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Odonata (Insecta) as a tool for the biomonitoring of environmental quality

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ABSTRACT

Despite the fundamental dependence of human populations on water resources, a range of anthropogenic impacts, in particular the removal of riparian vegetation, threaten freshwater environments. One of the most effective means of evaluating the effects of anthropogenic disturbance in aquatic ecosystems is the use of bioindicators, and the insects of the order Odonata are among the most efficient indicators, due to their enormous sensitivity to environmental changes. In this context, the present study aimed to verify which parameters of the odonate community (species richness, abundance/biomass, composition, taxonomic diversity and taxonomic/phylogenetic distinctness) are most effective for the evaluation of the loss of environmental integrity. The study focused on 50 streams in the northeast of the Brazilian state of Pará. The streams were sampled during the dry season, between June and August 2011. The physical characteristics of each stream were evaluated using a Habitat Integrity Index (HII). The species composition provided the best parameter for the evaluation of ecological integrity, providing a relatively accurate assessment at a lower mean research cost than other parameters. Taxonomic diversity and distinctness also provided relatively reliable results, contributed additional information on the evolutionary relationships among the odonate taxa, and also provided a low-cost approach. Deconstructing communities is necessary to detect impacts, considering the considerable variation in the environmental requirements of the different species. Overall, the parameter that best responded to gradients of disturbance was species composition, followed by diversity and taxonomic distinctness. Given these findings, odonate-based biomonitoring should focus on these parameters to guarantee the optimal detection and evaluation of habitat alterations.

1. Introduction

Despite the fundamental dependence of human populations on aquatic resources, freshwater ecosystems are among the most threatened environments on Earth (Dudgeon et al., 2006; Vörösmarty et al., 2010). The loss of biodiversity in freshwater environments may be up to five times higher than in terrestrial environments (Sala et al., 2000; Dudgeon et al., 2006; Dudgeon, 2010). A number of different types of anthropogenic impact affect freshwater ecosystems, in particular the disturbance of substrates. These processes alter natural environmental gradients (Couceiro et al., 2012) and reduce the variability of habitats by homogenizing conditions (Bleich et al., 2015). This disruption leads to a shift in the natural dynamics of biological communities (Goulart and Callisto, 2003; Couceiro et al., 2011, 2012).

The removal of the riparian vegetation from areas bordering aquatic ecosystems aggravates these impacts, and affects aquatic communities by increasing the input of sediment into the bodies of water (Nakamura and Yamada, 2005). The absence of marginal vegetation also results in a reduction in the amount of debris and organic matter found in the stream bed (Price et al., 2003), and an increase in the flow of water and the penetration of sunlight (Macdonald et al., 2003). This favors primary production, leading to an increase in the availability of prey for predatory insects, such as odonates (Oliveira Junior et al., 2013; Carvalho et al., 2013).

In aquatic systems, one of the most effective means of evaluating anthropogenic is the use of bioindicators, which are organisms or communities with functional characteristics so closely related to specific environmental factors that any change in the environment can provoke a predictable shift in the biota (Silva et al., 2010). These bioindicators may respond to habitat change on multiple spatial and temporal scales, including land use (Ometo et al., 2000; Sponseller et al., 2001; Ligeiro et al., 2013; Macedo et al., 2014), riparian vegetation (Monteiro-Júnior et al., 2013; Oliveira Junior et al., 2015), habitat complexity (Weigel et al., 2003), and physical and chemical

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variables of the water (Anjos and Takeda, 2005). The insects of the order Odonata are particularly effective bioindicators for the assessment of aquatic environments. These insects occupy the interface between aquatic and terrestrial ecosystems and are highly sensitive to environmental changes (Carvalho et al., 2013; Monteiro-Júnior et al., 2013; Oliveira Junior et al., 2015), and are extremely diverse in tropical regions (Kalkman et al., 2008). There is also a major division within the order in terms of the ecophysiological requirements of the different species (De Marco et al., 2015), and the structure of odonate communities can shift predictably in response to changes in local environmental conditions (Corbet, 1999; Juen et al., 2007; Juen and De Marco, 2011; Monteiro-Júnior et al., 2013). In particular, disturbance of the riparian vegetation has a direct effect on the structure of the adult odonate community, given that ambient temperatures have a direct influence on the occurrence of species and their reproductive cycles (Samways and Steytler, 1996). Reproductive behavior and mate choice is also impaired, given that females select males that guard the best oviposition sites in the riparian vegetation (De Marco and Resende, 2004).

Understanding patterns of species diversity related to the quality of the environment is crucial to the definition of adequate strategies for the conservation of biological diversity (Veech et al., 2002). One widely-used approach to the assessment of ecological integrity is the application of indices of biological integrity (IBI). This approach was originally proposed by Karr (1981) for North American fish communities, but it is now used in many different contexts worldwide. These indices are compiled by comparing the values of biological metrics recorded in highly degraded areas with those obtained under reference conditions, typically the least impacted habitats found within the local region (Hughes, 1995). The IBI approach, and the use of multimetric indices, has become extremely popular in North America (Angermeier and Karr, 1986; Miller et al., 1988; Whittier et al., 2007; Pyron et al., 2008), Europe (Oberdorff and Hughes, 1992; Angermeier and Davideanu, 2004), Central America (Lyons et al., 1995), India (Ganasan and Hughes, 1998), Africa (Kamdem Toham and Teugels, 1999) South America (Moya et al., 2011; Araújo et al., 2003; Bozzetti and Schulz, 2004; Terra et al., 2013; Macedo et al., 2016), and New Zealand (Joy and Death, 2004). This tool has allowed conservationists and policy makers to establish systematic priorities for biodiversity conservation in many regions (Pont et al., 2006; Ruaro and Gubiani, 2013).

