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Do fallen fruit-dwelling chironomids in streams respond to riparian degradation?

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Abstract. There is little information on the impacts of deforestation on the aquatic insects associated with fallen-fruits in Neotropical streams. Given the argumentation that fallen-fruit dwelling insects may depend on the availability of fruits in streams and consequently on the riparian forest condition, we hypothesized that fallen-fruit dwelling chironomid Endotribelos would differ in streams whose catchments differed in land use, particularly riparian forest conditions. To test this hypothesis we experimentally placed fruits in streams characterized by a gradient of riparian forest degradation We applied correlation analysis between Endotribelos mean density by fruit, number of colonized fruits, and environmental variables. All results evidenced that fallen-fruit chironomid Endotribelos were affected by riparian degradation.

Key words: Chironomidae, Endotribelos, lotic systems, anthropogenic impacts, deforestation

Resumo. Chironomidae em frutos caídos em córregos respondem à degradação da mata ripícola? Existem poucas informações sobre repostas de insetos que vivem em frutos caídos em córregos frente ao desmatamento e à degradação da mata ripícola na região Neotropical. Considerando a argumentação que insetos vivendo em frutos caídos podem depender da disponibilidade de frutos em córregos e, consequentemente, da condição da floresta ripícola, nós hipotetizamos que Chironomideos Endotribelos seriam diferentes em córregos em diferentes usos do solo, particularmente na condição de mata ripícola. Para testar essa hipótese, experimentalmente colocamos frutos em córregos caracterizados por gradiente de degradação de mata ripícola. Nós avaliamos relações entre a densidade média de Endotribelos por frutos, número de frutos colonizados e variáveis ambientais. Todos os resultados evidenciaram que Chironomidae, particularmente Endotribelos, em frutos respondem previsivelmente à condição da mata ripícola.

Palavras-chave: Chironomidae, Entotribelos, sistema lótico, impacto antropico, desmatamento

Introduction

The effects of land use on aquatic insects have been documented in different parts of the world, but there is still much debate regarding the predictability of the responses of different taxa under different terrestrial disturbances (Bonada *et al*. 2006). In general, it has been suggested that aquatic insects respond to point source pollution in a very predictable way, but respond to diffuse pollution in a more complex and variable manner (e.g. Allan 2004, Downes *et al*. 2005).

Tropical forests host intriguing interactions between fruits and fruit-eating animals in both terrestrial and aquatic habitats (Janzen 1974, Araujo-Lima & Goulding 1997, Wantzen & Junk 2006). In these areas, there is a great amount of fruits falling into streams. This fruit input may occur continuously over the year, and consists mostly of large, fleshy fruits that are of high nutritional value. Therefore, fallen fruits potentially represent an important resource for stream macroinvertebrates (Larned *et al.* 2001, Roque *et al.* 2005). Among aquatic insects inhabiting fallen fruits**,** the larvae of the chironomid *Endotribelos* Grodhaus, 1987, are the most common insects inside fallen-fruits in Neotropical streams (Roque *et al.* 2005, Roque & Trivinho-Strixino 2008). *Endotribelos* larvae have also been reported living in macrophytes, detritus, wood, leaves, and freshwater sponges (Grodhaus 1987; Roque et al. 2005).

Endotribelos larvae are a potentially useful group for assessing diffuse anthropogenic impacts on streams, because of their dependence on resources from the riparian forests. Furthermore, there are advantages in using fallen fruits as a natural ecological unit in sampling designs due to their ephemeral, patchy distribution and discrete character that allow testing hypotheses that explicitly address influence of landscape use, habitat, and resources on distribution of aquatic insects. This is particularly worthwhile because in most studies on aquatic systems, the delineation of sampling units is arbitrary, which result, in many cases, in problems with statistical assumptions and biological meanings.

There are several mechanisms through which riparian degradation may affect insects inhabiting fallen fruits in aquatic systems. These include a reduction in the number of fallen fruits in the stream, an increase in sediments, and an increase in primary productivity. In this study we hypothesized that riparian degradation may lower the availability of primary resources for chironomids, either directly (i.e. reduce the number of fallen fruits) or indirectly (i.e. reduce the accessibility of fruits by insects, through sedimentation). To test the stated hypothesis, we experimentally placed fruits in streams and evaluated whether abundance and frequency of *Endotribelos* is related to riparian forest degradation. Considering that (i) resource may be defined as an organism requirement for its survival, growth and reproduction; (ii) the availability of resources can influences the structure and dynamics of ecological systems; (iii) in general the primary resources limit the community productivity (Nowlin *et al.* 2008), we expect that fallen fruit-dwelling chironomids would differ in streams whose catchments differed in land use, particularly riparian forest conditions.

