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Chironomidae from Eastern Amazon: Understanding the differences of land-use on functional feeding groups

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ABSTRACT

Deforestation for agricultural purposes is the most dangerous human action against the conservation of the Brazilian Amazon Forest; its rates reached almost 20% of the original forested area. Many studies have been conducted on Chironomidae systematics and ecology over the Amazon biome, but most concerned the Central Amazon, while little is known about Chironomidae diversity and the effects of land development and agriculture intensification on the aquatic biota from Eastern Brazilian Amazon. The present study analyzed the effects of different land-use and land-cover on Chironomidae assemblages. Land-Use and Land-Cover (LULC) at the riparian zone were assessed from satellite imagery and three categories were defined: Forest, Secondary (Capoeira) and Agriculture. Ten catchments were selected: two for Forest, five for Agriculture and three for Secondary. For each catchment we characterized habitat and sampled insects. We hypothesized that i) the assemblage taxonomic richness will change across different land uses on riparian zones and ii) feeding functionality (FFG) is a better information than taxonomic resolution to show the importance of LULC upon stream. A total of 20,884 individuals were sampled from the streams, abundance was higher in Agriculture streams. *Corynoneura* (18.4%), *Pentaneura* (14.6%) and *Rheotanytarus* (14.0%) were the most abundant genera in Agriculture streams; *Corynoneura* (17.8%), *Caladomyia* (13.6%), *Paratanytarsus* (13.1%) and *Beardius* (10.9%) dominated Forest streams; *Goeldichironomus* (25.9%), *Rheotanytarus* (17.6%) and *Polypedilum* (13.2%) dominated Capoeira streams. Regarding FFG, gatherers were the most numeric abundant in Forest (50.3%), followed by filterers (38.7%), predators (6.6%) and shredders (4.2%). In Capoeira, filterers were the main FFG (61.1%), gatherers (27.9%), predators (7.7%) and shredders (3.3%). In Agriculture streams, predators, filterers and gatherers had close numeric participation, 34.9%, 32.4% and 32.2%, respectively. Shredders performed a smaller fraction (0.4%). In Forest and Agriculture, scraper's participation was under 0.2%, while it was absent at Capoeira. Permutation tests showed significant differences among assemblages, based on numerical abundance of genera and on functional feeding group data. Even though, shredders showed a discrete participation in all three LULC, it was statistically significant higher at Forest streams when compared to Agriculture ones. Our study was able to demonstrate taxonomic differences of all LULC analyzed and it also showed the importance in considering the feeding behavior to understand the effects of land-use and land-covers changes.

Key words: Rainforest; land-cover; watershed management; aquatic insects; agriculture; Neotropical.

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INTRODUCTION

Deforestation for agricultural purposes is the most dangerous human action against the conservation of the Brazilian Amazon Forest (Coe *et al*., 2009); currently reaching almost 19% of the original forested area (Aguiar *et al*., 2016). Deforestation increased again after a decade of stability since the Brazilian Forest Law has been changed recently (Brasil, 2012). The consequences of the historical deforestation begin to show up in the last years, even though the alteration in rainfall and water balance, changes on atmospheric chemistry, wide range of varying temperatures on the seasons were foreseen long ago (Ojima *et al*., 1994).

It is also expected that the change on climate will impact forest evapotranspiration which is an important source of atmospheric moisture that is recycled as precipitation regionally and also over the subtropical La Plata basin (Eltahir and Bras, 1994; Zemp *et al*., 2014; Zemp *et al*., 2017). To decrease the climate change effects, the restoration of deforested areas to intact ecosystems and their functions is a need and also a challenge (Lester and Boulton, 2008). Understanding the impact of land-use and land-cover (LULC) over aquatic insects is a key step for further ecosystem restoration projects.

Chironomidae have been described as the most abundant aquatic family at the macroinvertebrate communities sampled around the world (Ferrington, 2008); their importance is recognized as their role as food source item, either as prey or as predator, acting on the conversion of organic material to animal protein (Armitage, 1995; Maasri *et al*., 2008) to mention a few. Moreover, the importance of analyzing traits is highlighted by some authors (Cummins *et al*., 2005; Merritt *et al*., 2017) because they demonstrate the ability of the species to deal with environmental problems and opportunities (Verberk *et al*., 2013).

