UNIVERSIDADE FEDERAL DO PARÁ

NÚCLEO DE ECOLOGIA AQUÁTICA E PESCA DA AMAZÔNIA

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA AQUÁTICA E PESCA

RODRIGO ARISON BARBOSA RIBEIRO

AS CONDIÇÕES DO HABITAT DENTRO DOS RIACHOS E AS ASSEMBLEIAS DE ODONATA (INSECTA) IMATUROS NA AMAZÔNIA ORIENTAL

BELÉM-PA

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Dissertação apresentada ao Programa de Pós-graduação em Ecologia Aquática e Pesca da Universidade Federal do Pará, como requisito para obtenção do título de mestre em Ecologia Aquática e Pesca.

Orientador: Prof. Dr. Leandro Schlemmer Brasil
Coorientador: Prof. Dr. Leandro Juen

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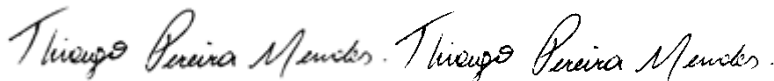Núcleo de Ecologia Aquática e Pesca da Amazônia, NEAP/UFPA (Titular)

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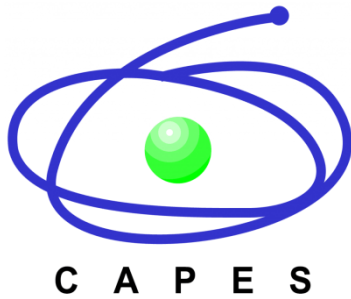Instituto de Ciências Biológicas, ICB/UFPA (Titular)

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Belém, 27/ 02/ 2021

INSTITUIÇÕES E FONTES FINANCIADORAS

Dedico este trabalho à natureza.

AGRADECIMENTOS

SUMÁRIO

Apresentação da dissertação

Essa dissertação é composta por um resumo geral, uma introdução geral, um artigo completo e uma conclusão geral. As seções, resumo geral, introdução geral e conclusão geral foram inseridas em português, uma vez que o artigo está em inglês.

Resumo

As mudanças no uso da terra, provocadas por atividades socioeconômicas, acarretam forte modificação da paisagem e causam alterações nas características ambientais dos riachos amazônicos, o que tem acarretado efeitos danosos sobre o ambiente e a biodiversidade aquática. Nesse contexto, nosso objetivo foi avaliar como as alterações nas condições abióticas no interior dos riachos afetam as assembleias de Odonata imaturos na Amazônia Oriental. Testamos a hipótese de que as condições ambientais locais dos riachos são importantes preditores das assembleias de Odonata imaturos. Foram amostrados 30 riachos de cabeceira de 1ª até a 3ª ordem no município de Paragominas, sudeste do estado do Pará, durante a estação de estiagem nos anos de 2015 e 2017. Os usos da terra foram mensurados usando imagens de satélite e as variáveis do hábitat local com auxílio do protocolo de avaliação de riachos e com base na literatura. A nossa hipótese de que mudanças em escala local são importantes para a predição das assembleias de imaturos de Odonata foi corroborada. Nossos resultados sugerem que os usos da terra em escala de paisagem afetam as condições do hábitat local dentro dos riachos. Tais fatores locais fornecem recursos para a permanência e desenvolvimento do estágio larval de Odonata e, portanto, são essenciais para a manutenção da estrutura das assembleias. Nessa perspectiva, tendo em vista as rápidas mudanças da paisagem no cenário atual, é substancial levar em consideração as diferentes escalas ambientais para um melhor entendimento da origem e dos efeitos do impacto, e assim elaborar estratégias de restauração mais eficientes da integridade dos riachos amazônicos e das assembleias aquáticas.

Palavras-chave: Anisoptera, Mineração, Pecuária, Sistemas lóticos, Zygoptera.

INTRODUÇÃO GERAL

A crescente necessidade das populações humanas por recursos naturais tem causado um aumento na ocupação e desmatamento de áreas naturais, especialmente em biomas tropicais (Hansen et al., 2010; Gardner et al., 2013). Paralelamente, o crescimento populacional não planejado e o desmatamento causaram mudanças significativas na dinâmica paisagística da região amazônica (Fearnside et al., 2005). Essas alterações criam mosaicos de paisagens originadas de um histórico de múltiplos usos da terra em meio a remanescentes cada vez menores de vegetação nativa (Gardner et al., 2013; Chen et al., 2017).

Na Amazônia brasileira, a mudança no uso da terra começa com o desmatamento para exploração madeireira (Rivero et al., 2009), o que geralmente é seguido por usos mais intensos e prejudiciais à biodiversidade, como agricultura e pecuária. Juntos, eles são responsáveis por mais da metade do desmatamento da floresta amazônica (Almeida et al., 2016). Essas atividades, associadas a outras de importância socioeconômica na região, a exemplo da mineração e as hidrelétricas, configuram-se como a principal causa da redução das áreas de mata nativa (Almeida & Vieira 2010). Em consequência disso, por serem sistemas abertos e dinâmicos e apresentarem elevada dependência da vegetação ripária, os riachos são facilmente afetados por quaisquer atividades às quais sua rede de drenagem esteja sujeita. Portanto, mudanças no uso e ocupação de ambientes terrestres adjacentes podem afetar diretamente o ambiente aquático (Allan, 2004; Molina et al., 2017).

As mudanças nas condições naturais dos sistemas biológicos podem resultar em mudanças na distribuição espacial das espécies (Oliveira-Junior & Juen, 2019). Segundo a Teoria do Nicho (Hutchinson, 1957), a coexistência de um alto número de espécies está relacionada à maior diversidade de nichos e disponibilidade de abrigo e recursos alimentares. Todos esses fatores, por sua vez, estão atrelados à complexidade estrutural do ambiente. Assim, a ocorrência de um táxon em um determinado local é relacionada também com as condições ambientais em escala de paisagem, como a quantidade de vegetação nativa, e da qualidade do habitat local, como a estrutura física do canal e condições físico-químicas da água (Mendenhall et al., 2014). Fatores regionais, como configuração da paisagem, podem limitar a dispersão das espécies e, como resultado, afetar sua distribuição (Mendes et al., 2017). Portanto, embora o habitat

local seja determinante para a estrutura das assembleias biológicas, considerar o contexto regional também é de grande importância para avaliar os efeitos do uso da terra na distribuição das espécies (Brasil et al., 2019).

