

Response of aquatic insect assemblages to the activities of traditional populations in eastern Amazonia

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Received: 19 August 2016 / Revised: 5 May 2017 / Accepted: 15 May 2017
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Abstract This study investigated the effects of activities carried out by traditional populations on aquatic ecosystems using the assemblages of Ephemeroptera, Plecoptera, and Trichoptera insect orders, and identified fluvial habitat characteristics modified by the disturbances. We surveyed two groups of streams—17 streams representing control conditions (CON) and 17 streams influenced by traditional population settlements (TPO). Genera richness and abundance of individuals did not vary between groups. With regard to physical habitat metrics, the percentage of leaf litter, amount of woody debris in the channel, proximity to farming, percentage of slow water in the channel, and the mean riparian vegetation cover all

influenced benthic macroinvertebrate assemblages. Considerable differences were found in genera composition between the two groups. The genera *Ulmeritoides*, *Miroculis*, and *Brasilocaenis* were associated with the CON group, and *Macronema* and *Campsurus* with the TPO group. We conclude that even small-scale impacts, such as those performed by traditional Amazonian populations, can have major effects on aquatic biota, which reiterates the fragile nature of these ecosystems and emphasizes the need for adequate management of these activities.

Keywords Subsistence farming · Environmental integrity · Ephemeroptera · Plecoptera · Trichoptera

Handling editor: Marcelo S. Moretti

Electronic supplementary material The online version of this article (doi:[10.1007/s10750-017-3238-8](https://doi.org/10.1007/s10750-017-3238-8)) contains supplementary material, which is available to authorized users.

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Introduction

In the absence of adequate environmental planning, economic growth can have far-reaching impacts on the diversity of a region's fauna and flora (Gibson et al., 2011), which may ultimately lead to the local extinction of many species (Green et al., 2005). The Brazilian Amazon is not immune to this (Lobón-Cerviá et al., 2015). Large-scale anthropogenic modifications to the landscape such as logging, farming, and ranching impact the natural landscape (Laurance et al., 2014), reducing the diversity of terrestrial and aquatic habitats in natural ecosystems and, ultimately, decreasing species diversity (Brand & Miserendino,

2015). Changes that occur in aquatic ecosystems are intensified when riparian forest is cleared or degraded. This vegetation is established along the margins of water bodies and filters pollutants, impedes stream bed sedimentation, intercepts and absorbs sunlight, and provides resources that guarantee the dynamics of energy flow and functioning of aquatic ecosystems (Armaiz et al., 2011). Therefore, changes to the structure of riparian vegetation place significant pressures on the integrity of aquatic communities (Leite et al., 2015).

The physical conditions of habitats in lotic ecosystems are important in structuring biological communities. Selective environmental pressures limit the local persistence of some species as they have specific environmental requirements (Southwood, 1977; Poff & Ward, 1990), for example the physiological adjustment of an organism to live in low-oxygen environments. This relationship is clearly observed in benthic macroinvertebrates, including insects of the orders Ephemeroptera, Plecoptera, and Trichoptera, i.e., EPT (Dias-Silva et al., 2010; Pereira et al., 2012; Brasil et al., 2014; Ferreira et al., 2014; Cunha et al., 2015; Oliveira-Júnior et al., 2015; Shimano & Juen, 2016). In response to habitat deterioration, the abundance of these insects tends to decline given their reduced tolerance to environmental modification (Townsend et al., 2003; Wahizatul et al., 2011; Ligeiro et al., 2013; Shimano et al., 2013; Brasil et al., 2014). This makes them excellent ecological indicators (Pereira et al., 2012; Shimano & Juen, 2016).

The Brazilian Amazon contains a complex hydrographic network and a high biodiversity (Heckenberger et al., 2007; Wandelli & Fearnside, 2015). This biodiversity supports traditional populations by providing essential resources such as game, fish, lumber, transportation, and building materials (Santana & Lisboa, 2002; Silveira & Quaresma, 2013), while the river networks facilitate the transportation of produce and residents of the local riverside communities. These populations, called “ribeirinhos”, are descendants of Europeans, Africans, and native indigenous people which have been living for generations along the margins of streams and rivers in the Amazon basin. Natural resources are exploited using traditional techniques, based on social ties, most of which have been acquired over generations (Diegues, 2000; Fraxe et al., 2007). However, these traditional techniques are

now being modified in response to growing economic pressures, leading to intensified alteration of aquatic ecosystems. In this context, even small-scale activities may have a major effect on the integrity of ecosystems and their biota (Hughes et al., 2015), by increasing nutrient input and other pollutants (Nessimian et al., 2008), as well as modifications to the physical structure of the drainage channel.

