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Application of a statistical model for the assessment of environmental quality in neotropical semi-arid reservoirs

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Abstract The aim of this study was to develop a statistical model to assess the environmental quality of reservoirs located in semi-arid region using metrics of anthropogenic disturbance, water quality variables, and benthic macroinvertebrate communities as indicators. The proposed model was applied to 60 sites located in three reservoirs in the Paraíba river basin, Brazilian semi-arid region. Collections were made in December 2011. In each site, we collected one sample of benthic macroinvertebrates and one water sample for the determination of physical and chemical parameters. Characterization of the landscape was made through application of 10 physical habitat protocols on each site for the collected information on disturbance and subsequent calculation of disturbance metrics. The results showed the formation of two groups: group 1, consisting of 16 minimally altered sites, and group 2, with 44 severely altered sites. The proposed statistical model was sensitive enough to detect changes. In the minimally altered group, the Chironomids *Aedokritus* and *Fissimentum* were dominant, indicating a higher environmental quality, while *Coelotanypus* and *Chironomus* were abundant in severely altered sites with lower environmental quality. The conservation and management of reservoirs in semi-arid regions should be intensified in view of the need to maintain the environmental quality of these ecosystems.

Keywords Benthic macroinvertebrates · Bioindicators · Disturbance · Monitoring

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Introduction

The development and maintenance of humanity depend of the conservation of freshwater resources (Karr 1999; Ligeiro et al. 2013), which is fundamental to environmental quality. Semi-arid regions are subject to high water stress due the low average rainfall and long periods of drought. This hinders economic development, human subsistence, and environmental quality, putting substantial pressure on water resources (Ragabe and Motenegro Ragab and Montenegro 2012).

In the Brazilian semi-arid region, an alternative to mitigate drought problems is the construction of reservoirs (Gutiérrez et al. 2014). These ecosystems, although artificial, have important ecological, social, and economic functions (Tundisi 1999; Tundisi et al. 2008) and are subject to intense human pressure, such as from supply abstraction, irrigation, recreation, fisheries, and shellfish production (Pamplin et al. 2006; Mustapha

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2008). Anthropic alterations in the riparian and floodable zone of aquatic ecosystems, such as constructions, agricultural, and industrial activities (Huang et al. 2013; Kaufmann et al. Kaufmann et al. 2014a; Kaufmann et al. Kaufmann et al. 2014b), are likely to increase soil erosion, alter ecosystem services, cause biodiversity losses, and decrease water quality (Vitousek et al. 1997; Mas et al. 2004; Kindu et al. 2013).

In this context, studies on the quality of aquatic ecosystems have lately been following the tendency of being broadly conducted, considering physical and chemical characteristics of the water, morphometric data, and biological communities (Metcalfe 1989; Oliveira and Cortes 2006; Molozzi et al. 2012; Molozzi et al. 2013). The benthic macroinvertebrate community has been widely used in biomonitoring studies of aquatic ecosystems (Archaimbault et al. 2010; Wildsmith et al. 2011; Tweedley et al. 2012). This community has several features that provide information on sporadic, cumulative, and chronic environmental changes (Barbour et al. 1995; Abilio et al. Abílio et al. 2005; Gorni and Alves 2012). These organisms feature specific characteristics, such as diversity of life forms and habitats, limited mobility, large species numbers, and the possibility of an entire community to respond to environmental changes (Nazarova et al. 2004; Roque et al. 2009; Morais et al. 2010; Fu et al. 2012).

Environmental protocols have been used to assess environmental quality (Barbour et al. 1999; Buss and Vitorino 2010; Callisto et al. 2011; Macedo et al. 2012; Feio et al. 2015; Azevêdo et al. 2014). The US Environmental Protection Agency (US-EPA) has developed protocols for the characterization of physical habitats, such as rivers, lakes, and reservoirs, in terms of human disturbances. The resulting information enables the conduction of studies that include characterization of human disturbances on the banks of the ecosystem (e.g., Molozzi et al. 2013; Ligeiro et al. 2013; Feio et al. 2014; Callisto et al. 2014), given that the use of a human disturbance gradient may be advantageous for the classification of more or less disturbed sites.

In this study, we propose a statistical model of conceptual assessment to establish the environmental quality of reservoirs in semi-arid regions based on anthropogenic disturbance data (e.g., agriculture, pasture, constructions, docks/boats, and transmission lines) in floodable and riparian zones of reservoirs, using environmental variables and characteristics of the benthic macroinvertebrate community. The proposal was elaborated according to the approach of Kaufmann et al. (2014a) and Kaufmann et al. (2014b), with the aim to provide support for the management and conservation of these aquatic ecosystems. We hypothesize that sites with a lower environmental quality exhibit higher proportions of disturbance; we also expect high concentrations of nutrients and indicator taxa of macroinvertebrates in impacted sites and a higher incidence of alien species due to environmental changes.

Material and methods

Study area

The study was performed in the semi-arid region of Brazil, Paraíba river basin. The Paraíba river basin covers an area of 20,071.83 km^2 and is the second largest river basin in the state of Paraíba, northeast Brazil. Predominant soils are noncalcic brown soils. The reservoirs have an increased water residence time due to the hydrological cycle, with long drought periods (Table 1), favoring the retention of nutrients and exported sediments from the drainage basin (Freitas et al. 2011).

