Environ Biol Fish (2018) 101:547–562
https://doi.org/10.1007/s10641-018-0716-4

Effects of oil palm plantations on habitat structure and fish assemblages in Amazon streams

Márcio Cunha Ferreira · Tiago Octavio Begot · Bruno da Silveira Prudente · Leandro Juen · Luciano Fogaça de Assis Montag

Received: 5 October 2016 / Accepted: 4 January 2018 / Published online: 6 February 2018

Abstract The aim of this research is to assess the effects of oil palm plantations on stream habitat and their fish assemblage diversity. We hypothesize that streams which drain through oil palm plantations tend to be less heterogeneous, limiting the occurrence of many species, than streams that drain through forest fragments, which support higher fish diversity. A total of 17 streams were sampled; eight in forest fragments and nine in oil palm plantations. Environmental and biological variables were sampled along 150 m stretch in each stream. Of the 242 environmental variables measured, ten were considered important to assess the condition of structural habitat, and out of these variables, four were considered relevant in the distinction between streams in oil palm plantations and forest fragments. A total of 7245 fishes were collected, belonging to 63 species. Unlike our original hypothesis, the species richness did not differ between forest fragment and oil palm plantations streams, showing that it is not a good divert measure in streams disturbance assessment. However, fish assemblages differed in species composition, and 56 species were recorded in oil palm plantation streams, while 44 species were recorded in forest fragments streams. Some species were identified as indicators of either altered (*Aequidens tetramerus* and *Apistogramma agassizii)* or undisturbed areas (*Helogenes marmoratus)*. Overall, oil palm plantations were proven to change stream habitat structure and fish species distribution, corroborating other studies that have evidenced changes in patterns of biological community structure due to impacts by different land uses.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10641-018-0716-4) contains supplementary material, which is available to authorized users.

M. C. Ferreira
Laboratório de Morfofisiologia e Sanidade Animal, Universidade do Estado do Amapá, Macapá, Amapá, Brazil

M. C. Ferreira · T. O. Begot (✉) · B. da Silveira Prudente · L. Juen · L. F. de Assis Montag
Laboratório de Ecologia e Conservação, Instituto de Ciências Biológicas, Universidade Federal do Pará, Belém, Pará, Brazil
e-mail: tbegot@gmail.com

T. O. Begot
Programa de Pós-Graduação em Zoologia, Universidade Federal do Pará/ Museu Paraense Emilio Goeldi, Belém, Pará, Brazil

B. da Silveira Prudente
Programa de Capacitação Institucional, Coordenação de Zoologia, Museu Paraense Emílio Goeldi, Belém, Pará, Brazil

Keywords Habitat condition · Land use · Agriculture · *Elaeis guineensis* · Neotropical ichthyofauna

Introduction

With a cultivated area of approximately 16.3 million hectares of oil palm (*Elaeis guineensis* Jacq) in the world, this monoculture is one of the most rapidly growing agricultural land uses in the tropical region (FAO 2013). The increasing demand for oil palm for production of foodstuff derivatives, cosmetics, and biofuels is one of the main reasons for its expansion (Da Silva 2013). Currently, South East Asia concentrates

60% of oil palm plantations worldwide; however, the high cost of creating new plantation areas and the new restrictions adopted by environmental politics have made it difficult to expand this activity in the region (Kongsager and Reenberg 2012). Therefore, the Brazilian Amazon has been considered an area with high potential for oil palm expansion (Persson and Azar 2010), with 140,000 ha of already cultivated land, and another 190,000 with soil conditions and ideal climate. Thus, approximately 330,000 ha in the Brazilian Amazon are expected to be used for oil palm plantation by 2020 (Ramalho-Filho et al. 2010).

Higher carbon stock rate and economic profitability compared to other cash crop activities are amongst the main arguments in favor of oil palm expansion in the Amazon (Müller et al. 2006). On the other hand, characteristics such as lower structural complexity, smaller canopy cover than in forested areas, climatic instability, use of fertilizers and pesticides, the need for total replacement of plantations, which takes from 25 to 30 years, and the impact of these changes in biodiversity (Fitzherbert et al. 2008; Savilaakso et al. 2014; Luke et al. 2016) indicate that oil palm plantation could be a new environmental threat to the Amazon (Butler and Laurence 2009). However, there are still few studies on the effects of this activity on the Amazon biodiversity (Correa et al. 2015; Lees et al. 2015; Almeida et al. 2016), and knowledge is even more limited regarding aquatic ecosystems (Cunha et al. 2015; Shimano and Juen 2016).

Habitat homogenization deriving from the deployment of monoculture and from native vegetation suppression has been considered an important threat to stream ecological integrity (Allan 2004). Changes in land use throughout catchment result in the loss of structure complexity, which affects stream habitat structure (Poff and Ward 1990; Clapcott et al. 2012), both directly and indirectly, due to margin erosion, silting, or to changes in the type of energy source in the system (from allochthonous to autochthonous) (Karr 1981; Dayang-Norwana et al. 2011; Senior et al. 2013). Therefore, understanding the mechanisms of habitat simplification and indicating which variables generate this condition is an effective way to measure environmental impacts. This approach can effectively measure changes in channel morphology, hydrodynamics, shelter availability for living organisms, adjacent vegetation density, substrate composition, among others, thus yielding a complex and comprehensive analysis of waterbody features (Barbour et al. 1999; Kaufmann et al. 1999).

Changes in stream habitat structure may also result in environmental conditions changes, which are considered important selective forces of the adaptive features of species in a given environment ('Habitat Templet Theory' Southwood 1977, 1988). In a reduced time scale, such changes might work as a possible environmental filters that affect species distribution, particularly in habitat specialist species, resulting in changes in biological community structure (Scarsbrook and Townsend 1993). Among aquatic organisms, fishes have proven to be important indicators of stream ecological integrity (Mendonça et al. 2005); they comprise individuals of different trophic levels, occupy different micro-habitats, are resistant to different levels of anthropic changes, and have relatively well known both life history and taxonomy compared to other aquatic organisms (Fausch et al. 1990; Harris 1995; Scott and Hall Jr 1997).

