Development of a benthic multimetric index for biomonitoring of a neotropical watershed

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(With 4 figures)

Abstract

Biotic indices are important tools for evaluating water quality in Biomonitoring Programmes of river basins. The objective of this study was to develop a Benthic Multimetric Index (BMI) to evaluate the water quality in a neotropical catchment in southeastern Brazil. Thirty metrics were evaluated and six were selected to calculate the BMI: family richness, % Oligochaeta, % Chironomidae + Oligochaeta (% CHOL), % EPT (Ephemeroptera, Plecoptera and Trichoptera), % Collector-gatherers, and BMWP-CETEC biotic index. Sampling was carried in triplicate at 21 sampling sites (8 in the river channel and 13 in the tributaries) during 4 annual collecting trips from June 2004 to November 2007, making a total of 945 samples. Scores (5, 3 or 1) were attributed to each chosen metric and were added up to establish the water quality criteria (a score of 6-12 – poor; 13-18 – intermediate; 19-24 – good; and 25-30 – very good water quality). Our results indicated that 48% of the sampling sites analysed in the catchment basin presented very good water quality, 14% good quality, 19% regular, and 19% poor water quality. This methodology proved to be an efficient tool for evaluating water quality in the Biomonitoring Programme of the Velhas River basin, and that it may serve to evaluate water quality in other river basins in South America.

Keywords: benthic multimetric index, biomonitoring, water quality, macroinvertebrates.

Desenvolvimento de um Índice Multimétrico Bentônico para o biomonitoramento de uma bacia hidrográfica neotropical

Resumo

Índices bióticos bentônicos são importantes ferramentas na avaliação da qualidade de água em programas de biomonitoramento de bacias hidrográficas. O objetivo deste estudo foi desenvolver um Índice Multimétrico Bentônico (IMB) para avaliar a qualidade das águas em uma bacia hidrográfica no sudeste do Brasil. Trinta métricas foram avaliadas e 6 foram selecionadas para compor o IMB: riqueza de famílias, % Oligochaeta, % Chironomidae + Oligochaeta (% CHOL), % EPT (Ephemeroptera, Plecoptera e Trichoptera), % Coletores-catadores e índice BMWP-CETEC. Foram realizadas amostragens em triplicatas em 21 estações amostrais (8 na calha do rio e 13 nos tributários) em 4 coletas anuais de junho de 2004 a novembro de 2007, totalizando 945 amostras. Foram atribuídos escores (5, 3 ou 1) a cada métrica selecionada e somados para o estabelecimento do critério de qualidade de água (escore de 6 -12 – águas de qualidade ruim; 13-18 – regular; 19-24 – boa; 25-30 – muito boa). Nossos resultados mostraram que 48% das estações de amostragem analisadas na bacia apresentaram águas de muito boa qualidade, 14% de qualidade boa, 19% regular e 19% de qualidade ruim. Esta metodologia apresentou-se como eficiente ferramenta de avaliação da qualidade de água no programa de biomonitoramento da bacia hidrográfica do Rio das Velhas e poderá contribuir para a avaliação da qualidade de água de outras bacias hidrográficas na América do Sul.

Palavras-chave: índice multimétrico bentônico, biomonitoramento, qualidade de água, macroinvertebrados.

1. Introduction

The main environmental problems responsible for the degradation of water quality are caused by human activities. Rapid population growth and industrialisation have put aquatic ecosystems under increasing pressure, particularly in developing countries (Thorne and Williams, 1997; Souza and Tundisi, 2003). The multiple anthropic impacts include artificial eutrophication, siltation, homogenisation of the river channel, construction of dams, removal of riparian vegetation, and introduction of alien species (Goulart and Callisto, 2003; Camargo et al., 2004; Hall et al., 2006).

Ecological studies have used a variety of approaches to evaluate the quality of water and the degree of degradation of freshwater ecosystems in response to different levels of pollution. For example, knowledge of the characteristics of aquatic assemblages can demonstrate some of the characteristics of the ecosystem, such as information about its current status and spatial and temporal changes (Usseglio-Polatera et al., 2000).

Biomonitoring is defined as the systematic use of response of biological variables to evaluate changes in the environment, usually caused by anthropogenic actions (Rosenberg and Resh, 1993; Buss et al., 2003). The organisms considered bioindicators are chosen for their sensitivity or tolerance to the presence of stressors (Bonada et al., 2006). Their abundance and behaviour reflect the effects of the stressor on the biota (Barbour et al., 1996).

At the end of the 80s, special attention was focused on benthic macroinvertebrates in the development of biotic indices using the score system (Baptista et al., 2007) for evaluating water quality in river basin biomonitoring programmes (Armitage et al.,1983; Wright and Armitage, 1993; Smith et al., 1999; Stoddard et al., 2005; Feio et al., 2009). Most of these indices are based on the structure of benthic macroinvertebrate communities and on their degree of tolerance to different levels of environmental stress (Yuan, 2004; Feio et al., 2009).