Table 1 Characteristics of Argemiro de Figueiredo, Epitácio Pessoa, and Poções reservoirs, Paraiba river basin, Paraíba state, Brazil (source: AESA 2012)

Reservoirs	Argemiro de Figueiredo	Epitácio Pessoa	Poções
Geographical localization	7° 27.5′ 3″ S, 35° 35′ 52.6″ W	7° 29′ 20″ S, 36° 17′ 3″ W	7° 53′ 38″ S, 37° 0′ 30″ W
Capacity (m^3)	253,000,000	418,088,514	29,861,562
Reflecting pool (m^2)	18,768,815.69	48,443,154.35	1,900,595.06
Volume % (December 2011)	81.6%	90.8%	51.5%
Construction year	2001	1956	1982
Water residence time (years)	3–5	3–5	3–5

Sampling design

In December 2010, we collected samples from 60 sites distributed in three reservoirs (Argemiro de Figueiredo, Epitácio Pessoa, and Poções) in the Paraiba river basin. In each reservoir, 20 sites along the littoral zone were selected of equidistantly form. At each sampling site, we collected one water sample (for analysis of physical and chemical parameters), one sediment sample (for granulometry and organic matter analysis), and one macroinvertebrate sample (for community metrics) and performed 10 habitat characterization protocols per site (for anthropogenic disturbance metrics). All parameters were used for assessment of the environmental quality of the reservoirs.

Physical and chemical parameters

Water samples were stored in plastic bottles and refrigerated until arrival at the laboratory. In situ, the transparency of the water was measured using a Secchi disk. With the aid of a multi-analyzer (Horiba/U-50), temperature (°C), pH, electrical conductivity ($\mu S/cm^2$), turbidity (NTU), dissolved oxygen (mg/L), total dissolved solids (TDS), and salinity (‰) were measured.

In the laboratory, we determined total alkalinity using the titration method (Mackereth et al. 1978) and subsequently filtered the samples through Whatman GF/C filters. Dissolved nutrient concentrations were analyzed according to the Standard Methods for the Examination of Water and Wastewater (Apha-Federation 2005). The filtered samples were submitted to analysis of ammonium ions ($N\text{-}NH_4$, endofenol method), nitrate ($N\text{-}NO_3$, by reduction of cadmium), and nitrite ($N\text{-}NO_2$, sulfanilamide method). The unfiltered aliquots of the samples were subjected to total phosphorous and total nitrogen analyses through digestion with potassium persulfate.

Sediment granulometry and organic matter content

At each site, sediment samples were collected to assess sediment size. The sediment samples were dried at 60 °C for 72 h, and particle size analysis was performed via mechanical separation by sieving the samples using a column with five sieves with different mesh sizes (2 mm, gravel; 0.5 mm, coarse sand; 0.25 mm, medium sand; 0.125 mm, fine sand; silt/clay <0.063 mm) for the complete separation of grains (Suguio 1973; Callisto and Esteves 1996).

Sediment organic matter contents were determined using the gravimetric method. In brief, a 0.3-g aliquot was calcined at 550 °C for 4 h in a muffle furnace. Subsequently, samples were weighed, and the difference between initial weight and weight after calcination was calculated (% dry weight).

Benthic macroinvertebrates

Macroinvertebrate samples were collected in 60 sites located in the littoral zone of the 3 reservoirs using a Van Veen dredge ($477 cm^2$). The samples were transferred to plastic bags and stored in 4% formaldehyde. In the laboratory, samples were rinsed in sieves with 1- and 0.50-mm mesh sizes and stored in plastic pots with 70% alcohol. Subsequently, the invertebrates were identified using a stereoscope and specialized bibliography (Ward and Whipple 1959; Hawking and Smith 1997; Mugnai et al. 2010). Chironomidae larvae (Diptera, Insecta) were identified to the genus level using Trivinho-Strixino (2011).

Physical habitat

For each sampling site, 10 protocols were applied, totaling 600 protocols. For the application of the protocols, we used the methodology determined by the US Environmental Protection Agency (US-EPA 2012), by which an observation area for the collection of data on physical habitats and human disturbance was defined. The observations were made in three zones (littoral, floodable zone, and riparian). The application of the protocol consisted of the following: littoral zone, 10 m wide and 15 m long; floodable zone, 15 m wide and with variable length; and riparian zone, 15 m long and 15 m wide (Macedo et al. 2014).

In this protocol, we evaluated bottom substrate of the littoral zone, presence and type of aquatic macrophytes, shelter for fish, canopy of the riparian and floodable zones, and type of undergrowth vegetation. Types of human influences also were evaluated, including presence of buildings, commercial zones, ramp/artificial beaches, presence of boats, transmission lines, fences, dike garbage or rubble, roads or railways, grain crops, pastures, orchards, and parks/lawns, among other human influences that could be detected at the time of sampling. To each evaluated item, we attributed a number from 0 to 4, corresponding to the degree of impact.

