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PRIMARY RESEARCH PAPER

Influence of a forest remnant on macroinvertebrate communities in a degraded tropical stream

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Abstract Land use changes have resulted in large environmental impacts, and in agricultural landscapes sometimes only forest fragments remain. Riparian forest remnants can positively influence stream water quality, and serve as refuges for aquatic species. We evaluated whether the presence of a riparian forest remnant influenced the structure and composition of macroinvertebrate communities in a rural stream in southeastern Brazil. We sampled three reaches upstream (within abandoned sugarcane cultivation) and nine downstream the remnant edge, until 600 m inside the forested area, using leaf litter bags. The abundances of Elmidae, Chironomidae, and total macroinvertebrates increased along the forest remnant, whereas the abundance of Baetidae, proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT), rarefied taxonomic richness, and diversity decreased. Taxon richness and EPT abundance did not vary along the forest remnant. Increases in Chironomidae and total abundance within the forest remnant can be related to moderate increases in nutrient concentrations, or to the availability of high quality leaf litter patches. Forest remnants can influence macroinvertebrate communities, although variation both in temperate and tropical studies can be related to local agricultural practices and land use at the watershed scale. Forest remnants are important in maintaining stream water quality in rural landscapes, and deserve attention in watershed management projects.

Keywords Land use change · Rural landscapes · Forest fragmentation · Degraded streams

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Introduction

Land use changes have severely impacted aquatic ecosystems worldwide, and a major source of impact is deforestation for pasture and agriculture, mainly of riparian forests. When conversion of landscapes to agriculture is intense, only fragments of riparian forests are found around the watercourses, but these forest remnants may not have the same role as continuous forests in relation to stream water quality (Harding et al., 2006). Habitat loss, fragment isolation, and increased edge effects result from forest fragmentation, and can reduce species diversity and lead to changes in composition of aquatic and terrestrial communities (Saunders et al., 1991; Robinson et al., 1992; Zwick, 1992; Ward & Tockner, 2001; Fahrig, 2003).

In southeastern Brazil, fragmentation and degradation of riparian forests result from the expansion of agricultural activities; in São Paulo state, mainly for sugarcane cultivation and pasture (Corbi & Trivinho-Strixino, 2008). Thus, many studies have been carried out to evaluate the effects of deforestation and other land use changes in water systems (Ometo et al., 2000; Corbi & Trivinho-Strixino, 2008; Nessimian et al., 2008). Riparian vegetation reduces the input of pesticides and fertilizers to stream water (Shortle et al., 2001), reduce the incidence of solar radiation, contributing to the maintenance of natural temperature and humidity levels, and contribute to the preservation of watercourses by reducing margin erosion and channel sedimentation (Allan, 2004; Naiman et al., 2005). Further, riparian forests contribute to stream ecosystem functioning, since they are the main source of allochthonous material in headwaters, increasing the diversity of shelter and food items due to the input of leaf litter, fruits, and logs, thus influencing food webs (Cummins, 1974; Vannote et al., 1980).

Both resource availability and environmental conditions related to water and streambed characteristics strongly influence aquatic communities (Silver et al., 2004). The distribution and diversity of macroinvertebrates are directly related to abiotic factors such as temperature, dissolved oxygen, nutrient concentrations, water flow, and substrate type (Ward, 1992). Macroinvertebrates have morphological, physiological, and behavioral adaptations, and thus react distinctly to environmental impacts (Rosenberg & Resh, 1993). The structure of macroinvertebrate communities can reflect the integrity of aquatic ecosystems, and is commonly used as an indicator of water quality (Maloney et al., 2009). In forested streams, a higher diversity and presence of taxa sensitive to pollution such as insects of the orders Ephemeroptera, Plecoptera and Trichoptera (EPT) are expected, whereas in degraded systems, higher abundances of generalists and tolerant taxa such as Chironomidae and Oligochaeta are commonly found (Rosenberg & Resh, 1993). These changes in macroinvertebrate community structure can also influence the relative abundance of functional feeding groups, potentially influencing ecosystem functions such as energy flows and nutrient cycling (Graça, 2001).