Some authors emphasise the importance of using bioindicators to diagnose impacts on aquatic ecosystems spatially and temporally. Callisto and Moreno (2005) used benthic macroinvertebrates to evaluate the impacts on a eutrophised urban reservoir and its tributaries. Their use may reveal pollution of anthropogenic origin and habitat degradation, as well as underpin the development of multimetric indices of biotic integrity (Semenchenko and Moroz, 2005; Walsh, 2006; Baptista et al., 2007).

The first official use of a biological method for assessing water quality in British rivers was in 1970. Later, in response to criticisms about the adequacy of the method, the BMWP index (Biological Monitoring Working Party) was developed in 1976 and recommended for use in river pollution surveys (Hawks, 1997).

The use of multimetric approaches to evaluate water quality in freshwater ecosystem monitoring programmes has gained increasing attention in the last 15 years (Barbour et al., 1996; Pinto et al., 2004). However, multimetric approaches should be used cautiously due to the natural variability inherent to many metrics. Regional variation in the indication of multimetric indices can potentially limit their applicability on broader spatial and temporal scales (Bonada et al., 2006).

The objective of this study was to evaluate the water quality of a river basin in southeastern Brazil by developing and applying a Benthic Multimetric Index (BMI), using the methodology based on the approach of Barbour et al. (1996) and Baptista et al. (2007). We tested the hypothesis that the metrics resulting from bioindicator taxa chosen to compose the BMI reflect the intensity and magnitude of anthropic impacts on aquatic ecosystems. The predictions were that: i) pollution from untreated domestic and industrial effluents increases the predominance of pollution-tolerant benthic taxa; and ii) that habitat degradation due to anthropic activities leads to loss of benthic diversity.

2. Material and Methods

2.1. Study area

The Velhas River basin is located in the central region of the state of Minas Gerais, southeastern Brazil (Figure 1). It has a length of 801 km and drains an area of 29,173 km^2 (Paz et al., 2008). The basin encompasses 51 municipalities with a population of approximately 4.5 million inhabitants. The economic importance of these municipalities represents 42% of the Gross Domestic Product of the state of Minas Gerais, while the metropolitan region of Belo Horizonte, the state's capital city, has a population of approximately 2.4 million (Paz et al., 2008; Moreno et al., 2009).

The main impacts in the metropolitan region of Belo Horizonte are caused by industrial activities, principally mining; disposal of raw domestic sewage; removal of riparian vegetation; construction of dams for electrical power generation and supply; and the introduction of alien species (Callisto et al., 2005; Muzzi and Stehmann, 2005; Moreno et al., 2009). As a consequence of these impacts, there is a considerable loss of quality of the water and aquatic biodiversity in several stretches of the basin (Callisto et al., 2005).

Several tributaries distributed along the basin in protected areas have good water quality and sufficient habitats for the maintenance of several species of benthic macrofauna (Paz et al., 2008; Moreno et al., 2009).

2.2. Field and laboratory activities

From a total of twenty-one sampling sites (Figure 1), thirteen were used to develop the index (nine reference and four impacted sites - P5, P6, P7 and P11). Sampling was carried out four times a year, from June 2004 to November 2007 (twice during the rainy season in November and February and twice in the dry season in May and August, except in 2004, when only three campaigns were carried out). A total of 945 samples of benthic organisms were collected in triplicate, using a Surber sampler (0.09 m^2 and 250 µm mesh size) in the 15 collection periods. Benthic macroinvertebrates were identified at the family level with the help of identification keys (Pérez, 1988; Merritt and Cummins, 1996; Wiggins, 1996; Ward et al., 2002; Pés et al., 2005; Mugnai et al., 2009). Functional feeding groups were classified according to Merritt and Cummins (1996) and Cummins et al. (2005). Mollusks, annelids and crustaceans were identified only as classes. Sediment samples were collected at each sampling site for analysis of their granulometric composition. Physicochemical parameters were measured in the sub-surface of the water column (electrical conductivity, pH, temperature and total dissolved solids), using portable Digimed devices. Total nitrogen and phosphorus (mg/L) concentrations were measured in the laboratory following the methodology proposed by MacKereth et al. (1989) and Strickland and Parsons (1960), respectively.

The indices of Pielou's evenness and Shannon-Wiener diversity were calculated (Magurran, 1991) and BMWP - CETEC (Biological Monitoring Working Party) (Junqueira et al., 2000).

