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Analysis of urban impacts on aquatic habitats in the central Amazon basin: Adult odonates as bioindicators of environmental quality

Cláudio da Silva Monteiro Júnior[a,b,*], Leandro Juen[b], Neusa Hamada[a]

[a] Coordenação de Biodiversidade, Instituto Nacional de Pesquisas da Amazônia, Av. André Araújo, 2936, Petrópolis, CEP 69067-375 Manaus, Amazonas, Brazil

[b] Laboratório de Ecologia e Conservação, Instituto de Ciências Biológicas, Universidade Federal do Pará, Rua Augusto Correia, N° 1 Bairro Guamá, CEP 66.075-110 Belém, Pará, Brazil

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ABSTRACT

Thirty streams were surveyed in urban and natural settings in the municipality of Manaus in the central Amazon basin (Brazil) with the objective of identifying the species of adult odonates that can be used as bioindicators of environmental quality. The data collected were used to test the hypothesis that species in the suborder Zygoptera are indicators of better-preserved environments due to their smaller body sizes and reduced tolerances to habitat modification, whereas species in the suborder Anisoptera were presumed to be indicators of impacted habitats with no vegetation. The habitats were classified as preserved, intermediate, and degraded, based on their environmental characteristics. A total of 908 specimens were collected, representing 60 species. The results of the indicator value (IndVal) identified 13 species as indicators of environmental quality, of which nine were typical of preserved habitats, two of intermediate habitats, and four of modified habitats (intermediate or degraded). Odonate species richness declined with increasing urbanization, a pattern also presented by the zygopterans, although anisopteran species richness was higher in intermediate habitats. Zygopteran species showed high fidelity/specificity for preserved habitats, although a small number of the species of this suborder showed a similar relationship with intermediate or degraded habitats, whereas anisopterans were associated only with disturbed habitats (intermediate and degraded). Overall, the results indicate that the diagnosis of the adult odonate community can provide a rapid and effective tool for evaluation of environmental quality. As many species are stenotopic, they can be used as indicators of good habitat quality, whereas some of the more eurytopic species can indicate disturbed habitats.

1. Introduction

The ongoing growth of human populations worldwide causes a series of environmental problems, including the increasing demands for foodstuffs and natural resources, as well as the expansion of urban centers (McKinney, 2006; Lal, 2007). Urbanization causes numerous changes in the landscape through the construction of buildings, paving of streets, the reduction of native habitats, and the introduction of exotic species (Booth and Jackson, 1997). The consequences of these modifications for the species will depend on the degree of disturbance and the characteristics of the organisms themselves. In birds, for example, species richness tends to be lower in urban areas (Cam et al., 2000). On the other hand, an apparent increase in the number of butterfly species was reported by Blair and Launer (1997) in areas with an intermediate degree of urbanization. However, the typical pattern for other invertebrates is a reduction of species richness, as seen in bees (Matteson et al., 2008), beetles (Sadler et al., 2006), and ants (Majer and Brown, 1986). Most of these studies have discussed the ability of a species to persist in urban environments as a function of its tolerance to habitat disturbance and its capacity for dispersal and to avoid urban hazards (Germaine and Wakeling, 2001).

In the specific case of aquatic environments, urban development typically leads to an increase in the quantity of sediments being deposited in rivers and streams, in addition to the reduction or elimination of the vegetation of the riparian zone. Urbanization also causes a reduction in the input of woody material, depriving these environments of debris that may help to dissipate the flow of energy and protect stream beds and margins from erosion. There is

* Corresponding author at: Laboratório de Ecologia e Conservação, Instituto de Ciências Biológicas, Universidade Federal do Pará, Rua Augusto Correia, N° 1 Bairro Guamá, CEP 66.075-110 Belém, Pará, Brazil. Tel.: +55 91 3201 8896.
E-mail addresses: csmonteirojr@gmail.com, claudiomonteiro80@hotmail.com (C.d.S. Monteiro Júnior).

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also a greater input of nutrients and contaminants, leading to the eutrophication of these environments (Couceiro et al., 2007). Typically, the riparian vegetation is substituted initially by grasses with superficial roots that provide little resistance to the widening of the channel (Booth and Jackson, 1994). The canopy cover over the watercourse is also lost, eliminating the shade that regulates both temperature and the input of leaf litter into the aquatic food chain (Booth and Jackson, 1997), often resulting in greater microclimatic variation.

Many organisms are sensitive to such changes in the environment due to biological characteristics such as their naturally low abundance, microhabitat requirements or the need for relatively large areas in which to establish their populations (Henle et al., 2004). This indicates that the loss of species is not random, but rather affects organisms that share certain specific ecological traits (Williams et al., 2010) that make them more vulnerable to habitat disturbance (Berry et al., 2006). In undisturbed habitats, on the other hand, established species may be able to impede the invasion of new species, and intermediate levels of disturbance may interrupt competitive hierarchies, leading to an increase in mortality and allowing the establishment of less-competitive species (Connell, 1978). Habitat disturbance may thus alter the structure of the landscape and favor certain groups of species, depending on their habitat preferences and on their behavioral and physiological characteristics.

