

Odonata Concordance amongst aquatic taxa in Brazilian savanna streams

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Research Article

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All relevant data are within the paper and its [Supporting Information files](#).

Abstract. Environmental management is one of the most important activities in ecological conservation at present. Faced with various socioeconomic impacts (e.g., urbanization, agriculture, and logging), practical and effective ways to analyze and determine how biodiversity is affected by these anthropogenic activities are essential. Utilizing niche theory helps to understand how similar groups of organisms respond to environmental changes based on the assumption that organisms with some niche overlap (i.e., similar resources) will respond similarly to these changes. Members of the order Odonata are frequently used as biological indicators due to their low survey costs, relatively easy taxonomic identification, and sensibility to environmental changes. In this study, using the PROTEST method, we analyze the cross-taxon congruence between Odonata and two aquatic organisms in Brazilian savanna streams: Gerromorpha and fishes. Although congruence was found between aquatic insects (~ 45%), this result changed when we only considered the species' genera: no congruence for the aquatic insects was found, but instead we found a congruence between Odonata and fishes (~ 44%). Since Odonata showed congruence with the other groups in different taxonomical resolutions and it is a relatively easy and cheap group to collect and identify, we suggest that Odonata could be used as an indicator of disturbance for this set of organisms and hence serve as an alternative method to traditional environmental management techniques.

Key words. Dragonfly, Heteroptera, Odonata, congruence, fish, environmental management, taxonomic resolution

Introduction

A fundamental matter for environmental management is to understand species distribution over landscapes (Richardson & Whittaker, 2010). The need for studies aiming at answering related questions becomes even more greater in response to the advance of anthropogenic activities (Dedieu et al., 2015; Monteiro-Júnior et al., 2014; de Oliveira-Junior et al., 2015) that induce habitat loss and environmental homogenization (Brasil et al., 2017; Gardner et al., 2013). The scenario of increasing environmental change is even more threatening because of persisting gaps in the knowledge of biodiversity, becoming a great challenge especially in countries with scarce public research investments (Gibney, 2015). Under these restrictions, it is difficult to predict how a set of species will respond to advancing anthropogenic activities, given that each species has its own life history and

responds differently to environmental factors. If those different groups also present discrepant responses to environmental gradients, any common generalization will only be partial. A conservation strategy or management option based on information about a subset of the total biodiversity will fail to efficiently encompass several species. Thus, the resources needed to develop and implement efficient and comprehensive methodological options are inevitably higher. An alternative that might decrease those costs is evaluating if species respond similarly to environmental modification.

If a set of species responds similarly to environmental stressors, designing conservation actions is simpler. Several studies have explored the congruence between taxonomic groups (higher-taxa) and numeric resolution (across-taxa) along spatial and environmental gradients, especially in aquatic environments (Bini et al., 2008; Giehl et al., 2014; Jackson, 1995; Lopes et al., 2011). By identifying such congruent taxa, it is possible to assess a common response, thus optimizing time, sampling effort and costs (Cameron et al., 2008). From a practical perspective, the existence of higher congruent ecological communities allows for a reduced effort to find ecological indicators for environmental change (Brito et al., 2018; Landeiro et al., 2012; Valente-Neto et al., 2018) and higher efficiency in spatial conservation prioritization (Cadotte & Tucker, 2018; Noss, 1990) since most species will respond similarly to environmental alterations. Nevertheless, it is possible that species distributions across environmental gradients may follow different patterns. We assume co-occurring species diverge in some dimensions of ecological space (Gause, 1934; Hardin, 1960). Accordingly, similar species should not occur in the same location at the same period of time (Tilman, 2001), thus, to be congruent, these different taxa must be functionally complementary (Tilman, 1982). For instance, in aquatic ecosystems, there are diverse life forms with various life strategies and cycles, such as fishes and insects with an aquatic larval stage and a terrestrial adult stage (Allan & Castillo, 2007). It is also a theoretical expectation that communities subject to intense environmental stress are more likely to become more homogeneous communities (Donohue et al., 2009; McGoff et al., 2013; Rooney et al., 2004). This biological homogenization process will result from the exclusion or introduction of species and groups from a given area and will produce more congruent communities (McKinney & Lockwood, 1999; Olden & Poff, 2003; Olden et al., 2004). Considering these arguments, evaluating the degree of congruence in ecological communities may support those theoretical predictions and inform about the practical use of those species as conservation bioindicators (Bilton et al., 2006; Rodrigues & Brooks, 2007; Slimani et al., 2019).