The family or subsistence farming practiced by traditional populations is generally considered to have a reduced impact on natural ecosystems (Reijntjes et al., 1992). In Amazonia, this type of farming is migratory or itinerant, alternating between periods of cultivation and fallow (Moran, 2009). In the fallow period, the cultivated plot is isolated and nutrients lost from the soil during the crop phase are replenished (Kleinman et al., 1996; Szott & Palm, 1996; Hölscher et al., 1997).

The technique normally used is slash-and-burn or swidden farming, which results in the loss of soil nutrients, the emission of noxious gases, and risks of starting bush fires (Hölscher et al., 1997). No systematic management techniques have been developed for forest clearance or burn-off, so the effects of these practices on the physical conditions of the habitat and on the biological communities of aquatic ecosystems are still poorly understood.

Subsistence is also supported by the harvesting of natural plant and animal resources, and many families in Amazonia either directly or indirectly dependent on these activities (Homma, 1993, 2012). These extractive activities are practiced in a number of different forms by riverside populations, including farming, hunting, fishing, and the harvesting of plant oils, fruit, and roots for the production of homemade remedies. In this context, riparian vegetation is often logged and the timber removed from the river channels for the construction of houses, to facilitate harvesting of the açai berry, and to allow the passage of small water vessels. Therefore, our objective was to assess the effects of these traditional “ribeirinho” populations on aquatic ecosystems, using EPT as environmental bioindicators. We assessed the following hypotheses: (i) areas occupied by traditional populations present streams with significantly altered physical structure; (ii) the species richness and abundance of EPT decrease in areas occupied by traditional populations, with significant differences in the taxonomic composition of this group in comparison with control streams

located in pristine areas; (iii) changes to the physical structure of streams affect the sensitive EPT genera, and only the most tolerant genera will be associated with occupied areas.

Materials and methods

Study area

The study area is located in the municipalities of Portel and Melgaço, eastern Amazonia, Pará, Brazil, centered on 01°42'30"S and 51°31'45"W. The mean altitude is 62 m (Fig. 1), and the region's climate is of the "Am" subtype as described in the Köppen classification system (Peel et al., 2007). There are high levels of precipitation between January and June, and a short dry season between July and December, with a mean annual rainfall of 2107 mm. Mean annual temperature is 26.7°C, with relative humidity at 82% (ICMBIO, 2012).

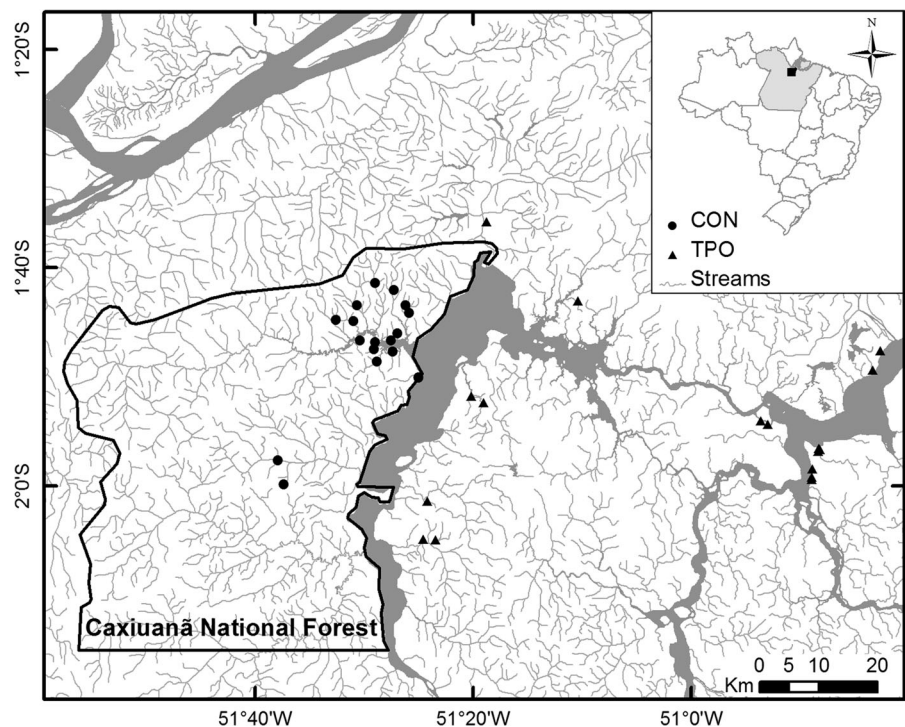
The region is a lowland plain which includes the Caxiuanã Bay, part of the Anapu River (Behling & Costa, 2000), and is formed by four hydrographic basins—the Caxiuanã, Caquajó, Cariatuba, and Pracupi basins (ICMBIO, 2012). The fluctuation in river

level is primarily influenced by local tides, with little variation being found in the water level or in the hydrogeochemical factors between wet and dry seasons (Hilda et al., 1997; Melo et al., 2013).