Those assumptions based our goal to analyze the Chironomidae assemblages from streams reaches bordered by different riparian vegetation (Forest, secondary forest - named capoeira - and agriculture) over assemblage taxonomy and trait information based on functional feeding group (FFG). Thus, we sought to understand which assemblage information is the most effective to respond the land-use and land-cover alteration.

To accomplish that goal, we surveyed ten streams reaches differing in local riparian land-use and the numerical abundances of taxon and feeding categories of Chironomidae assemblages. We hypothesized that i) the assemblage taxonomic richness will change across different land-use and land-covers on riparian zones and ii) functional feeding group is a better information than taxonomic resolution to show the importance of LULC over the stream biota.

METHODS

Study area

The study was focused on the Northeastern region of Pará State. This region covers over 50,000 km^2 East of the Araguaia-Tocantins drainage, and the Northern lowlands areas are drained by several river drainages in the Brazilian Amazon (Fig. 1A). The climate in the study area is tropical, varying from *Am* (monsoon) to *Af* (equatorial) in the Köppen-Geiger climate classification. Mean summer (July) temperature is 32.2°C and mean winter temperature is 21.7°C, while the mean annual precipitation varies from 2,302.5 to 2,857.4 mm (Pachêco and Bastos, 2011). Land-use and land-cover in the study area (Fig. 1A) is a mosaic composed mostly of varied Capoeira seral stages of native vegetation patches (‘capoeira’ - fallow stages of the slash-and-burn, itinerant agriculture system; mostly resulting from clearcutting former capoeira, or native forest remnants), pastures, small agriculture fields and forest remnants (Watrin *et al*., 2009, Almeida *et al*., 2010).

Site selection, site characterization, sampling and sample processing

Four sampling areas were selected: two (1 and 2) were located in the Marapanim River watershed and two (3 and 4) in the Capim-Guamá River drainage (Fig. 1). Areas 1 and 3 were selected as agricultural watersheds; areas 2 and 4 were forest fragments in near pristine condition in the range of 1000 to 2000 hectares (Fig. 1B). Catchment delineation was based on a 30-m Digital Terrain Model, and resulted in segmentation of 100-600 hectares such hydrological units. In each catchment, the lowermost 150-m long stream reach was selected for physical and biological measurements. The selection of the ten catchments was based on LULC dominance on the 30-m wide riparian areas of the sampling reach, into three categories: (1) Forest (5 streams), (2) Capoeira (2 streams) and (3) Agriculture (3 streams). Catchment drainage area and Horton-Strahler stream order were computed on a GIS environment. Channels discharges were measured with a digital flowmeter using the area velocity method (Gordon *et al*., 2004). Each stream was sampled once, from July to October 2010, during the dry season. Streams names, characteristics of the sampling sites and catchments were informed in Tab. 1.

Tab. 1. Sampling sites and catchment characteristics in the Eastern Amazon, Brazil. Coordinates are projected on the UTM system, datum WGS84, zone 23S.

Stream name	Latitude	Longitude	DCs	HS	CD	DA
Muquem	231,584	9,771,106	a	2	0.076	222.1
Areia	232,110	9,771,330	a	1	0.029	130.7
Haras	211,447	9,893,014	c	1	0.029	119.0
Pardal	209,695	9,887,742	f	2	0.030	118.5
Tomé	210,773	9,886,056	a	2	0.129	419.5
Buiuna	206,194	9,886,658	f	2	0.045	220.0
Timboteua	209,683	9,883,338	f	1	0.048	138.7
Malva	230,624	9,779,294	c	1	0.001	220.2
Água Fria	240,666	9,756,702	f	2	0.008	255.7
Uromã	187,829	9,879,133	f	2	0.033	100.0

DCs, dominant cover at the local scale (a, agriculture; c, capoeira; f, forest); HS, Horton-Strahler stream order; CD, channel discharge (m^3 s^{-1}); DA, drainage area (ha).

