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The influence of small hydroelectric power plants on the richness and composition of Odonata species in the Brazilian Savanna

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Regardless of the economic and social development that damming processes related to hydroelectric power plants bring to a region, they represent a wide range of disturbances to the physical, chemical, and biological characteristics of rivers. We evaluated the effects of dams on Odonata communities from the southeastern region of Goiás, Brazil. Thirteen streams connected to three dams were studied: seven were used as reference samples (located upstream from the damming site, therefore not directly affected by damming) and six were used as affected area samples (located downstream from the dam). A total of 1128 odonates from six families, 22 genera, and 39 species were captured and identified. The results showed that Odonata richness was affected by the presence of dams, with different effects on Anisoptera and Zygoptera suborders. We discuss that these effects are related mostly to the physical and chemical variables in waterbodies directly affected by small hydroelectric power plants (SHPs). It is possible that negative effects on the Odonata community in SHP areas are related to changes in waterflow, pH and turbidity.

Keywords: Anisoptera; Zygoptera; river; dams; anthropogenic influences; dragonfly

Introduction

The construction of reservoirs is one of the oldest forms of human intervention in aquatic ecosystems (Agostinho, Julio, & Petrere, 1994; Fernandez, Agostinho, Bini, & Gomes, 2007). These reservoirs have multiple purposes such as the production of electricity, provision of industrial and domestic goods, transportation, irrigation and aquaculture. Considering the economic importance of such uses, it was expected that these reservoirs would have become more and more prolific as components of human-dominated landscapes. For instance, almost all principal rivers in Brazil have been dammed with the main purpose of generating electricity (Agostinho et al., 1994). Although there is an obvious economic impact derived from hydroelectric power plants in Brazil,

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*Corresponding author. Email: nelsonsilvapinto@gmail.com there is a growing conservation concern about the impacts on ecological processes in these landscapes (Agostinho, Pelicice, & Gomes, 2008; Álvarez-Troncoso, Benetti, Sarr, Pérez-Bilbao, & Garrido, 2015; Armanini, 2015) which demands further studies (e.g. Álvares-Troncoso et al., 2015; Richards, Gates, & Kerans, 2013).

It has been suggested that small hydroelectric power plants (power plants with capacity of 1–30 MW and maximum reservoir area of 3 km^2, hereafter SHPs) could be an alternative to traditional hydroelectric power plants, minimizing human-related impacts (Perius & Carregaro, 2012). However, studies on the environmental impacts of SHPs are still needed. One possible approach to estimate the effects of SHPs in rivers is to measure changes in the water's physical and chemical properties. This approach allows the evaluation of environmental impacts by detecting modified variables and determining their modified concentration. However, this system presents disadvantages as the variables can be volatile, revealing only a momentary picture of what could be a highly dynamic situation (Buss, Baptista, & Nessimian, 2003; De Marco & Vianna, 2005). Furthermore, waterways may capture surface runoff (i.e. nutrients and sediments from within the catchment), which can be directly affected by agricultural activities. In this way, it is possible that measuring effects on the composition and structure of biological assemblages may allow one to draw a better picture of SHP environmental impacts (Álvarez-Troncoso et al., 2015; Baxter, 1977).

Biological communities in aquatic ecosystems are thought to present evolutionary adaptations to determined environmental conditions and limited tolerance to alterations of these conditions (Statzner, Bonada, & Doledec, 2007). For instance, fish assemblages were directly affected with reductions in richness due to changes in river flow (Agostinho et al., 2008). Thus, variations in richness (or estimated richness, Agostinho et al., 2008) at a specific site are indirect but reliable measurements of the characteristics of that environment. In addition to other organisms, aquatic invertebrates are a remarkable group of organisms that are commonly used in these studies (Bonada, Rieradevall, & Prat, 2007; Statzner et al., 2007). Among the aquatic invertebrates, Odonata are one of the organisms most commonly used to evaluate human-related impacts (Monteiro, Juen, & Hamada, 2014; Miguel, Calvão, Vital, & Juen, 2017). Due to their sensitivity to environmental changes, they can be used to evaluate impacts related to human activities (reviewed in Miguel, Oliveira-Junior, Ligeiro, & Juen, 2017), as the composition of species can vary with changes in environmental conditions (Brasil et al., in press; Calvão, Nogueira, de Assis Montag, Lopes, & Juen, 2016; Carvalho, Pinto, Oliveira-Junior, & Juen, 2013; Juen & De Marco, 2011). Therefore, they can be a reliable tool in assessing the effects of SHPs on the aquatic environment.