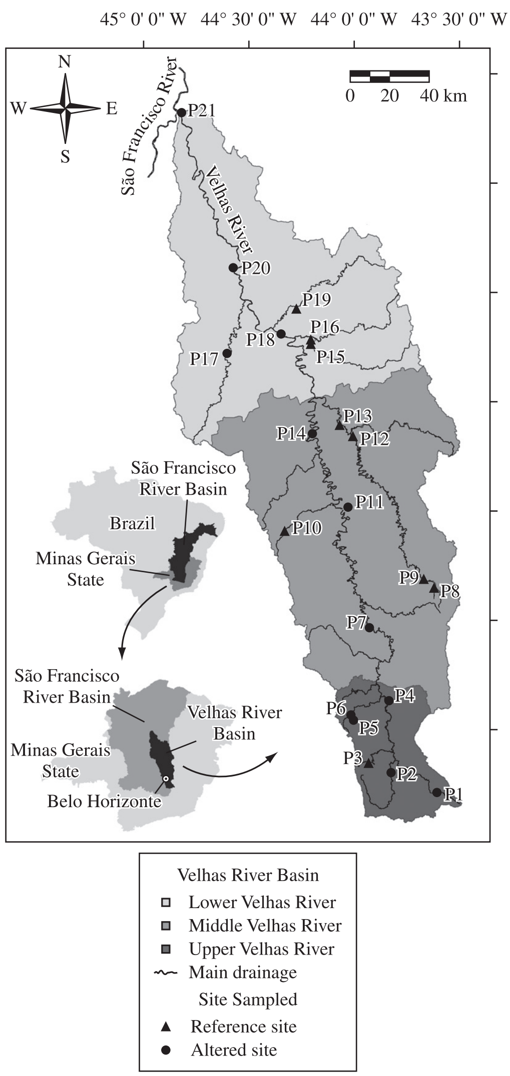

Figure 1. Map of the sampling sites in Velhas River basin (Laboratório NUVELHAS - Projeto Manuelzão/UFMG).

A total of nine reference sites were defined according to Paz et al. (2008) and Moreno et al. (2009). Stretches of rivers whose springs lie in protected areas (such as National Parks and Private Protected Areas), such as the Pedras stream located in the Parque Nacional da Serra do Cipó (PARNA Cipó) in the state of Minas Gerais and in minimally disturbed areas according to evaluations by the Rapid Assessment Protocol proposed by Callisto et al. (2002), were considered as reference sites. These stretches of rivers have sufficient habitats to maintain benthic organisms, and the values of their physicochemical parameters fall within the limits of tolerance for Class 1 waters established by current Brazilian legislation (Brasil, 2005).

2.3. Data analysis

2.3.1. Selection of benthic metrics

Thirty metrics were evaluated for this study in order to compose the Benthic Multimetric Index (BMI). The metrics were selected taking into consideration the ecological aspects of the communities of benthic macroinvertebrates and their responses to anthropic impacts in stretches of rivers of the Velhas River basin (Table 1).

The representativeness of the abundance of organisms and the Mann-Whitney test for comparing reference and impaired sites are examples of criteria for the selection of metrics.

2.4. Stage 1 – Sensitivity of the metrics

The sensitivity of the metrics that represent the differences between reference and altered sites were tested according to the degree of overlapping of the interquartiles of Box-and-Whisker plots, following the methodology proposed by Barbour et al. (1996) (Figure 2).

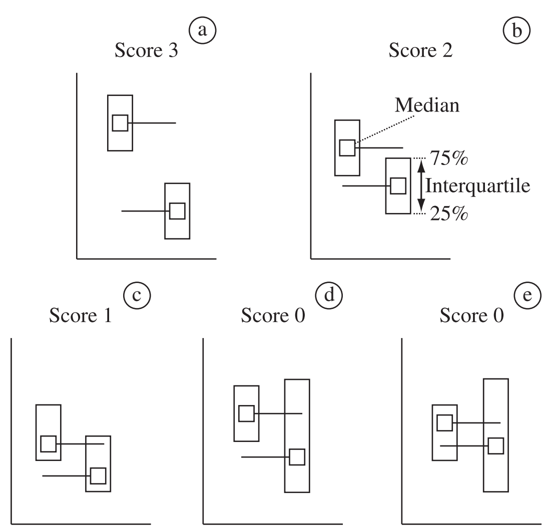

Figure 2. Sensitivity scores of the metrics according to the criteria proposed by Barbour et al. (1996). Box plots (smaller squares represent the medians and larger ones the interquartiles of 25-75%). a) score 3 – highest sensitivity; b) score 2; c) score 1; and d, e) score 0.

Core metrics were normalised into unitless scores. Because metrics have different numerical scales, they were normalised for aggregation into an index, as proposed by Karr et al. (1986), Karr (1991), Barbour et al. (1996), and Baptista et al. (2007).