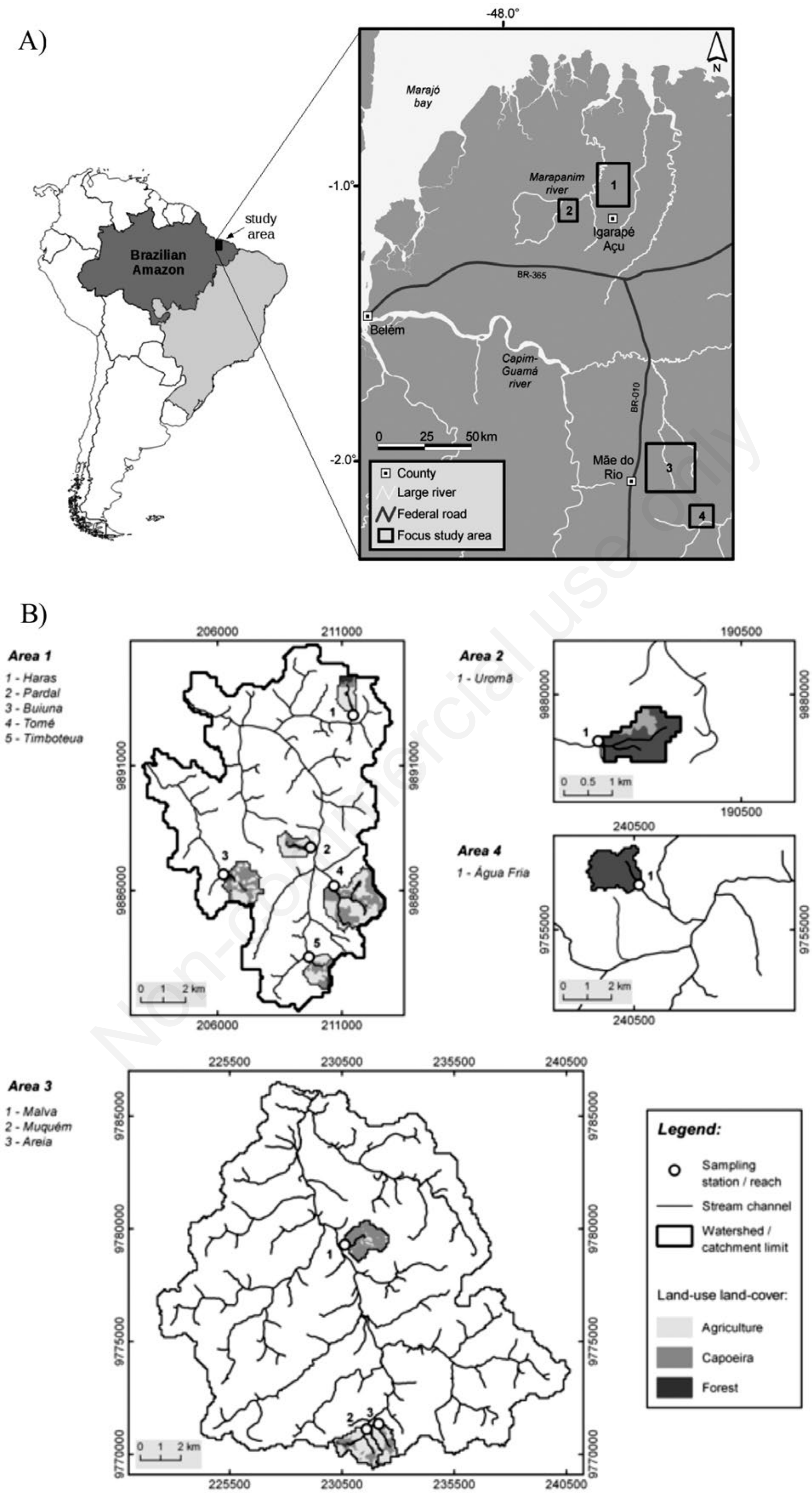

Fig. 1. Location of studied catchments on the Brazilian Amazon and Eastern Amazonia (A) and land-use and land-cover aspects (B).