Os efeitos das condições ambientais locais e da paisagem nas assembleias terrestres e aquáticas raramente são testados juntos (Karaouzas & Gritzalis, 2006; Mendenhall et al., 2014; Siegloch et al., 2017). Além disso, estudos que avaliem conjuntamente esses efeitos em diferentes escalas espaciais são escassos de forma geral e isso é mais acentuado nos ambientes tropicais (Brasil et al., 2020). Assim, compreender a interação entre os processos que ocorrem nas escalas regional e local é de fundamental importância para o entendimento da dinâmica das comunidades naturais (Leibold et al., 2004; Holyoak et al., 2005; Resetarits Jr, 2005), particularmente em ecossistemas aquáticos (Karaouzas & Gritzalis, 2006; Siegloch et al., 2017) de regiões tropicais (Brasil et al., 2019). Portanto, a intensificação das atividades antrópicas na bacia de drenagem pode causar alterações na zona ripária, na estrutura do habitat, na qualidade da água dos riachos amazônicos e nas comunidades biológicas (Almeida et al., 2016) (Figura 1).
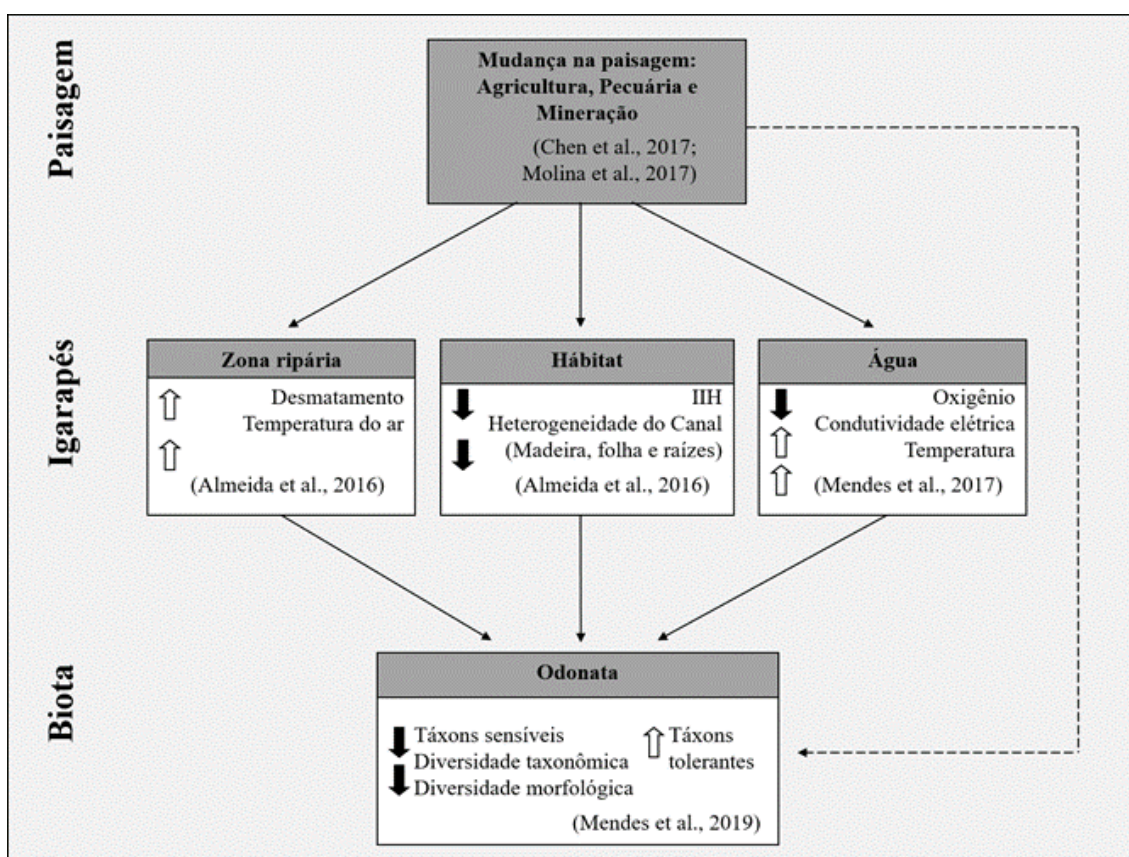
Figura 1. Modelo conceitual dos efeitos das mudanças do uso da terra nas comunidades

de Odonata imaturos dentro dos riachos da região amazônica. IIH: índice de Integridade de Hábitat.

Em geral, todas essas mudanças ambientais podem afetar negativamente a estrutura das assembleias dentro desses ambientes (Chen et al., 2017; Mendes et al., 2018; Oliveira-Junior et al., 2019), incluindo a dinâmica de macroinvertebrados aquáticos, tais como Odonata, Ephemeroptera, Plecoptera, Trichoptera e Heteroptera, em razão da sua alta sensibilidade às modificações no ambiente (Castro et al., 2017; Faria et al., 2017; Ferreira et al., 2017; Mendes et al., 2019). Nesse contexto, Odonata tem sido frequentemente utilizada como ferramenta de biomonitoramento ecológico, uma vez que refletem às modificações no ecossistema em diferentes escalas ambientais (Carvalho & Nessimian, 1998; Monteiro-Júnior et al., 2013; Oliveira-Junior et al., 2017; Carvalho et al., 2018; Mendes et al., 2019).

As formas imaturas das subordens Anisoptera e Zygoptera possuem diferentes requisitos ecológicos, que estão associados a especificidades no hábitat e nos tipos de substrato que ocupam (Mendes et al., 2015). Os imaturos de Zygoptera dispõem de estruturas branquiais na parte terminal do abdômen com função respiratória, são também pequenos e menos tolerantes a perturbações no ambiente aquático (Corbet, 1999). Os Anisoptera imaturos não possuem brânquias caudais, retirando o oxigênio do ambiente por meio de estruturas em formato de pirâmide, e são, em geral, maiores e menos sensíveis a variações nas condições do ecossistema aquático (Corbet, 1999). Essas disparidades ecomorfológicas entre as subordens podem gerar, portanto, diferentes padrões de respostas dentro das assembleias de Odonata imaturos (Mendes et al., 2019).

Nosso objetivo foi avaliar como as mudanças ambientais em diferentes escalas espaciais influenciam a estruturação das assembleias de Odonata imaturos em riachos da Amazônia Oriental. Acreditamos que as alterações na paisagem advindas das atividades antrópicas em grande escala modificam as condições ambientais do hábitat, como a qualidade da água, estrutura do canal e disponibilidade de abrigo e alimento, e podem determinar a organização espacial das comunidades nos ecossistemas aquáticos. Acreditamos que levar em consideração as diferentes escalas espaciais contribuirá para uma melhor compreensão dos impactos das mudanças no uso da terra sobre o hábitat e a biodiversidade em riachos amazônicos.