Deforestation of riparian forests may result in scattered, small forest fragments in an agricultural landscape. A main question is whether these fragments can improve stream water quality and if they can function as refuges for the natural communities (Storey & Cowley, 1997). Several studies have been carried out to evaluate the effects of distinct land uses on stream water quality and biodiversity (Quinn et al., 1997; Townsend et al., 1997; Thompson & Townsend, 2004; Hepp & Santos, 2009). However, studies evaluating the effects of forest fragments within the same stream have been mainly carried out in pasture streams located in temperate regions (Storey & Cowley, 1997; Scarsbrook & Halliday, 1999; Harding et al., 2006; Arnaiz et al., 2011), so information on tropical regions is lacking (but see Chakona et al., 2009). Storey & Cowley (1997) found that macroinvertebrate communities changed from dominance of taxa tolerant to nutrient enrichment to one characteristic of clean waters as the stream entered the remnant, with higher taxon richness, whereas Scarsbrook & Halliday (1999) found higher densities of macroinvertebrates in pasture areas due to the dominance of Chironomidae, but higher proportions of EPT within the remnants. However, different results and some variation within studies have been found regarding the responses of macroinvertebrate communities to forest remnants (Table 1).

Here, we analyzed if the presence of a forest remnant influences the structure and composition of macroinvertebrate communities in a tropical stream located in a landscape dominated by a sugarcane plantation. We addressed the question of whether biological indicator variables and/or abundance of functional feeding groups changed along the longitudinal gradient as the stream passed through the forest remnant. We sampled communities upstream and downstream of the riparian forest edge, and expected that macroinvertebrate communities sampled within the forest remnant had characteristics similar to communities found in forested streams.

Materials and methods

Study area

This study was carried out in a stream located at Vassununga State Park (VSP), in the Mogi-Guaçu

Table 1 Responses of macroinvertebrate communities in degraded streams to the presence of riparian forest remnants

Variable	Storey & Cowley (1997)	Scarsbrook & Halliday (1999)	Harding et al. (2006)	Chakona et al. (2009)	Arnaiz et al. (2011)	This study
Total abundance	Increase	Decrease	No effects	Increase	No effects	Increase
Taxon richness	Increase	No effects	No effects	Increase	Increase	No effects
Shannon diversity index				Increase	No effects	Decrease
Pielou evenness index				No effects		No effects
EPT abundance				Increase[a]		No effects
Percentage EPT		Increase				Decrease
EPT taxon richness	Increase		No effects			Decrease

[a] Estimated

watershed, central São Paulo state, southeastern Brazil. Vassununga State Park is located in Santa Rita do Passa Quatro district, within the following coordinates: 21°20′–21°55′S, 47°32′–47°40′W. The VSP has a total area of 2,069.24 ha, and is formed by six large fragments that include tropical savannah (cerrado), semideciduous forest, riparian forest, and wetlands (Korman, 2003). Most areas of permanent preservation of the watercourses are degraded: 46 % are used for agriculture, 24 % have degraded riparian forests, and only 30 % correspond to intact riparian forests, so that some headwater streams have already disappeared due to sedimentation, whereas others have been degraded due to erosion of unprotected margins (Korman, 2003). The climate of the region according to Köppen classification is Cwa (Setzer, 1966), with mean monthly temperatures varying between 17.6 °C in July and 23.5 °C in February, and mean annual rainfall of 1,478 mm, concentrated in the summer months (Pivello & Varanda, 2005).

Sugarcane plantation causes several impacts on soil and aquatic systems, including erosion, sedimentation, nutrient enrichment, and contamination by pesticides and heavy metals (Martinelli & Filoso, 2008). In the studied area, sugarcane was planted until within the stream riparian zone, but has now been abandoned. Slow recovery by herbs and smaller plants and trees can now be found in the stream headwaters. We studied the Córrego da Gruta, a first-order stream that starts within the active sugarcane plantation and drains into the abandoned plantation, flows into Capetinga Oeste, a large forest fragment of the VSP, then exits the forest remnant before reaching the Mogi-Guaçu river. Capetinga Oeste is a large forest remnant with an area of 327.83 ha, with tall trees, and 91 tree species recorded (Martins, 1991).

Sampling

To evaluate if the presence of a riparian forest remnant influenced macroinvertebrate communities, we sampled 12 reaches of Córrego da Gruta from upstream to the inside of the remnant, between May and June 2011. Two sampling points were established upstream the fragment (−100, −50 m from the fragment edge), one at the edge (0 m) and nine downstream from the edge (50, 100, 150, 200, 250, 300, 400, 500, and 600 m distances). The sampled reach was 20 m long and was centered at each point; four sampling units distant 5 m from each other were deployed, two upstream and two downstream of the sampling point.

