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Functional attributes of Chironomidae for detecting anthropogenic impacts on reservoirs: A biomonitoring approach

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ABSTRACT

Organisms display sets of functional attributes that reflect local environmental conditions and can be used in environmental quality assessments. We analyzed the functional attributes of Chironomidae in reservoirs in the Brazilian semiarid region with different levels of anthropic disturbances. We examined the relationships of functional feeding groups, feeding strategies, body size, and the morphological adaptations of chironomid larvae with the environmental quality of 94 sites. The sites were classified according to their levels of anthropic disturbance based on environmental characteristics. To observe the relationship between the functional attributes of Chironomidae and the different levels of anthropic disturbance, we performed an RLQ. To test differences between the functional categories of Chironomidae, we use an analysis of variance (ANOVA). The functional categories of Chironomidae that indicated anthropic disturbances were: collector group, reduced pseudopods, abdominal tubule, and gatherers. The least disturbed sites showed higher relative abundances of engulfers, predators, organisms with elongated heads, and small body size. The observed relationships between Chironomid functional attributes and the levels of anthropic impacts on reservoirs in the semiarid region of Brazil allow their use as a tool for assessing the environmental qualities of lentic aquatic ecosystems.

1. Introduction

Intense exploitation of water resources can promote negative impacts on aquatic ecosystems, resulting in the degradation of water quality, the homogenization of their biotas, and consequent losses of ecosystem services (Duffy et al., 2007; Feio et al., 2015). Numerous countries have undertaken biomonitoring programs using benthic macroinvertebrate communities as biological indicators to accompany and evaluate water quality (Menezes et al., 2010; Feio and Dolédec, 2012; Molozzi et al., 2012, 2013; Gebrehiwot et al., 2017; Everall et al., 2017). Many characteristics of aquatic communities can be considered in those types of evaluations, and biomonitoring programs have now incorporated the functional attributes of benthic communities as alternatives, or complements to, taxonomic approaches (Bonada et al., 2006; Menezes et al., 2010; Culp et al., 2011; Feio and Dolédec, 2012; Saito et al., 2014; Dedieu et al., 2015; Vinagre et al., 2017).

Functional attributes represent measurable species characteristics linked to their adaptations to environmental drivers (Poff et al., 2006; Verberk et al., 2008a,b), and relationships between functional attributes and environmental characteristics have been fundamented on ecological theories developed in recent decades (Southwood, 1977. 1988; Townsend and Hildrew, 1994; Poff, 1997; Statzner et al., 2001; Lamouroux et al., 2004; Poff et al., 2006). The principal theoretical basis is the "habitat template", as proposed by Southwood (1977, 1988) and adapted to aquatic ecosystems by Townsend and Hildrew (1994). That theory assumes that species possess sets of attributes adequate for survival under local environmental conditions and that those attributes are independent of the specific biogeographic region under consideration.

Among the functional attributes used in biomonitoring programs to evaluate environmental conditions are functional feeding groups and body size (Feio and Dolédec, 2012; Feio et al., 2015; Saulino et al., 2016; Beauchard et al., 2017; Kuzmanovic et al., 2017; Serra et al., 2017; Castro et al., 2018). Evaluations of functional feeding groups can

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provide information concerning the processing of organic material, the availability and utilization of food resources, habitat conditions, and trophic dynamics (Feio and Dolédec, 2012; Gebrehiwot et al., 2017). Environments with large quantities of organic matter favor the occurrence of collector organisms (Armitage et al., 1995; Mondy and Usseglio-Polatera, 2014), and body size is known to vary according to the level of environmental disturbance (Basset and Angelis, 2007; Boets et al., 2013). Organisms with reduced body lengths are typical of environments subjected to high levels of disturbance, because they are directly related to short life cycles that give them greater post-disturbance resilience (Serra et al., 2017; Castro et al., 2018).

The family Chironomidae (Insecta-Diptera) have other specific attributes that can be used to evaluate local environmental conditions, including morphological adaptations, such as reduced pseudopods and elongated heads (both, typical of taxa that occur in habitats subject to constant changes), and the presence of abdominal tubules (that aid osmotic regulation and respiration under low dissolved oxygen conditions) (Armitage et al., 1995; Trivinho-Strixino, 2011). Independent of the levels of environmental degradation and the geographical location, chironomid larvae normally show high abundances when compared to other group of the benthic community, especially in reservoirs (Morais et al., 2010; Zhang et al., 2010; Molozzi et al., 2012, 2013; Li et al., 2015; Magbanua et al., 2015).

Our limited knowledge of chironomid larval attributes, however, has largely excluded them from environmental quality assessment studies (e.g., Statzner and Beche, 2010) or, if that information was included, it only considered higher taxonomic levels such as family or subfamily (Feio and Dolédec, 2012; Feio et al., 2015). A recent study indicated that functional attributes of Chironomidae could be used to differentiate between the natural characteristics of permanent and intermittent rivers in Portugal (Serra et al., 2017). The present study is the first to use a set of chironomid larval attributes (feeding groups, feeding strategies, body size and morphological adaptations) to evaluate the environmental quality of Neotropical reservoirs. Thus, we intend to verify if functional attributes of Chironomidae respond to anthropic disturbances in reservoirs in the semiarid region of Brazil.