Material and Methods

Study area. We conducted the experiment in six streams in São Carlos city, southeastern Brazil (22°01’S, 47°53’W). The region was characterized in the past by extensive areas of Cerrado (savanna) and Atlantic semi-deciduous forest (Soares *et al.* 2003), both considered hot spots of biodiversity (Myers *et al.* 2000). Currently, the area is dominated by sugar cane plantations, pastures, small forest fragments, and riparian buffer strips along the streams with different levels of connectivity, size and preservation. Regional climate is Cwa (Köppen classification), with wet summer and dry winter. All study sites were first and second order streams with similar topographic gradients ($<5^o$), but located in pasture areas with varied condition of riparian forest.

Stream and riparian forest variables. We measured environmental variables at each site to characterize habitat conditions and degree of human disturbance. Conductivity and pH were measured in 3 different sections of each site using a Horiba U-10 or a Yellow Springs-556 water checker equipped with multiple probes. We used the mean of these measures in the statistical analyses. Predominant substrates were estimated visually as the proportion of the stream bottom covered by boulder and cobble (>256 mm), gravel (2-255 mm), sand (0.125-2 mm), and mud (<0.125 mm). To assess physical and biological conditions of the riparian zone and stream channel morphology at the local scale, we applied 7 metrics and their respective scores from the “Riparian Channel and Environmental Inventory” (RCE) for small streams (Petersen Jr. 1992). The RCE scores were applied to each sampling site, which consisted of 100m of stream. These metrics were: 1) land-use pattern beyond the immediate riparian zone, 2) width of riparian zone from stream edge to field, 3) completeness of riparian zone, 4) vegetation of riparian zone within 10m of channel, 5) retention devices, 6) channel sediments, and 7) stream-bank structure. Thus, our RCE final score for each stream refers to the sum of scores of these 7 metrics and higher RCE scores are associated with more intact riparian areas.

Selected fruits. *Syagrus romanzoffiana* (Chamisso) Glassman, popularly called Jerivá, is a common palm in semi-deciduous forest and riparian forests in South-eastern Brazil and their fruits are considered important resources to terrestrial fruit-eating animals. The fruit is an ovoid drupe 15cm in diameter with a soft endocarp and woody endocarp. Individuals of these plants produce fruit all the year round. We collected fruits of *S. romanzoffiana* from tree individuals in the campus of the Universidade Federal de São Carlos, São Carlos, following three criteria: similar size, ripeness and level of herbivory.

Sampling design. We threaded a nylon line through 21 fruits from which we made three "necklaces" with 7 fruits each. These were randomly placed in pool areas of each stream. The insertion of the nylon line in the fruits likely did not influence the larval colonization process, because decomposition starts from the top of the fruit and most of the larvae occupy these areas (personal observation).

The fruits were placed in the streams on 10-11 August 2006 and removed after seven days. Each fruit was isolated and transported to the laboratory. This period of exposure (seven days) was defined after a preliminary experiment conducted by the authors (unpublished data). No large rainfall event occurred in our study area during this period.

Data analysis. We sorted and identified all insects of each fruit. Some fruits were lost during the experiment, so we standardized the number of fruits used in the analyses by those found not completely embedded by sediments.

We did not analyze the number of lost fruits and fruit embeddedness as a surrogate measure of anthropogenic impacts, because in two low impacted streams (Canchim and Aeroporto stream), despite having a wide forest buffer, the stream-banks had been disturbed by foraging pigs which covered many fruits by sediments and some fruits were eaten by terrestrial frugivores.

Larval densities were expressed as the mean number of larvae per fruit and the proportion frequency of colonized fruits (number of fruit with larvae/total of number). To choose meaningful non-correlated environmental predictors we carried out a Principal Component Analysis on all measured stream and riparian forest variables. The Broken-Stick method (Jackson 1993) was used as a stopping-rule in the PCA.

After that we performed correlation analysis for the (*Endotribelos*) chironomid mean density (log x+1) and frequency of colonized fruits (response variables) against the selected axes of PCA (predictor variables). We report R^2 for each correlation. Because geographical data such as these are generally spatially autocorrelated (Legendre 1993), so that degrees of freedom are inflated and P-values for R are underestimated. To correct for spatial autocorrelation, we calculated for each correlation the effective number of degrees of freedom according to Dutilleul's method (Dutilleul 1993). We report adjusted P-values based on the effective degrees of freedom. The analyses were performed using the package Spatial Analysis Macroecology v. 3.0, SAM (Rangel *et al.* 2006).

Results

Endotribelos mean density and frequency of colonized fruits varied considerably among streams and the values were highest at conserved areas (Table I).

The first principal component axis accounted for 63% of the variability in stream environmental variables and it was the only one selected by Broken stick model. PC1 evidenced a gradient of riparian degradation. Sites with lower PC1 scores were degraded areas (most correlated with high values of conductivity and smaller values of RCE scores) while those with higher PC1 scores were located in conserved areas (correlated with high values of RCE and DO scores) (Tables I and II).