The study area is covered by dense lowland *terra firme* forest and flooded (*várzea* and *igapó*) forests. The flooded forests are exposed to the daily tidal oscillation and the seasonal variation in river levels (Ferreira et al., 1997). The waters of Caxiuanã Bay and its tributaries contain low amounts of suspended sediment and high amounts of organic debris (fine particulate organic matter—FPOM), characteristic of the black water substrates of the Amazon region (Costa et al., 2002).

Data were collected during the dry season, in October and November 2012 and October 2013. Several studies have shown that aquatic insects are more abundant during the dry season (Bispo et al., 2001; Righi-Cavallaro et al., 2010). A total of 34 streams were sampled, of which 17 were located in well-preserved areas of native forest. These sites were located far from traditional settlements and were used as control (CON) sites. The remaining 17 streams were selected from areas settled by traditional riverside (*ribeirinho*) populations (Traditional Populations—TPO). Sites were selected after extensive field

Fig. 1 Geographical location of 34 streams in eastern Amazonia, Pará, Brazil. Some sites can be overlaid on the map because of the varying distances between sites used in the study



recognition in order to ensure that CON sites exhibited low human interference and TPO sites represented the typical human uses in the aquatic ecosystems of the region. In general, these populations use their land to cultivate açai berry (*Euterpe oleracea* Mart) and cassava (*Manihot esculenta* Crantz), complementing these activities with the harvesting of plant resources, hunting, and fishing. Populations that live along the margins of rivers and streams use these water bodies to navigate between their home settlements and other localities. The local populations practice slash-and-burn farming using only handheld tools (Santos & Santana, 2012).

Biological sampling

A 150-m reach of each stream was demarcated and subdivided into 10 longitudinal sections of 15 m, each with three segments of 5 m. Only the first two segments of each section were sampled, with a total of 20 segments being sampled per stream. The third segment of each section was used to access the environmental variables of the next stream section, thus avoiding disturbance of the substrate before being sampled. This sampling procedure was designed to best represent the heterogeneity of the substrates and the surface flow profiles (rapids and pools) found in each stream.

The physical and chemical characteristics of the water were measured in three sections of each stream, with a mean value for each variable obtained for each stream. For the collection of EPT specimens, two substrate samples were extracted from each segment using an 18-cm-diameter dipnet with 250- μ m mesh (Shimano & Juen, 2016). This allows for the efficient capture of both small- and large-sized taxa. Specimens from each segment were combined into a single sample representing the stream. Sorting of the biological material was performed in the field and specimens fixed in 85% ethanol. In the laboratory, specimens were identified using the keys of Pes et al. (2005), (Domínguez et al. 2006), Salles & Lima (2014), (Olifiers et al. 2004), Hamada & Couceiro (2003), and Salles & Dominguez (2012).

Species-level and morphotype identifications for immature macroinvertebrates are often discouraged for many reasons, such as the ontogenetic changes between instars (life stages), the small size of aquatic invertebrates, and limitations of the taxonomic

literature for immature instars (Feminella, 2000). Thus, we used the Procrustes analysis to compare our community data using a matrix with the taxonomic resolution of genus and a matrix with morphotypes and species (Jackson, 1995). The data on genera and morphotypes/species presented a significant degree of congruence (Procrustes, $m^2 = 0.342$, $r = 0.811$, $P < 0.001$). Given this, the taxonomic resolution was standardized to genus. The identification to family or genus has been shown to be adequate in many ecological studies, given the marked congruence of the data with those obtained for species, permitting detailed analysis of the effects of anthropogenic impacts (Lenat & Resh, 2001; Melo, 2005; Törnblom et al., 2011; Giehl et al., 2014).

Evaluation of physical habitat conditions

To evaluate the physical condition of the stream habitats, the American Environmental Protection Agency (US-EPA) protocol was adapted following the procedures described by Peck et al. (2006). A number of the channel's features were measured, including morphology, type of substrate, diversity of refuges available to biota, amount of woody debris in the channel, riparian vegetation, water flow type, and the influence of human activities, resulting in seven blocks of variables. The measurements were taken along the longitudinal sections in each stream. Environmental metrics were determined following Kaufmann et al. (1999). The high variety of metrics measured at each site allowed a precise evaluation of the relationship between local habitats and anthropogenic impacts, and the identification of the most informative metrics for monitoring the streams' environmental conditions (sensu Roper et al., 2002).