2. Methods

2.1. Study area

Five reservoirs in two watersheds in northeastern Brazil were selected for investigation: the Sabugí and Cruzeta reservoirs, located in the Piranhas-Assu River watershed in Rio Grande do Norte State (RN); and the Cordeiro, Sumé, and Poções reservoirs, located in the Paraíba River watershed in Paraíba State (PB) (Fig. 1; Table 1). The predominant climate in that region is BSh (following the Köppen classification), with a 9–10 month-long dry season, and a mean annual rainfall of approximately 800 mm in Rio Grande do Norte and 400 mm in Paraíba (Alvares et al., 2013).

2.2. Sampling sites

We sampled 94 sites distributed among five reservoirs. The sites were pre-selected to represent different levels of anthropic disturbance. The sampling was carried out in June/2014, at the beginning of the dry period in the region (AESA, 2015). All environmental and biological variables were measured along the littoral region of the reservoirs (at an average depth of 60 cm) where the greatest species richness and abundances of benthic macroinvertebrates are generally found (Magbanua et al., 2015).

2.3. Environmental characteristics

2.3.1. Physical and chemical parameters

Dissolved oxygen levels (DO mg/L) and total dissolved solids (STD g/L) were measured at each site using a multi-parameter probe (Horiba/U-50). For the chemical analyses, a liter of sub-surface water was collected to determine the concentrations of total phosphorus (TP μg/L – utilizing the ascorbic acid method after digestion with persulfate); reactive soluble phosphate (PO_4^- μg/L – utilizing the ascorbic acid method); and total nitrogen (TN μg/L – utilizing the oxidative method). All analyses were made in accordance with the "Standard Methods for the Examination of Water and Waste Water" (APHA, 2005). The concentrations of chlorophyll-*a* (Chlo-*a* μg/L) were estimated by extraction in 90% acetone, according to the method proposed by Lorenzen (1967).

The trophic classification of each site was based on the Trophic State Index (TSI) proposed by Carlson (1977) and modified by Toledo et al. (1983). That index is calculated based on the concentrations of TP (μg/L), PO_4- (μg/L), and Chlo-*a* (μg/L) and water transparency, and is considered the index most efficient for evaluating the trophic levels of reservoirs in the Brazilian semiarid region (Azevêdo et al., 2015). Values from 0 to 44 correspond to oligotrophic environments; from 45 to 54 to mesotrophic environments; > 54 to eutrophic environments.

2.3.2. Granulometric and organic material compositions of sediments

Sediment samples were collected at each site using an Eckman-Birge dredger (area 0.225 m^2). The granulometric composition was determined following the methodology proposed by Suguio (1973) and modified by Callisto and Esteves (1996). The sediment samples were dried at 60 °C for 72 h and then agitated in a series of sieves; the particles were then classified into the categories: gravel (> 1.000 μm); coarse sand (500–1.000 μm); middle sand (250–500 μm); fine sand (250–125 μm); silt (125–68 μm); and mud (< 68 μm).

The organic material contents of the sediments were determined using a gravimetric methodology, with 3 g sediment samples being charred in a muffle at 550 °C for four hours. The organic material percentages where then calculated based on the differences between their initial and final weights.

2.4. Chironomidae assemblages

Chironomidae assemblages were collected using an Eckman-Birge dredger (area 0.225 m^2), and subsequently fixed *in situ* with 10% formaldehyde. The samples were washed in the laboratory using 1.00 and 0.50 mm sieves, and the organisms encountered were examined under a microscope and identified using specialized identification keys (Trivinho-Strixino and Strixino, 1995; Trivinho-Strixino, 2011).

Four chironomid larvae attributes (and 15 categories) were selected for the study: functional feeding group, feeding strategy, body size, and morphological adaptations (Table 2). All of the categories were evaluated at the genus level. Information concerning functional feeding groups and feeding strategies were obtained following Saulino et al. (2016) and Butakka et al. (2014), based on studies conducted in neotropical environments. Among the categories of functional feeding groups are: i) shredders that consume wood and leaf litter; ii) collectors that consume decomposing vascular plants and fine particulate organic matter (FPOM); iii) predators that usually consume diatoms and animal tissue. Among the feeding strategies are: i) filter feeders (fine detritus particles); ii) gatherers (medium detritus particles); iii) herbivores (coarse detritus particles), and iv) engulfers (algae, planktonic, benthic). The morphological adaptations evaluated were observed directly on the collected organisms, and were categorized following Trivinho-Strixino (2011). Body size was measured as the distance from the initial portion of the head to the final portion of the abdomen (cephalic and terminal appendices were not considered). The organisms were grouped into five length categories, following Serra et al. (2015): size 1 (< 2.5 mm); size 2 (2.5–5 mm); size 3 (5–10 mm); size 4 (10–20 mm); and size 5 (20–40 mm).