In the Amazon River Basin, small first- and second-order streams according to Strahler's scale (Strahler 1957) may account for greater than 80% of total channel length in meso-scale, and the rapid expansion of cash crop in this area is one of the main threats to these systems (McClain and Elsenbeer 2001). Despite of this close relationship between the streams ecological integrity and the landscape use along the catchments, features such as the high dimension, structural complexity, and high biological diversity of the Amazon Basin have hindered the understanding on how these anthropogenic changes affect stream biodiversity. Consequently, these features also hinder the development of management, monitoring and conservation strategy of these system.

Therefore, our study aimed to assess how the presence of oil palm cultivation around the streams affect their habitat structure and fish assemblage structure in relation to streams that drain through forested areas present along of this anthropogenic landscape. We hypothesize that streams draining oil palm plantations have lower habitat heterogeneity leading to a fish assemblage composition destabilization with lower richness and increase of more generalist species abundance when compared to streams draining forest fragments.

Material and methods

Study area

We sampled wadable streams in the Acará and Mojú Rivers basin, located in Northeastern mesoregion of

Pará state (2°13′00”S / 2°43′00”S and 48°54′00”W / 48°28′00”W), in a geographic unit denominated Belém Endemism Area (AEB) (Fig. 1). This unit was proposed based in their biodiversity endemism and geographic peculiarities, and has being suggested as a basic unit for development of conservation strategy for Amazon (Almeida and Vieira 2013). The AEB has approximately 243,000 km^2, contemplating 27 protected areas, 14 indigenous land areas (Almeida and Vieira 2013) and concentrates the majority of oil palm production in the Amazon (Müller et al. 2006), thus comprising an extensive mosaic of both preserved and altered lands.

The vegetation in the study area is comprised by 28% of ombrophilous forest and 82% converted into several land uses, among which one the most significant is oil palm plantation (Almeida and Vieira 2013). The climate in the region is tropical humid, subtype “Af”, according to Köppen’s classification adapted by Peel et al. (2007), with a rainy season from December to May and a dry season from June to November. Mean annual rainfall in the region is 2344 mm^3, reaching a monthly maximum of 427 mm^3 in March, and a minimum of 54 mm^3 in September (Albuquerque et al. 2012). Mean temperature in the region is 26 °C and mean air humidity reaches up to 85% (Oliveira et al. 2002).

Data sampling

We sampled 17 streams, eight of them within preserved forested area and nine in oil palm plantations areas. Streams were selected according to the following criteria: a) river source inside the treatment (oil palm or forest); b) areas used for planting at similar times, and; c) absence of other impacts, such as urbanization and short-cycle monocultures, not deriving from the activities within the scope of this paper.

In each stream, we selected a 150 m stretch that was subdivided in ten 15 m long transects. In each transect, we performed the characterization of the habitat and sampled fish specimens. All streams were sampled

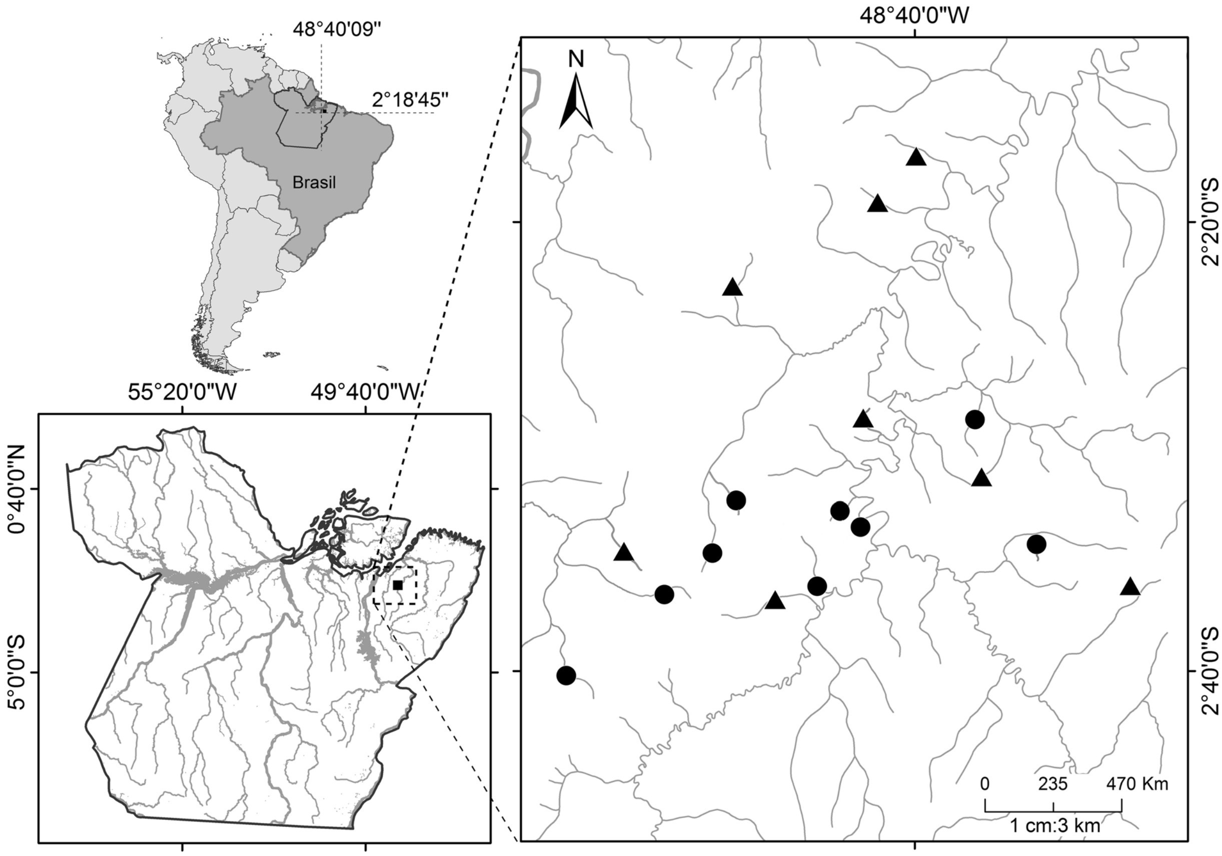

Fig. 1 Spatial distribution of the sampled streams in northeastern Pará state, Brazil. Triangles represent streams sampled in forested areas and circles represent streams sampled in oil palm plantations