Aquatic macroinvertebrates such as Odonata and Heteroptera have been frequently used as bioindicators (Brasil et al., 2014; Dutra & De Marco, 2015; de Oliveira-Junior et al., 2015) since these organisms are easily sampled and have a high environmental sensibility

(Dias-Silva et al., 2010; Oertli, 2008). Additionally, studies for fishes are also recurrent (de Andrade et al., 2004; Teresa & Casatti, 2017), presenting a wide set of characteristics (e.g., body size, trophic level and longevity) that render them good models for bioindicator species (Chovanec et al., 2003). Although these organisms appear as good choices for bioindicator surveys, they present divergent responses to environmental disturbances (Marzin et al., 2012), which reveals a need to search for different optimal metrics and groups in environmental assessments. Congruence tests provide a way to evaluate such characteristics even within clades, which makes it possible to plan more efficient strategies according to the knowledge of resemblance between clades (Valente-Neto et al., 2016).

In this study we evaluate the pattern of environmental concordance between three different aquatic groups (fishes, Heteroptera—specifically, the infraorder Gerromorpha—and Odonata) in streams of the Brazilian savanna (hereafter, Cerrado). Both Heteroptera and Odonata are highly affected by vegetation and stream structure (de Carvalho et al., 2013; De Marco Júnior et al., 2015; Dias-Silva et al., 2010; Karaouzas & Gritzalis, 2006; Souza et al., 2015) and are predators (Klecka & Boukal, 2012). Due to those similarities in habitat requirements and resource utilization, we expect Gerromorpha and Odonata to be more congruent with each other than with fishes.

Material and methods

Study area

We studied Cerrado streams in the northern parts of Goiás state (Table 1), in the municipalities of Barro Alto (Fig. 1A) and Niquelândia (Figs 1B+C). Of the 21 streams selected (Fig. 1), seven are surrounded by natural vegetation; nine by pastures; and five by eucalyptus monocultures. These streams had the following average characteristics: depth of 26 cm, width of 3.15 m, flow rate of $0.32 \text{ m}^3 \cdot \text{s}^{-1}$, and declivity of 0.10 m. Regarding their physico-chemical conditions, the averages were: pH of 7.77, dissolved oxygen of 14.05%, and turbidity of 1.48 NTU.

Sampling and species identification

Communities of Odonata, Gerromorpha and fishes were surveyed in the dry season of 2011 (March and July). Since seasonality can affect the distributions of aquatic insects, dry seasons are better suited for sampling, especially in Cerrado areas, as this biome has two well-defined seasons and this period is more stable due to less perturbations (Bispo et al., 2006).

Surveys for all groups were made in the same 100-m linear transect delineated along each stream. Odonata adults were collected with an entomological net as they were spotted during a 60-minute period. As both

Table 1. Collection dates of samples, spatial descriptions, and land use at sites.

Site	City	Date	Coordinates (GMS)		Matrix
NI01	Niquelândia	6/14/2011	-14.183	-48.35	Forest
NI02	Niquelândia	6/14/2011	-14.215	-48.328	Pasture
NI03	Niquelândia	6/15/2011	-14.252	-48.337	Pasture
NI04	Niquelândia	6/15/2011	-14.331	-48.309	Pasture
NI05	Niquelândia	6/16/2011	-14.277	-48.726	Forest
NI06	Niquelândia	6/16/2011	-14.277	-48.726	Eucalyptus
NI07	Niquelândia	6/17/2011	-14.365	-48.718	Eucalyptus
NI08	Niquelândia	6/17/2011	-14.399	-48.727	Eucalyptus
NI09	Niquelândia	6/17/2011	-14.42	-48.735	Eucalyptus
NI10	Niquelândia	6/18/2011	-14.397	-48.355	Eucalyptus
NI11	Niquelândia	6/18/2011	-14.453	-48.368	Forest
NI12	Niquelândia	6/19/2011	-14.497	-48.658	Forest
NI13	Niquelândia	7/19/2011	-15.078	-48.965	Pasture
BA01	Barro Alto	7/20/2011	-15.094	-48.985	Pasture
BA02	Barro Alto	7/20/2011	-15.048	-48.949	Forest
BA03	Barro Alto	7/21/2011	-15.015	-48.95	Pasture
BA04	Barro Alto	7/21/2011	-15.004	-48.953	Pasture
BA05	Barro Alto	7/21/2011	-14.982	-48.94	Pasture
BA06	Barro Alto	7/22/2011	-15.132	-47.042	Forest
BA07	Barro Alto	7/22/2011	-15.096	-49.04	Pasture
BA08	Barro Alto	7/23/2011	-15.108	-49.022	Forest