Data analysis

The final set of environmental metrics used in the subsequent statistical analyses were selected through three steps: (i) metrics with a coefficient of variation (CV, mean/standard deviation) of less than 0.2 were excluded; (ii) using Pearson correlations, metrics that presented $|r| > 0.7$ with other metrics were also excluded due to the redundancy of the information they provide, and (iii) through a Principal Component Analysis (PCA) of the remaining metrics of all the blocks, those with a loading above 0.8 on the first axis

were maintained. The broken-stick model was used as selection criteria of the axes (Jackson, 1993). The set of environmental characteristics selected is provided in Supporting Material (Table S1). This allowed the selection of a set of metrics with optimum dispersal among sites, enabling evaluation of the full variation among ecosystems. The metrics selected were a farmland proximity index, amount of woody debris found within the channel, percentage of leaf litter, percentage of glide flow in the channel, and mean riparian cover.

The percentage of glide flow corresponds to the proportion of stream in which the water flows slowly (low turbulence). Mean riparian cover refers to the combined measure of riparian cover of large (>5 m in height) and small trees (0.5–5.0 m in height) found along the two margins of the channel. The percentage of leaf litter is the availability of leaves derived from riparian vegetation in the channel bed. The amount of woody debris in the channel refers to the number of trunks between 1.5 and 15.0 m in length with a diameter of between 0.1 and 0.8 m. The farmland proximity index was derived from observations conducted along both margins, considering the distance from the channel to the nearest plantations.

Each stream was considered to be a sampling unit for analyses. The selected environmental variables were used to evaluate variation between the CON and TPO sites using a Canonical Analysis of Principal Coordinates (CAP: Anderson & Wilis, 2003). This analysis is based on a Principal Coordinates Analysis (PCoA) of a normalized environmental matrix, followed by a Discriminate Analysis. The Euclidean distance matrix was calculated for the study streams based on the normalized environmental variables. The significance of the relationships was tested with 9999 permutations.

Analysis of Covariance (ANCOVA) was used to verify differences in taxonomic richness and abundance of EPT assemblages between the CON and TPO treatments ($\alpha = 0.05$), using the first axis of CAP as a covariate. A Principal Coordinates Analysis (PCoA) was used to analyze variation in genera composition, for which the abundance data were also log-transformed ($\log_{10}(x + 1)$), and the Bray–Curtis index (Legendre & Legendre, 1998) was used as the dissimilarity measure. A Permutational Multivariate Analysis of Variance (PERMANOVA: Anderson, 2001) was used to test for significant differences in

composition of the two groups of streams based on the Bray–Curtis index with 9999 permutations, with the assumption of homogeneity of dispersal being tested a priori by PERMDISP (Anderson, 2006).

In order to assess how the environmental variables affected the taxonomic richness and composition of EPT genera, we performed multiple regressions, using the best subset procedure to obtain all the possible combinations among the predictors. The corrected Akaike Information Criterion (AICc) was used to select the best models (Sakamoto et al., 1986), choosing those with the best coefficients of determination (AdjR^2) and fewer variables ($\Delta\text{AIC} < 2$) (Burnham & Anderson, 2002) (Table S2). The first axis of the PCoA was used as a response variable, representing genera composition. The residues and homogeneity of variance in the environmental metrics were tested (Zar, 1999). The normalized residuals of the linear regression model were plotted in a bubble graph (see Table 3) considering the spatial coordinates (latitude and longitude) (Zuur et al., 2009) (Fig S1).

An analysis of indicator species (Dufrene & Legendre, 1997) was conducted to determine the degree of association between EPT genera and the CON or TPO streams. This test identifies the taxa whose occurrence differs more between the two groups of streams than expected by chance, with the significance being tested by Monte Carlo randomizations (Legendre & Legendre, 1998).

All analyses were run in R software (R Core Team, 2016), using the *vegan* (Oksanen et al., 2015), *MASS* (Venables & Ripley, 2002), *indicspecies* (Caceres & Legendre, 2009), and *BiodiversityR* (Kindt & Coe, 2005) packages.

Results

The environmental conditions of the streams were significantly different between CON and TPO sites (CAP, trace: 4, $P = 0.001$) (Fig. 2). The environmental variables related to the first axis indicated that the CON streams had slower water velocity, a larger amount of woody debris in the stream channel, greater native riparian cover, and greater distances from the influence of farmlands (Table 1).