Calculation of anthropogenic disturbance metrics in the floodable and riparian zones was performed according to the methodology developed by Kaufmann et al. (2014a) and Kaufmann et al. (2014b). In this work, extension and intensity indexes of human disturbance were used in riparian and floodable zones for the composition of the metrics. According to these two studies, the human disturbance index in the riparian zone and floodable zone takes into account 12 types of impacts or human activities. Four impacts are related to agriculture (grain crops, pastures, orchards, parks/lawns) and eight to other types of disturbance (construction, commercial zones, ramp/artificial beach, docks/boats, walls/dike garbage/debris, roads/railways, transmission lines). The disturbance metric is calculated considering the presence and absence of disturbance inside or outside the analyzed plot, in that 0 corresponds to of the absence of a disturbance, 1 corresponds to the presence of a disturbance, and 0.5 to the presence of adjacent disturbances at the analyzed plot. Thus, the values can be weighted for the final calculation of the metric. The index that composes the final metric (*RDis IX*) has values ranging from 0 to 1, considering that smaller values indicate a lower degree of disturbance and higher values represent more intense disturbance. In this work, we adopted the term *RDis_IX riparian* for the disturbance metric in the riparian zone and the term *RDis_IX floodable* for disturbances in the floodable zone.

Data analysis for the application of the model for assessment of environmental quality reservoirs in semi-arid region

Development of the statistical model (Fig. 1) consists of the following steps:

1. Building a classification system based on the groups of disturbance metrics in the floodable zone (*RDis_IX floodable*) and the riparian zone (*RDis_IX riparian*) in relation to the sampling sites. Routine clustering was performed using the coefficient of Euclidean distance (CLUSTER). After formation of the groups, composed of disturbance metrics, a significance analysis was performed, using 999 permutations (permutational analysis of variance (PERMANOVA); Anderson 2001; Anderson et al. 2008). To view the intervals of disturbance metric values and the cutoff value of metrics related to the degree of disturbance, a scatter plot (*XY*) was generated in Excel X.0.
2. Assessing whether the physical and chemical variables and the benthic community for the groups formed are significantly different (using PERMANOVA). Physical and chemical data were standardized and log-transformed (log $(x + 1)$), and Euclidian distance was chosen as similarity matrix. Particle size data were transformed in arcsine to standardize data (Zar 1999). All environmental data were normalized prior to analysis. Macroinvertebrate abundance data were transformed in fourth root and the similarity of Bray-Curtis was used. The analyzes can be performed using the whole community or only Chironomidae (Diptera). PERMANOVA was used with 999 permutations (Anderson 2001; Anderson et al. 2008).
3. Characterization of the groups. Subsequent analyzes can be performed using only the genera of Chironomidae (Diptera). Principal coordinate (PCO) analysis was performed to assess which chemical and physical variables were correlated with each of the groups formed by disturbance metrics (Gower 1966). To assess correlation between variables in the environmental data matrix, Pearson's correlation (≥0.5) was performed. For the identification of predictive variables for the Chironomidae fauna, distance-based linear model (DistLM) analysis was performed with fourth-root transformed data using Bray-Curtis similarity (Legendre and Anderson 1999; Mcardle and Anderson 2001). For this analysis, the criterion Akaike Information Criterion (AIC) was chosen. The model with the lower value for AIC was considered the best-fit model. Similarity percentage (SIMPER) was used to assess the contribution of up to 90% for each of the genres between the groups; data were transformed into fourth root. All statistical analyses were performed with PRIMER-6 + PERMANOVA software (Systat Software, Cranes Software International Ltd. 2008).

Results

Considering the cluster analysis performed with human disturbance metrics in the floodable zone (*RDis_IX*

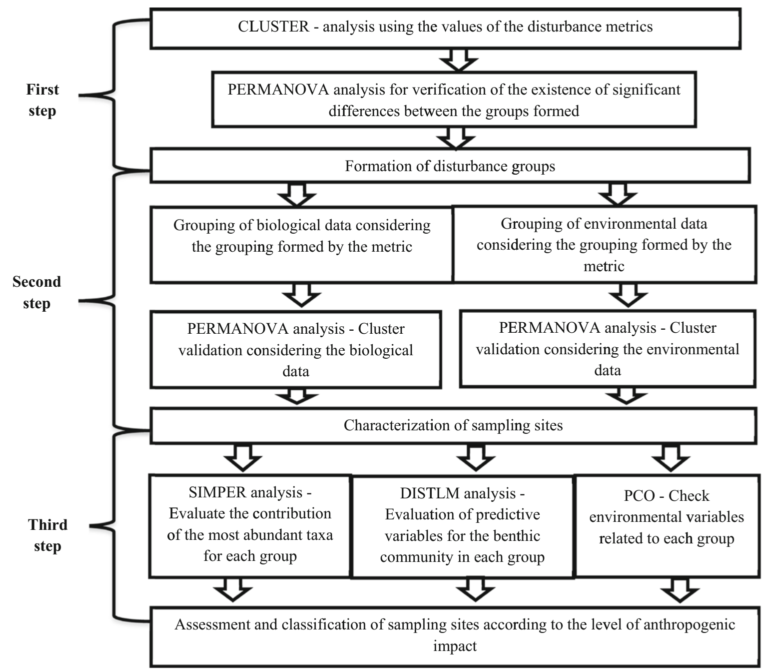

Fig. 1 Methodology used to develop the model for the environmental quality assessment of reservoirs, using metrics of anthropogenic disturbance, environmental variables, and benthic macroinvertebrates