Furthermore, considering that Odonata suborders (i.e. Anisoptera and Zygoptera) present different thermoregulatory requirements (Carvalho et al., 2013), suborder richness may be used as a tool to assess human-related impacts. According to the ecophysiological hypothesis (De Marco, Batista, & Cabette, 2015), the interaction of thermoregulation, body size and degree of available sunlight in small streams are the main predictors of local diversity patterns. Due to the limitations of thermoregulation, shaded sites in tropical regions are expected to have greater Zygoptera diversity, sharing an inverse relationship with increasing light (De Marco et al., 2015). Our objective was to evaluate the effect of damming small rivers on Odonata communities. To accomplish this task, we tested the hypothesis that Odonata richness would decrease in areas with SHPs compared to areas without SHPs (hereafter control areas). When evaluated separately, our prediction was that Anisoptera richness would be greater in SHP areas than in control areas. In contrast, we predicted that Zygoptera richness would be lower in SHP areas than in control areas due to thermoregulation restrictions (De Marco et al., 2015) and their sensitivity to changes in environmental characteristics (Carvalho et al., 2013; Juen, Oliveira-Junior, & Shimano, 2014). We predict that Odonata richness would decrease overall in dammed areas. We expect that the loss of species of Zygoptera will be larger than the increase of species of Anisoptera, because in general there is larger Zygoptera richness in streams.

Materials and methods

Study area

The study area is a core Cerrado region in the state of Goiás (Figure 1). Table 1 presents detailed information on stream location and the abbreviation list used in this study. The Cerrado biome is one of the world's biodiversity hotspots (Myers, Mittermeier, Mittermeier, Fonseca, & Kent,

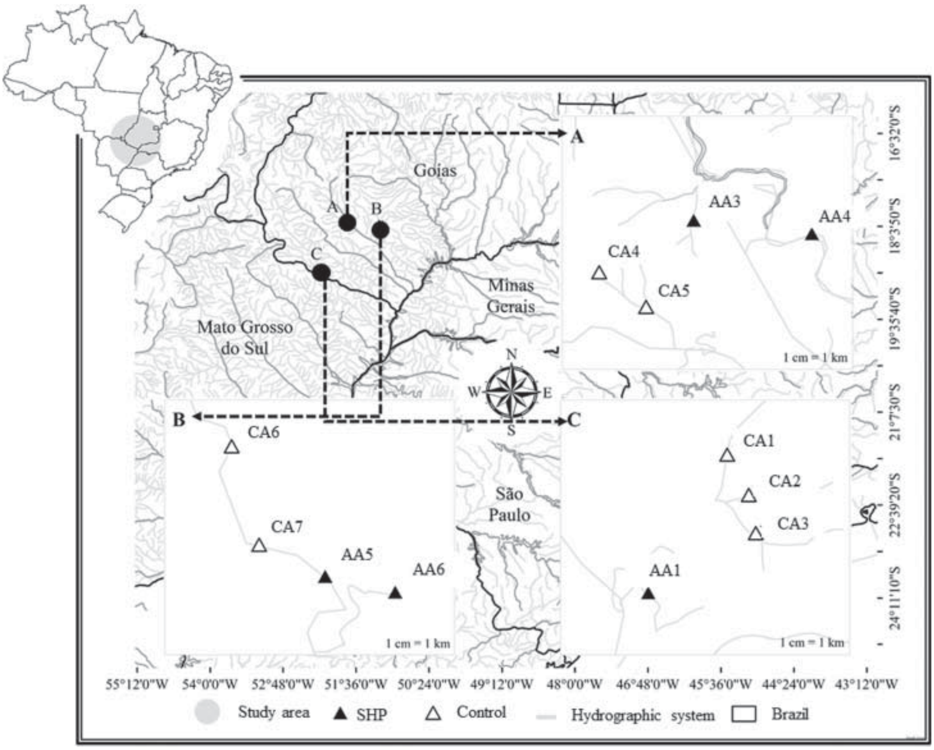

Figure 1. Geographic location of study area in the state of Goiás, Brazil. The map shows the sampled points. SHP refers to sampled points near to SHP dams. Control refers to sampled points in areas without effects of SHP dams. Refer to Table 1 for abbreviations.