The taxonomic richness and relative abundance of species are among the biological variables used most frequently in environmental assessments and multimetric indices (Clarke and Warwick, 2001), although the reliable measurement of species richness is a major problem (Gotelli and Cowell, 2001). Taxonomic richness also attributes equal importance to all species, regardless of their conservation value (Cianciaruso et al., 2009). In fact, taxonomic richness may not be sensitive to environmental impacts at all in communities where the reduction of the richness of the most sensitive species is counterbalanced by an increase in the number of more generalist species, which are resistant to changes in the environment (Carvalho et al., 2013). This is the reason why species richness and abundance are not the only biological variables used to measure environmental integrity.

The "ABC curve" (Abundance Biomass Comparison) is another method of detecting anthropogenic impacts (Warwick, 1986). This approach is based a detailed comparison of the distribution of abundance and biomass among the different species in each sample, based on the classical evolutionary theory of *r* and K selection (Clarke and Warwick, 2001). In pristine environments, communities are dominated by K strategists, dominated by relatively large organisms, resulting in a biomass curve entirely located above the abundance curve. When the system is disturbed, it will favor the emergence of r-strategists, with a predominance of relatively small individuals, and an abundance curve entirely above the biomass curve (Warwick, 1986). While this is a potentially lucrative approach, no study has yet applied it to odonate communities.

Many indices of biodiversity do not include information on the number of species or individuals in the communities (Cianciaruso et al., 2009). Metrics such as taxonomic diversity (Δ) and distinctness (Δ *), which were initially used to assess the response of benthic communities to anthropogenic disturbance (Warwick and Clarke, 1995, 1998) are highly robust, given that they take into account the phylogenetic relationships of the species based on the taxonomic classification of pairs of species in the community. These metrics are also less dependent on sampling effort because they are based on non-quantitative (presence or absence) data and are easily calculated and applied to the simultaneous analysis of a number of different communities (Clarke and Warwick, 1998; Magurran, 2004).

Given the current scenario of environmental degradation and the lack of reliable data on the distribution of most species, the development of effective strategies for the rapid and accurate assessment of ecosystems is an important priority. The present study investigated and evaluated the different types of univariate and multivariate assemblage characteristics that can be used to assess the loss of environmental integrity, with the primary objective of identifying the parameters that provide the most effective measure for the detection of impacts. The metrics tested here are standard measures used in ecological studies, including taxonomic richness, ABC curves, taxonomic composition, taxonomic diversity, and the taxonomic/phylogenetic distinctness of the target odonate assemblages.

2. Material and methods

2.1. Study area

The study was carried out in 50 stream reaches in the municipality of Paragominas, located in the northeastern portion of the state of Pará, Brazil (2°25′–4°09′ S, 46°25′–48°54′ W) (Watrin and Rocha, 1992) (Fig. 1). The predominant climate of the study region is of the "Aw" type in the Köppen classification system, that is, tropical rainy, with a short, well-defined dry season, with monthly precipitation below 60 mm, mean annual temperature of 27.2 °C, relative humidity of 81%, and mean annual precipitation of 2000 mm. Water is least available between June and December (Diniz, 1986).

The vegetation of the study area was classified, following Veloso et al. (1991), as dense rainforest, mixed open rainforest with lianas and palms, and dense alluvial forest. The most deforested area is located in the northeastern portion of the municipality, in a logging zone where hundreds of sawmills until the end of the twentieth century. Following this peak in logging, land was converted to cattle ranching and cash crop farming, activities that now predominate the local landscape (Fearnside, 2001; Pezzuti and Silva, 2009).

2.2. Data collection

2.2.1. Biological sampling

The 50 stream reaches were sampled during the dry season (from June to August 2011) given that the intense precipitation typical of the rainy season impedes access to the study sites and the collection of many variables, including adult odonate specimens, given their ecophysiological demands (May, 1976, 1991; Corbet, 1999; De Marco et al., 2015). A 150 m reach of each study stream was delimited and then subdivided into 10 sections 15 m long, separated by 11 transects (following Peck et al., 2006). The physical characteristics of the habitat of the stream channel and the riparian vegetation were measured in each transect and along the sections. Each section was subdivided in three segments of 5 m for the collection of adult odonates, with only the first two segments of each section being sampled, resulting in a sample of 20 segments per stream. All the specimens collected at a stream were combined to form a single sample for that stream. The adults were collected using an entomological net (40 cm in diameter, with a 65 cm net and an aluminum handle 90 cm long). The mean sampling time at