Along each of the studied streams, ten Surber samples of two minutes each were taken from sandy or leaf/vegetal debris packs in medium to fast water current habitat units. Three handnet samples were taken from litter patches intertwined to twigs and roots instream. All material was processed immediately by washing it and transferred to bottles containing 4% formaldehyde for two days and then preserved in a 70% ethanol solution. Chironomidae larvae were identified into genera using a Brazilian key (Trivinho-Strixino, 2011). Functional feeding groups (FFG) classification followed Silva *et al*. (2008), Sonoda *et al*. (2009) and Galizzi *et al*. (2012).

Data analysis

Upon taxa identification to genera level, individuals were counted and a Functional Feeding Group was assigned to each taxon. Two Chironomidae abundance matrices were analyzed: total of individuals per genera by stream and total individuals per FFG by stream. Prior to statistical analysis, numerical abundance data were log transformed and, when necessary the abundance matrix was transformed into a distance matrix with the Kulczynski distance. The analysis focused on detecting and describing differences in samples belonging to each of the local riparian dominant LULC category (DCs). First, the homogeneity of multivariate dispersions was analyzed, followed by pairwise comparisons by a permutation test, employing the *betadisper* and *permutest* procedures of package "vegan", ver. 2.4.6 (Oksanen *et al*., 2018). Second, non-metric multidimensional scaling ordinations were constructed with both matrices with the procedure metaMDS. Sample coordinates in dimensions 1 and 2 were related to the DCs variable by a Kruskall-Wallis and Wilcoxon paired comparisons, both non-parametric analyses. Third, these non-parametric techniques were employed to compare the ranked-abundance of each of the FFG detected in the samples to the *DCs* factor.

RESULTS

Chironomidae assemblages

A total of 20,884 individuals were sampled from the streams, comprising 64 genera. The majority of the genera was of the subfamily Chironominae (37 genera). In Agriculture streams, 58 genera were sampled, followed by 52 genera in Forest and 30 genera in Capoeira. Abundance was higher in Agriculture streams, even if compensated by number of samples: 66.3% individuals, compared to only 4.9% in Capoeira streams and 28.8% in Forest. *Corynoneura* (18.4%), *Pentaneura* (14.6%) and *Rheotanytarus* (14.0%) were the most abundant at Agriculture streams; *Corynoneura* (17.8%), *Caladomyia* (13.6%), *Paratanytarsus* (13.1%) and *Beardius* (10.9%) dominated forested streams; *Goeldichironomus* (25.9%), *Rheotanytarus* (17.6%) and *Polypedilum* (13.2%) dominated Capoeira streams.

Regarding FFG, gatherers were the most numeric abundant in Forest (50.3%), followed by filterers (38.7%), predators (6.6%) and shredders (4.2%). In Capoeira, filterers were the main FFG (61.1%), followed by gatherers (27.9%), predators (7.7%) and shredders (3.3%). In Agriculture streams, predators, filterers and gatherers had close numeric participation, 34.9%, 32.4% and 32.2%, respectively. Shredders performed a smaller fraction (0.4%). In Forest and Agriculture, scrapers participation was under 0.2%, while it was absent at Capoeira.

Chironomidae assemblage patterns

The *betadisper* and *permutest* procedures revealed significant differences on the homogeneity of multivariate dispersion, either in terms of taxonomic and functional structure (see Fig. 2 for group statistics). Differences among stream groups (Forest × Capoeira × Agriculture) in genera composition and abundance was significant: F=20.527, P=0.002 (2 and 7 degrees of freedom for group and residuals, respectively); pairwise comparisons indicated significant differences between Forest and Capoeira (P=0.012) and Agriculture and Capoeira (P=0.020). Differences among stream groups in FFG were also significant (F=5.400, P=0.034) (2 and 7 degrees of freedom for group and residuals, respectively); pairwise comparisons showed differences only between Agriculture and Forest groups (P=0.027).

The NMDS ordinations revealed good 2-dimension solutions for assemblage structure based on both taxonomic and functional aspects (Stress measures were 0.0698 and 0.0274, respectively) (Fig. 3). The ordination of genera (Fig. 3A) resulted in a clumped distribution of streams of the three main land-uses, while for the FFG ordination, the second dimension presents clearer segregation of such classes. The scores of the ten streams on the two NMDS dimensions were compared among the LULC categories by means of the Kruskal-Wallis rank sum test. The ordination based on FFGs presented significant differences only for NMDS2 (Kruskal-Wallis rank sum test H=7.6364, P=0.02197, 2 degrees of freedom). Subsequent Wilcoxon rank sum test indicated significance only for the Agriculture × Forest comparison (P=0.036).