Each sampling unit consisted of a leaf litter bag containing leaves of *Cecropia pachystachya* Trécul (Urticaceae), a common species in the region whose leaves are a high quality food resource for stream macroinvertebrates in the region (Janke & Trivinho-Strixino, 2007). The leaves were previously collected and left drying in the sun. We used 10 × 15 cm bags, with 5-mm mesh size, which were filled with 5 g of dry leaves. After 28 days, the litter bags were recovered and stored within plastic bags filled with 10 % formaldehyde and were transported to the lab. The contents of each bag was washed into a 250 μm sieve, macroinvertebrates were separated from the leaf material on a plastic tray by visual inspection, and preserved in 70 % ethanol. Macroinvertebrates were identified to family or higher taxonomic levels, sufficient to classify them to functional feeding groups following Cummins et al. (2005).

We measured water physicochemical variables on August 2011 at each sampling point, and data were presented in Fernandes et al. (unpublished). We measured electric conductivity and pH with a multi-parameter Horiba U-10 water quality meter, whereas dissolved oxygen (DO) was determined with a YSI-55 portable meter. To obtain nutrient concentrations, two samples of surface stream water were also obtained from each reach, frozen, and later analyzed in the laboratory; total nitrogen (TN) and total phosphorus (TP) concentrations were determined following Valderrama (1981).

Data analysis

We expected that community responses to the forest remnant presence were non-linear, as suggested by Harding et al. (2006). So, we used a first-order exponential decay model to relate each response variable to the distance from the fragment edge:

$$y = y_0 + Ae^{-x/t},$$

where y_0, A and t are the model parameters. Models were fitted using the Levenberg–Marquadt algorithm to adjust the parameter values in an iterative procedure, using the routines for non-linear curve fitting in the statistical software OriginPro v.8.0.

Abundances were transformed to $\ln(x + 1)$ to obtain data normality. We used the mean values of the sampling units per point, resulting in $n = 12$. Since there was a large variation in total abundance among sampling units (from 81 to 963 individuals), taxonomic richness was also estimated by individual rarefaction following Gotelli & Colwell (2001) with the statistical software Primer 6.0 (Clarke & Gorley, 2006). In the same way, we estimated the Shannon diversity index using the modification by Chao & Shen (2003), to avoid the effect of differences in number of individuals sampled using the software SPADE (Chao & Shen, 2010).

To evaluate community composition variation along the forest remnant, we used a multidimensional scaling analysis (MDS), calculated on a similarity matrix using the Bray–Curtis index (Clarke, 1993). Taxon abundances were previously transformed to $\ln(x + 1)$, and mean values per sampling point were obtained, before calculating the similarity matrix; analyses were carried out using the software Primer 6.0 (Clarke & Gorley, 2006). The MDS scores of the first two axes were than adjusted to the exponential model described above.

We related the abundances of functional feeding groups to total abundance using the Pearson correlation coefficient.

Results

The presence of the forest remnant influenced some of the physicochemical variables of the stream water (Fig. 1). Dissolved oxygen concentrations steadily increased as the stream entered the remnant. TP concentrations also increased, although very low values were recorded. TN concentrations and pH did not respond to the presence of the forest remnant, whereas a trend for decreased electric conductivity along the forest remnant was recorded.

We found 33 macroinvertebrate taxa in the leaf litter packs (Table 2). Nine taxa were dominant, and represented 97% of all sampled individuals: Chironomidae (55.9 %), Elmidae (18.7 %), Leptohyphidae (9.4 %), Oligochaeta (3.6 %), Baetidae (2.6 %), Simuliidae (2.6 %), Leptophlebiidae (1.8 %), Hydropsychidae (1.7 %) and Calamoceratidae (1.1 %). Chironomidae was dominant at all sampling points, and represented 32.7 % (500 m) to 79.0 % (600 m) of all individuals. The second most dominant taxon was Baetidae upstream the forest remnant, whereas Elmidae was the second most dominant at points within the remnant, varying between 9.8 % at point 600 m and 27.7 % at point 200 m.

Of the 20 invertebrate variables analyzed, eight responded significantly to the distance along the forest remnant (Fig. 2). Three variables responded positively to the presence of the remnant: abundances of Elmidae, Chironomidae, and total macroinvertebrates (Table 2). We found no significant relationship between taxon richness and distance along the riparian forest remnant, although we found significant decreases in both rarefied taxon richness and Shannon diversity index (Fig. 2). Numbers of EPT were not related with distance along the riparian forest remnant, but EPT relative abundance, EPT taxon richness, EPT:Chironomidae ratio, and Baetidae (Ephemeroptera) abundance significantly decreased along the forest remnant gradient (Fig. 2; Table 2).