Endotribelos mean density and frequency of colonized fruits seem to increase with increasing PCA scores (good condition of riparian forest), as evidenced by positive values of correlations (r^2 = 0.77; P_{adj} = 0.06 and r^2 = 0.79; P_{adj} = 0.05, respectively).

Table I. *Endotribelos* mean density, frequency of colonized fruits, and environmental variables across different streams in the State of São Paulo, Brazil.

Streams	Mean density	Frequency	RCE	pH	Conductivity	DO	Canopy	Lat (Y)	Long (X)
1	0.00	0.00	28	6.60	94	2.50	1	-22.039	-47.829
2	1.80	0.80	135	6.70	13	5.70	3	-21.882	-47.906
3	0.18	0.18	65	6.00	12	6.00	2	-21.019	-47.836
4	0.61	0.38	115	7.20	12	7.20	2	-21.954	-47.837
5	0.50	0.40	175	7.00	16	7.30	3	-21.926	-47.911
6	0.07	0.07	24	6.80	16	6.40	1	-22.038	-47.780
7	21.80	1.00	160	6.60	14	5.20	3	-22.044	-47.824
8	2.90	1.00	185	5.40	10	7.90	3	-21.951	-47.838

Table II. Summary of the environmental variables and of the results of Principal Component Analysis across different streams in the State of São Paulo, Brazil, and correlation coefficients between principal component scores and the environmental variables.

	Streams		Principal Components
Variables	Mean	SD	PC-1
RCE	92	63.99	0.825
pH	6.45	0.64	-0.473
Conductivity (µS cm^{-1})	26.16	33.28	-0.879
DO (Mgl^{-1})	5.95	1.87	0.938
Variance explained %			63% (Broken stick 52%)

Discussion

The negative effects of degradation of riparian cover caused by deforestation, overgrazing and other land use practices on macroinvertebrate communities have been reported worldwide (e.g. Iwata *et al.* 2003, Allan 2004, Sweeney *et al.* 2004, Couceiro *et al.* 2007). Although researchers report that row crop and other forms of intensive cultivation strongly affect stream condition, the influence of pasture agriculture (Strayer *et al.* 2003) and forest fragmentation (Nessimian *et al.* 2008) may be less pronounced.

Fallen-fruit dwelling insects may depend on the availability of fruits in streams and consequently on the riparian forest condition, and regarding the advantages in using them as indicators of less pronounced and diffuse impacts, it would be expected that the distribution of these animals could be predict based on environmental variables related to anthropogenic impacts. Our results support this expectation. The negative effects of the riparian degradation on frequency of colonized fruits and on *Endotribelos* mean density by fruit may be attributable to a number of interacting reasons. The principal reasons, by which forest degradation influences stream macroinvertebrate densities, are sedimentation, hydraulic alteration, and loss of large organic matter inputs (Allan 2004). Environmental disturbances in degraded streams, such as sedimentation, have long been suggested to be one of the most important causes for loss of species and reduction in density of some macroinvertebrate groups. The principal mechanisms behind are: (i) increasing turbidity, scouring and abrasion, (ii) impairing substrate suitability for biofilm production, (iii) decreasing food quality causing bottom-up effects through food webs, (iv) in-filling of interstitial habitat that harms crevice-occupying invertebrates (v) coating of gills and respiratory surfaces and (vi) reducing stream habitat heterogeneity (Cordone & Kelly 1961, Quinn *et al.* 1992, Wood & Armitage 1997, Wantzen 1998, Allan 2004).

An increase in primary productivity is also expected to occur in some deforested small streams, with consequences in macroinvertebrate communities. The most common effect is a positive and food related association between macroinvertebrate abundance and periphyton biomass, and also functional changes characterized by higher dominance of collectors and grazers (Vannote *et al.* 1980, Bojsen & Jacobsen 2003). In our study, we could observe high amounts of periphyton on the surface of the fruits in the most degraded streams and occurrence of non-specialists fruit dwelling chironomids (e.g. *Chironomus*) living around the fruits. This observation, associated with the smaller frequency of colonized fruits by *Endotribelos*, indicates a replacement of "typical dwelling fruit chironomids" by more tolerant taxa. Moreover, animals influenced by or depend on basal food resources from riparian vegetation can suffer additional negative effects on its occurrences and densities due to direct losses, changes and decreases of the basal resources (Benstead & Pringle 2004).

From a bioassessment perspective, despite the potential application of fallen-fruit dwelling insect information, we consider that before using *Endotribelos* as an indicator group of forest degradation, at least for non extreme situations that are more difficult to assess, we need to know threshold levels of disruption involving linkages between terrestrial and stream habitats and resources that affect fallen-fruit dwelling insect abundances.

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