Table 1. Location coordinates and abbreviations for each sampled point. SHP treatment refers to streams affected by dams due to SHP located upstream. Control treatment refers to streams that do not have dams due to upstream SHP.

Municipality	Abbreviation	Treatment	Latitude	Longitude
Aporé	AA1	SHP	18.824	52.173
Aporé	AA2	SHP	18.830	52.172
Aporé	CA1	Control	18.798	52.158
Aporé	CA2	Control	18.807	52.154
Aporé	CA3	Control	18.810	52.157
Jataí	AA3	SHP	17.929	51.751
Jataí	AA4	SHP	17.941	51.717
Jataí	CA4	Control	17.961	51.775
Jataí	CA5	Control	17.961	51.767
Aparecida do rio doce	AA5	SHP	18.066	51.167
Aparecida do rio doce	AA6	SHP	18.069	51.168
Aparecida do rio doce	CA6	Control	18.047	51.219
Aparecida do rio doce	CA7	Control	18.068	51.205

2000) and is currently affected by rapid habitat loss due to human-related activities (Brooks et al., 2002; Carvalho, De Marco, & Ferreira, 2009). The region's climate is CW mesothermic tropical (according to the Köppen Climate Classification System). There are two well-defined seasons, with high rainfall between October and April, and low rainfall between May and September. The temperature during winter varies between 10°C and 27°C. Summer temperatures vary between 18°C and 35°C.

We sampled Odonata communities from 13 streams, distributed in areas impacted by dams, and areas without impacts from dams – the reference streams. Streams affected by dams due to SHP located upstream were labeled as subject sampling points. Streams that did not have dams due to upstream SHP were defined as control sampling points. Subject sampling points were streams in the Irara SHP, Retiro Velho SHP, and Jataí SHP. These SHP are located in the Aparecida do Rio Doce, Aporé and Jataí municipalities, respectively. All control sampling points were streams in these same municipalities, but are not directly affected by SHP.

Biota sampling

We collected Odonata specimens using the method of fixed area scanning (De Marco, 1998). This method consists of sampling all specimens within a 100 m section of the subject water body, using 20 segments of 5 m. To avoid momentary climate variations, we sampled each point over three consecutive days. Sampling was conducted between 10 am and 3 pm, and only during temperatures above 19°C to ensure that sampling was performed during the insects' period of highest activity (May, 1976). We performed all collections at the end of the dry season in October of 2011. Collected material was placed in paper envelopes and submerged in acetone P.A. for 12 h for specimens of the Zygoptera suborder, and for 48–72 h for specimens of the Anisoptera suborder, for optimal preservation. Specimens were deposited as voucher material at the *Universidade Federal de Goiás* biological collection. Species were identified using specific keys (Garrison, 1990; Garrison & von Ellenrieder, 1991; Lencioni, 2005, 2006; von Ellenrieder & Garrison, 2007) and through comparisons with reference specimens from the *Universidade Federal de Goiás* collection, when necessary.

Physical and chemical measurements

We estimated the physical and chemical variables within each stream using two complementary approaches. First, we used the habitat integrity index (HII, Nessimian et al., 2008) to evaluate the physical integrity of each stream. This protocol is based on 12 questions about the stream's physical characteristics and surrounding environment. Some examples of the parameters which the HII evaluates in order to describe a stream's environmental condition are riparian vegetation width, sediment presence and characteristics, occurrence of aquatic vegetation, and patterns of land use beyond the riparian zone. The HII varies from 0 to 1, with values close to 1 representing pristine areas. Secondly, we obtained information about pH and dissolved oxygen (mg l^{-1}) with a portable pH meter and oximeter, respectively.

Statistical analysis

We compared possible differences in physical integrity between subject streams and control streams using a *t*-test. We used the HII values for each stream as the response variable and treatment (whether the stream was in an affected or control area) as the predictor variable.