floodable) and the riparian zone (*RDis_IX riparian*) of the sampling sites, two distinct, significantly different metric groups could be observed (Fig. 2; PERMANOVA: pseudo-$F_{1,59}$ = 86.65; P = 0.001). Thus, 16 sites were classified into group 1, of which 11 sites were located in the Argemiro de Figueiredo reservoir, 4 in the Epitácio Pessoa reservoir, and 1 in the Poções reservoir. The remaining 44 sites could be classified into group 2, with 9 sites in the Argemiro de Figueiredo reservoir, 16 in the Epitácio Pessoa reservoir, and 19 in the Poções reservoir. Group 1 had the lowest values for disturbance metrics in floodable and riparian zones. The sites established in the groups corresponded to the group formed by the CLUSTER, which was confirmed by dispersion analysis (Figs. 2 and 3).

The sites classified in group 1 showed lower proportions of activities related to anthropogenic disturbance, such as presence of constructions (3%), docks/boats, walls/dikes, and orchards (1.3%) (Table 2). In contrast, sites classified in group 2 showed higher proportions of

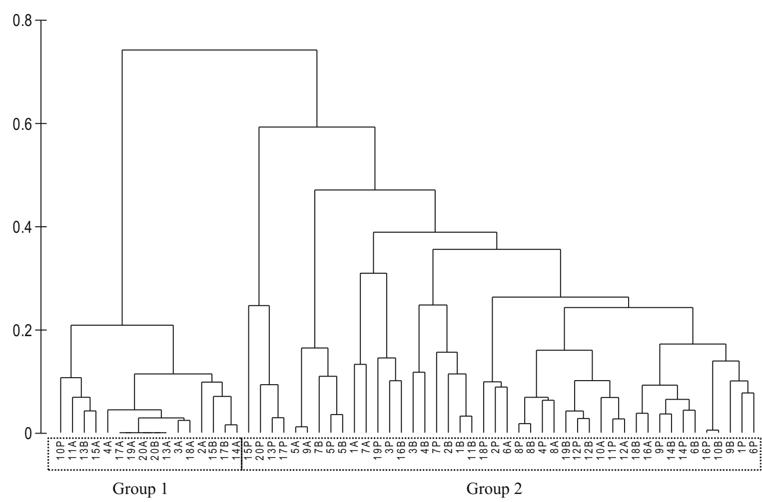

Fig. 2 Sampling sites according to the values of the disturbance metrics in the floodable zone (*RDis_IX floodable*) and riparian zone (*RDis_IX riparian*), Argemiro de Figueiredo, Epitácio Pessoa, and Poções reservoirs, Paraíba river basin, Paraíba state, Brazil

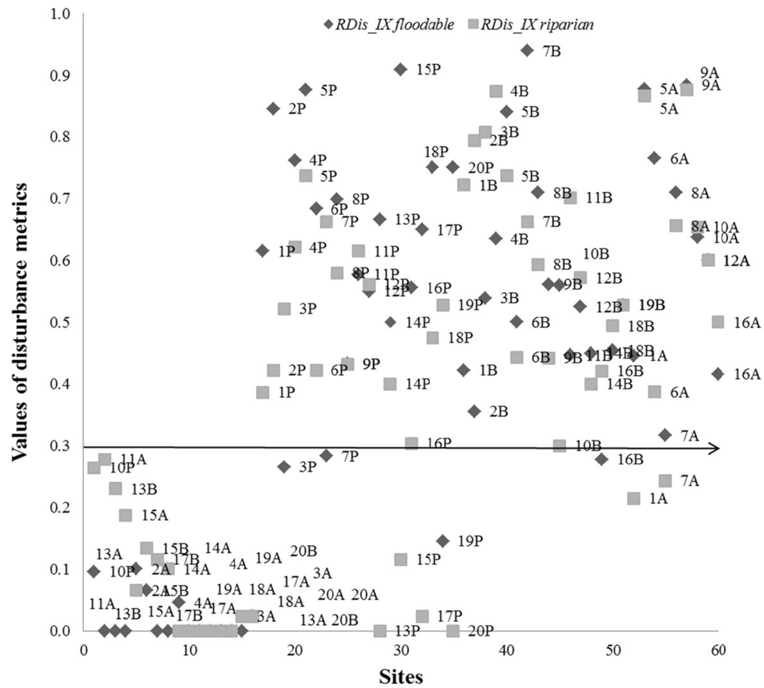

Fig. 3 Values for metrics of disturbance ranging from 0 to 1 in the floodable zone (*RDis_IX floodable*) and riparian zone (*RDis_IX riparian*). Minor disturbance values between 0 and 0.3, where *A* Argemiro de Figueiredo, *B* Epitácio Pessoa, and *P* Poções reservoirs, Paraíba river basin, Paraíba state, Brazil

activities related to anthropogenic disturbance, such as construction (15.4%), transmission lines (13.7%), pastures (11%), and docks/boats (9.4%) (Table 2).