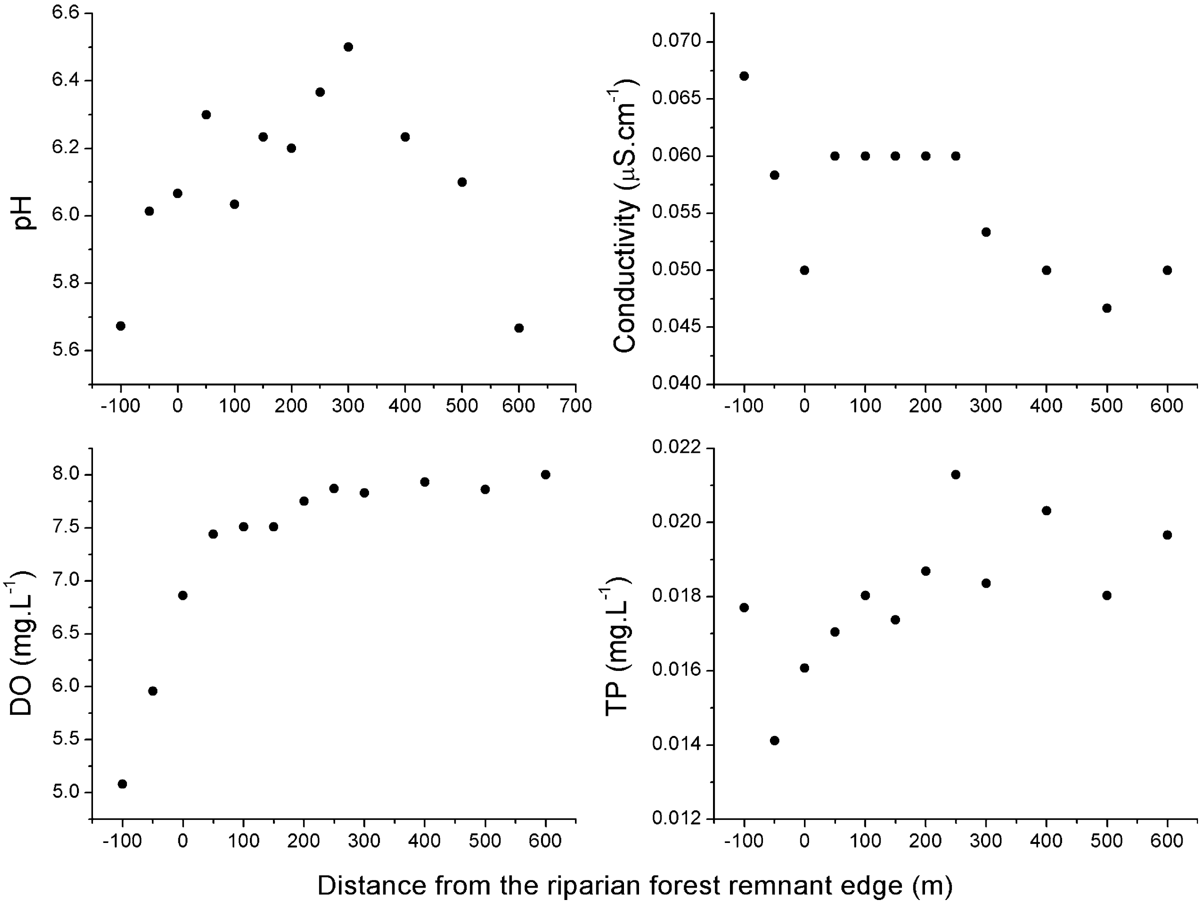


Fig. 1 Variation of water physicochemical variables in a rural stream at different distances from the riparian forest remnant edge. Data from Fernandes et al. (unpublished)

As the stream flowed through the forest remnant, Chironomidae and total abundances increased, whereas the values of biotic indicators commonly related with water quality decreased. These indicators were negatively correlated with the abundance of Chironomidae, and were not necessarily related with a reduction in water quality, as can be seen for EPT relative abundance ($r = -0.841$, Pearson correlation coefficient), EPT:Chironomidae ratio ($r = -0.935$), taxonomic richness ($r = -0.653$), and Shannon diversity index ($r = -0.813$).