A total of 2261 EPT specimens were collected from the 34 streams, representing 13 families and 27 genera

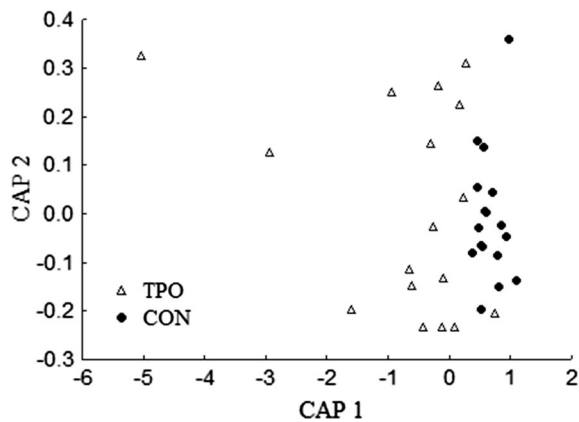


Fig. 2 Environmental variation between control conditions (CON) and settlements of traditional populations (TPO) in eastern Amazonia, Pará, Brazil

(Table 2). The order Ephemeroptera contributed with 81.9% of the specimens, and the families with the greatest number of specimens were Leptophlebiidae (CON 6 ± 8.2 and TPO 79.9 ± 112.4), Hydropsychidae (CON 15.3 ± 30.7 and TPO 0.9 ± 2.4), Caenidae (CON 1.1 ± 1.5 and TPO 6.1 ± 9.7), and Polymitarcyidae (CON 6 ± 12.5 and TPO 0.3 ± 0.6). The most abundant genera were *Miroculis*, *Ulmeritoides*, *Macronema*, *Brasilocaenis*, and *Simothraulopsis*. In contrast, the order Plecoptera was represented by only a single individual of the genus *Macrognoplox* (Perlidae).

The composition of EPT genera varied significantly between control and TPO environments (PERMANOVA, $pseudo-F_{(1,32)} = 6.533$, $P < 0.001$). The first two axes of the PCoA explained 49% of the variation, 26% on the first axis and 23% on the second (Fig. 3). The environmental variables explained 41% of the variation in composition of EPT genera ($r^2 = 0.410$, $F_{(2,31)} = 10.758$, $P < 0.001$). The results indicate that genera composition is related to the presence of

leaf litter and the quantity of woody debris found within the stream channel (Table 3).

No significant difference in abundance of EPT (ANCOVA, $F = 3.165$, $P = 0.085$) was observed between the CON and TPO treatments and in interaction between factors (ANCOVA, $F < 0.001$, $P = 0.999$). The covariate was also non-significant (ANCOVA, $F = 1.748$, $P = 0.196$). EPT richness was also not different between treatments (ANCOVA, $F = 0.723$, $P = 0.401$). Again, the covariate and interaction were non-significant (ANCOVA, $F = 1.095$, $p = 0.304$; $F = 0.674$, $p = 0.418$), respectively. However, the variation of this metric among sites was strongly influenced by the physical conditions of the habitat. The best multiple regression model explained nearly 72% of the variation in richness ($r^2 = 0.717$, $F_{(3,30)} = 25.312$, $P < 0.001$). EPT genera richness increased with the amount of riparian cover and EPT genus abundance, and decreased with the percentage of leaf litter in the channel (Table 3).

Five of the 27 genera analyzed were associated with one of the two groups of streams. *Macronema* and *Campsurus* were associated only with control streams, while *Ulmeritoides*, *Miroculis*, and *Brasilocaenis* were associated with TPO streams (Table 4).

Discussion

The integrity of aquatic ecosystems depends on the conditions of their terrestrial catchments (Pringle, 2001; Allan, 2004) as human activities in these areas are relevant in predicting impacts on the aquatic communities (Vondracek et al., 2005; Ligeiro et al., 2013). Despite the small-scale and rudimentary impacts observed in areas occupied by traditional populations, alterations resulting from their subsistence activities modified the physical conditions of the stream habitats, corroborating our first hypothesis. The

Table 1 Importance of components and loadings obtained in the Canonical Analysis of Principal Coordinates (CAP)

Variable	Axis			
	CAP1	% Explained	CAP2	% Explained
Proximity index of agricultural disturbance	-0.309	0.173	0.036	0.018
Number of wood debris within channel/m ²	0.107	0.060	0.374	0.186
Leaf litter (%)	-0.043	0.024	-0.459	0.229
Slow flow in the channel (glide) (%)	0.716	0.400	-0.563	0.280
Mean riparian cover	-0.615	0.344	-0.576	0.287

Table 2 Total number of specimens (abundance*) and mean and standard deviation (SD) of density (Ind./m²) of Ephemeroptera, Plecoptera, and Trichoptera (EPT) in the streams of each of treatment in eastern Amazonia, Pará, Brazil, sampled during the dry period in the years 2012 and 2013. CON represent control conditions and TPO are settlements of traditional populations