The lowest values of disturbance metrics (*RDis_IX floodable* and *RDis_IX riparian*) were between 0 and 0.3 (Fig. 3), while the other sites had values greater than 0.3 for both or one of the disturbance metrics. Sites 16P and 10B did not fit into group 1 because the disturbance in the riparian zone was at the cutoff limit, and the value of the metric disturbance in the flood zone was greater than 0.3 (Fig. 3). Thus, sites with the value of only one of the disturbance metrics (*RDis_IX floodable* and *RDis_IX riparian*) greater than 0.3 were grouped in group 2.

Table 2 Proportion of activities related to anthropogenic disturbance in sites classified in the groups 1 and 2

	Group 1	Group 2
Construction (%)	3.0 (*n* = 7)	15.4 (*n* = 36)
Commercial zones (%)	[a]	2.6 (*n* = 6)
Ramp/artificial beach (%)	0.9 (*n* = 2)	5.1 (*n* = 12)
Docks/boats (%)	1.3 (*n* = 3)	9.4 (*n* = 22)
walls/dike (%)	1.3 (*n* = 3)	9.0 (*n* = 21)
Garbage/debris (%)	0.9 (*n* = 2)	8.5 (*n* = 20)
Roads/railways (%)	[a]	2.6 (*n* = 6)
Transmission lines (%)	0.9 (*n* = 2)	13.7 (*n* = 32)
Grain crops (%)	[a]	1.7 (*n* = 4)
Pasture (%)	0.4 (*n* = 1)	11.1 (*n* = 26)
Orchard (%)	1.3 (*n* = 3)	6.4 (*n* = 15)
Park/lawn (%)	0.4 (*n* = 1)	4.3 (*n* = 10)

n corresponds to the number of sampling sites

[a] Nonrecorded

We found significant differences between the two groups in terms of physical and chemical variables (PERMANOVA: pseudo-$F_{1,59}$ = 4.7651; P = 0.001). Group 1 was lower in total P (total phosphorous, 637.5 mg/L ± 434.48), P-PO_4 (orthophosphate, 55.87 g/L ± 83.18), N-NO_3^- (nitrate, 31.31 ± 11.62), N-NO_2^- (nitrite, 5.07 ± 2.23), and middle sand (12.62% ± 6.85) compared to group 2 (Table 3). The other variables, pH, total-N (total nitrogen), N-NH_4 (ammonia), gravel, coarse sand, fine sand, silt/clay, and organic matter showed no significant differences between the two groups; some sites classified in group 1 showed high values, which explains the high standard deviation (Table 3). The first axis of the principal coordinates analysis explained 48% of the total variation of data, while the second axis explained 22.9% (Fig. 4). The results show that group 2 was characterized by highest values of total P, P-PO_4, N-NO_3^-, N-NO_2^-, and middle sand (Fig. 4 and Table 3).

Table 3 Mean values of physical and chemical variables in both groups of disturb

Minimum, maximum, and mean values of the environmental variables				
	Group 1		Group 2	
	Min-Max	Mean	Min-Max	Mean
Temperature (°C)	25–31	28.9 ± 1.12	26–32	28.61 ± 1.39
pH	7.40–8.8	8.1 ± 0.30	7.12–8.82	7.99 ± 0.40
Oxi-redox potential (mV)	142–226	197.5 ± 21.61	87–240	184.63 ± 30.11
Conductivity (mS/cm)	0.72–1.12	1.015 ± 0.15	0.72–1.12	0.85 ± 0.13
Turbidity (NTU)	17.6–326	116.8 ± 97.39	1.6–628	129.1 ± 160.40
Dissolved oxygen (mg/L)	7.17–11.55	9.64 ± 0.97	1.84–14.16	8.96 ± 2.33
Total dissolved solids (g/L)	0.464–0.716	0.64 ± 0.09	0.464–0.715	0.54 ± 0.08
Salinity %o	0.04–0.06	0.04 ± 0.007	0.04–006	0.04 ± 0.004
Alkalinity (mg/L $CaCo_3$)	13–27	21.37 ± 3.96	4–29	21.61 ± 6.21
Total phosphorous (μg/L)[a]	235–1515	637.5 ± 434.48	265–1635	1009.7 ± 378.16
$P\text{-}PO_4$ (μg/L)[a]	4–359	55.87 ± 83.18	4–449	191.15 ± 170.93
Total nitrogen (μg/L)	326–1493	907.07 ± 356.37	129–1782	874.9 ± 584.52
$N\text{-}NH_4$ (μg/L)	1.46–298	53.57 ± 72.86	1.44–618	124.6 ± 155.04
$N\text{-}NO_3^-$ (μg/L)[a]	17–63.17	31.31 ± 11.62	7.45–67.19	41.5 ± 13.29
$N\text{-}NO_2^-$ (μg/L)[a]	2.63–12.38	5.07 ± 2.23	0.26–23.71	8.44 ± 5.90
Chlorophyll a (μg/L)	0.449–196	14.94 ± 48.53	0.449–228	49.4 ± 64.42
Organic matter (% DW)	1.05–9.88	3.52 ± 2.77	0.53–15	5.22 ± 4.58
Gravel (%)	3.15–4.75	38.43 ± 22.89	2.34–74	27.14 ± 23.20
Coarse sand (%)	75–77	24.43 ± 16.51	9–45	23.87 ± 9.00
Average sand (%)[a]	3–26	12.62 ± 6.85	5–47	17.94 ± 8.06
Fine sand (%)	0.43–25	13.41 ± 7.70	1.2–60	17.7 ± 12.26
Silt/argile (%)	0.02–37	11.09 ± 11.51	0–38	13.3 ± 11.50