during the dry season to minimize seasonal effects on habitat structure and on fish assemblages. Habitat structure was assessed using the Field Operations Manual for Wadeable Streams proposed by Peck et al. (2006) and adapted by Callisto et al. (2014), with data reduction and metric calculation following Kaufmann et al. (1999). This methodology result in a set of variables, which includes information on the channel morphology, substrate, hydraulic features, flow currents types, channel declivity and sinuosity, canopy cover, riparian vegetation structure, availability of refuges for fish and presence of human impact. Water physical-chemical characteristics, such as pH, conductivity ($\mu S\ cm^{-1}$), turbidity (NTU), temperature (°C), and dissolved oxygen ($mg\ L^{-1}$), were measured at three equidistant points in the sampling stretch using a Horiba U50 multiparameter. Detailed description about how environmental variables were measured can be found in Juen et al. (2016). This field operation has been widely used in international (Kaufmann and Hughes 2006; Bryce et al. 2010) and national studies (Macedo et al. 2014a; Cunha et al. 2015; Prudente et al. 2016) involving stream ecosystems.

Fish assemblages were sampled using two hand nets with 55 cm diameter (3 mm mesh) during three hours (18 min in each long transect). This method is considered as an efficient technique for estimating fish assemblage structure in low order streams (Uieda and Castro 1999) and has been frequently used to assess the fish assemblage in small amazon streams (Prudente et al. 2016). Fishes were tagged separately by transect, preserved in 10% formalin for approximately 48 h, transferred to 70% ethanol, and deposited in the ichthyological collection of Museu Paraense Emilio Goeldi (MPEG) in Belém, Pará (Brazil).

Data analyses

Each stream was considered an independent sample, totaling 17 samples in the analyses. The environmental variables measured were submitted to a pre-selection process, and all variables with zero value in more than 80% of the samples and with coefficients of variation lower than 10% were initially excluded. Selected variables were assessed regarding their capacity to discriminate forested areas from oil palm plantations by analyzing the overlap between interquartile ranges in the box-and-whisker plots (Barbour et al. 1996). Variables with no overlap between quartiles or small overlaps between quartiles and no overlaps between medians were considered sensitive. Variable sensitivity was confirmed through a Student t-test for independent samples with a 5% significance level. Lastly, a Spearman correlation test was used to evaluate the redundancy between selected environmental variables. In the case of redundant metrics ($r^2 > 0.75$, $p < 0.05$), those pointed out in literature as important in structuring stream fish assemblages were maintained (Fernandes et al. 2012; Macedo et al. 2014b; Giam et al. 2015; Prudente et al. 2016).

Environmental variables selected were standardized and submitted a principal component analysis (PCA) based on a Euclidean distance matrix (Legendre and Legendre 1998) to check which variables contributed the most to distinguish the stream habitat between forest fragments and oil palm plantation streams. PCA axes were selected through the broken-stick criterion where a given axis may be retained when their observed eigenvalues exceed the expected eigenvalues generated by the broken stick (Jackson 1993). Variables with loading values higher than 0.60 were maintained for PCA axes interpretation.

Since the fish abundance in oil palm plantation streams was higher than in forested streams, the species richness for each sample was assessed using an individual-based rarefaction method considering the smaller abundance value recorded ($n = 230$) (Gotelli and Colwell 2001). The richness value was tested between the treatments using a Student t-test for independent samples with a 5% significance level. The hypothesis that fish assemblage composition is different between forest fragments streams and oil palm plantation streams was assessed using the non-metric multidimensional scaling method (NMDS), based on a distance matrix calculated from the Bray-Curtis similarity index. Potential differences in this composition were tested using abundance log values, which were submitted to a permutation multivariate analysis (PERMANOVA - Permutation Multivariate Analyses of Variance). The PERMANOVA probability value was obtained through a Monte Carlo randomization method, based on 9999 randomizations (Anderson 2005; Anderson et al. 2008).

We used a Threshold Indicator Taxa Analysis (TITAN) to detect change points in the fish assemblages in response to an environmental gradient (Baker and King 2010, 2013). In this study, the PCA axes selected by the broken stick method represented the environmental gradient. This analysis identifies individual taxon contribution and optimal values of predictor variable based on binary partition of samples by indicator value scores (IndVal; Dufrêne and Legendre 1997), which integrate occurrence frequency and relative abundance of each taxon. Just as in classification and regression trees, this analysis use a deviance reduction measure to partition sample units at a given predictor variable value (De'ath and Fabricius 2000).

The TITAN analysis considered purity and reliability properties measured in the calculation of indication value (IndVal; Dufrêne and Legendre 1997), together with Change Point Analysis - nCPA (King and Richardson 2003). Results were verified with 500 bootstraps yielding confidence intervals and change points at which the assemblage responded negatively [sum(z-)] and positively [sum(z+)] to predictor variable (Baker and King 2010). Following the recommendations of Baker and King (2010), we excluded taxa that occurred at less than three sites and with fewer than five individuals (36 retained species). Abundances maintained were logarithmically transformed ($\log_{(x+1)}$) to reduce the influence of highly variable taxa on indicator score calculations in each data set, which was particularly important for taxa with low occurrence frequencies. Species shall be significantly associated to a higher or lower habitat condition if IndVal <0.05, purity >0.95, and reliability >0.95 (Baker and King 2010; Cardoso et al. 2013). The TITAN interpretation was carried out based in environmental variables selected for each PCA axis interpretation, based in their loadings values.

All analyses were performed with the R software (R Development Core Team 2003) using the packages FactoMineR (Lê et al. 2008), TITAN2 (Baker and King 2010) and vegan (Oksanen et al. 2016).