	CON*	Mean \pm SD	TPO*	Mean \pm SD
Ephemeroptera				
Baetidae				
<i>Aturbina</i> Lugo-Ortiz & McCafferty, 1996	8	19 \pm 43	18	42 \pm 128
<i>Callibaetis</i> Eaton, 1881	1	2 \pm 10	5	12 \pm 34
<i>Waltzophius</i> McCafferty & Lugo-Ortiz, 1995	1	2 \pm 10	4	9 \pm 30
<i>Zelus</i> Lugo-Ortiz & McCafferty, 1998	0	0 \pm 0	3	7 \pm 21
Caenidae				
<i>Brasilocaenis</i> Puthz, 1975	19	45 \pm 61	102	240 \pm 390
<i>Caenis</i> Stephens, 1835	0	0 \pm 0	1	2 \pm 10
Coryphoridae				
<i>Coryphorus</i> Peters, 1981	20	47 \pm 127	0	0 \pm 0
Euthyplociidae				
<i>Campylocia</i> Needham & Murphy, 1924	75	176 \pm 336	0	0 \pm 0
Leptohyphidae				
<i>Amanahyphes</i> Salles & Molineri, 2006	6	14 \pm 31	2	5 \pm 19
<i>Tricorythodes</i> , Ulmer, 1920	0	0 \pm 0	21	49 \pm 125
<i>Tricorythopsis</i> Traver, 1958	1	2 \pm 10	0	0 \pm 0
Leptophlebiidae				
<i>Microphlebia</i> Savage & Peters, 1983	6	14 \pm 28	0	0 \pm 0
<i>Miroculis</i> Edmunds, 1963	92	216 \pm 330	733	1725 \pm 2685
<i>Simothraulopsis</i> Demoulin, 1966	4	9 \pm 22	112	264 \pm 382
<i>Ulmeritoides</i> Traver, 1959	0	0 \pm 0	511	1202 \pm 1819
Polymitarcyidae				
<i>Asthenopus</i> Eaton, 1871	5	12 \pm 49	5	12 \pm 24
<i>Campsurus</i> Eaton, 1868	97	228 \pm 470	0	0 \pm 0
Plecoptera				
Perlidae				
<i>Macrogynoplax</i> Enderlein, 1909	1	2 \pm 10	0	0 \pm 0
Trichoptera				
Calamoceratidae				
<i>Phylloicus</i> Muller, 1880	2	5 \pm 13	11	26 \pm 56
Hydropsychidae				
<i>Leptonema</i> Guérin, 1843	1	2 \pm 10	0	0 \pm 0
<i>Macronema</i> Pictet, 1836	259	609 \pm 1229	16	38 \pm 96
Leptoceridae				
<i>Nectopsyche</i> Muller, 1879	2	5 \pm 13	4	9 \pm 39
<i>Oecetis</i> McLachlan, 1877	7	16 \pm 28	9	21 \pm 35
<i>Triplectides</i> Kolenati, 1859	57	134 \pm 287	4	9 \pm 22
Philopotamidae				
<i>Chimarra</i> Stephens, 1829	6	14 \pm 49	0	0 \pm 0
Polycentropodidae				
<i>Cernotina</i> Ross, 1938	22	52 \pm 85	3	7 \pm 16
<i>Cymellus</i> Banks, 1913	3	7 \pm 16	2	5 \pm 13
Total	695		1.566	

The density of each genus is calculated based on the circumference area of the dipnet (diameter of 18 cm)

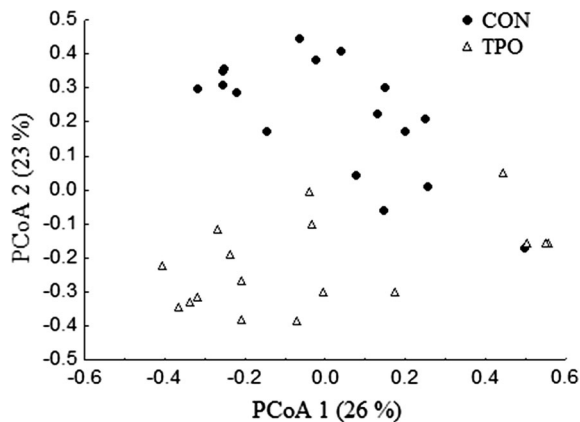


Fig. 3 Principal Coordinates Analysis (PCoA) of EPT composition in 34 streams, 17 in control conditions (CON) and 17 settlements of traditional populations (TPO), in eastern Amazonia, Pará, Brazil

impacts on EPT communities were primarily related to reduced riparian cover, amount of woody debris in the stream, and the quantity of leaf litter.