Prior to our analyses in relation to Odonata richness, we estimated richness using the jackknife first-class method (Krebs, 1999). This technique produces a better estimate of species richness within a community, with a confidence interval that allows for statistical comparisons between two or more sampled regions, and is a better measure of richness as there is a bias of the observed species richness (Colwell & Coddington, 1994; Krebs, 1999). Species richness was estimated separately for each control and treatment area using the segments as samples (Colwell & Coddington, 1994) with the software EstimateS Win 7.5.0 (Colwell, 2005). The variation in the estimated species richness was calculated using the confidence interval inference technique. We used confidence intervals to compare the estimated richness for affected and control sample points. This comparison was done for Odonata (an analysis encompassing estimated Odonata richness), Anisoptera only (an analysis encompassing only estimated Anisoptera richness) and Zygoptera only (an analysis encompassing only estimated Zygoptera richness).

To test for differences in estimated Odonata richness related to the influence of treatment (affected or control areas), HII, pH, dissolved oxygen and water turbidity were used in an ANCOVA with Gaussian residual errors (Zar, 1999). To do this, we used the estimated richness as the response variable, treatment as the categorical predictor variable, and the HII, pH, dissolved oxygen and water turbidity measurements as continuous predictor variables. We also performed similar analyses for Anisoptera and Zygoptera separately.

Results

General description of Odonata assemblage

A total of 1128 adult individuals were collected, distributed in five families (Aeshnidae, Gomphidae, Libellulidae, Calopterygidae, Coenagrionidae), 22 genera, and 39 species (Table 2). Five out of the 14 families recorded in Brazil were identified in the study area. Amongst these, Libellulidae was the most abundant with 563 individuals distributed in 10 genera and 16 species, followed by Coenagrionidae with 380 individuals, eight genera, and 17 species, and Calopterygidae with 175 individuals, two genera, and three species. *Erythrodiplax* presented the largest number of individuals ($n = 494$), followed by *Argia*, with 220 individuals, and *Hetaerina*, with 159 individuals.

Physical integrity comparison between SHP and control treatments

We observed differences between HII means for SHP and control areas. The mean HII for control areas was 0.14 points higher than the mean HII for affected areas ($t = 3.08$; df $= 11$; $p = 0.01$; Figure 2).

Estimated richness

There was a difference in mean estimated richness (mean jackknife) between SHP and control areas. The estimated Odonata richness was higher in control areas than in SHP areas (Figure 3). There was also a difference between mean estimated Anisoptera richness between SHP and control areas, with higher estimated Anisoptera richness in SHP areas (Figure 4). There was also a difference between mean estimated Zygoptera richness between SHP and control areas, with higher estimated Zygoptera richness in control areas (Figure 5).

Effects of SHP, HII, pH, dissolved oxygen and water turbidity on estimated richness

There were effects of SHP, HII and water turbidity on estimated Odonata richness ($R^2 = 0.85$; $F_{5,7} = 14.83$, $p = 0.001$; Table 3). There were no effects of dissolved oxygen and pH on estimated Odonata richness (Table 3).

Table 2. Occurrence and abundance of adult Odonata species in the control and SHP affected areas in the Southwestern region of Goiás.

Suborder	Family	Species	Control	SHP	Total
Anisoptera	Aeshnidae	*Triacanthagyna caribbea*	1	0	1
	Gomphidae	*Progomphus intricatus*	5	1	6
	Libellulidae	*Diastatops obscura*	2	0	2
		Elasmothemis cannacrioides	2	5	7
		Erythemis credula	1	0	1
		Erythemis haematogastra	0	3	3
		Erythrodiplax basalis	3	45	48
		Erythrodiplax fusca	39	262	301
		Erythrodiplax juliana	10	0	10
		Erythrodiplax latimaculata	22	102	124
		Erythrodiplax maculosa	1	6	7
		Erythrodiplax paraguayensis	4	0	4
		Macrothemis sp1	0	14	14
		Micrathyria ocellata dentiens	1	0	1
		Orthemis discolor	7	22	29
		Pantala flavescens	2	7	9
		Perithemis mooma	0	1	1
		Planiplax phoenicura	0	2	2
		Elasmothemis williamsoni	1	2	3
Zygoptera	Calopterygidae	*Hetaerina rosea*	56	103	159
		Mnesarete guttifera	13	0	13
		Mnesarete pudica	3	0	3
	Coenagrionidade	*Acanthagrion cuyabae*	9	10	19
		Acanthagrion gracile	7	4	11
		Acanthagrion truncatum	3	0	3
		Argia chapadae	109	2	111
		Argia lilacina	13	2	15
		Argia mollis	1	0	1
		Argia smithiana	1	0	1
		Argia sp1	13	0	13
		Argia sp2	6	0	6
		Argia sp3	18	0	18
		Argia tinctipennis	44	11	55
		Cyanallagma ferenrigum	8	2	10
		Ischnura capreolus	16	20	36
		Telebasis carmesina	4	0	4
		Tigriagrion aurantinigrum	0	5	5
		Epipleoneura willliamsoni	2	5	7
		Neoneura sylvatica	1	64	65