For metrics whose numbers were expected to decrease with increasing pollution or disturbance, numbers above the lower quartile (25%) of the reference distribution were given a score of 5. On the other hand, for metrics whose numbers were expected to increase in response to disturbance, each value below the upper quartile (75%) of the reference distribution was given a score of 5. Therefore, the appropriate quartile was used as a threshold, depending on the type of response to degradation. A score of 5 indicated that the sample is part of the reference population, a score of 3 indicated an intermediate condition, and a score of 1 indicated the highest deviation from the expected numbers for reference sites (Figure 3).

2.5. Stage 2 – Redundancy among metrics

To avoid redundant information and simplify the index, a Spearman correlation was drawn with paired metrics. Metrics with Spearman correlation values of r > 0.75 were considered redundant and at least one of them was eliminated.

2.6. Development of the Benthic Multimetric Index (BMI)

The limit value (6 to 30) obtained from the aggregation of the scores attributed to each metric was quadrisected (in bands of equal values) in order to establish the four ordinal categories of water quality: Very good (25-30): waters of excellent quality and ecological reference conditions; Good

Table 1. Metrics selected and prediction of responses to disturbances in aquatic ecosystems (Barbour et al., 1996; Baptista et al., 2007) (EPT – Ephemeroptera, Plecoptera and Trichoptera; % CHOL – Chironomidae and Oligochaeta; BMWP - Biological Monitoring Working Party; ASPT – Average Score Per Taxon; CETEC – Centro Tecnológico de Minas Gerais; Col - *Colombia*).

Category	Metrics	Predictions of responses against the impacts	Observation
Number of *taxa*	Richness	Decrease	High values were related to environments with good water quality and habitat sufficient for sustainability of macrofauna
	Ephemeroptera *taxa*	Decrease	
	Plecoptera *taxa*	Decrease	
	Trichoptera *taxa*	Decrease	
	Coleoptera *taxa*	Decrease	
	EPT *taxa*	Decrease	
Tolerance measures	BMWP-CETEC	Decrease	The number indicates the degree of sensitivity of organisms to different types and levels of anthropogenic impacts
	ASPT-CETEC	Decrease	
	BMWP-Col	Decrease	
	ASPT-Col	Decrease	
	EPT/Chironomidae	Decrease	
	Baetidae/Ephemeroptera	Increase	
Composition measures	Diversity of Shannon-Wiener	Decrease	Diversity and composition of organisms
	Evennes	Decrease	
	% Chironomidae	Increase	Relative abundance of a particular family or group for the total fauna
	% Oligochaeta	Increase	
	% CHOL	Increase	
	% EPT	Decrease	
	% Ephemeroptera	Decrease	
	% Plecoptera	Decrease	
	% Trichoptera	Decrease	
	% Coleoptera	Decrease	
	% Diptera	Increase	
	% Odonata	Increase	
	% Gastropoda	Decrease	
Trophic measures	% Collector-filterers	Decrease	Relative abundance of organisms according to their feeding strategy in trophic structure of assemblages of macroinvertebrates
	% Collector-gatherers	Variable	
	% Shredders	Decrease	
	% Scrapers	Decrease	
	% Predators	Variable	

(19-24): waters with a low degree of alteration with good quality ecological characteristics; Regular (13-18): waters with a considerable degree of alteration, compromising the establishment of many benthic organisms sensitive to pollution; and Poor (6-12): which represents waters with a high degree of impact, containing domestic sewage, low dissolved oxygen concentrations, and degraded habitats, favouring the colonisation of tolerant organisms such as Oligochaeta and Chironomidae larvae (Baptista et al., 2007).

We used Pearson correlation with the metrics of BMI and physical and chemical variables of the studied ecosystems, using Excel software, Office 2007 for Windows, in order to determine which metrics were positively or negatively influenced by physical and chemical variables.

3. Results

The assessment of the ecological characteristics of the evaluated sites using the rapid assessment protocol (Callisto et al., 2002) showed that 10 (47.6%) had scores ranging from 62-87, characterising these sites as well preserved or natural. Eight (38.1%) of the sites were altered and presented a score of 42-60. Three (14.3%) of the sites were impacted due to loss of habitat, sediment deposition in the channel, presence of raw sewage and removal of riparian vegetation and presented a score of ranging 33-40.

3.1. Metrics decision

Of the thirty metrics evaluated, 15 were considered sensitive according to Box-and-Whisker plots graphs (Figure 4) and significantly different in a comparison of the reference and impacted sites ($p < 0.05$ – Mann-Whitney test) (Table 5).