Results

Sampled streams had a mean width of 3.42 m, Standard Deviation ±1.10 (with an average of 3.39 m ± 1.08 in plantation areas, and 3.45 m ± 1.20 in forested areas), and a mean depth of 0.34 m ± 0.14 (0.38 m ± 0.14 in plantation areas and 0.30 m ± 0.14 in forested areas). The water in these streams was predominantly acidic with an average pH of 4.8 ± 0.24 (4.9 ± 0.15 in plantation areas and 4.7 ± 0.25 in forested areas), with mean dissolved oxygen of 6.96 mg/l ± 1.40 (6.71 ± 0.83 in plantation areas and 7.23 ± 1.88 in forested areas), and mean temperature of 25.8 °C ± 0.88 (26.2 °C ± 0.67 in plantation areas and 25.4 °C ± 0.96 in forested areas).

Of the 242 variables measured using the habitat assessment protocol, 44 were removed from the analysis because they had zero values in more than 80% of the samples, and 21 were removed because they had a coefficient of variation lower than 10%. The visual assessment of interquartile overlap, followed by confirmation through a Student t-test, resulted in the exclusion of 127 variables. Finally, the correlation analysis indicated only ten variables for evaluating environmental conditions of structural habitat (Table 1, Additional figure is given in online resource 1). The environmental variables selected were: thalweg mean depth; % fine substrate (silt/clay/mud; size <0.6 mm of diameter); riparian canopy cover by thin trees estimation (> 5 m high and <0.3 m of diameter); large woody debris in active channel (pieces/reach >0.3 m of diameter); large woody debris above active channel (pieces/reach >0.3 m of diameter); large woody debris volume in and above active channel (m3/reach >0.8 m of diameter); fish cover by overhanging vegetation; fish cover by undercut banks; proportion of riparian non-agricultural human disturbance; Oxidation Reduction Potential of water (Additional figure is given in online resource 1).

The principal component analysis showed that the variables selected had a significant contribution to the distinction of stream habitat between forested and oil palm plantations areas. Only the first principal component was selected for the interpretation of results, explaining 37.04% of the variation in the habitat structure of streams. Plantation areas were characterized by a high proportion of non-agricultural human impact (HNOAG) and higher percentage of fine substrate (PCT_FN), while forested areas had a higher large woody debris volume in and above active channel (LWDVC), as well as high values of water oxidation and reduction (ORP) (Table 1, Fig. 2).

A total of 7245 fish specimens were sampled; 4333 (56 species) in oil palm plantation streams and 2912 (42 species) in forest fragments streams (Table 2). However, the richness based on individual-based rarefaction method did not differ between these treatments ($t = 2.62$, df = 1, $p > 0.05$). The total richness was 63 species, allocated in six orders and 24 families. A higher abundance was observed in the order Characiformes (21 species; 60.10% of the specimens sampled), followed by Siluriformes (18; 16.08%) and Perciformes (7; 14.45%). The most abundant species were *Microcharacidium weitzmani* (37.2%), *Apistogramma* gr. *regani* (9.41%), *Trichomycterus hasemani* (8.30%),

Table 1 Environmental variables selected for stream habitat characterization in oil palm plantations and forested fragments in Eastern Amazon, northeastern Pará State, Brazil, and their respective scores resulting from Principal Components (PCA). Marked in bold indicate the principal components selected

Environmental Variables	PCA I	PCA II
Thalweg mean depth (XDEPTH)	−0.593	−0.163
Substrate % fine (silt/ clay/ mud; < 0.6 mm) (PCT_FN)	**−0.682**	−0.023
Riparian canopy (> 5 m high) cover (XCS)	−0.364	0.496
Large Woody Debris in active channel (pieces/reach) (LWDINC)	0.581	0.587
Large Woody Debris above active channel (pieces/reach) (LWDAC)	0.476	−0.144
Large Woody Debris volume in and above active channel (m^3/reach) (LWDVC)	**0.646**	0.517
Fish cover by overhanging vegetation (OVNHRG)	−0.457	−0.313
Fish cover by undercut banks (UNDCUT)	0.474	−0.693
Proportion of riparian human non-agricultural disturbance (HNOAG)	**−0.934**	−0.001
Oxidation Reduction Potential of water (ORP)	**0.727**	−0.487
Explanation %	37.656	17.203
Eingenvalue	3.766	1.720
Broken-Stick	2.929	1.929

and *Hyphessobrycon heterorhabdus* (8.26%) (Table 2). The ordination yielded by NMDS evidenced a distinction between species composition of oil palm plantations and forest fragments, and it was corroborated by the PERMANOVA result ($_{pseudo}F = 2.82$; $p < 0.01$) (Fig. 3). Of the total species captured, 21 occurred only in oil palm plantation streams, with highlight to the exclusiveness of families Poeciliidae ($N = 4$, occurring in a single sample), Polycentridae ($N = 1$, one sample), Auchenipteridae ($N = 2$, two samples), and Doradidae ($N = 49$, three samples). In forested areas, four exclusive species were observed, *Megalechis thoracata, Batrochoglanis raninus*, *Ammocriptocharax elegans*, and *Denticetopsis epa*, with emphasis on the exclusiveness of families Callichthyidae and Pseudopimelodidae (Table 2).

TITAN (*Threshold Indicator Taxa Analysis*) indicated a small difference in species ecological limits associated to variation in habitat condition (z- = 1.52 and sum z + = −1.22). In addition, of the 36 analyzed species, *Aequidens tetramerus*, *Apistogramma agassizii* and *Microcharacidium weitzmani* were positively

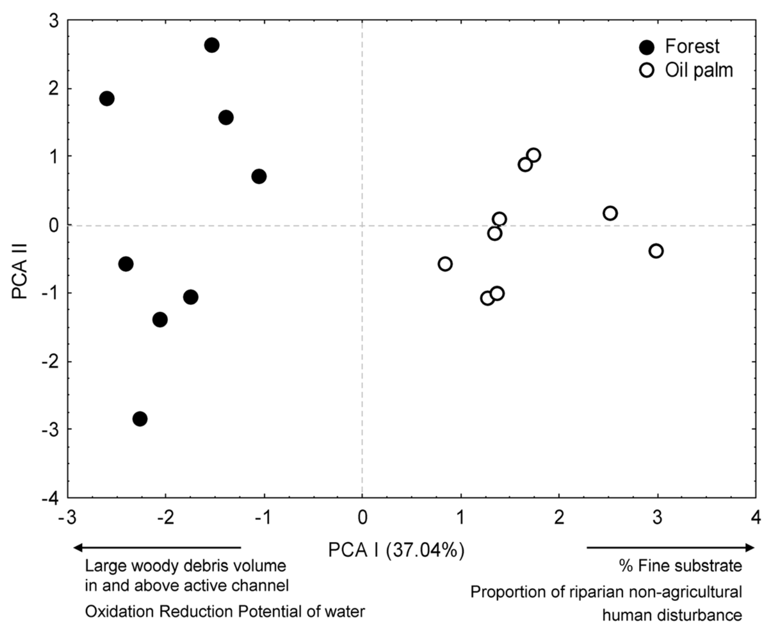

Fig. 2 Ordinations resulting from the principal components analysis (PCA) representing the habitat variables (vectors) measured in stream reaches (symbols) sampled located in oil palm plantations and forested areas in northeastern Pará state, Brazil. Open circle (○) represents streams in oil palm plantation area and closed circles (●) represent streams in forested area