Five functional feeding groups were calculated, and gathering-collectors dominated with 81.0 % of all individuals. The other groups were predators (7.3 %), shredders (6.0 %), filtering-collectors (4.5 %), and scrappers (1.1 %). However, the relative abundances of the functional feeding groups showed little variation along the stream. For example, relative abundances of gathering-collectors varied between 72.6 % (point −50 m) to 84.8 % (point 600 m). Total abundance was strongly correlated with the abundance of gathering-collectors ($r = 0.998$, $P < 0.001$), predators ($r = 0.886$, $P < 0.001$), and shredders ($r = 0.760$, $P < 0.01$). Thus, these three groups also increased exponentially with distance along the forest remnant (Table 2).

The composition of macroinvertebrate communities formed a gradient along the distance through the forest remnant, as shown by the MDS (Fig. 3). The main taxa responsible for this gradient were Chironomidae and Elmidae, whose abundances increased along the gradient, and Baetidae, whose abundances decreased. Points located upstream the remnant had low abundances of Leptohyphidae. The points near the edge, from 0 to 200 m were more similar to each other, with moderate abundances of Oligochaeta and higher abundances of

Table 2 Results of the first-order exponential model relating the response variables (structure, abundance, biological indicators and functional feeding groups of the macroinvertebrate communities) to distances from the forest remnant edge

Variable	y_0	*A*	*t*	R^2	*P*
Taxon richness					NS
Rarefied taxon richness	6.494	2.453	172.8	0.81	<0.001
Shannon diversity index	3.029	−1.430	−2199.3	0.31	<0.001
Pielou's evenness index					NS
Total abundance	6.304	−0.590	123.1	0.58	<0.001
Ephemeroptera abundance					NS
Plecoptera abundance					NS
Trichoptera abundance	1.925	0.663	348.4	0.11	<0.001
EPT taxon richness	2.483	3.060	861.3	0.11	<0.001
EPT abundance					NS
EPT relative abundance	13.880	11.844	100.3	0.79	<0.001
EPT:Chironomidae	0.279	0.373	112.1	0.56	<0.001
Elmidae abundance	5.053	−1.857	123.1	0.82	<0.001
Chironomidae abundance	5.678	−0.598	110.0	0.46	<0.001
Simuliidae abundance					NS
Baetidae abundance	−0.265	2.529	236.2	0.82	<0.001
Leptohyphidae abundance					NS
Leptophlebiidae abundance					NS
Calamoceratidaeabundance					NS
Hydropsychidae abundance					NS
Oligochaeta abundance					NS
Gathering-collectors	6.126	−0.670	130.4	0.60	<0.001
Filtering-collectors					NS
Shredders	3.391	−0.212	52.2	0.67	<0.001
Predators	3.612	−0.381	109.3	0.25	<0.001
Scrapers					NS
MDS axis 1	−0.725	1.310	147.6	0.83	<0.001
MDS axis 2	−0.099	<0.0001	−19.9	0.22	NS