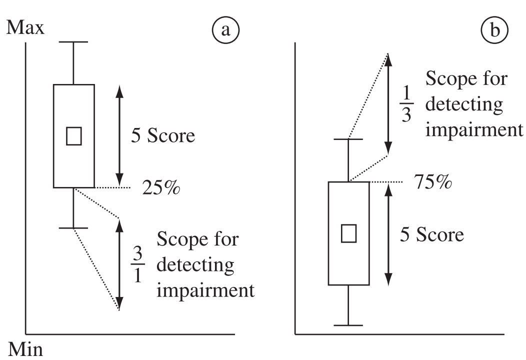

Figure 3. Criteria for the establishment of the scores of the metrics for the detection of anthropic impact: a) metrics that reduce the values in response to the increase of anthropic impacts, and score 5 represents the values found above the percentile of 25%; and b) metrics that increase the values in response to the increase of anthropic impacts, and score 5 represents the values below the percentile of 75%. Smaller squares represent the median values and the boxes represent the interquartiles (percentile of 25-75%), modified from Barbour et al. (1996).

Some of the metrics were redundant (Richness vs. Evenness; % EPT vs. EPT taxa; BMWP – CETEC vs. BMWP – Col.; ASPT – CETEC vs. ASPT Col.) (Table 2). Whenever a pair of metrics showed a high correlation ($r > 0.75$), one of them was excluded. The BMWP-CETEC metric was selected because it was adapted to the upper stretch of the basin under study. Metrics showing the highest representativeness were also chosen to distinguish the reference sites from impacted sites (taxonomic richness, % CHOL – aggregation of Chironomidae and Oligochaeta, % Oligochaeta, % EPT). Relative abundances of feeding groups (% Collector-gatherers, % Collector-filterers, % Shredders, % Scrapers and % Predators) were used as metrics to develop the BMI. Among the metrics that allocate organisms into functional feeding groups, the metric % of collector-gatherers was chosen due to its higher representativeness and abundance of organisms in a comparison of the reference sites and the altered sites. The analysis was carried out with Statistica version 6, 2001, software StatSoft, Inc.

Thus, 6 metrics were selected to establish the BMI taking into account the metrics that yielded the highest values in the Mann-Whitney test (Taxonomic Richness; % Oligochaeta; % CHOL; % EPT; % Collector-gatherers and BMWP-CETEC) (Table 3).

3.2. Correlation of the metrics that comprise the BMI and physicochemical variables in the water column and sediments

An analysis of Pearson's correlation indicated that the metrics that make up the BMI showed a correlation ($p < 0.05$) of the parameters of electrical conductivity, total-P, total-N, dissolved oxygen, total dissolved solids, pebbles, gravel, coarse sand, silt and clay, and the result of the application of the Rapid Assessment Protocol of ecological conditions (Table 4).

3.3. Testing the BMI

In our evaluation of the water quality of the Velhas River basin, the BMI was tested at the 13 sites used to develop the index and at 8 other sites along the watershed. Among the twenty-one sites, 10 (48%) presented waters of very good quality, 3 showed (14%) good quality, 4 (19%) regular quality, and 4 (19%) poor quality.

These data corroborate the physicochemical parameters analysed over stretches of the rivers sampled. The city of Belo Horizonte is the main contributor to the degradation of ecological conditions in the basin of the Velhas River where the sampled portions of the metropolitan area and surrounding areas (P4, P5, P6, P7 and P12) showed the highest concentrations of nitrogen and phosphorus originating from the discharge of raw sewage. The highest values of total P-total and N-total were found at site P6 (0.81 and 16.2 mg/L) and the lowest values were found at site P4 (0.1 and 1.6 mg / L). In other parts upstream and downstream of the city of Belo Horizonte where the rivers had waters ranging from regular to very good quality, the values of P-total ranged from 0.01 to 0.11 mg/L and total-N ranged 0.2 to 1.6 mg/L.

Table 2. Spearman correlation to verify redundancy (r > 75%) in the metrics elected as valid for inclusion in the Benthic Multimetric Index of the Velhas River basin (EPT – Ephemeroptera, Plecoptera and Trichoptera; % CHOL – Chironomidae + Oligochaeta; BMWP - Biological Monitoring Working Party; ASPT – Average Score Per Taxon; CETEC – Centro Tecnológico de Minas Gerais; Col. - *Colombia*). Bold values are significant for redundant metrics.

	Richness	Evenness	Oligochaeta (%)	CHOL (%)	EPT (%)	Trichoptera (%)	EPT Taxa	Collector filterers (%)	Collector gatherers (%)	Scrapers (%)	BMWP CETEC	ASPT CETEC	BMWP COL	ASPT COL
Richness	-													
Evenness	**0.76**	-												
Oligochaeta (%)	–0.43	–0.30	-											
CHOL (%)	–0.65	–0.85	0.46	-										
EPT (%)	0.79	0.81	–0.50	–0.80	-									
Trichoptera (%)	0.76	0.76	–0.45	–0.70	**0.87**	-								
EPT taxa	0.93	0.72	–0.52	–0.63	**0.85**	0.82	-							
Collector- filterers (%)	0.65	0.59	–0.46	–0.62	0.72	0.73	0.67	-						
Collector-gatherers %	–0.50	–0.45	0.61	0.59	–0.47	–0.49	–0.48	–0.62	-					
Scrapers (%)	0.67	0.58	–0.48	–0.55	0.68	0.52	0.67	0.44	–0.52	-				
BMWP-CETEC	0.96	0.75	–0.48	–0.66	0.82	0.80	0.96	0.70	–0.48	0.62	-			
ASPT-CETEC	0.86	0.70	–0.63	–0.68	0.80	0.74	0.90	0.62	–0.55	0.68	**0.90**	-		
BMWP-COL	0.97	0.75	–0.47	–0.64	0.80	0.79	0.95	0.67	–0.46	0.62	**0.99**	0.89	-	
ASPT-COL	0.84	0.70	–0.60	–0.64	0.79	0.77	0.91	0.62	–0.48	0.62	**0.90**	0.93	0.91	-