Table 2 Taxonomic composition and abundance of fish assemblages in streams located in oil palm plantations and in forest fragments in the Eastern Amazon, northeastern Pará State, Brazil

Taxa/Authority	Oil Palm	Forest	Total
Characiformes			
Characidae			
Bryconops cf. *caudomaculatus* (Günther 1864)	1	–	1
Gnathocharax steindachneri Fowler 1913	4	–	4
Hemigrammus bellottii (Steindachner 1882)	72	25	97
Hemigrammus ocelifer (Steindachner 1882)	26	7	33
Hyphessobrycon heterorhabdus (Ulrey 1894)	182	554	736
Hyphessobrycon bentosi Durbin 1908	14	–	14
Moenkhausia collettii (Steindachner 1882)	4	–	4
Moenkhausia comma Eigenmann 1908	10	–	10
Crenuchidae			
Ammocriptocharax elegans Weitzman and Kanazawa 1976	–	3	3
Crenuchus spilurus Günther 1863	4	6	10
Melanocharacidium cf. *dispilomma* Buckup 1993	1	1	2
Microcharacidium weitzmani Buckup 1993	2833	736	3569
Erythrinidae			
Erythrinus erythrinus (Bloch and Schneider 1801)	4	11	15
Hoplias malabaricus (Bloch 1794)	4	4	8
Gasteropelecidae			
Carnegiella strigata (Günther 1864)	66	3	69
Iguanodectidae			
Iguanodectes rachovii Regan 1912	110	78	188
Lebiasinidae			
Copella arnoldi (Regan 1912)	205	295	500
Nannostomus eques Steindachner 1876	2	–	2
Nannostomus nitidus Weitzman 1978	3	–	3
Nannostomus trifasciatus Steindachner 1876	38	19	57
Pyrrhulina gr. *brevis*	11	34	45
Cyprinodontiformes			
Poeciliidae			
Fluviphylax cf. *palikur* Costa and Le Bail 1999	4	–	4
Rivulidae			
Anablepsoides cf. *urophthalmus* (Günther 1866)	59	76	135
Laimosemion cf. *strigatus* (Regan 1912)	70	57	127
Gymnotiformes			
Gymnotidae			
Gymnotus gr. *carapo* Linnaeus 1758	1	3	4
Gymnotus gr. *coropinae* Hoedeman 1962	21	11	32
Hypopomidae			
Brachyhypopomus aff. *bullocki* Sullivan and Hopkins 2009	17	14	31
Brachyhypopomus beebei (Schultz 1944)	12	86	98
Brachyhypopomus brevirostris (Steindachner 1868)	37	9	46
Hypopygus lepturus Hoedeman 1962	32	22	54
Microsternarchus aff. *bilineatus* Fernández-Yépez 1968	21	–	21

Table 2 (continued)

Taxa/Authority	Oil Palm	Forest	Total
Steatogenys elegans (Steindachner 1880)	7	4	11
Rhamphichthyidae			
Gymnorhamphichthys petiti Géry and Vu 1964	156	48	204
Sternopygidae			
Eigenmannia aff. *trilineata* López and Castello 1966	7	–	7
Sternopygus macrurus (Bloch and Schneider 1801)	1	1	2
Perciformes			
Cichlidae			
Aequidens tetramerus (Heckel 1840)	44	2	46
Apistogramma agassizii (Steindachner 1875)	118	14	132
Apistogramma gr. *regani* Kullander 1980	579	341	920
Crenicara cf. *punctulatum* (Günther 1863)	2	–	2
Crenicichla gr. *saxatilis* (Linnaeus 1758)	3	1	4
Geophagus sp.	2	–	2
Hypselecara cf. *temporalis* (Günther 1862)	2	–	2
Nannacara cf. *taenia* Regan 1912	64	33	97
Polycentridae			
Monocirrhus polyacanthus Heckel 1840	1	–	1
Siluriformes			
Aspredinidae			
Bunocephalus coracoideus (Cope 1874)	30	4	34
Auchenipteridae			
Tetranematichthys barthemi Peixoto and Wosiacki 2010	2	–	2
Callichthyidae			
Megalechis thoracata (Valenciennes 1840)	–	4	4
Cetopsidae			
Denticetopsis epa Vari, Ferraris and de Pinna 2005	–	4	4
Helogenes marmoratus Günther 1863	81	121	202
Doradidae			
Physopyxis ananas Sousa and Rapp Py-Daniel 2005	49	–	49
Heptapteridae			
Gladioglanis conquistador Lundberg, Bornbusch and Mago-Leccia 1991	73	85	158
Mastiglanis asopos Bockmann 1994	9	–	9
Phreatobius cisternarum Goeldi 1905	1	–	1
Rhamdia quellen (Quoy and Gaimard 1824)	8	1	9
Loricariidae			
Ancistrus sp.	1	–	1
Farlowella amazona (Günther 1864)	15	4	19
Otocinclus mura Schaefer 1997	18	–	18
Rineloricaria hasemani Isbrücker and Nijssen 1979	3	–	3
Pseudopimelodidae			
Batrochoglanis raninus (Eigenmann 1912)	–	1	1
Trichomycteridae			
Ituglanis amazonicus (Steindachner 1882)	49	20	69

Table 2 (continued)

Taxa/Authority	Oil Palm	Forest	Total
Paracanthopoma parva Giltay 1935	53	8	61
Trichomycterus hasemani (Eigenmann 1914)	740	160	900
Synbranchiformes			
Synbranchidae			
Synbranchus marmoratus Bloch 1795	12	2	14
Total	5998	2912	8910

associated to first PCA axis, that based on axis interpretation, means an occurrence increase of these species followed by increase in percentage of fine substrate and proportion of non-agricultural human impact (Fig. 4). On the other hand, only *Helogenes marmoratus* was negatively associated to first PCA axis, that mean an occurrence increase followed by increase in large woody debris volume in and above active channel and Oxireduction Potential of water (Table 3, Fig. 4).