PO_4 orthophosphate, *NH_4* ammonia, *NO_3* nitrate, *NO_2* nitrite, *Min.* minimum, *Max.* maximum

[a] Significantly different variables among groups of disturbance

Across the 60 samples sites, we collected a total of 11,145 macroinvertebrates belonging to 23 taxa (4 Mollusca, 2 Annelida, 11 Diptera, 3 Odonata, 1 Heteroptera, 1 Ephemeroptera, and 1 Decapoda) (Table 4). Considering all taxa, there was no significant difference between groups. However, using only Chironomidae genera (Diptera, Insecta), significant differences were observed between the two groups (PERMANOVA: pseudo-$F_{1.35}$ = 3.5916; P = 0.005) (Table 3). This was corroborated by SIMPER analysis, which showed that groups had a 91.48% dissimilarity regarding the contribution of Chironomidae genera. In group 1, the genera *Goeldichironomus* and *Aedokritus* were the major contributors, with 71 and 28%, respectively (Table 5). The genera that most contributed to group 2 were *Goeldichironomus*, *Coelotanypus*, and *Chironomus*, with a contribution of 56, 32, and 11%, respectively (Table 5).

The genus *Chironomus* showed a higher density in group 2 (145.32 ind/m^2 ± 725.27), followed by *Goeldichironomus* (273.96 ind/m^2 ± 1121.71). The genus *Fissimentum* was recorded with a higher density in sites located in group 1, with a density of 7.86 ind/m^2 ± 31.44. In contrast, *Parachironomus* and *Coelotanypus* were restricted only to sampling sites grouped in group 2 (Table 4).

The DistLM analysis showed that the predictive variables for the Chironomidae fauna in group 1 were mainly fine sand, orthophosphate, and coarse sand, while the fauna grouped in group 2 was mainly predicted by conductivity, gravel, sand average, and temperature (Table 6). This analysis was also performed to

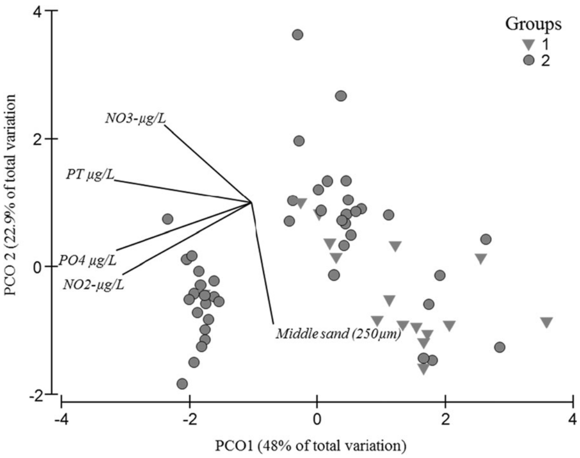

Fig. 4 Principal coordinates analysis showing the relationship of the groups of sites with indicator variables of environmental impact (PT, P-PO_4, N-NO_3^-, and N-NO_2^-), Argemiro de Figueiredo, Epitácio Pessoa, and Poções reservoirs, Paraíba river basin, Paraíba state, Brazil

verify the environmental variables that influenced *Melanoides tuberculata* (Müller 1774) clams, mainly pH, TDS, total P, and N-NO_3^- ($R^2 = 0.35$).

Analysis of disturbance metric assessment of physical and chemical characteristics of water and evaluation of Chironomidae fauna allowed to classify 25% of the sampling sites as minimally altered (group 1) and 75% as severely altered (group 2).

Discussion

In this study, we showed that the statistical model proposed by the characterization protocol of physical habitats, physical and chemical parameters, and Chironomidae genera can be used to assess the water quality of reservoirs in semi-arid regions. The purpose of the model was to include the whole benthic community; however, the high abundance of the exotic species *M. tuberculata* impeded the recognizability of differences in terms of disturbance metrics. Due to the high ecological plasticity among Chironomidae genera, organisms with fragile and strong dynamics were found, which suggests that they are suitable environmental indicators particularly in aquatic ecosystems of semi-arid regions, which have more extreme environmental conditions (Barbosa et al. 2012). Thus, we advise that tests in each area are performed both including the whole community and using only Chironomidae.