There were effects of treatment, HII, dissolved oxygen and water turbidity on estimated Anisoptera richness ($R^2 = 0.88$; $F_{5,7} = 19.08$, $p = 0.001$; Table 4). There were no effects of pH on estimated Odonata richness (Table 4).

Only dissolved oxygen had an effect on estimated Zygoptera richness ($R^2 = 0.79$; $F_{5,7} = 9.00$, $p = 0.005$; Table 5). There were no effects of treatment, HII, water turbidity and pH on estimated Zygoptera richness (Table 5).

Discussion

The lower mean in overall estimated richness in the SHP areas highlights that the dams had a possible negative effect on the dragonfly communities in these areas. These impacts may also represent the accumulation of minor impacts (Candiani, Penteado, Cendretti, Santos, &

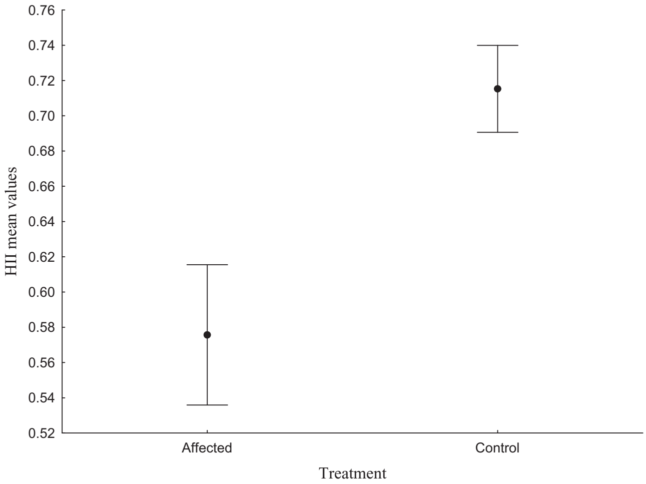

Figure 2. Mean differences in HII values in relation to treatment (SHP and control areas). SHP refers to sampled points near to SHP dams. Control refers to sampled points in areas without effects of SHP dams. Points represent mean and bars represent standard error.

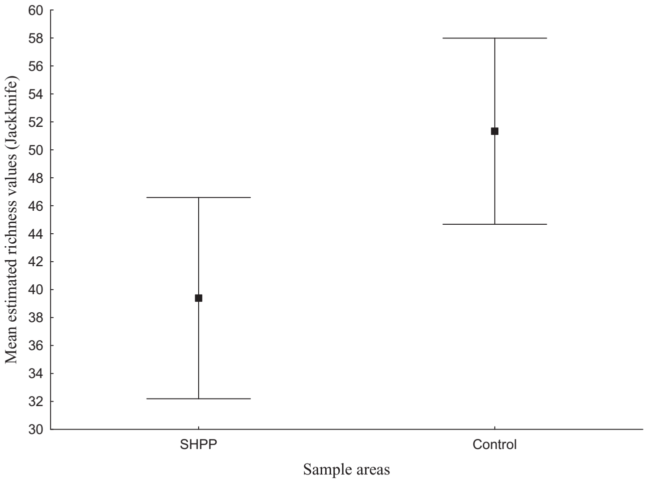

Figure 3. Mean differences in Odonata richness in relation to treatment (SHP and control areas). SHP refers to sampled points near to SHP dams. Control refers to sampled points in areas without effects of SHP dams. Squares represent mean and bars represent standard error.