Communities of adult and larval odonates may be affected by modifications in environmental conditions, such as presence of riparian habitats, the hydroperiod, air temperature, the concentrations of pollutants in the water and its physical–chemical characteristics (electrical conductivity, pH, dissolved oxygen and temperature), flow rates, and discharge (Corbet, 1999; Remsburg et al., 2008; Remsburg and Turner, 2009). This sensitivity to environmental conditions and the distinct phases of the life cycle of these insects, which is characterized by aquatic immature phases and terrestrial/aerial adults, may potentially provide insights into disturbances in both aquatic and terrestrial systems (Butler and de Maynadier, 2008; Foote and Hornung, 2005; Oertli, 2008).

Odonata have a wide distribution among habitats, but specific species occur in each habitat, thus making them useful as indicators of environmental quality (Clark and Samways, 1996; Monteiro-Júnior et al., 2013; Samways and Steytler, 1996; Silva et al., 2010). Many species are habitat specialists, being sensitive to changes in the environment, and may become extinct more than generalist species (Dolný et al., 2012; Suhonen et al., 2010). In the case of damselflies (Zygoptera), species diversity appears to be influenced primarily by environmental heterogeneity (McPeek, 2008), with more complex habitats favoring the establishment of larger numbers of species, given that these insects require riparian vegetation with perches due to their reduced dispersal capacity, as well as areas for foraging and reproducing, and to provide refuge from predators (Corbet, 1999; Johansson, 2000). By contrast, the removal of riparian vegetation may be favorable to the dragonflies (Anisoptera), which are generally larger in size and more tolerant of disturbance, given that they require open areas, such as forest clearings, in which to absorb sunlight (De Marco and Resende, 2002; May, 1976, 1979, 1991). Clearing therefore leads to an increase in dragonfly species richness.

Urbanization is a major cause of environmental homogenization (McKinney, 2002), and this brings as a consequence the loss of biodiversity through decreases in the richness of many species (McKinney, 2008), including odonates (Willigalla and Fartmann, 2012). However, most studies evaluating the effects of urbanization that have been conducted in lentic environments such as lakes, ponds and temporary pools either claim that there is an increase in species richness (Ackerman and Galloway, 2003; Craves and O'Brien, 2013) or did not find any indication of change (Goertzen and Suhling, 2013). However, information on the effect of the urbanization on species in tropical rainforest is scarce or nonexistent (Monteiro-Júnior et al., 2014).

In the present study we evaluate the effect of urbanization on adult odonates with change in the landscape. We evaluated the potential of odonate species as bioindicators of environmental quality in areas impacted by the urbanization process in the central Amazon basin. Specifically, we test the following hypotheses: (i) there is a higher proportion of sensitive species of Zygoptera than Anisoptera in pristine environments, and (ii) habitat integrity near streams is associated with higher species richness of odonates. We model environmental parameters that affect species richness, in particular Zygoptera, and identify potential bioindicator species of adult Odonata associated with the habitat integrity index in central Amazonia, for urban and pristine areas and for intermediate and degraded locations.

2. Materials and methods

2.1. Study area

The present study focused on streams in the Brazilian municipality of Manaus (Amazonas state), including modified watercourses within the urban zone and in well-preserved environments in the Ducke Forest Reserve, which is located on the outskirts of the city (Fig. 1). The climate is hot and humid equatorial, Am in the Köppen classification (Peel et al., 2007), with two seasons, a rainy season between November and June and a dry season between July and October. The streams have different levels of disturbance resulting from the discharge of domestic effluents directly into the water and from the total or partial removal of the riparian vegetation. The few well-preserved urban streams are found where the headwaters coincide with protected fragments of forest, as is the case for the campus of the Universidade Federal do Amazonas, which is free of domestic effluents (Couceiro et al., 2007).

The streams in the city of Manaus have a range of characteristics, ranging from heavily built-up areas with large quantities of refuse (considered to be degraded) to "intermediate" areas with fewer buildings and with vegetation on at least one margin, to relatively well-preserved habitats that have no domestic refuse and where there are adjacent areas of primary forest.

Brazil has 3,562,800 km^2 of the Amazon and state of Amazonas, with 1,531,122 km^2, has the largest area among Brazilian states (Skole and Tucker, 1993). Our study was done in an area of 400 km^2 (Fig. 1) encompassing the city of Manaus and its surroundings, this being a single sampling area with the same characteristics. The Ducke Forest Reserve, which serves as our principal site of reference, is located north of the city of Manaus. This reserve preserves its natural characteristics and represents the conditions that prevailed at the collection sites in the city before urbanization. Manaus is probably unique among major tropical cities in having a large area of protected rainforest immediately adjacent to the city, making this an ideal location for a study such as this. In 1963 when the Ducke Forest Reserve was created the city's population was estimated at about 40,000 people (Hopkins, 2005), while today it is nearly 2 million (IBGE, 2013). With this unplanned growth of population of the city of Manaus, the forest in the city has been reduced to small fragments, thus modifying these environments, including the rivers and streams that cross the city (Couceiro et al., 2007).

2.2. Data collection

The present study focused on 30 streams with differing degrees of environmental disturbance. The data were collected on the