Significant differences in Functional Feeding Groups among groups was revealed only for shredders (H=6.9091, P=0.0316, 2 degrees of freedom). The pairwise comparisons using Wilcoxon rank sum test revealed significance differences between Forest and Agriculture streams only (P=0.036).

DISCUSSION

The importance of the land-use and land-cover on the environmental quality of streams/watersheds and the associated biota has been documented worldwide during decades (Allan *et al*., 1997; Davies *et al*., 2010; French and McCauley, 2018). More recently, negative impacts of agroecosystems lands on streams degradation have been described at the Eastern Amazon region (Leal *et al*., 2016; de Faria *et al*., 2017).

Our results showed differences among all three LULC on the abundances of taxonomic composition of genera and FFG and a significant difference between forest and agriculture streams on functional feeding groups, mainly because shredders abundances. The understanding of FFG in relation to LULC changes is an important approach for

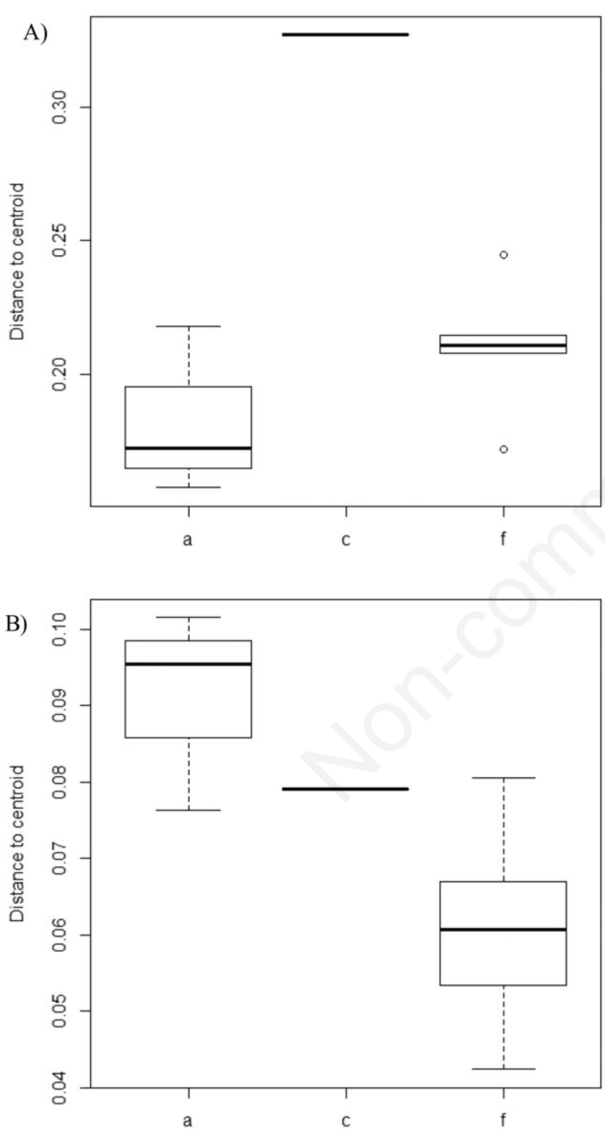

Fig. 2. Box-plots of Chironomidae larvae abundance of individuals in genera (A) and individuals in functional feeding groups (B) compared along Agriculture (a), Capoeira (c) and Forest (f) streams groups. Statistics computed in relation to distance-to-centroids of groups from PCoA ordinations. See text for details.