Discussion

In the present study, oil palm plantations have proven to be an important modifying agent of stream ecosystem structures, since the presence of this activity resulted in changes both in habitat structure, and in water physical-chemical characteristics, which reflected in stream fish assemblages. In the Eastern Amazon, streams draining oil palm plantations showed an increase in percentage of

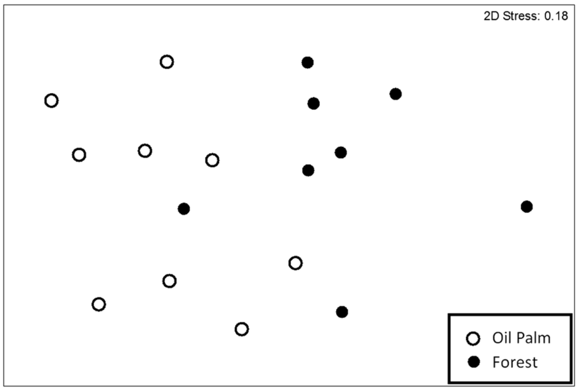

Fig. 3 Ordination resulting from the non-metric multi-dimensional scaling analysis (NMDS) based on species composition of fishes collected in oil palm plantation and forest fragments streams in northeastern Pará state, Brazil. Open circle (○) represents streams in oil palm plantation area and closed circles (●) represent streams in forested area

fine substrate and in the proportion of non-agricultural human impact, along with a decrease in large woody debris volume in and above active channel (LWDVC) and in water oxidation and reduction. We also recorded changes in the fish assemblage composition, where generalist species were predominant and general richness and abundance of species were higher when compared with streams of forested areas.

The relationship between stream habitat structure and cash crops has been widely described in literature (Moerke and Lamberti 2006; Hrodey et al. 2009; Santos et al. 2015; Luke et al. 2016). Changes in land use along the catchment, such as agriculture, affect negatively the structure of remaining riparian vegetation (Heartsill-Scalley and Aide 2003). Consequently, these changes affect the stream habitat due to a higher incidence of light, reduction of allochthonous organic matter input (Fernandes et al. 2012), changes in chemical elements of water (De Souza et al. 2013), and reducing the offer of shelter for organisms (Crook and Robertson 1999; Wrigth and Flecker 2004). The network of dirt roads used for cash crops has also been considered an important modifying agent of stream habitat, mainly contributing with the siltation of this system, which affects the water physical-chemical feature and biodiversity (McClain and Elsenbeer 2001; Wantzen and Mol 2013). In the present study, we believe that both changes in riparian vegetation structure and the presence of dirt roads, contributed to stream habitat changes in oil palm plantation areas. Besides, the Brazilian environmental laws (Law n° 12.651, May 25, 2012), consider dirt roads and bridges as a low impact disturbance and their construction is permitted in permanent preservation areas (APP – *Área de Preservação Permanente* in Portuguese), which includes a 30 m strip of riparian vegetation area in both side of streams less than ten meters wide. This situation tend to contribute even more to the input of sediments and organic matter in the streams, as

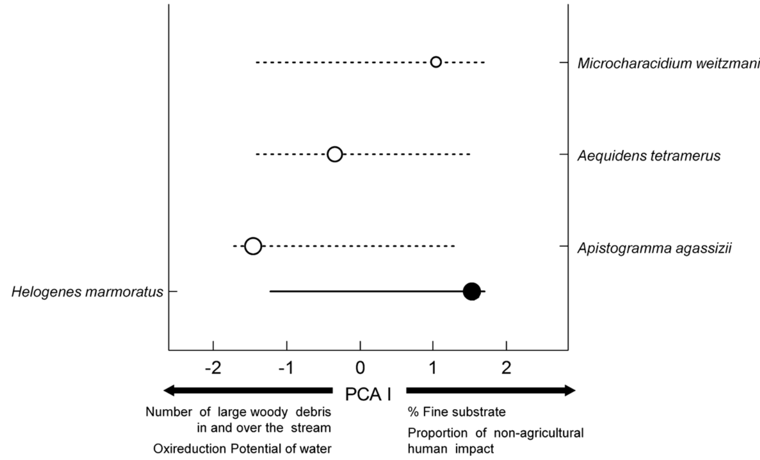

Fig. 4 Change points and 90% confidence limits of significant indicator taxa along the first PCA axis (Threshold Indicator Taxa Analysis, $p < 0.05$, purity >0.95, reliability >0.95 for $p < 0.05$, 500 bootstrap and 1000 permutation replicates). Change points are sized in proportion to the magnitude of the response (z scores)

well as with changes in the physical and chemical characteristics of water.

The changes observed in the habitat corroborate the results presented by Dosskey et al. (2010), who considers the riparian vegetation as responsible for maintaining the physical-chemical properties of streams draining. Changes in stream habitat was also observed by Cunha et al. (2015) in a study conducted in Amazonia, who found that the highest proportion of non-agricultural human impact was caused by changes in habitat integrity of streams due to land use for oil palm plantation. With lower amount of woody debris, and substrates with smaller diameter in oil palm plantation streams, which are thus characterized as sites with lower heterogeneity and lower offer of habitats. These metrics were sensitive to compare and distinguish forest fragments from oil palm plantations, and are directly related to the preservation state and configuration of riparian vegetation, which are key factors to the good functioning of the natural conditions of aquatic ecosystems (Pusey and Arthington 2003). On the other hand, a higher canopy cover was observed in the oil palm plantation, however, this riparian vegetation is composed by thin trees (<30 cm), suggesting a regenerating or recent vegetation. In addition, the significant number of thin trees is driven by the absence of larger trees, which are considered to be strong contenders for resources since they present a greater demand (Coomes and Allen 2007).