In contrast with our initial expectations for the second hypothesis, the species richness and abundance of EPT were not lower in streams affected by human activities. The farming system used by local populations usually leaves intact remnant riparian vegetation, which may provide natural resources and maintain habitat complexity (Kaufmann & Faustini, 2012), contributing to the local maintenance of EPT richness and abundance. However, given the role of the environmental metrics for genera richness, the increasing proximity of farmland in the case of the TPO streams can lead to a predictable loss of biodiversity in these streams. In addition, the progressive pressure exerted by traditional populations on the

Table 4 Ephemeroptera, Plecoptera, and Trichoptera (EPT) indicators of reference streams (CON) and sites under the influence of traditional populations (TPO) in the Amazon, Pará, Brazil

Genus	CON	TPO	IndVal	P
<i>Ulmetitoides</i>	0 ± 0	30 ± 45	0.840	0.005
<i>Miroculis</i>	5 ± 8	43 ± 67	0.792	0.030
<i>Brasilocaenis</i>	1 ± 1	6 ± 10	0.771	0.040
<i>Macronema</i>	15 ± 31	1 ± 2	0.881	0.005
<i>Campsurus</i>	6 ± 12	0 ± 0	0.728	0.005

It is being presented the mean and standard deviation of the abundance of individuals in each group

aquatic ecosystems and the resulting modification of drainage channels, principally through the reduction in the amount of woody debris, may have significant long-term effects on the richness and abundance of these assemblages.

The order Ephemeroptera was the most abundant (81.9% of specimens collected). In addition to being the dominant group in Amazonian black water systems (Walker, 1994), Romero et al. (2013) observed that in environments with low levels of disturbance part of the heterogeneity of the physical habitat is maintained, permitting an increase in the number of Ephemeroptera genera. Conversely, the reduced abundance of Plecoptera in the samples may be associated with the unique characteristics of the study streams. The high concentrations of humic acids, together with low levels of dissolved oxygen and low pH, are unfavorable to insects of this order, which usually prefer environments with high oxygen concentrations and fast running waters (Merritt et al., 2008).

Table 3 Results of multiple regression analyses, having as independent variables the environmental metrics (metrics of the best subset Akaike model) and as dependent variables the

	Beta	Std. err. of beta	t	P
EPT genus composition (PCoA 1)				
Leaf litter (%)	−0.308	0.143	−2.158	0.039
Number of wood debris within channel/m ²	0.487	0.143	3.406	0.002
EPT genus richness				
EPT genus abundance	0.415	0.118	3.519	0.001
Leaf litter (%)	−0.667	0.122	−5.483	0.000
Mean riparian cover	0.332	0.111	2.979	0.006

Aquatic organisms are sensitive to environmental changes in the aquatic ecosystems they inhabit. Consequently, their responses vary according to the types of land use surrounding streams and the impacts these have on the ecosystems (Allan, 2004). A common response is the decrease and loss of sensitive taxa and the persistence of the tolerant ones. Changes in the composition of the Ephemeroptera, Plecoptera, and Trichoptera assemblages between control and impacted streams are normally related to the restructuring of physical habitat conditions (Shimano et al., 2010; Nogueira et al., 2011; Ligeiro et al., 2013; Brasil et al., 2014), such as the reduction in riparian cover and the amount of woody debris in the channels. As they are narrow and shallow ecosystems, streams favor the accumulation of leaves falling from the surrounding vegetation (Wohl & Jaeger, 2009; Carvalho & Uieda, 2010). These banks of leaf litter provide aquatic insects with refuges and dietary resources (Oliveira et al., 2014) which, together with other types of substrates such as sand and roots, have a positive influence on EPT abundance and richness (Ferreira et al., 2014). However, in the present study large quantities of leaf litter in the channel reduced EPT abundance and richness. In general, coarse particulate organic matter tends to accumulate in areas where water velocity decreases (Nakajima et al., 2006). The excessive accumulation of plant detritus may lead to a deficit of dissolved oxygen and a decrease in the pH of the water, resulting in a reduction in the abundance of these insects, leading to a predominance of species with a higher tolerance to hypoxic and anoxic conditions (Hynes, 1970; Samways et al., 1996).