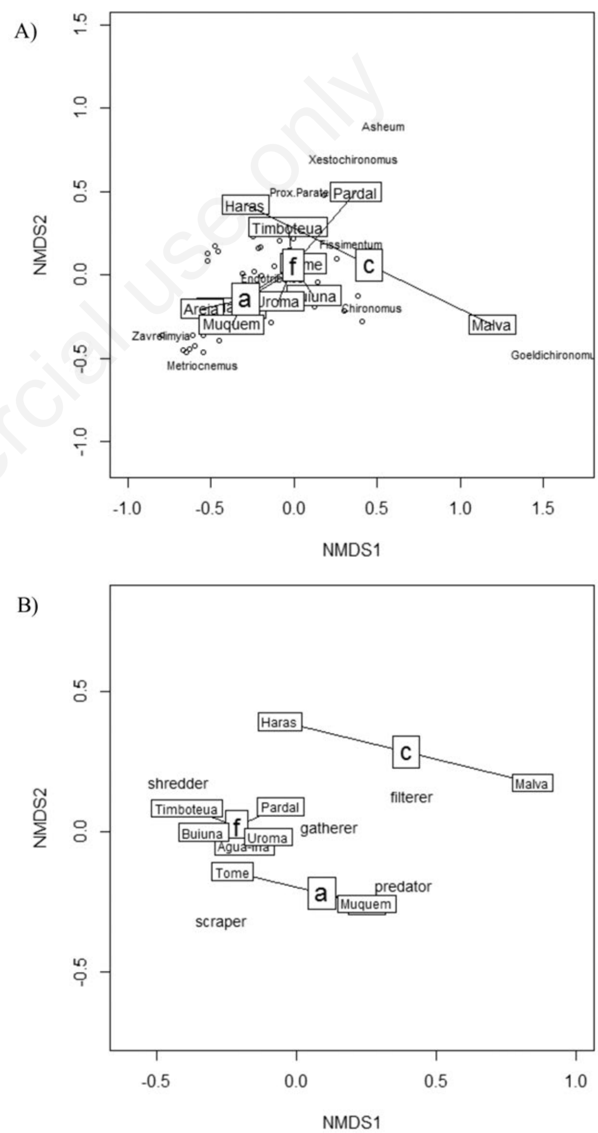

Fig. 3. Ordination plots of NMDS based on Chironomidae genera (A) and functional feeding groups (B). Lines link sample streams (name labels) to centroids of groups (letters). Streams are grouped according to riparian buffer LULC dominance of either Agriculture (a), Capoeira (c) or Forest (f). Labels outside box are selected genera (part A) and functional feeding groups (B).

a holistic understanding and management of running waters (Montoya *et al*., 2015; Merritt *et al*., 2017). Several studies compared the proportion of FFGs in streams (Couceiro *et al*., 2011; Kohlmann *et al*., 2015) and some refer to the decrease of shredders at agriculture streams rather than forested ones (Death *et al*., 2009; Sonoda *et al*., 2009; Astudillo *et al*., 2016).

Some explanations are found at the literature to explain the impact of agriculture land-use and land-cover on the aquatic system, such as imbalance of chironomids abundance relative to an increase in the number of agricultural streams (Sonoda *et al*., 2011; Corbi *et al*., 2013; Suriano and Fonseca-Gessner, 2013) and sediment addition (Matthaei *et al*., 2010). Sediment deposition is more pronounced in pasture streams than forested ones (Somura *et al*., 2012), with significant decrease on shredder abundance (Magierowski *et al*., 2015), fact also observed on our study. We also registered the imbalance of chironomids quantities on forest to agriculture streams; besides we did not study sediment addition, we observed higher amount of macrophytes at agriculture streams. That is an important fact since studies on other Brazilian regions revealed the increase on Chironomidae abundance related to macrophytes (Sonoda and Trivinho-Strixino, 2000; Trivinho-Strixino *et al*., 2000), what may explain, along with sediment deposition, the higher Chironomidae participation at agriculture streams.

CONCLUSIONS

We presented results of Chironomidae from streams at Eastern Amazon, a region which aquatic entomofauna is poorly known. Our study was able to satisfy our goals since the taxonomic richness and abundance changed accordingly to land-use and land-cover on riparian zones (hypothesis 1); and the functional feeding groups (shredders) were appropriate to demonstrate the importance of riparian forest at the streams (hypothesis 2).

Our study is an important contribution to the improvement of regional knowledge and may contribute in land development decisions, since Amazonian region deforestation is increasing to replace forest by agriculture practices. The need for higher amount of agriculture areas should consider the consequences on water quality (locally) and availability (globally, such as La Plata River Basin), as commented at the introduction section.

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