Table 3. Standard score of each metric of the Benthic Multimetric Index in the Velhas River basin, MG (BMWP - Biological Monitoring Working Party; CETEC – Centro Tecnológico de Minas Gerais).

Metrics	Descriptive statistics/Box-plots value					Scores		
	Min	25%	50%	75%	Max	5	3	1
Richness	1.0	9.0	14.5	20.0	33.0	>9	8-6	<5
% Oligochaeta	0	0.1	1.0	5.0	97.0	<5	6-46	>47<97
% CHOL	1.0	26.1	48.2	73.0	100.0	<73	74-86	>87<100
% EPT	0.6	6.2	20.8	40.0	75.0	>6	5-3	<2
% Collector-gatherers	1.4	28.6	48.2	64.0	99.0	<64	65-83	>84<99
BMWP-CETEC	1.0	36.0	66.0	97.0	179.0	>36	35-18	<17

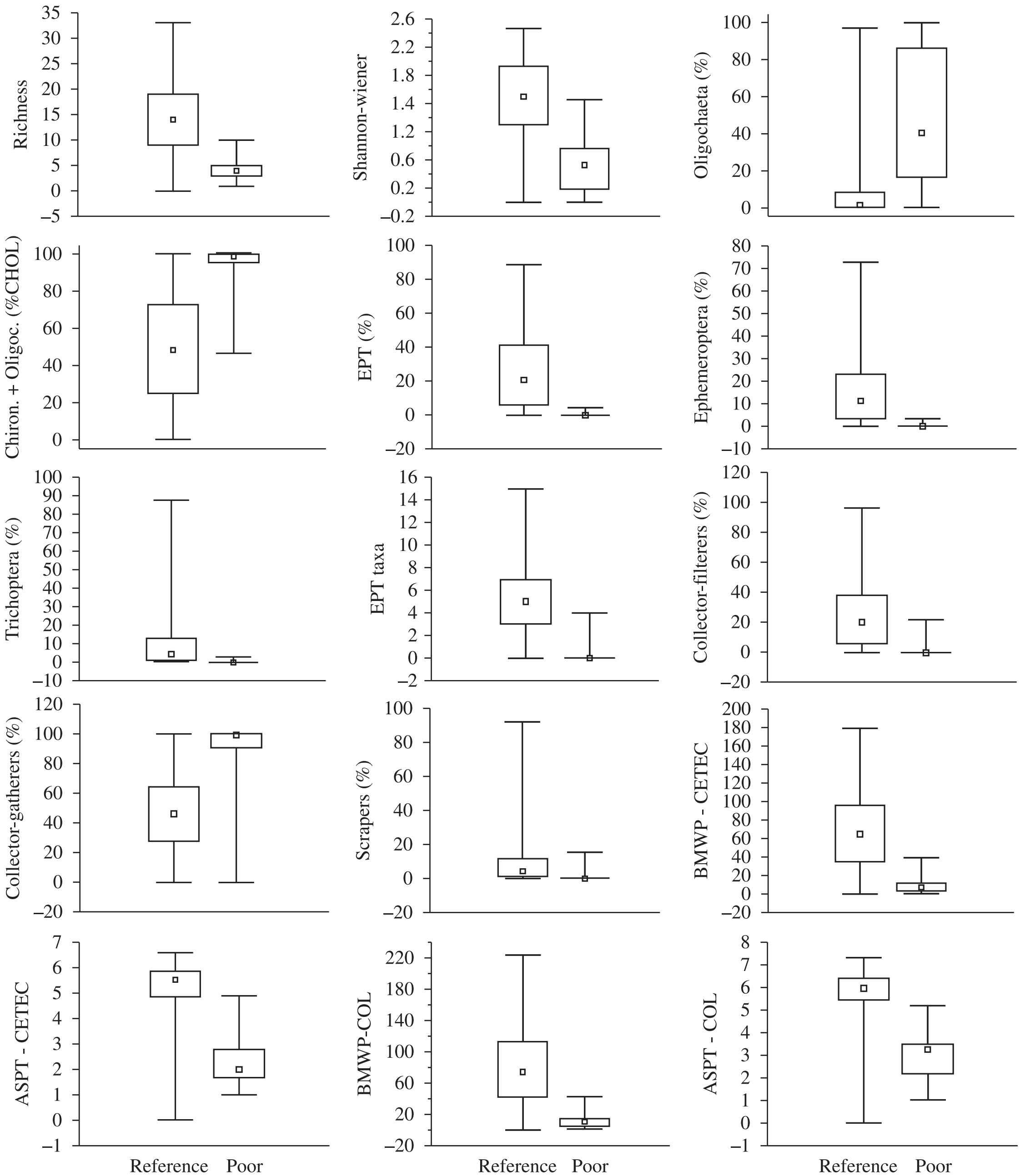

Figure 4. Box plot of the sensitive metrics (score 3) valid for distinguishing between reference and altered stretches of the Velhas River basin.

Table 4. Pearson correlation among the metrics for the Benthic Multimetric Index of the Velhas River basin and physico-chemical variables obtained throughout the sampling sites (* $p < 0.05$).

Physical and chemical variables	Benthic Multimetric Index					
	Richness	Oligochaeta (%)	CHOL (%)	EPT (%)	Collector gatherers (%)	BMWP CETEC
Conductivity	–0.4997*	+0.4340*	+0.4309	–0.3151	+0.6575*	–0.5053*
P-total	–0.6571*	+0.5171*	+0.7767*	–0.6270*	+0.8362*	–0.6611*
N-total	–0.5447*	+0.3875	+0.6382*	–0.5066*	+0.7060*	–0.5452*
Dissolved oxygen	+0.7175*	–0.6696*	–0.7144*	+0.6434*	–0.7096*	+0.7107*
Total dissolved solid	–0.4511*	+0.4046	+0.3766	–0.2492	+0.6353*	–0.4533*
Pebbles	+0.5447	–0.4143	–0.4715*	+0.4768*	–0.4057	+0.5579*
Gravel	+0.3970	–0.4349*	–0.3577	+0.3645	–0.2044	+0.4082