adult and larval Odonata can be used for biomonitoring purposes (Mendes et al., 2017), we did not survey immatures in this study. To avoid bias stemming from thermoregulatory behavior, the Odonata surveys were conducted between 10:00 and 14:00 h on sunny and clear days. This is a common procedure for Odonata sampling in Cerrado streams (Brasil et al., 2014; De Marco Júnior et al., 2015; Dutra & De Marco, 2015). Odonata specimens were identified to species level following specific Neotropical taxonomic keys (Garrison et al., 2006, 2010; Lencioni, 2005). Gerromorpha samplings followed Cabette et al. (2010), with 20 segments of 5 m as sample. Each sample consisted of three sub-samples in each segment. The biological material was prepared and fixed in 85% alcohol, identified with taxonomic keys (Nieser & Melo, 1997; Pereira & Melo, 2007; Polhemus, 1997) to genus level and deposited in the Theory, Metacommunity and Landscape Laboratory collection at the Federal University of Goiás. Fish samples were collected in each stream from within 10 transects of 10 m (sampled patch per stream = 100 m). In each section, we trawled upstream (against the water flow), collecting all individuals. Fishes were euthanized in anesthetic solution (eugenol 5%) and preserved in formalin 10% solution after 15 minutes. Collected fish specimens were identified at the laboratory, preserved in alcohol 70% solution and deposited in the Zoological