The natural resources (soils, vegetation, and water) available within the study area are exploited in a number of different ways to guarantee the economic and/or subsistence needs of the local populations, although monocultures are not common (Noda et al., 2002). The combination of natural resource exploitation with different production systems (açai berry, cassava) creates different pressures on the environment, primarily in relation to the integrity of stream margins and the availability of microhabitats (woody debris and leaf litter). In addition to farming, the riverside communities of Caxiuanã Bay remove debris from the channel and dredge the stream bed at specific points, modifying the morphology of the stream, which tends to become deeper. This allows small boats to

pass, the only means of transportation in the area. The transit of boats, removal of woody debris, and channel dredging usually alter and destabilize substrates, impacting the composition of macroinvertebrate assemblages (Righi-Cavallaro et al., 2010; Hamid & Rawi, 2014), primarily through the reduction or loss of the more sensitive organisms (e.g., Ephemeroptera genera) and an increase in the more tolerant taxa (e.g., Oligochaeta) (Azrina et al., 2006). Our findings thus indicate that characteristics of the area adjacent to the stream have a significant influence on EPT composition, as we expected in our second hypothesis, given that the dredging of the channel modified both stream morphology and the resident biota.

A good ecological indicator of anthropogenic impacts ideally should be both easily measured and sensitive to changes in environmental gradients (Dale & Beyeler, 2001; Maloney et al., 2008). As we expected in our third hypothesis, in this study the most tolerant genera were associated with occupied areas, such as *Ulmeritoides*, *Miroculis*, and *Brasilocaenis* (Ephemeroptera), while the more sensitive genera *Macronema* (Trichoptera) and *Campsurus* (Ephemeroptera) were associated with areas of preserved forest. The genus *Macronema* is abundant in areas with dense riparian cover and accumulated leaf litter (Bispo et al., 2006). As a digger, *Campsurus* has a greater affinity with fine substrates as well as areas with slow currents (Edmunds et al., 1976; Domínguez et al., 2001), like those sampled in the present study. The genera *Miroculis* and *Ulmeritoides* were more abundant in areas of anthropogenic impact. *Ulmeritoides* prefers semi-lotic habitats such as marshes (Da-Silva et al., 2002) and has gill structures adapted for survival in water with low concentrations of dissolved oxygen (Da-Silva et al., 2010). While research on benthic communities has advanced in recent years, the data for some groups, such as the family Caenidae, are still incipient (Salles & Lima, 2014). Based on our findings, it seems possible that some genera of this family are more tolerant of anthropogenic impacts, given that *Brasilocaenis* was an indicator of altered areas.

Conclusions

We found that even in subsistence farming systems, it is necessary to manage the exploitation of natural

resources to maintain certain ecological features such as habitat connectivity and structural heterogeneity, in this way supporting aquatic biodiversity. Appropriate management measures could help mitigate environmental impacts and guarantee ecosystem function and interactions. These measures must include environmental education of riverside communities, focusing on the effects their farming and dredging practices have on the aquatic ecosystem. The adoption of sustainable practices by these populations is essential to the conservation of local biodiversity, as well as the long-term subsistence of the populations themselves. Our results also indicate that the first step in the restoration of streams modified by the activities of riverside populations is the reconstitution of riparian vegetation and physical structure of stream channels.

The structural integrity of the stream is an important determinant in the structure of EPT assemblages, and was affected profoundly by subsistence farming practices and modification of stream morphology. We demonstrated that the preservation of riparian vegetation and stream morphology is essential to the maintenance of stream ecological integrity and the assemblage of aquatic insects that inhabit it. Given this, even small-scale impacts created by the subsistence practices of traditional populations may have substantial effects on aquatic ecosystems, reinforcing the need for adequate management of these practices. The systematic evaluation of these rudimentary agricultural practices could provide important guidelines in the development of measures to preserve riparian vegetation and minimize the structural modifications of streams affected by these activities.

Acknowledgements We thank the Programa de Pesquisa em Biodiversidade da Amazônia Oriental (PPBio) and Fundação Amazônia Paraense de Amparo à Pesquisa (FAPESPA) (FAPESPA: ICAAF 03/2011) for financial support to this study. The Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (Process no. 130468/2013-4) provided APJF with a graduate stipend, and LJ (process 307597/2016-4) and MC were awarded research productivity (CNPq no. 303380/2015-2), research project (CNPq no. 446155/2014-4), and Minas Gerais research (FAPEMIG PPM-IX—00525-15) grants. We thank Dr. Ana Maria O. Pes; Dr. Neusa Hamada; Dr. Frederico Falcão Salles; Patrick Barcellos, MSc; Lucas Lima, MSc; and Mylena Cardoso, MSc, for assistance with the identification of specimens. We would like to also thank Erlane Cunha, MSc, for providing area maps; Dr. Lenize Batista Calvão for her critical reading of the manuscript; and Dr. Bruno Spacek Godoy for assistance in statistical analysis. We are grateful to Leyton James Tierney for reviewing the English and officials of

the Estação Científica Ferreira Penna for their coordination. Collection of biological materials was authorized by the Sistema de Autorização e Informação em Biodiversidade—SISBIO (n. 11841).

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