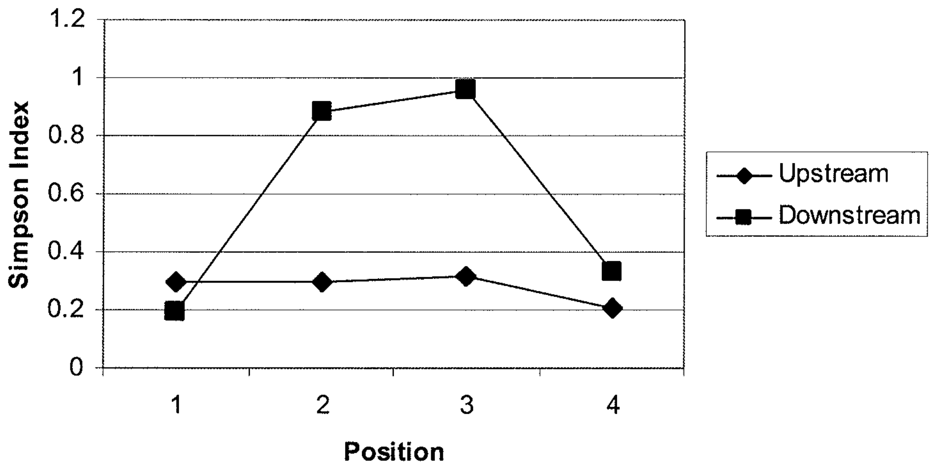

Figure 11: Simpson index calculated for each sampling site (position) in the Upstream and Downstream wetland sections.

The diversity and richness may be underestimated due to the effect of sampling because some of the sampling plates were partially covered with sediment. Clustering based on the Jaccard coefficients showed that the sites are different from each other, with values higher than 0.3 for all pairs (Figure 12). The most similar sites are positions 2 and 3 within the downstream section.

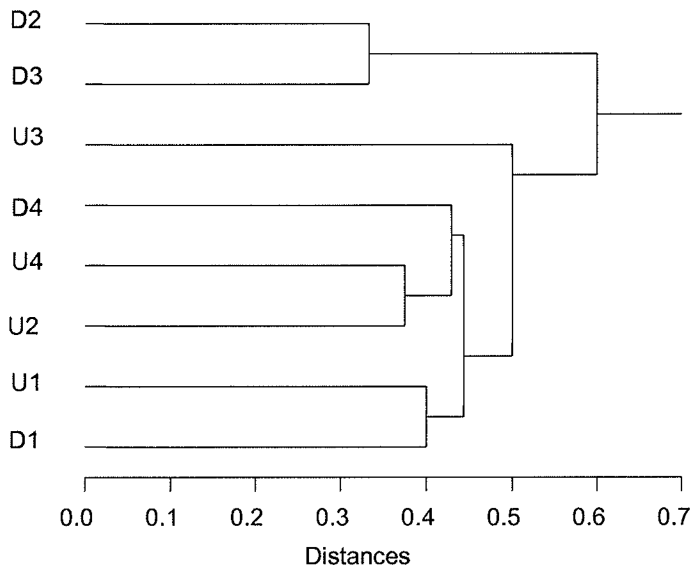

Figure 12. Hierarchical clustering based on a matrix of Jaccard coefficients (presence – absence). Higher values for pairs or clusters indicate greater dissimilarity. U= Upstream section, D= Downstream section, 1-4 indicate the position with the wetland.

Bacteria analysis results

Plate counts for total coliform, *E. coli*, and HPC were returned for positions 1 and 4 within each wetland -- the most upstream and most downstream. Total coliform increased from upstream to downstream, while *E. coli* and HPC decreased (Figure 13). The results for *E.coli* were not significant at $\alpha=0.05$ ($T = 1.51$, $df = 6$, $p<0.10$).

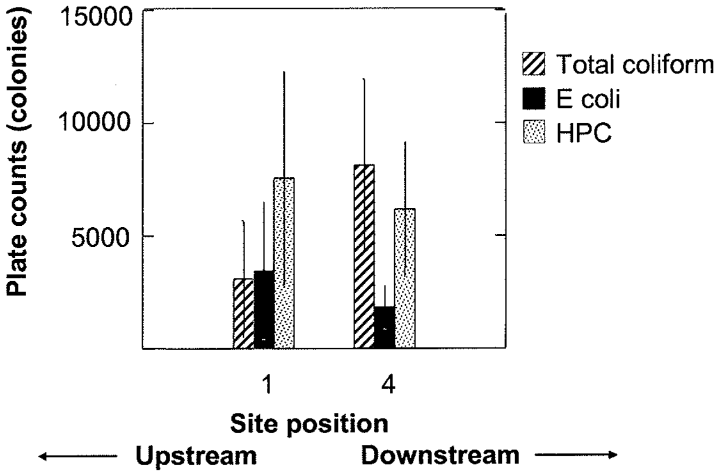

Figure 13. Bacteria plate counts, total coliform, *E. coli*, and HPC, averaged at the two wetland sections. Samples for bacteria analysis were taken only at positions 1 and 4 in both wetlands.