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Artigo: **Habitat conditions in stream influence Odonata larvae assemblages in the Eastern Amazon**

O capítulo único desta dissertação foi elaborado conforme as normas para publicação científica da revista *Marine Freshwater Research*, disponível em: <https://www.publish.csiro.au/mf/forauthors/AuthorInstructions>

1   **Habitat conditions in stream influence Odonata larvae assemblages in the eastern**

2   **Amazon**

3

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12

13   **Abstract**

14   Odonata have been widely used as indicators for the biomonitoring of habitats

15   due to their sensitivity to environmental impacts. The growth of agricultural and mining

16   activities in the Amazon has impacted land-use and strong changes in the local

17   environmental conditions of streams. In the face of these changes, our study aimed at

18   assessing how environmental changes affect Odonata larvae assemblages in streams

19   from the Eastern Amazon. We hypothesize that habitat conditions in stream are strong

20   predictors of Odonata larvae assemblages. We sampled 30 headwater streams (1st

21   through 3rd order) in the Eastern Amazon. We corroborated our hypotheses that regional

22   and local scale environmental changes are important predictors of the Odonata larvae

23   assemblage structure. Most important environmental variables for the assemblages in

24   this study are related to riparian vegetation, temperature, types of substrates and the

25   presence of natural shelters. These results indicate that environmental conditions inside

26   the stream channel are important to maintain Odonata larvae assemblages as they

27   provide important resources for larval development. For new study possibilities, we

28 recommend the assessment of temporal dynamics to evaluate if these patterns are stable

29 across time. Finally, evaluating different environmental scales of the impact origin is

30 extremely relevant for preventing or recuperating the aquatic assemblages from

31 Amazonian streams considering the rapid environmental changes and deforestation in

32 the region. Our findings further reinforce the potential bioindicator of Odonata in

33 relation to changes in environmental conditions. Here we demonstrate that in-stream

34 environmental conditions are important for the assemblage structure and this must be

35 considered in the environmental restoration plans.

36

37 **Key-words:** Landscape change, Land-use, Cattle raising, Mining, Dragonflies,

38 Damselflies, Lotic systems

39

40 **INTRODUCTION**

41   Environmental changes in streams, in limnological water characteristics, and

42 habitat structure, have a substantial effect on aquatic insect assemblages, especially for

43 those that are highly sensitive to environmental changes, such as some species of

44 mayflies (Ephemeroptera), odonates (Odonata), stoneflies (Plecoptera) and caddisflies

45 (Trichoptera) (Castro *et al.* 2017; Faria *et al.* 2017; Ferreira *et al.* 2017; Mendes *et al.*

46 2019). Any changes in the abundance or species composition of these taxa in aquatic

47 assemblages are of concern because they play an important role in nutrient cycling and

48 energy flow (Castro *et al.* 2019). Among aquatic insects, odonates stand out as

49 important indicators of habitat quality due to the group's high diversity and sensitivity

50 to environmental change (Carvalho and Nessimian, 1998; Mendes *et al.* 2015).

51 Additionally, because they are predators, they play an important role in aquatic trophic

52 webs (Corbet, 1999; Pires *et al.* 2020).

53   Odonates exhibit aquatic larvae and flying terrestrial adult stages. They are

54 extremely abundant and diverse, which allows them to occupy a wide variety of

55 microhabitats in lentic and lotic environments (Corbet, 1999). In their aquatic stage,

56 changes in land-use (Mendes *et al.* 2017; 2019), habitat structure, and limnological

57 parameters (*e.g.,* temperature, pH, conductivity, and dissolved oxygen) can result in

58 important changes in assemblage properties, such as richness, species composition and

59 abundance patterns (Mendes *et al.* 2017; Pires *et al.* 2020). These changes in the

60 assemblage structure are related to their physiological needs: the characteristics of

61 thermoregulation in adults (De Marco *et al.* 2015) and the characteristics of breathing in

62 larval instars (Corbet, 1999). Therefore, changes in the landscape are usually more

63 important for adults (De Marco *et al.* 2015) and in-stream changes in the immature

64 (Mendes *et al.* 2017; 2019).

65   Our study aimed at assessing how environmental changes affect Odonata larvae

66 assemblages in streams from the Eastern Amazon. We hypothesize that habitat

67 conditions in stream are strong predictors of Odonata larvae assemblages. Our

68 hypothesis is based on the premise that the amount of original vegetation and the

69 heterogeneity in environmental conditions within streams directly affect water quality,

70 shelter, and food availability for aquatic insects (Martins *et al.* 2018; Castro *et al.* 2019).

71 This is due to a hierarchical mechanism, where climate and dispersal affect assemblages

72 on a landscape scale, contributing to regional and biogeographic patterns (Brasil *et al.*

73 2019), whereas local habitat characteristics are important for the spatial organization on

74 smaller scales, at the metacommunity level (Montag *et al.* 2019; Oliveira-Junior *et al.*

75 2019).

76 **MATERIAL AND METHODS**
77 *Study area*

78   The study was conducted in the Rio Capim river basin, in the municipality of

79 Paragominas, southeast of the State of Pará (Fig. 1). The region has approximately

80 150,000 ha of forested area, of which 18,000 are pasture areas, 11,000 are Permanent

81 Protection Areas (PPA), 15,000 are logging areas and 98,000 are native forest. The Rio

82 Capim River basin has a drainage area of around 37,000 km², mostly due to the slope of

83 the region, which has a slightly rectangular shape (Lima and Ponte, 2012). The forest

84 comprises dense tropical rainforests (Almeida and Vieira 2010) and has a humid

85 equatorial climate, with an average rainfall of 1,743 mm per year. The rainy season lasts

86 from December to May, and the dry season from June to November (Alvares *et al.*

87 2013). The average relative humidity is around 81% and the average annual temperature