Following the same reasoning, the increase in sedimentation found in oil palm plantation streams might be associated to changes in riparian vegetation, which works as a filter for water volume and for the amount of transported sediment coming from the adjacent forest fragments and into the streams (Pusey and Arthington 2003; De Souza et al. 2013). In streams surrounded by less dense vegetation resulting from oil palm plantations, the volume of water input in the streams is higher, as is sediment load, corroborating Restrepo et al. (2015), who found changes in the sedimentation process of water bodies in Rio Magdalena basin, Colombia, resulting from the suppression of primary vegetation over the years. In addition, according to Bonachea et al. (2010), in a process similar to the sedimentation of water bodies, habitat loss deriving from homogenization caused by changes in the native vegetation is also another relevant consequence of disorganized human activities as it decreases the offer of shelter, foraging sites, and reproductive sites in several aquatic organisms (Casatti et al. 2012).

On the other hand, biodiversity also suffers the impacts of palm monoculture. However, most studies address terrestrial organisms, e.g., the study by Lees et al. (2015) in the Eastern Amazon, who observed differences in avifauna richness between oil palm plantation, primary forest, secondary forest, and pasture. Oil palm plantation samples had the lowest richness in the study. In another study carried out in the same area, Correa et al. (2015) recorded higher anuran richness in forest fragments than in oil palm plantations; however, they found no difference in the abundance of these animals. Also, regarding terrestrial fauna, in a study conducted in Malaysia, Turner and Foster (2009) evidenced that terrestrial invertebrate abundance and biomass decrease in oil palm plantations compared to primary forest fragments and logged forest fragments. Regarding aquatic organisms, some studies have indicated relationships similar to those observed for terrestrial organisms. Rawi et al. (2013) observed a lower diversity

Table 3 Results of the TITAN Analysis for fish species collected in Eastern Amazon streams. Where bold species were considered indicative of forest or oil palm environments

Species	Environmental change point	Frequence		IndVal	p (IndVal)	z	z (5%)	z (95%)	Purity	Reliability	Indication
		Forest	Oil Palm								
Aequidens tetramerus	**−1.22**	**1**	**7**	**86.82**	**0.030**	**3.07**	**−1.29**	**1.70**	**1.00**	**0.98**	**z+**
Anablepsoides cf. *urophthalmus*	1.35	7	6	84.65	0.022	2.4	−2.27	1.70	0.98	0.81	z-
Apistogramma agassizii	**−1.46**	**2**	**8**	**90.91**	**0.002**	**4.38**	**−1.72**	**1.74**	**1.00**	**1.00**	**z+**
Apistogramma gr. *regani*	−1.91	7	9	81.00	0.006	3.24	−2.16	1.51	0.92	0.83	z+
Brachyhypopomus aff. *bullocki*	−2.16	3	4	50.00	0.140	0.77	−2.24	1.70	0.73	0.33	z+
Brachyhypopomus beebei	−1.91	6	5	95.99	0.014	3.13	−2.16	2.13	0.89	0.75	z-
Brachyhypopomus brevirostris	−1.22	2	7	76.24	0.006	3.15	−1.41	1.70	1.00	0.90	z+
Bunocephalus caracoideus	−1.91	3	6	69.23	0.070	2.01	−2.01	1.50	0.97	0.79	z+
Carnegiella strigata	1.05	2	6	71.47	0.008	3.13	−1.91	2.09	0.99	0.86	z+
Copella arnoldi	1.30	8	9	69.64	0.086	1.53	−2.16	1.32	0.81	0.44	z-
Crenuchus spilurus	1.52	4	3	53.85	0.180	1.46	−2.34	1.56	0.87	0.39	z-
Erythrinus erythrinus	−1.46	5	3	72.54	0.002	3.53	−2.16	1.11	0.96	0.84	z-
Farlowella amazona	1.70	2	5	89.53	0.012	3.51	−1.57	2.09	1.00	0.88	z+
Gladioglanis conquistador	1.35	7	7	63.07	0.210	0.96	−2.34	1.52	0.62	0.52	z+
Gymnorhamphichthys petiti	−2.16	7	9	86.41	0.010	2.33	−2.24	2.52	0.94	0.79	z+
Gymnotus gr. *coropinae*	1.05	7	6	51.07	0.386	−0.09	−2.34	2.13	0.53	0.38	z-
Helogenes marmoratus	**1.52**	**8**	**8**	**86.73**	**0.004**	**4.15**	**−1.22**	**1.70**	**1.00**	**0.99**	**z-**
Hemigrammus bellottii	1.05	2	6	56.32	0.080	1.61	−2.34	1.74	0.81	0.61	z+
Hemigrammus oceliffer	−1.22	2	6	63.30	0.024	2.41	−1.56	1.52	0.96	0.76	z+
Hoplias malabaricus	1.52	3	2	35.45	0.464	0.53	−2.34	2.52	0.48	0.40	z+
Hyphessobrycon heterorhabdus	1.30	7	7	73.19	0.088	1.52	−2.34	1.74	0.83	0.51	z-
Hypopygus lepturus	−1.22	5	4	47.56	0.424	0.21	−2.42	2.52	0.58	0.41	z-
Iguanodectes rachovii	−1.91	7	8	56.16	0.546	−0.3	−2.16	1.70	0.55	0.27	z-
Ituglanis amazonicus	1.37	5	6	65.93	0.170	1.17	−2.41	1.51	0.47	0.52	z+
Laimosemion cf. *strigatus*	−0.11	6	5	51.03	0.310	0.29	−2.34	2.32	0.52	0.33	z-
Microcharacidium weitzmani	**1.05**	**8**	**9**	**73.17**	**0.004**	**3.15**	**−1.41**	**1.70**	**1.00**	**0.98**	**z+**
Microsternarchus aff. *bilineatus*	1.70	0	5	94.92	0.012	4.64	0.11	2.09	1.00	0.88	z+
Moenkhausia comma	1.05	0	3	38.02	0.018	1.71	−0.13	2.52	0.95	0.45	z+
Nannacara cf. *taenia*	−1.91	6	5	64.92	0.178	1.11	−2.16	2.52	0.68	0.40	z-
Nannostomus trifasciatus	−2.16	5	8	78.40	0.014	2.31	−2.24	2.13	0.94	0.67	z+
Paracanthopoma parva	1.37	2	6	62.80	0.050	2.17	−2.41	2.09	0.90	0.70	z+
Pyrrhulina sp.	1.30	5	5	60.26	0.104	1.3	−2.43	1.53	0.80	0.45	z-
Rhamdia quellen	−1.46	1	3	36.36	0.218	1.44	−1.72	1.52	0.73	0.22	z+
Steatogenys elegans	1.70	1	5	75.68	0.036	2.74	−1.80	2.09	0.99	0.76	z+
Synbranchus marmoratus	1.05	2	4	39.87	0.174	1.02	−2.34	2.52	0.52	0.47	z+
Trichomycterus hasemani	1.05	8	9	74.87	0.054	1.91	−2.34	1.52	0.80	0.55	z+