Sand	–0.1523	–0.0796	+0.2714	–0.1894	+0.4911*	–0.1732
Silt and clay	–0.3985*	+0.5601*	+0.3112	–0.3519	+0.2329	–0.3960
Protocol	+0.7021*	–0.5636*	–0.6199*	+0.5986*	–0.7011*	+0.7190*

Table 5. Responses for metric comparison between reference and impaired sites (Stage 1 refers to score for each metric based on box-and-whisker plots and results of the Mann-Whitney *U*-test - p-level).

Metrics	Stage 1	*U*-test	P-level	Metrics decision
Richness	3	9.3	0.000000	x
Ephemeroptera *taxa*	3	9.5	0.000000	
Plecoptera *taxa*	1	4.1	0.000048	
Trichoptera *taxa*	3	9.1	0.000000	
Coleoptera *taxa*	1	3.1	0.001945	
EPT *taxa*	3	9.8	0.000000	
BMWP-CETEC	3	10.1	0.000000	x
ASPT-CETEC	3	10.4	0.000000	
BMWP-Col	3	9.8	0.000000	
ASPT-Col	3	10.1	0.000000	
EPT/Chironomidae	3	9.7	0.000000	
Baetidae/Ephemeroptera	3	7.9	0.000000	
Evenness	2	4.7	0.000002	
Diversity	3	8.9	0.000000	
% Chironomidae	0	–0.6	0.566859	
% Oligochaeta	3	–8.2	0.000000	
% CHOL	3	–10.0	0.000000	x
% EPT	3	10.0	0.000000	x
% Ephemeroptera	3	9.7	0.000000	x
% Plecoptera	1	4.1	0.000048	
% Trichoptera	3	8.9	0.000000	
% Coleoptera	3	9.7	0.000000	
% Diptera	0	0.0	1.000000	
% Odonata	3	7.9	0.000000	
% Gastropoda	0	1.1	0.290586	
% Collector-filterers	3	9.2	0.000000	
% Collector-gatherers	3	–9.5	0.000000	x
% Shredders	2	7.4	0.000000	
% Scrapers	3	8.7	0.000000	
% Predators	2	6.2	0.000000	

The highest P-total was found at site P14 (0.11 mg/L) and the lowest at sites P8 and P9 (0.01 mg/L). The highest total-N was found at site P14 (1.6 mg/L) and the lowest value was found at sites P8 and P13 (0.2 mg/L).