Human influence around the sites promotes increased nutrients, reducing environmental quality (Verdonschot et al. 2012; Barbone et al. 2012) and changes to aquatic communities, as observed in our study (Navarro et al. 2009), considering that the sites classified as severely altered (group 2) had higher nutrient concentrations. The highest degree of disturbance in these sites was related to higher proportions of construction, transmission lines, and pastures. Human disturbance around the reservoirs directly affects the Chironomidae fauna (Simião-Ferreira et al. 2009), which was reflected by the presence of the genus *Chironomus* at severely altered locations. The presence of irrigated crops around reservoirs in the Brazilian semi-arid region causes an increase in organic nutrients and, therefore, a response by the benthic fauna, as noted by the increase in genera indicators in impacted environments (Abílio et al. 2005, 2007). In a study in rivers with trout farming in Guadalajara, Spain, Camargo et al. (2011) showed that sites with lower environmental quality were influenced by high concentrations of nutrients, particularly ammonia and phosphate.

High degrees of disturbance favor high densities of generalist organisms (Brauns 2007). Santana et al. (2009), studying a stream in the Brazilian semi-arid region, associated the dominance of a single group of macroinvertebrates, or the presence of few species, to anthropogenic disturbance, which was observed in our study, with the dominance of the exotic mollusk *M. tuberculata* in both groups. However, in studies conducted in tropical reservoirs, a difference in the abundance of these exotic organisms was observed in places with maximum ecological potential and impacted sites (Molozzi et al. 2013). This was not observed in our study, since minimally and severely altered sites showed high densities of this mollusk. However, *M. tuberculata* is commonly very abundant in aquatic ecosystems in Brazilian semi-arid regions (Paz et al. 1995; Abílio 2002; Abílio et al. 2006). This may be related to the basic pH of the water in this area and to high concentrations of carbonate ions, which favor the formation of shells in the mollusks. It also emphasizes the ability of *M. tuberculata* to burrow into the sediment closing its lid, increasing resistance to desiccation and enabling survival up to 26 months in aestivation (Abílio et al. 2007). Such behavior also increases the potential for recolonization in periods of water stress as observed in semi-arid regions.

Table 4 Average density (ind/m^2) of macroinvertebrates in the two disturbance groups, Argemiro de Figueiredo, Epitácio Pessoa, and Poções reservoirs, Paraíba river basin, Paraíba state, Brazil

Taxons	Group 1	Group 2 (ind/m^2)
Mollusca		
Melanoides tuberculata, Müller, 1774	3486.63 ± 3479.50	3227.55 ± 3401.99
Planorbidae	[a]	41.92 ± 111.66
Pomacea	[a]	0.47 ± 3.16
Corbicula largillierti, Philippi, 1844	[a]	0.47 ± 3.16
Annelida		
Oligochaeta	47.16 ± 167.62	82.42 ± 295.45
Hirudinea	1.31 ± 5.24	9.52 ± 25.35
Diptera		
Ceratopogonidae	[a]	0.95 ± 4.41
Chironomidae		
Chironomus, Meigen, 1803	1.31 ± 5.24	273.96 ± 1121.71
Goeldichironomus, Fittkau, 1965	26.2 ± 62.42	145.32 ± 725.27
Fissimentum, Cranston & Nolte, 1996	7.86 ± 31.44	0.95 ± 6.32
Parachironomus, Lenz, 1921	[a]	0.95 ± 4.41
Aedokritus, Roback, 1958	18.34 ± 47.11	0.95 ± 6.32
Asheum, Sublette & Sublette, 1983	1.31 ± 5.24	[a]
Coelotanypus, Kieffer, 1913	[a]	103.39 ± 337.62
Clinotanypus, Kieffer, 1913	[a]	0.47 ± 3.16
Thienemanniella, Fittkau, 1957	[a]	0.47 ± 3.16
Cladopelma, Kieffer, 1921	1.31 ± 5.24	[a]
Odonata		
Gomphidae	3.93 ± 11.40	1.42 ± 5.34
Libellulidae	[a]	2.38 ± 8.10
Coenagrionidae	[a]	0.95 ± 4.41
Heteroptera		
Corixidae	[a]	0.47 ± 3.16
Ephemeroptera		
Baetidae	1.31 ± 5.24	[a]
Crustacea		
Decapoda	32.75 ± 93.43	7.14 ± 27.10

[a] Nonrecorded

Díaz et al. (2008), studying Spain's semi-arid rivers, related anthropogenic disturbances such as agriculture, quality of riparian vegetation, and nutrient supply to the influence in the organization of the benthic macroinvertebrate community. This was not observed in this study when analyzing the whole community, although positive responses were observed with the use of Chironomidae genera, as observed in studies carried out by Brauns (2007) in German lakes, which showed a 72.5% increase in the abundance of Chironomidae in lakes with low levels of disturbance and 96.4% in more disturbed lakes. This was also observed in our study, in which higher densities of disturbance indicator genera, such as *Goeldichironomus*, *Chironomus*, and *Coelotanypus*, occurred in severely altered sites (group 2). The presence of *Chironomus* was related to sites with higher concentrations of $P\text{-}PO_4$, $N\text{-}NO_3^-$, and $N\text{-}NO_2^-$. In studies conducted in reservoirs in the Brazilian