NS $P > 0.05$

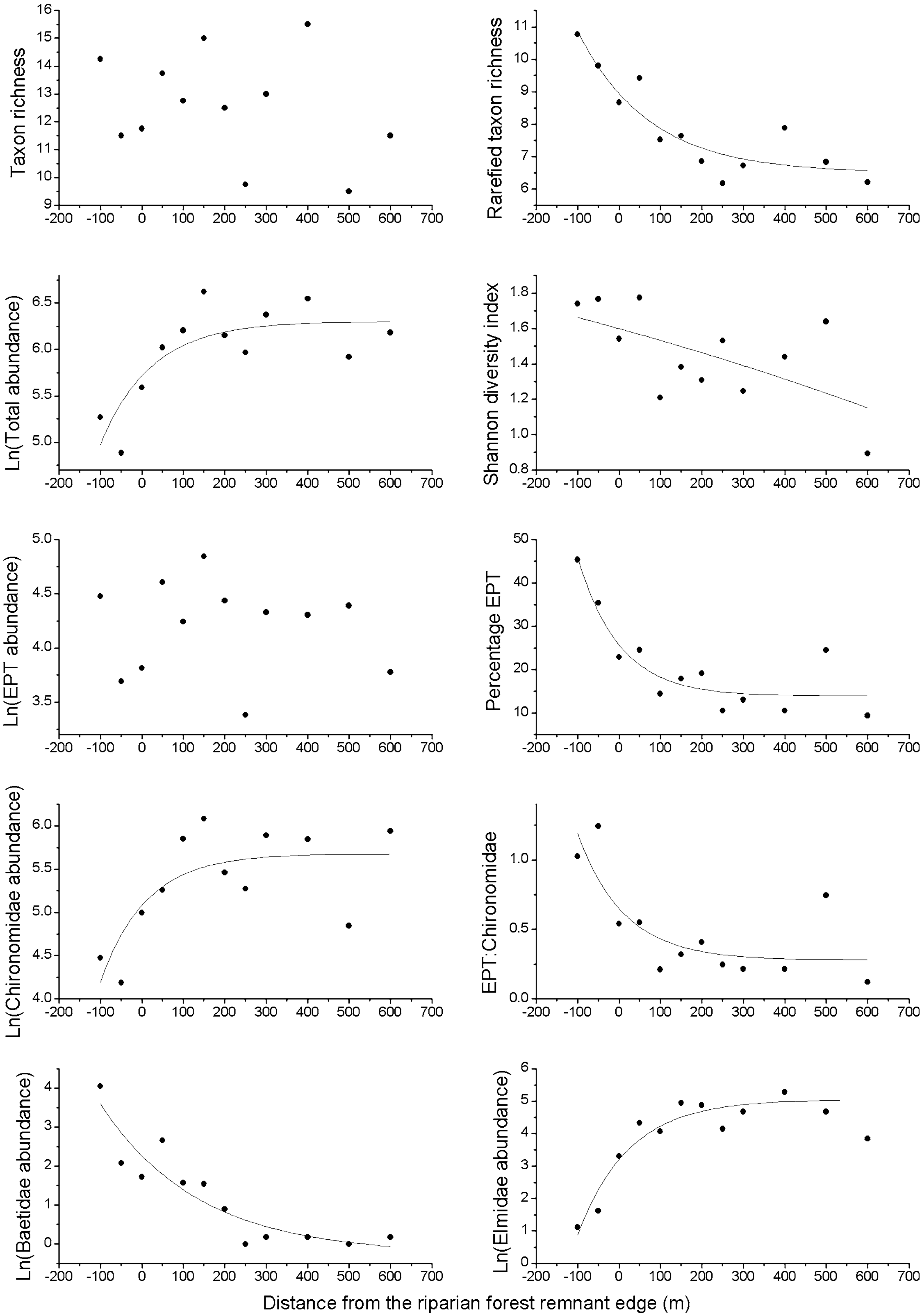
Empididae and Calopterygidae. Finally, the furthest points (250 to 600 m) were more heterogeneous, but with higher abundances of both Chironomidae and Oligochaeta.

Community composition was related to the distance along the forest remnant, having a significant relationship with MDS axis 1, but without a significant relationship with MDS axis 2 (Table 2; Fig. 4).

Discussion

The presence of riparian forest remnants can influence stream water quality, as studied mainly in New Zealand, with an improvement in macroinvertebrate indicators as the stream passes through the remnant (Storey & Cowley, 1997; Scarsbrook & Halliday, 1999). However, there was variation in patterns described within each study, and studies carried out in southeastern Australia (Arnaiz et al., 2011) and Zimbabwe (Chakona et al., 2009) found more variation (Table 1). In our study, we found no effects on taxonomic richness, as also recorded by Scarsbrook & Halliday (1999) and Harding et al. (2006), and

Fig. 2 Relationship between macroinvertebrate community variables sampled in a rural stream at different distances from the riparian forest remnant edge ▶


Taxon richness
Rarefied taxon richness
Ln(Total abundance)
Shannon diversity index
Ln(EPT abundance)
Percentage EPT
Ln(Chironomidae abundance)
EPT:Chironomidae
Ln(Baetidae abundance)
Ln(Elmidae abundance)
Distance from the riparian forest remnant edge (m)

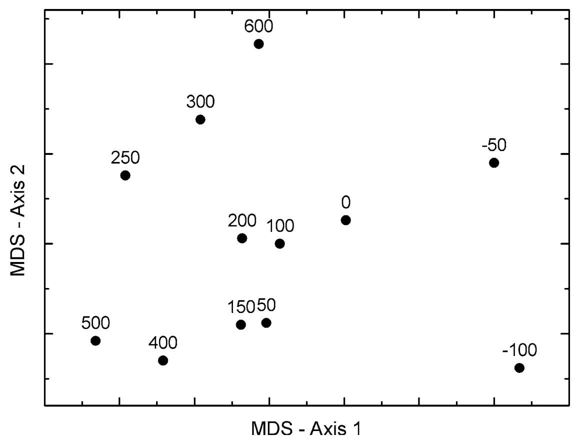


Fig. 3 MDS ordination of macroinvertebrate communities sampled in a rural stream at different distances from the forest remnant edge