88 is 26.3 °C (Francez *et al.* 2009).
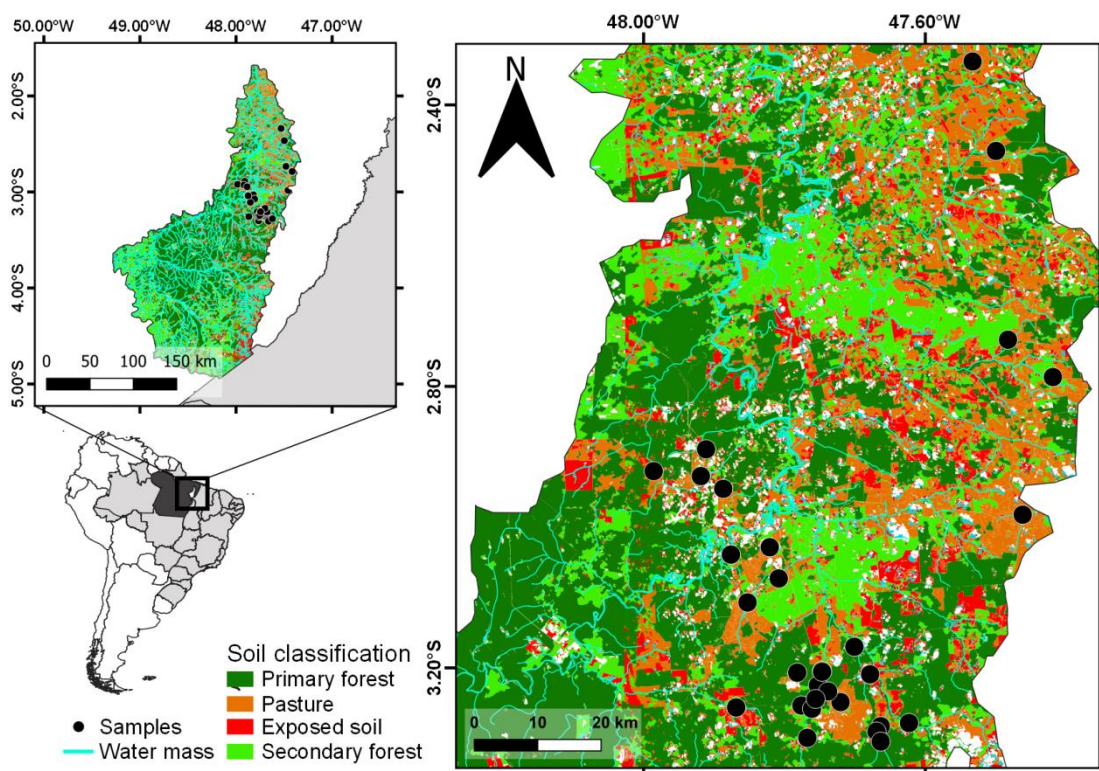
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90 **Figure 1.** Location of the 30 sampling sites in the Rio Capim river basin, on the
91 municipality of Paragominas, State of Pará, Brazil.

92

93   Since the second half of the 20th century, the municipality of Paragominas has

94 suffered from high rates of deforestation due to the intensification of anthropogenic

95   activities. In this context, the Rio Capim river basin displays a mosaic that encompasses

96   different land-uses, such as areas for agriculture and cattle raising.

97   *Sampling Design*

98   The aquatic ecosystems of the Amazon region are highly variable in size and

99   shape. Thus, we standardized our sampling procedure by selecting 30 streams of first-

100   through third order (according to Strahler's classification, 1957). The surveys were

101   carried out in the years of 2015 and 2017, always in the period of lower rainfall to

102   reduce possible seasonal effects. In each stream, we delimited a 150 meter reach divided

103   into 10 sections of 15 meters, each of them separated by a cross-sectional transect (Fig.

104   2). Each of the 11 transects was named from "A" to "K" from downstream to upstream.

105   Within each of the 10 sections, we sampled Odonata larvae and the habitat

106   physical and physicochemical parameters following the physical habitat monitoring and

107   assessment protocol of the United States Environmental Protection Agency (US-EPA)

108   (Kaufmann *et al.* 1999; Peck *et al.* 2006). This protocol records environmental

109   information from different categories: availability of shelter for aquatic communities,

110   the structure of riparian vegetation, channel morphology, human impact and water

111   limnological variables. The physical habitat characterization along each section was

112   carried out following the stream assessment methodology of Peck *et al.* (2006) and

113   Hughes and Peck (2008).
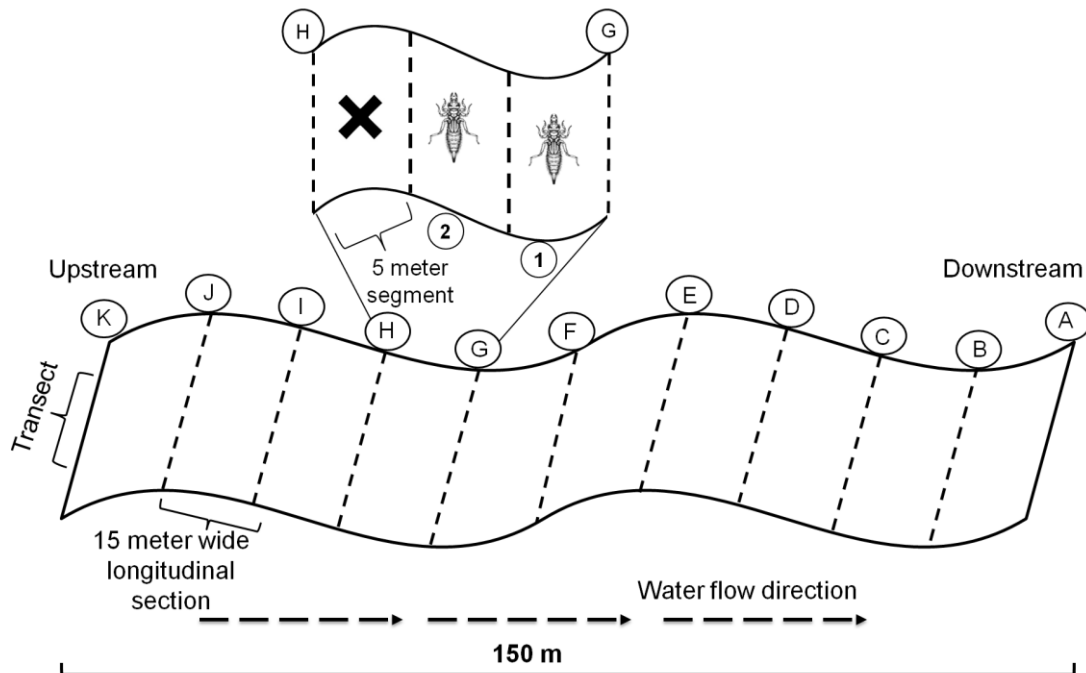
Figure 2. Diagram of the sampling design in each of the sampled streams in the Rio Capim river basin on the municipality of Paragominas, State of Pará, Brazil. We delimited a 150 meter transect in each sampled stream, which was then divided into ten 15 meter sections, each of them separated by a longitudinal transect named "A" to "H" from downstream to upstream.

Biological sampling

We further subdivided the cross-sectional sections into three fiver meter wide segments for the biological sampling of individuals and only the first two segments were sampled (Fig. 2). Thus, we sampled 20 segments of five-meter width in each stream. Sampling was carried out by sweeping the stream three times from the streambed towards the stream margins using a sieve of 18 cm of diameter and 250 μm mesh (Shimano and Juen., 2016; Mendes *et al.* 2019). Sampled individuals were brought to the laboratory, preserved in 85% ethanol, and then identified using taxonomical dichotomous keys (Heckman, 2006; Neiss and Hamada, 2014). All sampled organisms were stored in the Zoology Collection of the Federal University of Pará, UFPA (Belém - PA, Brazil).