Biondi, 2013) from the damming process (e.g. change in water flow, increasing or decreasing pH, changes in turbidity). The accumulation of these minor impacts may negatively affect the suitability of areas for larval development of some species (Lima, 1989). Water flow changes resulting in the conversion of lotic environments into lentic areas may favor some Anisoptera species and exclude some Zygoptera species (Carvalho et al., 2013). As an example, changes in water flow allow the colonization of generalist species (e.g. *E. fusca*) that occupy both affected and unaffected environments (Ferreira-Peruquetti & De Marco, 2002). Therefore, the changes observed in this study due to presence of dams may affect the occupation of these areas by species with a narrower niche and lead to local extinction.

According to our predictions, Anisoptera presented higher estimated richness in affected areas, and in contrast, Zygoptera presented higher richness in control areas. Two of the main differences

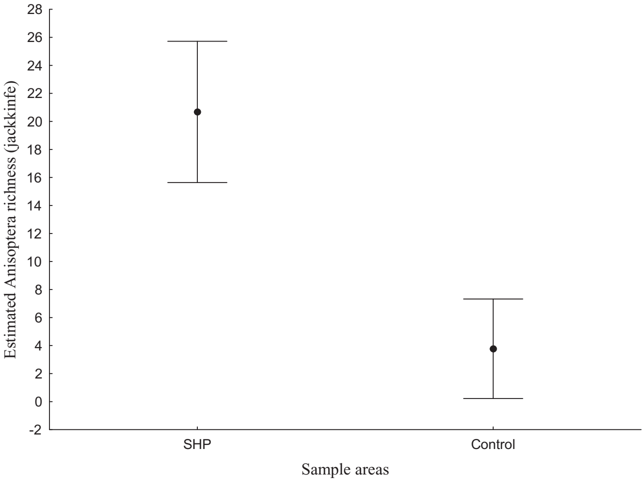

Figure 4. Mean differences in estimated Anisoptera richness in relation to treatment (SHP and control areas). SHP refers to sampled points near to SHP dams. Control refers to sampled points in areas without effects of SHP dams. Squares represent mean and bars represent standard error.

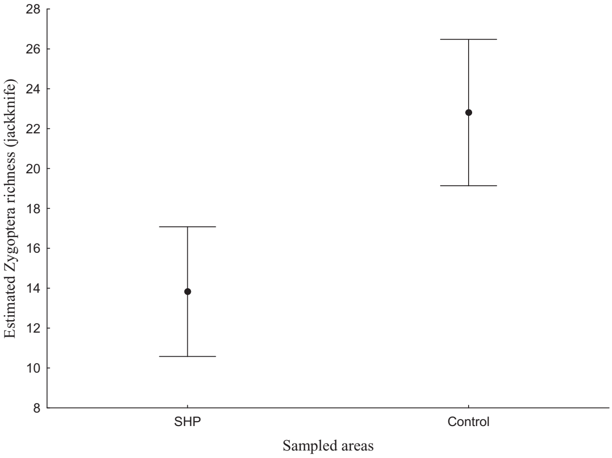

Figure 5. Mean differences in estimated Zygoptera richness in relation to treatment (SHP and control areas). SHP refers to sampled points near to SHP dams. Control refers to sampled points in areas without effects of SHP dams. Squares represent mean and bars represent standard error.

between the species of the two suborders are (1) body size, which may influence thermoregulation behavior; and (2) specific and endophytic egg laying, which could be related to lower tolerance to environmental disturbances (e.g. pH and turbidity) (De Marco et al., 2015; Juen, Cabette, & De Marco, 2007; Mendes, Luiza-Andrade, Cabette, & Juen, in press). Thermoregulation strategies in Odonata play an important role in the ability to tolerate direct insolation and higher temperatures (Corbet, 1999; May, 1976). Zygoptera species in general are smaller than Anisoptera, and thermoregulate via convection (Corbet & May, 2008). Additionally, structural changes (as highlighted by lower HII in affected areas) can maximize the incidence of light and exclude some small species. This in turn can lead to a process of community homogenization through the exclusion of species with restricted eco-physiological requirements and their replacement by Anisoptera species (Remsburg & Turner, 2009). This pattern is the same observed in other studies (Carvalho et al., 2013; Dias-Silva, Cabette, Juen, & De Marco, 2010; Juen et al.,

Table 3. ANCOVA results for treatment effects (SHP), HII, pH, dissolved oxygen and turbidity on estimated Odonata richness.