of aquatic insects in streams next to oil palm plantations compared to primary forest fragments streams and streams near highways. In another study carried out in the Amazon, Cunha et al. (2015) observed a lower richness of Heteroptera in oil palm plantation streams compared to primary forest fragments streams. However, there were no differences in the abundance of these insects.

Although the state of knowledge regarding changes caused by oil palm plantations in the natural community structure is significant, studies about the effects on ichthyofauna are still scarce. In a pioneer study, conducted in Indonesia, Giam et al. (2015) observed differences in fish assemblage structure; higher species richness was found in streams that drain through continuous forests and riparian vegetation fragments, compared to oil palm plantation streams, where a loss of approximately 42% in fish richness is estimated.

Unlike the hypothesized in the present study, the fish assemblage's richness did not differ between forest fragments and oil palm plantations streams. Similar pattern has also been observed and discussed in tropical streams submitted to a different type of environmental disturbances (Teresa and Casatti 2012), which was manly attributed to a higher evenness in the distribution of species within these streams and the fact that disturbed areas provide condition that favor the frequency increase of species that previously inhabited these areas. In some cases, the species richness in streams may also increase after disturbances (McCabe and Gotelli 2000). According to Huston's dynamic-equilibrium model, considered a good predictor model to streams communities, the species richness peak can be obtained in different disturbance intensity according to the rates of competitive exclusion and population (Huston 1979). In this sense, it is important to reinforce that species richness must be carefully evaluated and never used as the only measure of diversity streams disturbances assessment.

Regarding fish species composition, the results obtained indicate differences between streams in forest fragments and oil palm plantations. This composition difference may be related to environmental changes, since environmental features are determining factors for the occurrence of species in a given area (Jackson et al. 2001; Terra et al. 2015). Despite that, the fish species composition of one sampled stream in forest fragments was similar to streams in oil palm plantations in the NMDS ordination, this pattern may be leading because this site is surrounded by oil palm plantations, both downstream and upstream, but the stream source is located in forest fragments. However, this influence (distance of plantations) was not measured in our study and we suggest for a future landscape ecology studies to assess this relation and elucidate this question.

Therefore, fish species might be used as indicators of preserved or degraded areas (Ferreira and Cassati 2006). In the present study, the increase in abundance of *Aequidens tetramerus* and *Apistogramma agassizii* in oil palm plantations streams may be attributed to high tolerance and generality of many species of this family (Cichlidae) to lower environmental conditions (Burress 2015). In addition, the wide distribution of these two species in the Amazon basin (Kullander 2003) make them possible environmental indicators of areas disturbed by oil palm plantation. On the other hand, *Helogenes marmoratus* is associated to higher environmental conditions of structural heterogeneity (forest fragment streams), since their perpetuation depends on more specific environments, e.g., foliage bed and woody debris, deriving from riparian forests, which are deposited in the stream substrate, serving as shelter for these specie (Sazima et al. 2006).

Overall, changes in the patterns of biological community structure are common in face of the impacts caused by different land uses (Iwata et al. 2003; Deegan et al. 2011). In addition, the maintenance of riparian vegetation is essential to mitigate these impacts, since small streams depend on the structure of this marginal vegetation to maintain their natural features (Pusey and Arthington 2003; Casatti et al. 2012; De Souza et al. 2013). Therefore, monitoring studies on structural analyses (e.g.: amount of woody debris) of aquatic ecosystems have been carried out in the United States, Europe and Asia with the purpose of understanding their functioning and of creating conservation measures (Metzger and Casatti 2006; Li et al. 2010). In Brazil, however, these methodologies are still scarce.

Studies that add ecosystem structural information to biological information comprise an effective biodiversity monitoring tool used in temperate regions (Jaramillo-Villa and Caramaschi 2008); all the same, they can be widely adapted and practiced in tropical and subtropical regions such as the Brazilian Amazon. Hence, the results shown here indicate that the use of data on fish assemblage composition combined with structural habitat condition approach is effective in the assessment of streams and might subsidize strategies for the preservation and conservation of these ecosystems, as land use for oil palm plantations has been impacting the Amazon biodiversity. The conservation and monitoring of riparian vegetation corridors along all catchments in the studied area are of utmost importance. In addition, with a decrease in habitat quality, changes in species composition might occur, leading to the loss of more sensitive and forest-specialist species.

Acknowledgements The authors are grateful to financial support of Coordination for the Improvement of Higher Education Personnel (CAPES) and National Counsel of Technological and Scientific Development (CNPq); and logistic support for field research of the Conservation International (CI-Brazil) and Agropalma Group.

Funding Ferreira MC has received Granting Scholarship by Coordination for the Improvement of Higher Education Personnel (CAPES). Prudente BS has received Research Grant by National Councel of Technological and Scientific Development (CNPq) through the Programa de Capacitação Internacional (PCI). Juen L. and Montag LFA has received Research Grants by Coordination for the Improvement of Higher Education Personnel (CAPES) / *Pró-Reitoria de Pesquisa e Pós-Graduação* (PROPESP/UFPA) and Productivity Grants by National Counsel of Technological and Scientific Development (CNPq).

Compliance with ethical standards All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Conflict of interest The authors declare that they have no conflict of interest.

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