132   *Characterization of land-uses and vegetation cover*

133   We used images from the *Shuttle Radar Topography Mission* (SRTM) project

134   with a resolution of approximately 30 meters. These images were readjusted using

135   images from *Google Earth* (http://earth.google.com) and the TauDem version 5.3

136   through the geoprocessing software QGis version 2.18 (QGIS 157 Development Team,

137   2017). The interpretation of the different types of land-uses and vegetation cover was

138   performed using images from the Landsat 8 satellite obtained from the *United States*

139   *Geological Survey* (USGS) *Earth Explorer* project in 2015 and 2017, using the Semi-

140   Automatic Classification plug-in from the software QGis 2.18 (Macedo *et al.* 2014).

141   To minimize the effects of atmospheric reflectance, we applied the process of

142   atmospheric correction to the image set (Antunes *et al.* 2012). Later, the images were

143   classified into primary and secondary forest areas, pasture areas, and exposed soil areas

144   (where mining activities are concentrated). We validated the classification process by

145   visually inspecting images from Google Earth (http://earth.google.com). Finally, we

146   cropped a band of a 30 meters wide riparian zone from each of the stream margins. This

147   band had 600 linear meters of length following the drainage network. In addition, 30

148   meters is the width in which Brazilian law requires the preservation of native vegetation

149   in small streams. Therefore, our landscape matrix was composed of land use

150   percentages such as agriculture and livestock, exposed soil and native forest. These uses

151   were measured on the spatial scale explained above (30 m x 600 m).

152   *Physical habitat characterization*

153   We measured riparian vegetation structure, limnological variables, channel

154   morphology and anthropogenic impact. Each section was characterized by 10 Crosswise

155   equidistant point measures along the section. We recorded the depth of the thalweg,

156   number of water retention objects, presence of fine sediments, slope and sinuosity of the

157   channel, and type of channel. In each of the sections, we measured depth and presence

158   of the different types of substrate through visual inspection: sand, clay, consolidated

159   clay, leaf bank, coarse gravel, fine gravel, concrete, rock formations, wood, particulate

160   organic matter, macrophytes, and/or algae, roots, pebbles and silt.

161   The limnological parameters temperature (°C), pH (scale from 0 to 14), turbidity

162   (NTU), dissolved oxygen (mg/L), total dissolved solids (TDS) (ppm) and conductivity

163   (S) were measured with the multiparameter probe Horiba® U-50 (Ferreira *et al.* 2018).

164   Riparian vegetation structure and density were estimated by visually inspecting both

165   margins in a band of 100 m² for the following three types of vegetation: ground

166   vegetation (<0,5 m hight), understory vegetation (0,5 to 5 m hight), and canopy

167   vegetation (>5 m hight).

168   We also assessed habitat complexity in each section through visual inspection of

169   the surface covered by macrophytes, roots, leaves, algae, and wood fragments. We used

170   a spherical densitometer to measure the percentage of canopy cover on the stream main

171   channel at the central portion of each transect. We took six measures at the central

172   portion of each transect: left, right, center, center left, center right, center upstream,

173   center downstream. We took a total of 69 different measurements of the physical habitat

174   in each sampled stream based on Kaufmann *et al*. (1999) (see Supplementary Material

175   4).

176   *Data Analysis*

177   We performed a *forward selection* of variables that best explain the variation in

178   Odonata assemblages to reduce the number of habitat and landscape variables (Blanchet

179   *et al.* 2008). This selection uses the species matrix and the matrix of environmental

180   predictors. We use the forward.sel function of the R software adespatial package to

181   execute it. This selection is suggested by Borcard et al. (2018) for the selection of

182   variables to reduce the residual portion in analyzes such as RDA and CCA. After that,

183   to avoid autocorrelation among the selected variables, we used Spearman correlations to

184   exclude highly correlated environmental variables ($rs \geq$ 0,70). According to the

185   literature, we kept the one with greatest importance to odonate assemblages for each

186   pair of highly correlated variables. This prior variable selection procedure is important

187   to reduce the residual variability of our final explanatory model, which could be inflated

188   by a high number of predictor variables (Legendre and Legendre, 2012). We considered

189   each stream our sample units and the assemblages data, we summed the abundances

190   recorded at all sampled segments within the same stream. More details on

191   environmental variables can be seen in the supplementary material.

192   We ran a Redundancy Analysis (RDA) to verify the relationship between

193   assemblages and Odonata genera with the environmental variables selected in the

194   previous step. For this, we used this environmental variables as predictor and the genera

195   composition as our response matrix. Before running the analysis, we Hellinger

196   transformed our abundance data (Legendre and Gallagher, 2001) to maximize the

197   explanatory power of our model (i.e., adjusted R^2) (Peres-Neto *et al.* 2006). We built a

198   biplot using the RDA axes to visualize the association among the most important

199   environmental predictors and the odonate assemblages. We also used ANOVA to test

200   for the linear effects of the environmental predictors on the main RDA axis, which

201   represents the biotic matrix (Legendre and Legendre, 2012). All analyses were run with

202   the 'vegan' package, ver. 2.5–6 (Oksanen et al., 2020), adopting $\alpha = 0.05$.

203   **RESULTS**

204   *Assemblage description*

205   We sampled a total of 444 individuals from 37 genera, of which 11 (29,7%)

206   genera and 115 (25,9%) individuals were damselflies, and 26 (70,3%) genera and 329

207   (74,1%) individuals were dragonflies. Most abundant of the nine families we sampled

208   were Gomphidae (Anisoptera), with 42,34% of the individuals, followed by Libellulidae

209   (Anisoptera) and Coenagrionidae (Zygoptera) with 26,58% and 18,69% of the

210   individuals sampled, respectively.

211   Most abundant genera of the Gomphidae Family were *Zonophora* Selys, 1854,

212   with 55 individuals (29.25%), *Progomphus* Selys, 1854, with 45 individuals (23.94%),

213   *Phyllogomphoides* Belle, 1970, with 37 individuals (19.68%), and *Phyllocycla* Calvert,

214   1978, with 30 individuals sampled (15.96%). The *Gynothemis* Calvert in Ris, 1909

215   (21.19%) and *Oligoclada* Karsch, 1890 (20.34%) genera were the most abundant

216   among the Libellulidae, with 25 and 24 individuals, respectively. The genera

217   *Acanthagrion* Selys, 1876 and *Argia* Rambur, 1842 were the most abundant among the

218   Coenagrionidae with 24 individuals (28.91%) sampled each (see Supplementary

219   Material 1).

220   *Association among assemblages and the environmental predictors*

221   The *forward selection* procedure selected seven local environmental variables

222   related to the odonate assemblages: Average Intermediate Woody Canopy, Average

223   Natural Shelter, Percentage of Algae, Proportion of human impact per section,

224   Proportion of shelter as excavated margin, Temperature and Volume of Wood In The

225   Streambed (Table 1).

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Table 1: *Forward selection* results for the environment predictors related to the larval odonate assemblages in streams from the Rio Capim river basin, on the municipality of Paragominas, Pará, Brazil. AdjR^2 = adjusted R^2.