increased macroinvertebrate abundances (strongly influenced by Chironomidae abundance), as only found by Storey & Cowley (1997). On the other hand, the Shannon diversity index decreased along the forest remnant, contrary to findings by Chakona et al. (2009), and rarefied taxon richness also decreased. The results in rarefied taxon richness are interesting, because it presented a different pattern from taxon richness, and was contrary to the other studies mentioned above. Since significant changes in abundance are commonly reported (Table 1), differences in sampling effort on the patterns described can potentially influence patterns of taxonomic richness (Gotelli & Colwell, 2001), thus influencing the detected patterns.

Higher values of richness and diversity upstream of the fragment can be related both to the lower dominance of Chironomidae and to the existence of food resources and microhabitats that can be used by the fauna. Although the points −100 and −50 m are located outside the forest remnant, they are located in a transition area between sugarcane cultivation and forested areas, formed by an abandoned sugarcane plantation. In this transition zone, the streambed and margins are covered by several species of grasses, ferns, and shrubs, which can provide shelter and food for the macroinvertebrates (Menninger & Palmer, 2007). Also, the higher incidence of solar radiation favors periphyton growth on leaf surfaces, thus providing another food resource for the community (Kikuchi & Uieda, 2005). Thus, the attributes of more preserved reaches found in these points, such as higher taxon richness and proportion of EPT, could be influenced by the availability of microhabitats and niches provided by the herbs and grasses that colonized the abandoned sugarcane plantation at this site. In the interior of the studied forest remnant, the streambed does not present this diversity of resources and microhabitats, being shaded by the tree vegetation along the margins, resulting in a more simplified habitat. Fonseca (2011) found that, in denuded streams, higher macroinvertebrate diversity was found in reaches that had riparian herbs and grasses, when compared with reaches without these plants.

The abundances of Chironomidae clearly influenced the response of macroinvertebrate communities to the presence of the riparian forest fragment, and two

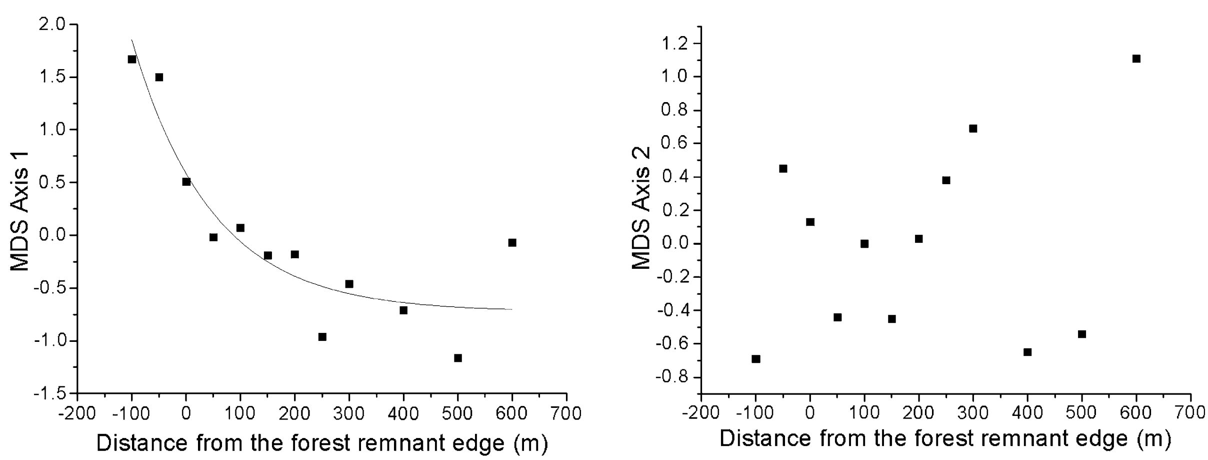


Fig. 4 Relationship between MDS axes and distances from the forest remnant edge

hypotheses can be proposed to explain these changes. First, in a study carried out at the same time in this stream, Fernandes et al. (unpublished) found increased concentrations of phosphorus and dissolved oxygen as the stream passed along the forest remnant, and also increases in leaf breakdown rates. These results suggest that although oxygen levels improved, increases in nutrient concentrations still may have been influencing the macroinvertebrate communities, resulting in higher densities of Chironomidae. Density increases related to higher nutrient concentrations have been observed in other studies (e.g., Morais et al., 2004), although abundances increased in response to moderate increases in nutrient concentrations (Ortiz & Puig, 2007), since high nutrient concentrations can stress the fauna, resulting in decreased abundances (Odum et al., 1979). In fact, the increase in phosphorus concentrations along the Córrego da Gruta was moderate, since maximum concentrations were 0.021 mg l^{-1}, an increase of 50 % relative to the smallest value recorded.