DISCUSSION

We predicted that measurable differences would be found in the biotic indices, bacteria levels, and water chemistry moving from upstream to downstream through the remnant wetlands. The results of the macroinvertebrate study do not show a clear trend, and do not support our hypothesis that water quality improves by passing through remnant wetland areas. The most striking result was that most of our sites had distinct communities. The chemical data do not suggest a cause for these differences and we conclude that the macroinvertebrate communities at these sites are influenced by factors that were not included in the study. Moreover, the benefits of the riparian wetlands to aquatic macroinvertebrates could be insufficient to counteract the influence of the very high level of impervious surface within the watershed. This would explain the absence of a clear trend. One study reviewed by Paul and Meyer (2003) found that in streams with impervious surface cover above 45% the aquatic macroinvertebrate community did not benefit from forest cover in the catchment; all sites showed a loss of biotic integrity. The

Patroon Creek watershed has somewhat less impervious surroundings, but the remnant wetlands have no distinguishable influence on the macroinvertebrate communities present in the creek.

The bacteria and major ion results are the most suggestive of wetland function. The increase in total coliform observed from the upstream to the downstream positions could be due to the bacteria in the soil and sediment in the wetlands and their comparative biotic richness. The decrease in *E. coli* suggests that the increase in bacteria is of types other than those associated with fecal contamination and indicates an improvement in water quality downstream of the wetlands. These results were not significant at the 5% confidence level, however. The bacterial data in this study are lower than means from previous summers for sites that were repeated. Sources of contamination may be fewer than in prior summers or higher stream flow may have had a diluting effect. The progressive change in dissolved oxygen observed in samples from upstream to downstream within the wetlands suggests biological activity within these sections. This would support our hypothesis that the riparian wetlands are buffering water quality.

We hypothesized that the water chemistry would show measurable changes from upstream to downstream within the wetland sections, assuming that the two sections would be similar enough to be pooled. Our results were too variable for chloride and associated ions to allow the planned comparisons of positions. Chloride is not expected to be held in the remnant wetlands, but to pass through these areas. The correlations found here between specific conductance and chloride as well as sodium and chloride, suggest a high variability across sampling sites for sodium and other ions directly associated with chloride. This could be due to the continuous inputs of contaminated stormwater along the creek channel. High chloride levels in warm seasons appear to be a growing phenomenon in areas where road salt is applied in winter (Kelly et al. 2008). The variability precluded establishing rates of change in ion concentrations within the remnant wetlands. Because sulfate concentrations were significantly correlated with the wetland section rather than with position, this correlation supports the evidence that the position within the stream (upstream or downstream) is important to the concentration of ions. Ammonium, the one ion that could be pooled across the two sections, showed a decrease with position within the wetlands, but this result was not significant at $p<0.10$. Several heavy rainfall events occurred the days that we collected water samples in July (samples taken on July 10 and 13), and this rainfall may be the reason for much of the variability in the ion data. The excessive runoff could have diluted the discharge in the stream. Alternatively, by causing more erosion, the storm events could have put more contaminants into solution.

The results of the dissolved oxygen (DO) sample analysis suggest some ecological function within the wetland sections. The decrease in DO moving from position 1 through position 3 within the wetland buffer areas may be due to biological activity in the wetland soils.

The differences in ion concentration between the two sections could be due to the influence of an increasingly urban landscape moving downstream and the downstream section receiving a greater portion of surface runoff. Also, a tributary that drains a large commercial and industrial zone enters the Patroon Creek between the two wetland areas, and this may also contribute to the differences observed between the two sections. The sections may have different rates of flow that could contribute to differences in the water quality results. A slower flow would allow more opportunity for contact with soil and vegetation and this would affect the transformation of nutrients.

Further research into the soils and riparian vegetation in the remnant wetland areas would provide additional information about the level of current and potential function. The level of the water table and the nature of the soils are important to denitrification and nitrification in wetland soils (Groffman, et al. 2003). The nature of the plant community in the remnant wetlands could influence the level of function in improving water quality (e.g. removal of nitrate; Groffman et al. 2003).

In the Patroon Creek watershed the buffering function of these remnant wetlands is certainly circumvented by entry of runoff from culverts all along its channel directly into the creek. These flows bypass the buffer areas altogether. Numerous culverts enter both sections of wetland, delivering an unknown amount of runoff from Interstate 90 and other surfaces directly to the creek. Restoration efforts would likely reroute these flows into buffer areas. An experimental study in which culverts are re-routed to vegetated buffer areas would yield more useful data for evaluating the effectiveness of buffer restoration. Our study may have failed to capture the functional capacity of the remnant wetlands because there are too many inputs circumventing the buffers.

Riparian buffers will continue to be important areas of restoration work in streams and rivers. Our findings suggest that in urban streams, restoration planners seeking evidence of ecological function need to look at factors beyond water chemistry and bacteria levels. In streams that receive high proportions of overland flow and discharge from culverts, the position of the wetland buffer within the watershed (upstream versus downstream) will be important to water quality.

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