Variable	Code	AdjR²	P
Average intermediate woody canopy	XCMW	0.072	<0.001
Temperature	TEMP	0.117	0.003
Average natural shelter (leaf bank and live roots)	XFC_LIF	0.150	0.013
Volume of wood in the streambed	V3W_150	0.180	0.020
Percentage of algae	PCT_AL	0.208	0.022
Proportion of shelter as excavated margin	PFC_UCB	0.208	0.050
Proportion of human impact per section	X_HAG	0.260	0.011

When we looked into the association among environmental predictors and the odonate assemblages, we found that they explained 25% of the variation contained in the first two RDA axes (ANOVA for test linearity relationship between environmental e biotic matrix; F=2.45; df=7; p<0.001). Both axes were negatively affected by temperature and the volume of wood in the streambed and positively affected by natural shelters (leaf banks and live roots) (see Supplementary Material).

The graphical representation of the association between the Odonata larvae assemblage and environment variables local and regional showed, in the first axis, a gradient from streams with larger amounts of woody vegetation (negatively related) to those with higher variation in algae percentage (positively related) (Fig. 3). The genera *Aeschnosoma* and *Phyllocycla* were closely related to streams with higher variability in the amount of algae. However, the second axis showed a gradient from streams with higher water temperature (negatively related) to streams with higher variability in natural shelters, such as leaf banks and roots (positively related). The *Zonophora* genera was more closely related to streams with a larger number of natural shelters and a higher percentage of algae (Fig. 3).

Figure 3. Redundancy analysis (RDA) plot showing the association among local habitat predictors and landscape predictors with the Odonata larvae assemblage. Different colors represent the different land-use types: Dark green: forest fragments; Light green: secondary forest; Yellow: pasture; Red: exposed soil.

DISCUSSION
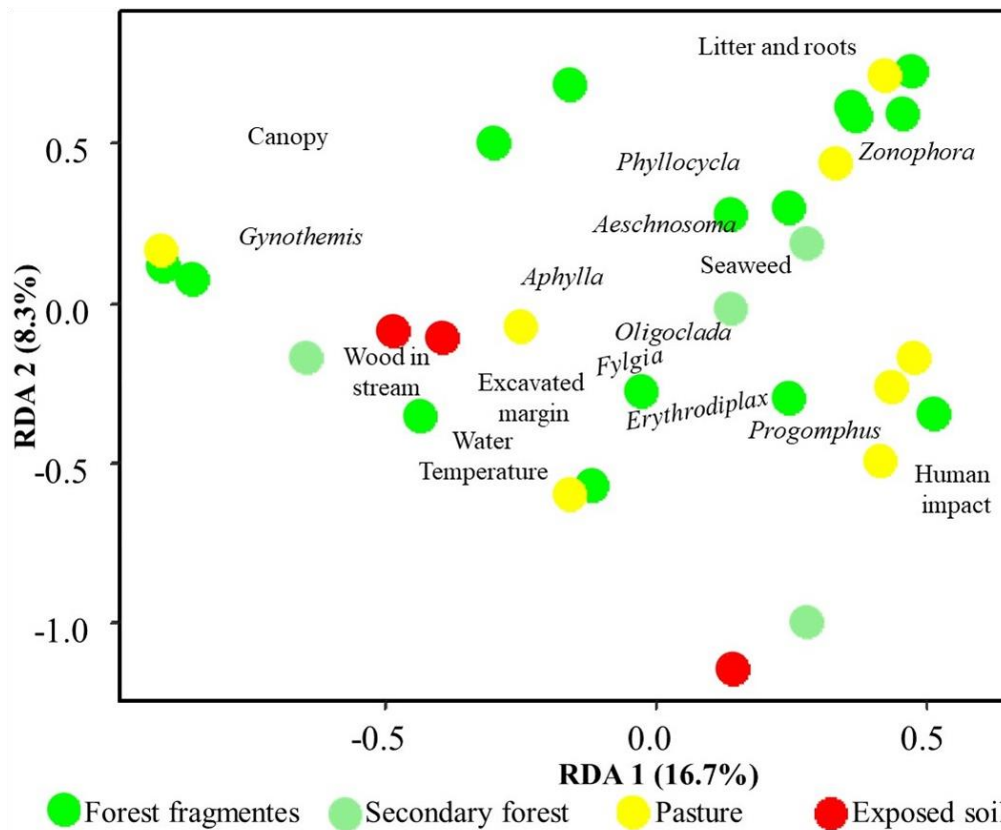
The variation in Odonata larvae assemblages was explained by the local conditions of the environment, supporting our hypothesis. This is a recurring pattern in studies that investigate the effects of environmental change on fish (Montag *et al.* 2019) and aquatic insect assemblages in tropical streams, such as mayfly, stonefly, and caddisfly assemblages (Siegloch *et al.* 2017), and adult odonate assemblages (Oliveira-Junior *et al.* 2019). Although changes in the landscape affect in-stream conditions (Leal et al., 2018). All the evidence cited above, together with our results, show that these changes in small spatial scales (in-stream) are the ones that directly affect aquatic diversity.

269   All environmental predictors that were important in explaining assemblage

270   variability were related to stream marginal vegetation cover (canopy cover, hanging

271   vegetation, leaf banks and roots, and wood fragments inside the channel). Additionally,

272   other predictors can be indirectly affected by deforestation, such as water temperature,

273   which can increase due to higher solar incidence (Carvalho *et al.* 2013), decrease in

274   thalweg depth due to higher sediment deposition (Wood and Armitage, 1997; Couceiro

275   *et al.* 2010), increase in stream margin excavation due to the lack of protecting

276   vegetation (Oliveira-Junior *et al.* 2017), and human impact, which is the cause of

277   deforestation in the first place (Sonter *et al.* 2017).

278   The local environmental changes caused by the alteration in the landscape due to

279   multiple land-uses were important predictors of the variation in Odonata larvae

280   assemblages (Juen *et al.* 2014; García-García *et al.* 2017; Mendes *et al.* 2018). A

281   possible explanation for this finding is that adult odonates are dependent on the physical

282   habitat structure, such as canopy cover and hanging vegetation (Vianna and De Marco,

283   2012; Mendes *et al.* 2017). Studies that considered both larval and adult odonates

284   assemblages in Brazilian streams found congruences in the spatial distribution of these

285   two life stages, which varied from >50% to >90% (Valente-Neto *et al.* 2016; Mendes *et*

286   *al.* 2017). Therefore, it is expected that environmental predictors related to light

287   exposure, such as canopy cover (De Marco *et al.* 2015), and the presence of perchers,

288   such as hanging vegetation (Rodrigues *et al.* 2019), which mostly affect adults, would

289   also indirectly affect the spatial distribution of their larvae.