Second, the addition of leaf litter can influence the distribution of macroinvertebrates within the streambed. Although we did not record the availability of this resource along the stream, the lower occurrence of herbs and grasses and the high water velocities recorded (mean values varied between 0.13 and 0.19 ms^{-1}; unpublished data) can reduce the accumulation of organic material due to floods, common in tropical systems (Smith et al., 2003). Also, as the species used in the colonization experiment is commonly used by the macroinvertebrates, the leaf litter bags could constitute high-quality patches in the streambed. Patches of high quality resources can be preferentially colonized by macroinvertebrates, as is the case with Chironomidae in unstable environments (Silver et al., 2004), resulting in higher densities in leaf patches when compared with the sediment substrate (Palmer et al., 2000).

The elevated dominance of gathering-collectors and the low representation of shredders found in our study are in accordance with other studies carried out in tropical streams (Boyero et al., 2009; Li & Dudgeon, 2009). Leaf breakdown can be related both to physical abrasion and disturbance, and to the action of shredders and microbial activity in tropical streams, but other taxa such as Chironomidae can also contribute to decomposition processes (Dudgeon & Gao, 2011). Mining Chironomidae could have also influenced leaf breakdown rates, since the most decomposed leaves were mainly those with higher abundances of leaf miners. Miners excavate the leaf interior, resulting in more fragile tissues that can be broken apart by water abrasion. The effect of leaf breakdown is to increase the availability of fine particulate organic matter to other functional feeding groups, mainly gathering-collectors, attracting individuals of Chironomidae and Elmidae to the samples, and consequently, the increase in predators.

Past studies carried out in pasture streams evaluated the effects of forest remnants on benthic fauna. Quinn et al. (1997) and Scarsbrook & Halliday (1999) found that when flowing through pasture areas, the streams had higher densities of macroinvertebrates—mainly Chironomidae—whereas forest reaches within the same stream presented higher proportions of EPT; thus, they found no differences in taxonomic richness between different reaches, but community composition was significantly different. On the other hand, Harding et al. (2006) found no differences in density, taxonomic richness, or EPT taxon richness when comparing reaches upstream, downstream, and within forest remnants in the same streams. Chakona et al. (2009) found increases in macroinvertebrate abundance, taxonomic richness, and diversity, whereas Arnaiz et al. (2011) found no effects on abundance and diversity, but increased taxonomic richness. The results of our study show different trends in macroinvertebrate community responses: higher total abundance along the forest remnant due to higher abundances of Chironomidae, and higher taxonomic richness upstream the edge of the remnant. Also, the results of this study corroborate findings by Quinn et al. (1997), Scarsbrook & Halliday (1999), Chakona et al. (2009), and Arnaiz et al. (2011), with significant differences in community composition between deforested and forested reaches within the same stream.

Several studies have been done to evaluate the effects of fragmentation on terrestrial and aquatic species, but in streams, water quality and the structure of aquatic communities are strongly influenced by the streamflow, and the effects of forest fragmentation on stream ecosystems are complex (Harding et al., 2006). The effects of land use at large spatial scales can sometimes be more important than the effects of local differences, but in many cases local effects can influence macroinvertebrate community composition (Sponseller et al., 2001; Mykrä et al., 2007). Thus, the presence of local factors such as forest remnants can influence biological communities and stream water quality, but the results can differ depending on large-scale land use patterns. To our knowledge, this is the second study that was carried out in tropical streams, and we found some differences relative to the other study, in Zimbabwe (Chakona et al., 2009). Although their patterns were generally in agreement with the streams studied by Storey & Cowley (1997), a great variation of patterns was found in the other temperate streams studied to date (Table 1). Both temperate and tropical streams are largely influenced by watershed land use, and with the exception of streams in New Zealand, which were all flowing through pasture, the other streams were located in watersheds with somewhat different land uses, although they were all dominated by agricultural activities. In any case, all studies indicate that forest remnants can be of great value to maintain or restore stream conditions and functions in agricultural landscapes, an urgent need in both temperate and tropical regions.

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