Table 5 Average abundance of taxa that contributed to 90% of Chironomidae fauna (Insecta, Diptera) (SIMPER analysis) between sampling sites in both groups, Argemiro de Figueiredo, Epitácio Pessoa, and Poções reservoirs, Paraíba river basin, Paraíba state, Brazil

Genera of Chironomidae	Group 1	Group 2
Goeldichironomus, Fittkau, 1965	71	56
Coelotanypus, Kieffer, 1913		32
Chironomus, Meigen, 1803		11
Aedokritus, Roback, 1958	28	

southeast, south, and in the semi-arid region, major contributions of the genus *Chironomus* were observed in eutrophic reservoirs (e.g., Dornfeld et al. 2005; Takahashi et al. 2008), demonstrating its relation to sites with organic enrichment (Abílio et al. 2005).

Highest environmental quality was observed in minimally altered sites, which was confirmed by the presence of the genera *Aedokritus* and *Fissimentum*. Although some studies associate *Aedokritus* to sites with organic enrichment (e.g., Dornfeld et al. 2005), in our study, the presence of this genus was related to better environmental conditions, as confirmed by the lower values of disturbance metrics and lower nutrient concentrations. The genus *Fissimentum* has already been recognized as an indicator of better environmental conditions. They are sensitive to organic pollution and usually live in relatively unaltered environments (Leal et al. 2004; Morais et al. 2010; Molozzi et al. 2013). The sites classified as minimally altered must be preserved and used as models for the recovery of other severely changed sites. The environmental assessment for conservation planning is of fundamental importance in the context of an anthropogenic influence that threatens biodiversity and integrity of natural ecosystems, mainly in semi-arid regions (Raunio et al. 2011).

Table 6 Environmental variables selected by distance based on linear model (DistLM) for the benthic macroinvertebrate community

Variables	Group 1				Group 2				
	AIC	Pseudo-*F*	*P* value	Cumul.	Variables	AIC	Pseudo-*F*	*P* value	Cumul.
Fine sand	44.86	30.60	0.001	0.42	Conductivity (mS/cm)	125.70	12.23	0.001	0.22
P-PO_4 (μg/L)	43.25	30.40	0.002	0.54	Alkalinity (mg $CaCo_3$/L)	116.70	11.67	0.001	0.40
Coarse sand	41.62	28.00	0.005	0.63	Gravel	109.00	98.70	0.001	0.52
pH	39.50	39.70	0.005	0.72	Sand average	104.60	60.80	0.001	0.58
Turbidity (NTU)	37.70	23.70	0.012	0.82	Temperature (°C)	100.37	57.77	0.001	0.64
Gravel	35.90	21.75	0.041	0.82	Fine sand	95.73	6.0	0.001	0.69
Alkalinity (mg $CaCo_3$/L)	33.31	23.00	0.037	0.87	Redox-potential-oxygen (mV)	90.78	6.20	0.001	0.73
Total phosphorous (μg/L)	30.10	23.10	0.055	0.90	pH	85.00	66.32	0.001	0.77
Dissolved oxygen (mg/L)	25.43	25.85	0.039	0.94	Coarse sand	78.60	7.23	0.001	0.81
P-ortho (mV)	20.52	21.60	0.107	0.95	N-NO_3^- (μg/L)	72.63	66.00	0.001	0.84
Temperature (°C)	13.19	23.76	0.115	0.97	Dissolved oxygen (mg/L)	65.74	71.64	0.001	0.87
Sand average	74.60	12.42	0.371	0.98	Organic matter (%DW)	59.00	67.70	0.001	0.89
Total nitrogen (μg/L)	−60.87	16.42	0.379	0.99	N-NO_2^- (μg/L)	51.90	69.43	0.001	0.91
					Turbidity (NTU)	44.60	6.81	0.001	0.93
Best solution group 1					Total nitrogen (μg/L)	36.67	70.95	0.001	0.94
AIC	R^2	Variables			N-NH_4 (μg/L)	31.50	48.00	0.003	0.95
−6.08	0.99	14			P-PO_4 (μg/L)	26.57	44.00	0.001	0.96
Best solution group 2					Salinity %	22.87	34.57	0.130	0.96
AIC	R^2	Variables			Total phosphorous (μg/L)	19.90	28.76	0.020	0.96
19.85	0.97	20			Silt/clay	19.90	10.86	0.350	0.97

PO_4 orthophosphate, *NH_4* ammonia, *NO_3* nitrate, *NO_2* nitrite

Conclusion

Minimally altered sites were identified by low values of disturbance metrics, by lower nutrient concentrations and by Chironomidae genera, which are indicators of relatively high environmental quality. Human activities on the perimeter of the reservoirs reduce the complexity of floodable and riparian zones, causing siltation and degradation of the ecosystem, thereby reducing environmental quality. In this light, the proposed statistical model proved to be an effective tool in assessing the environmental quality of semi-arid reservoirs. However, in reservoir evaluation studies of semi-arid regions, Chironomidae genera should be used due to the high abundance of *M. tuberculata* found in the region.

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