290   All taxa with the strongest relation to environmental variables were Dragonflies

291   (See Fig. 3 and Supplementary Material). This group is more tolerant of environmental

292   variation and potentially more prone to colonize habitats that are distant from those

293   where they emerged (Corbet, 1999). Thus, the presence of open areas allows them to

294 exhibit higher foraging activity and higher potential for dispersal and colonization of

295 new habitats for larval development (De Marco and Latini, 1998; Corbet, 1999). The

296 removal of marginal vegetation also caused the transport of alloctone debris and the

297 growth of macrophytes and algae, which can favor the occurrence of certain dragonfly

298 genera (Mendes *et al.* 2019). For example, the *Zonophora* e *Progomphus* individuals

299 were positively affected by the proportion of human impact on marginal vegetation. We

300 believe it happened because those organisms have fossorial behavior and a preference

301 for substrates with higher sediment deposition (Corbet, 1999; Carvalho and Nessimian,

302 1998). Therefore, because they have a narrower tolerance response to environmental

303 change, some dragonflies exhibit a lower dependence on habitat integrity for both

304 colonization and development on both regional and local scales.

305 Our results show that environment changes in local-scale can affect the structure

306 of Odonata larvae assemblages along the microbasin. We believe that the presence of an

307 altered environmental may be determinant for the contrasting results we found

308 regarding the number of genera and individuals of the two odonate suborders. Finally,

309 we suggest more studies that consider different spatial scales (local and regional) in

310 regions that are subject to multiple land-use types. Also, if possible, we suggest

311 measuring the temporal dynamics of those landscapes and the behavior and preferences

312 of Odonata larvae, as they are of fundamental importance to fill the knowledge gaps

313 concerning the effects of landscape changes on the environmental conditions of streams

314 and their biological diversity.

315 **Conflicts of interest**

316 The authors declare that they have no conflicts of interest.

317 **ACKNOWLEDGMENTS**

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SUPPLEMENTARY MATERIAL

Supplementary material 1: List of families and genera with the values of abundance (N) and relative frequency (RF) of conformity of the suborders Anisoptera and Zygoptera recorded in the 30 streams sampled in the Capim river basin, in the municipality of Paragominas, Pará, Brazil.

Family	Genera	N	RF (%)
Anisoptera			
Corduliidae	*Aeschnosoma* Selys, 1870	20	4.5
	Lauromacromia Geijskes, 1970	2	0.45
Gomphidae	*Aphylla* Selys, 1854	3	0.676
	Cacoides Erichson, 1848	1	0.225
	Cyanogomphus selys, 1873	1	0..225
	Ebegomphus Needham, 1944	10	2.25
	Erpetogomphus Selys, 1858	6	1.35
	Phyllocycla Calvert, 1948	30	6.76
	Phyllogomphoides Belle, 1970	37	8.33
	Progomphus Selys, 1854	45	10.13
	Zonophora Selys, 1854	55	12.39
Libellulidae	*Argyrothemis* Ris, 1909	14	3.15
	Brechmorhoga Kirby, 1894	6	1.35
	Dasythemis Karsch, 1890	3	0.676
	Diastatops Rambur, 1842	4	0.90
	Dythemis Calvet, 1906	1	0.225
	Elasmothemis Westfall, 1988	3	0.676
	Elga Ris, 1909	3	0.676
	Erythrodiplax Brauer, 1868	9	2.03
	Fylgia Kirby, 1889	10	2.25
	Gynothemis, Calvert in Ris, 1909	25	5.63
	Oligoclada Karsch, 1890	24	5.40
	Orthemis Hagen, 1861	5	1.13
	Perithemis Hagen, 1861	9	2.03
	Planiplax Muttkowski, 1910	2	0.45
Aeshnidae	*Coryphaeschna* Williamson,1903	1	0.225
Zygoptera			
Calopterygidae	*Mnesarete/Hetaerina*	8	1.80
Coenagrionidae	*Acanthagrion* Selys, 1876	24	5.40
	Argia Rambur, 1842	24	5.40
	Enallagma Calvert, 1907	5	1.13
	Epipleoneura Williamson, 1915	22	4.95
	Idioneura Selys, 1860	1	0.225

	Protoneura Selys in Sagra, 1857	7	1.58
Heteragrionidae	*Heteragrion* Selys, 1862	13	2.93
	Oxystigma Selys, 1862	5	1.13
Perilestidae	*Perissolestes* Kennedy, 1941	5	1.13
Polythoridae	*Chalcopteryx* Selys, 1853	1	0.225
Total		**444**	**100**

Supplementary material 2: *Loadings* of the Redundancy Analysis with the local and regional predictors for the Odonata larvae assemblage structure in streams sampled in the Rio Capim river basin, on the municipality of Paragominas, Pará, Brazil.

Variable	RDA1	RDA2
Average intermediate woody canopy	-0,587	0.413
Temperature	**-0.155**	**-0.354**
Average natural shelter (leaf bank and live roots)	**0.171**	**0.634**
Volume of wood in the streambed	**-0.366**	-0.069
Percentage of algae	0.080	0.088
Proportion of shelter as excavated margin	-0,143	-0,166
Proportion of human impact per section	0,493	-0,372

Supplementary material 3: Results of RDA correlations for composition of Odonata larvae of streams sampled in the Rio Capim river basin, Paragominas, Pará, Brazil. Bolds values are correlations higher than 0.1 and -0.1.

Genera	RDA1	RDA2
Acanthagrion	-0.096	-0.075
Aeschnosoma	0.122	0.108
Aphylla	-0.190	0.014
Argia	0.078	-0.088
Argyrothemis	0.081	0.098
Brechmorhoga	0.003	-0.072
Cacoides	0.000	0.015
Calopterygidae	0.024	-0.057
Chalcopteryx	0.003	0.004
Coryphaeschna	-0.002	-0.024
Cyanogomphus	0.000	0.015
Dasythemis	0.054	0.004
Diastatops	-0.004	-0.027
Dythemis	-0.002	-0.024

Ebegomphus	0.010	-0.022
Elasmothemis	-0.004	-0.042
Elga	-0.025	-0.007
Enallagma	0.047	-0.001
Epigomphus	0.004	-0.017
Epipleoneura	-0.015	0.003
Erythrodiplax	0.033	-0.117
Fylgia	-0.109	-0.061
Heteragrion	0.004	0.072
Idioneura	0.010	-0.027
Lauromacromia	0.011	-0.001
Gynothemis	-0.614	0.149
Oligoclada	-0.137	0.011
Orthemis	0.026	-0.087
Oxystigma	0.037	0.000
Perilestes	0.046	0.052
Perithemis	0.020	-0.037
Phyllocycla	0.183	0.097
Phyllogomphoides	0.005	-0.017
Planiplax	-0.006	-0.010
Progomphus	0.261	-0.374
Protoneura	0.057	-0.021
Zonophora	0.426	0.362