The lowest average values of dissolved oxygen were recorded in the metropolitan area of Belo Horizonte (sites P5= 3.8, P6= 4.7 and P7= 2.9 mg/L), while the values at other sites ranged from 4.9 to 7.8 mg/L. In the upper course of the river, the average values of electrical conductivity ranged from 26.5 (site P1) to 287.8 µS/cm (site P6). The values in the middle course values ranged from 4.7 (site P8) to 213.7 µS/cm (site P6) and in the lower course of the river, they ranged from 40.0 (site P19) to 133.0 µS/cm (site 20).

4. Discussion

In this study, we used metrics that represent the differences between reference sites, intermediate situation and altered sites. The six selected metrics proved satisfactory in the application of the water quality biomonitoring programme of the Velhas River basin. Moreover, these metrics ensured responses of the overall ecological status of water quality in the basin, since been identified river stretches were identified ranging from bad to very good quality, confirming other studies in Brazil (Baptista et al., 2007), in the U.S. (Barbour et al., 1996), and in Europe (Pinto et al., 2004).

Among the metrics selected to calculate the BMI in this study, taxonomic richness is a metric that reflects the diversity of aquatic organisms (number of taxa) and is related to the health of aquatic ecosystems (Baptista et al., 2007). In general, ecosystems with elevated taxonomic richness contain diversified physical habitats, physicochemical conditions of water quality and available food resources for the maintenance of many species (Barbour et al., 1996).

In view of the need to identify responses to environmental alterations caused by anthropic actions in the Velhas River basin, the metric % EPT was selected due to its high sensitivity to disturbances, which is reflected by the taxa Ephemeroptera, Plecoptera and Trichoptera, which are sensitive to anthropic impacts such as the discharge of raw sewage (Baptista et al., 2007).

To render the application of the BMI more efficient, we added to the index the food strategy of benthic macroinvertebrates based on the contribution of the different functional feeding groups to the total community (Cummins et al., 2005).

The metrics used to calculate the index were satisfactory in distinguishing between sites studied, like in other studies conducted in southeastern Brazil (Baptista et al., 2007) and in other countries such as the U.S. (Barbour et al., 1996) and Portugal (Pinto et al., 2004).

In the development of the Multimetric Index BMI, the metric % shredders was not representative in the composition of the index, unlike from other studies such as the SOMI developed by Baptista et al. (2007). This may be associated with the environmental characteristics of the Velhas River basin where the Cerrado biome predominates (Muzzi and Stehmann, 2005). In headwater streams in the Cerrado of southeastern Brazil, the low nutritional quality of the leaves of riparian plants and the high lignin contents give the leaves characteristics of hardness, rendering them unpalatable and little attractive to shredders (Gonçalves et al., 2007). This may explain the low abundance of this trophic group in the Velhas River basin, where collector-gatherers and collector-filterers were found to be more important as participants of the metrics in the evaluation of the basin's water quality.

Other studies performed in southern and southeastern Brazil, showed the strong connection of macroinvertebrate shredders in streams of the Atlantic Forest (Cummins et al., 2005; Silveira et al., 2006).

The metric % Chironomidae was not sufficiently sensitive to be used separately in the development of the BMI, but was added to the metric % Oligochaeta due to the importance of these two groups of organisms in the characterisation of impacted sites (Callisto and Moreno, 2005).

A comparison of the results obtained by the BMI against those obtained with the Rapid Assessment Protocol (Callisto et al., 2002) and the measurement of physicochemical parameters revealed the anthropic impacts on the basin as a consequence of disordered urbanisation, such as the removal of riparian vegetation, sediment deposition in the channel of the river, loss of habitat, straightening and channelling of the river. Thus, the impacts changed the hydrology, geomorphology, chemistry and biology of the water (Paul et al., 2009). Statistical tests revealed correlation of the metrics related to impacts with phosphorus and nitrogen contents in the water, which were directly related to the discharge of untreated domestic sewage into the river's waters. It was also possible to observe a greater representativeness of the metrics not related to impacts in stretches of the upper and lower course of the basin. This suggests a possible improvement in the environmental conditions related to the decrease in concentrations of nutrients and changes in some of the physicochemical parameters (e.g., dissolved oxygen, pH and electrical conductivity), resulting in the higher stability of the environments, and hence, reflecting in greater richness of benthic organisms.

In the middle and lower stretches of the Velhas River basin, several tributaries in reference conditions, such as the Pedras stream in the Serra do Cipó National Park, contribute with waters of excellent quality to the basin (Paz et al., 2008; Moreno et al., 2009). This suggests an improvement in water quality along the basin, minimising the impacts from upstream stretches, e.g., sewage discharge from the state's capital city Belo Horizonte.

It can be concluded that the newly developed multimetric index used in the Benthic Biomonitoring Programme of the Velhas River basin contributes as an important tool in assessing the quality of water together with physicochemical parameters. This index will allow the evolution of the ecological status of the basin's waters to be monitored, according to Moreno et al. (2009). Additionally, this study could be used in other watersheds with characteristics similar to those of the Velhas River basin.

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