Variable	Estimate	SE	*t*	*p*
Intercept	– 195.58	133.92	1.46	0.18
Treatment SHP	236.51	42.06	5.62	< 0.001
HII	357.63	151.19	2.36	0.04
pH	10.79	14.93	0.72	0.49
Dissolved oxygen	0.52	1.69	0.31	0.76
Turbidity	– 14.75	2.08	7.1	< 0.001

Table 4. ANCOVA results for treatment effects (SHP), HII, pH, dissolved oxygen and turbidity on estimated Anisoptera richness.

Variable	Estimate	SE	*t*	*p*
Intercept	–225.66	121.67	1.85	0.11
Treatment SHP	248	38.22	6.49	< 0.001
HII	354.76	137.35	2.58	0.03
pH	19.86	13.57	1.46	0.18
Dissolved oxygen	–4.21	1.53	2.75	0.03
Turbidity	–15.75	1.89	8.35	< 0.001

Table 5. ANCOVA results for treatment effects (SHP or control), HII, pH, dissolved oxygen and turbidity on estimated Zygoptera richness.

Variable	Estimate	SE	*t*	*p*
Intercept	30.08	105.02	0.28	0.78
Treatment SHP	18.6	96.39	0.19	0.85
HII	2.88	118.55	0.02	0.98
pH	–9.06	11.71	0.77	0.46
Dissolved oxygen	4.73	1.32	3.56	0.009
Turbidity	1.002	1.63	0.62	0.56

2014; Monteiro et al., 2015), and may indicate that light incidence plays an important role in these systems.

We found important results in environmental effects: integrity (measured by HII) was lower in affected areas, and this loss of integrity influences species richness. Narrow streams are strongly influenced by riparian forests as these forests contribute vegetative material to the streams (Vannote, Minshall, Cummins, Sedell, & Cushing, 1980). If the presence of dams modifies the dynamics of energy input, then we can expect that the richness of some groups may be lower. These factors decrease the local richness through changes in resource availability, directly affecting an area's richness (Ward & Stanford, 1982).

Although these effects were overarching, the suborders were affected differently. When we considered only Anisoptera richness, we found that the change in treatment (control to affected) increased richness. Furthermore, we found that richness increased with HII, which may indicate that there is a lower limit of environmental preservation status in which even Anisoptera may be excluded. Another interesting result is that with higher dissolved oxygen and water turbidity, there is a decrease in Anisoptera richness. Turbidity and lower levels of dissolved oxygen may be related to higher water temperature and lower water flow. If this relation is true, then areas with intermediate environmental integrity may be the optimal sites for Anisoptera establishment. In contrast, Zygoptera richness was only affected by dissolved oxygen, with increasing richness in areas with higher dissolved oxygen. It is possible that areas with greater amounts of riparian vegetation, or with higher water flow and lower water temperature, present increased dissolved oxygen. These areas would then be more suitable to Zygoptera. If the damming processes related to SHP construction affect this equilibrium, this may then affect Zygoptera occurrence and establishment. Although speculative, our results present potential trends that can be tested in future studies.

Impacts due to damming can include physical, chemical, geomorphological, and hydrologic modifications resulting from spatial and temporal redistribution of the river's water flow (Petts, 1994). The new river system develops through succession after the establishment of a dam, and can reach periods of increased stability or decreased functional variability (Fernandez et al., 2007). The reduction in flow variability is important for organisms such as dragonflies, because it leads to the selection of some species at the detriment of others, and an overall reduction in diversity and number of individuals at a particular site. The effect of dams on local communities should be taken into account prior to its installation. Because of increasing energy demands, the lack of delimited protected areas, including linear habitats such as rivers and their associated ecosystems, will certainly influence the overall loss of biodiversity, particularly aquatic biota.

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