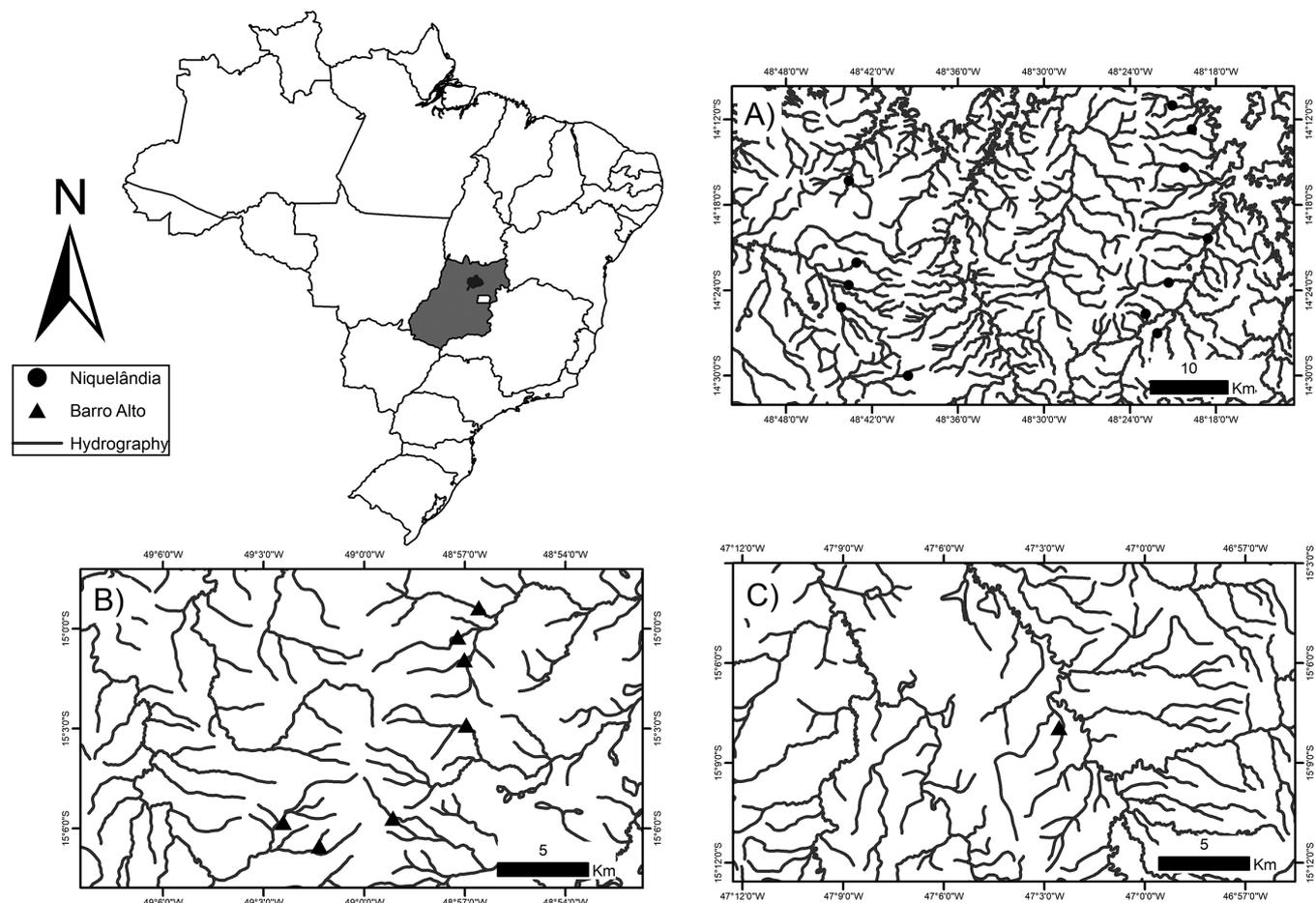


Figure 1. Sampling sites in Barro Alto and Niquelândia (dark grey), in Goiás state (light grey), Brazil. A – Survey sites in Niquelândia city (black dots); B + C – survey sites in the Barro Alto region (black triangles).

Collection of the Federal University of Goiás (ZUFG). We identified fish samples to the lowest taxonomic level possible, following literature (Buckup, 1993; Menezes, 1969; Vari & Malabarba, 1998; Vari & Reis, 1995).

Analytical procedures

Before performing the Procrustean analysis, we conducted some exploratory analysis to choose a distance measurement that best represented our original data. As both Bray-Curtis and Hellinger distances are appropriated to abundance data, we chose between these through the following procedure. First, we made a logarithmic transformation $\log(x+1)$ and calculated a Bray-Curtis and a Hellinger distance matrix. These matrices were submitted to a PCoA (Principal Coordinates Analysis) ordination and the correlation between the first two axes of the ordination and the original data was analyzed with a Pearson correlation to determine if our original data were well represented by each distance. The Bray-Curtis distance exhibited a high correlation with the abundance data of Odonata and Gerromorpha ($r = 0.607$ and $r = 0.853$, respectively; Table 2), while fishes presented a medium correlation ($r = 0.485$; Table 2). In comparison, the Hellinger distance was poorer for both Odonata and Gerromorpha and slightly better for fishes (Table 2). Hence, we performed all analyses with Bray-Curtis distances on the abundance data.

To test for congruence between Odonata, Gerromorpha and fish communities we used the PROTEST method (Legendre & Legendre, 2012; Peres-Neto & Jackson, 2001). This method analyses the relationship between two data matrices through a Procrustean superimposition of one of these matrices onto the other and then the final fit between the matrices is evaluated by a Procrustean Permutation Test (Jackson, 1995) in which the low statistic values represent high concordance between groups (Peres-Neto & Jackson, 2001). This PROTEST implementation is based on the TraceW statistic (Legendre & Legendre, 2012). Using the Bray-Curtis distance matrices, we ordinated the samples through a PCoA, whose scores were used to perform the Procrustes analysis between the groups. Also, to test for any taxonomic biases, we performed the PROTEST analysis previously explained at both species and genus levels (Gerromorpha was kept at the lowest taxonomic level identified, i.e., genus), thus testing for taxonomic resolution in our data. All the analytical procedures described here were performed using 'Software R' (R Core Team, 2020) and the package 'vegan' (Oksanen et al., 2019).

Results

We collected 67 taxa and 3549 individuals. There were 28 species and 502 individuals of Odonata, 12 genera and 2,308 individuals of Gerromorpha, and 27 species

Table 2. Correlation values between the original data and the first two axes of PCoA ordination for each methodology. R squared is given for each case. Acronyms: BC = Bray-Curtis distance; Hell = Hellinger distance.