Supplementary material 4. Local habitat structure variables obtained from the protocol for the 30 streams sampled in the Rio Capim river basin, municipality of Paragominas, Pará, Brazil. *Code, Mean and Standard deviation are informed.*

Categories of Local habitat variable	Habitat Structure Variable	Code	Mean	Standard deviation
Channel morphology	Mean thalweg depth (cm)	XDEPTH_T	17.456	5.989
	Standard deviation thalweg depth (cm)	XWIDTH	17.021	5.667
	Channel bar width (m)	XBAR	0.984	0.470
	Standard deviation width channel bars (m)	XBKF_H	4.304	3.623
	Mean height seasonal riverbed (m)	XWXD_P	6.534	6.139
	Wetted area section (width x depth) (m^2)	XWD_RAT_P	0.889	0.780
	Wetted area in Stretch (Width x Depth) (m^2)	XWXD	10.730	5.835
	Ratio width and depth in the section	XWD_RAT	4.823	4.888
	Angle margins (degrees)	XBKA	4.124	2.907
	Mean distance excavated margins (m)	XUN	26.367	14.870
Substrate	Mean immersion (channel) (%)	XCEMBED	50.499	15.719
	Immersion standard deviation (channel) (%)	VCEMBED	48.158	18.611
	Bedrock s - flat rock (%)	PCT_RL	50.108	18.562
	Substrate <16 mm diameter - Transect and Mesotransect (%)	PCT_SFGF	16.068	18.472
	Total organic matter (%)	PCT_ORG	27.051	24.574
	Wood (%)	PCT_WD	45.244	24.642
	Concrete (%)	PCT_RC	34.614	29.529
	Fine litter (%)	PCT_BF	9.719	8.525

Leaf bank (%)	PCT_AL	14.965	16.604
Algae (%)	PCT_MA	15.102	18.653
Macrophyte (%)	LSUB_DMM	458.232	983.288
Log10 Subst. D50	SUBDM(D50)	693.938	1019.614
SubDM(D50)	RP100	1.820	43.218
Hydraulic/Substrate — Mean residual pools (m^2 per 150m of canal)	RBS	14.168	7.759
Relative riverbed stability (critical diameter)	PCT_PR	54.844	32.808
Log10 Relative riverbed stability (critical diameter)	PCT_POOL	56.778	34.057
Impoundment pool (%)	SEQ_FLO_1	27.556	35.913
All pool types	SEQ_FLO_2	1.634	4.097
Sequence fast flow, smooth and pools (1 = Maximum heterogeneity, 0 = maximum homogeneity)	XCDENBK	47.657	37.639
Fast and slow flow sequence	VCDENBANK	46.136	37.730
Mean canopy margins (%)	XCL	51.261	38.751
Standard deviation canopy margins (%)	XCS	8.365	5.880
Mean canopy large trees	XMW	18.289	11.089
Mean canopy small trees	XMH	16.468	7.554
Mean sub woody grove	XGW	12.372	6.971
Mean sub grove herbs	XGH	12.508	8.049
Mean woody trail	XGB	14.037	8.561
Mean creeping herbs	XC	8.106	8.727

Row group labels:
- Hydraulic/Substrate
- Channel unit (types of flow)
- Riparian vegetation coverage

Mean soil exposed	XM	24.590	15.997
Mean canopy coverage	XG	26.322	10.985
Mean intermediate coverage	XCM	23.917	12.686
Mean low coverage	XCMW	45.748	26.337
Mean canopy intermediate	XCMG	37.665	21.835
Mean woody intermediate canopy	XCMGW	65.614	37.660
Mean total coverage	XPCAN	48.568	27990
Mean woody cover	C3W_150	22.556	22.712
Canopy presence by transect	C4W_150	7.000	8.970
Riverbed wood number / 150m - Size Class 3	V3W_150	3.882	8.678
Riverbed wood number / 150m - Size Class 4	V4W_150	4.581	7.454
Wood volume in riverbed / 150m - Size Class 3	C3T_150	26.978	26.032
Wood volume in riverbed / 150m - Size Class 4	C4T_150	8.289	9.393
Volume riverbed + Superior Wood / 150m - Size Class 3	V3T_150	11.677	14.704
Volume riverbed + Superior Wood / 150m - Size Class 4	V4T_150	10.270	14.167
Mean shelter - small wood	XFC_BRS	16.924	21.335
Mean shelter - living trees	XFC_ROT	11.629	12.108
Mean Shelter - leaf bank	XFC_LEB	12.833	9.529
Mean shelter - hanging vegetation	XFC_OHV	19.682	18.271
Mean shelter - excavated margin	XFC_UCB	27.053	21.725
Natural Shelter (leaf bank and live roots)	XFC_LIF	97.924	44.816
Mean anthropogenic shelter (artificial structures)	XFC_ANT	92.250	44.122
Mean large shelter	XFC_BIG	50.061	45.966
Shelter ratio - filamentous algae	PFC_ALG	18.432	22.413
Shelter ratio - Macrophyte	PFC_AQM	6.203	8.522

The row groups in the left margin are labelled "Wood" (beside the riverbed wood rows) and "Shelter" (beside the shelter rows).

	Shelter ratio - living trees	PFC_ROT	0.673	0.323
	Shelter ratio - leaf bank	PFC_LEB	0.833	0.224
	Shelter ratio - hanging vegetation	PFC_OHV	0.791	0.314
	Shelter ratio - excavated margin	PFC_UCB	0.797	0.297
Human impact	Proportion of human impact by section - Total	X_HALL	0.542	0.481
	Proportion of human agricultural impact by section - Total	X_HAG	0.445	0.415

CONCLUSÃO GERAL

Os nossos resultados demonstram que mudanças nas condições do habitat dentro dos riachos afetam a estrutura das comunidades de Odonata imaturos ao longo de microbacias impactadas por múltiplos usos do solo. Acreditamos que a presença de um ambiente alterado regionalmente foi determinante para os resultados contrastantes que encontramos em relação ao número de gêneros e indivíduos das duas subordens, regionalmente existindo mais Anisoptera do que Zygoptera. Por fim, sugerimos mais estudos que considerem diferentes escalas espaciais (locais e regionais) em regiões sujeitas a múltiplos tipos de uso do solo, uma vez que mesmo não encontrando uma relação direta das mudanças da paisagem com as comunidades de Odonata, fica evidente que as mudanças no habitat dentro dos riachos são em grande parte reflexos dessas atividades. Possivelmente, medir a dinâmica temporal dessas mudanças na paisagem, o comportamento e preferências das larvas de Odonata podem ser avanços importantes que devem ser investigados para preencher as lacunas de conhecimento sobre os efeitos das mudanças da paisagem nas condições ambientais dos riachos e sua diversidade biológica.