	Hell	BC
Gerromorpha	0.659	0.853
Odonata	0.572	0.607
Fish	0.509	0.485

and 739 individuals of fish. The mean (\pm standard deviation) richness and abundance per location were, respectively, 7 (± 3) and 24 (± 8) for Odonata; 5 (± 2) and 110 (± 59) for Gerromorpha; and 4 (± 2) and 35 (± 33) for fishes. We found a divergent result concerning the congruence between the three different groups of organisms (Fig. 2). With Odonata and fishes at species level, procrustean analysis showed that only Odonata and Gerromorpha communities were congruent at the lowest taxonomic level, being $\sim 45\%$ similar ($r = 0.448$, $p = 0.029$). Fishes did not display congruence with any other group (Fishes vs Odonata: $r = 0.415$, $p = 0.057$; Fishes vs Gerromorpha: $r = 0.267$, $p = 0.423$). Also, different taxonomic resolutions had different levels of congruence. Only Odonata and fishes were congruent at genus level, being $\sim 44\%$ similar ($r = 0.436$, $p = 0.036$), while Gerromorpha did not show congruence with any other group (Gerromorpha vs Odonata: $r = 0.413$, $p = 0.053$; Gerromorpha vs Fishes: $r = 0.267$, $p = 0.425$).

Discussion

In our study, insect communities were congruent, but results were affected by the taxonomic resolution applied. Odonata should be considered the best ecological indicator since it presents a higher congruence with both fish and Gerromorpha. Our results are in line with the literature where congruence between taxa is found but with low correlations (Lopes et al., 2011; Padial et al., 2012).

Local environmental characteristics, like vegetation structure (De Marco et al., 2014; van den Berg et al., 1997) and physico-chemical properties (Forio et al., 2018), may affect abundance and richness of aquatic organisms. Odonata and Heteroptera share similar diets, being predators (Andersen, 1997; Corbet, 1999; Motta & Uieda, 2004), while a great dietary diversity is found in fishes (Brejão et al., 2013). Moreover, Gerromorpha inhabit the water surface and depend more on the quality of riparian vegetation, a condition which is also known to affect Odonata (de Carvalho et al., 2013; Dias-Silva et al., 2010; de Oliveira-Junior et al., 2015; Vieira et al., 2015). Several ecological theories address how organisms with different natural histories respond to the environment in which they are found (Leibold et al., 2004) and it is well established that organisms

regulated by the same environmental factors respond similarly (Bini et al., 2008; Juen et al., 2013; Lopes et al., 2011). The ecophysiological theory (De Marco Júnior et al., 2015) suggests that stream width would be the best predictor of favorable environmental conditions in preserved habitats. However, we are comparing organisms with substantial ecological differences. Adult Odonata depend on the environmental conditions of marginal vegetation structure (De Marco Júnior et al., 2015; Dutra & De Marco, 2015). Besides riparian zone characteristics, Heteroptera are also affected by substrate composition and the physico-chemical conditions of streams (Brasil et al., 2017). Therefore, it is likely that the congruence between Odonata and Heteroptera is not explained by the regulation of these organisms by the same factors, but rather by the correlation between marginal vegetation characteristics and physico-chemical properties and substrate conditions of streams (Giehl et al., 2019).

Congruence patterns in different groups can be explained by a combination of biotic interactions and environmental characteristics (Heino, 2002) which, in our case, might explain the congruence found between 'genus of Odonata' and fishes. The most abundant Odonata genera in our survey were *Argia* and *Hetaerina*, both of which generally employ endo- or epiphytic oviposition (Vilela et al., 2016; Veras et al., 2020) and are frequently associated with macrophytes, which also provide structural complexity and refugia for fishes (Eadie & Keast, 1984). Accordingly, Heino et al. (2005) have demonstrated a relationship between bryophyta, fish and macroinvertebrate richness. Such local biotic relationships could explain why those organisms exhibited significant congruence.

Taxonomic resolution studies in macroinvertebrates have already revealed congruence between different levels of taxa (Giehl et al., 2014; Valente-Neto et al., 2016). Despite that, when using broader taxonomic

categories, information of processes on finer scales are lost (Anderson et al., 2005). This loss of information may explain the divergent results found between the different taxonomic resolutions used in our study, i.e., species and genus. For example, fishes may present a lot of variation in resource usage within the same genus (Lowe-McConnell, 1987), which causes the loss of a considerable part of that variation when analyses are performed at higher taxonomic levels. Nevertheless, the reduction of ecological variability while considering Odonata at genus level may explain the loss of congruence with Gerromorpha communities in this approach (Milošević et al., 2017).

A word of caution is called for here: even though congruence between aquatic insects was found in our work, some studies warn us about the dangers of implying a cross-taxon relationship with low levels of correlation ($r < 0.5$). Heino (2010) reviewed several cross-taxon congruence studies in inland aquatic ecosystems and demonstrated that, in general, no correlations are found in those systems. Westgate et al. (2014) found in their global meta-analysis that different taxa would be each other's surrogates only on a few occasions. In works of this type, statistical significance will be more probable to appear in tests that involve randomization, and environmental disturbances may prejudice local diversity, creating coldspots of biodiversity and influencing coincidence between taxa (Heino, 2010). There are many ways to test and evaluate congruence in the literature (Gioria et al., 2011) that show up many disadvantages (Lindenmayer & Likens, 2011). A framework accounting for many of these uncertainties was proposed by Lindenmayer et al. (2015). For environmental biomonitoring purposes, it is generally recommended that complementary and multi-approach studies should be used to enhance the assessment of conservation efforts (Doi et al., 2013; Heino, 2010) along an ideal spatial extent (Burrascano et al., 2018; Paavola et al., 2006; Santi et al., 2016).

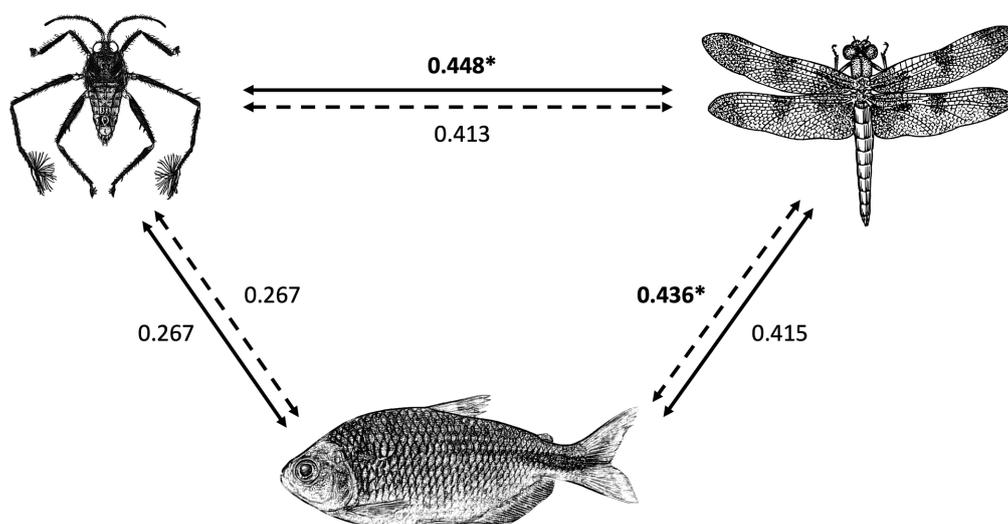


Figure 2. General congruence between Odonata, fishes and Gerromorpha communities found in this study. Full arrows represent relationships at the lowest taxonomic level, while dashed arrows are at genus level (all Gerromorpha are at genus level; see Methodology). Asterisks point out statistically significant relationships ($p < 0.05$).

Costs for field surveys and taxonomical identification are very high. They demand a considerable input of time and require highly trained professionals. The latter obstacle is aggravated by the low number of experts available as opposed to the immense Neotropical biodiversity, increasing a Linnean shortfall (Hortal et al., 2015). Finding a group that is tightly related to others may therefore lead to more effective and cheaper bioindication techniques (Carroll & Pearson, 1998; Sauberer et al., 2004).

Conclusions

We here present evidence for congruence between Odonata species and Gerromorpha genera, and between Odonata and fishes both at genus level, as well as a need for further investigations in all three groups. We preliminarily propose that adult odonates could be a good alternative bioindicator group for environmental management, as changes in this community may also indicate changes in fishes and Gerromorpha while being relatively easy to survey and identify at the same time.

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Supplementary material

Supplementary Figure S1. Procrustes analysis of Odonata and Heteroptera groups at species level.

Supplementary Figure S2. Procrustes analysis of Odonata and fishes' groups at genus level