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A macroinvertebrate multimetric index to evaluate the biological condition of streams in the Central Amazon region of Brazil

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ABSTRACT

Managers, researchers and technicians involved in the conservation and management of water resources in the Central Amazonia need a robust tool to assess biological quality in aquatic ecosystems. To provide such a tool, we developed a multimetric index based on stream macroinvertebrate data. We collected samples from eight reference (undisturbed) streams and 12 streams altered by deforestation and domestic sewage during two distinct seasons (dry and rainy) in the municipality of Manaus, Brazil. Metric candidates to compose the index were tested for: *Range*, *temporal variability* (stability), *sensitivity* in separating disturbed from reference streams, *correlation* with the anthropogenic disturbance gradient and natural stream variability and *redundancy* between metrics. Our final index included seven metrics: family, Trichoptera and Ephemeroptera–Plecoptera–Trichoptera (EPT) richness as richness measures, EPT percent abundance as a measure of composition, EPT/Chironomidae ratio and sensitive-taxa richness as tolerance measures and percent abundances of gathering-collectors and shredders as trophic measures. All metrics were scored relative to their range quartiles. The final index, derived from the sum of all metric scores (0–70), was divided into five sub-ranges to represent distinct levels of biological quality in streams (bad, poor, regular, good and excellent).

1. Introduction

Water quality is a subjective anthropocentric term that reflects the value of a hydrological resource for a given human application. It has as much to do with the natural state of the water and the organisms that live in the water as with the purity of the water itself.

In developed countries like Australia, the United States and countries in the European Community, the biological evaluation of rivers and streams is a government obligation and is regulated by federal laws. These evaluations complement physical–chemical characterizations and, because aquatic organisms interact with the aquatic environment during most or all of their lives, the evaluations also provide information about environmental stresses that preceded the sampling (e.g., Rosenberg and Resh, 1993).

"Biological integrity" represents the capability of the systems to support and maintain a balanced and integrated community of organisms comparable to that of the natural habitat (Karr and Dudley, 1981). Aquatic macroinvertebrates, among other groups, have been used to develop biotic water-quality indices based on sensitive taxa, tolerant taxa or other metrics that represent macroinvertebrate assemblages (Hering et al., 2006; R.B.S. Oliveira et al., 2008; Stoddard et al., 2008).

Biotic indices are tools for the sustainable management of water resources. They provide a coherent classification of water quality and also allow for the systematic evaluation of water quality degradation (e.g., excellent to poor) or improvement following mitigation or rehabilitation measures (poor or regular to good and excellent) (e.g., Silveira et al., 2005). A multimetric index provides a technically simple tool for summarizing the biological complexity of a system (Karr et al., 1986; Plafkin et al., 1989), where a gradient of perturbation can be effectively evaluated despite the limited sensitivity of individual metrics (Thorne and Williams, 1997).

In Brazil, the evaluation of water quality in aquatic environments is primarily focused on the analysis of physical–chemical data and can optionally include samplings of Chlorophyll-a and fecal coliforms; nevertheless, in most cases these are only used in large rivers (Buss, 2008). As a result, Brazilian environmental laws and regulatory processes do not require biological evaluations of aquatic ecosystems (Buss et al., 2003). Brazilian states and federal

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environmental agencies also have no clear standards for sampling and analysis of biological samples that can be used to monitor and evaluate these environments (Buss et al., 2003). Biological indices that are easily determined and evaluated are clearly needed for this purpose.

Macroinvertebrate indices have been developed recently for the evaluation of aquatic environments in hydrographic basins in southeastern Brazil (e.g., Junqueira and Campos, 1998; Junqueira et al., 2000; Buss et al., 2002; Silveira et al., 2005; Baptista et al., 2007; Mugnai et al., 2008). Multimetric indices have also been developed for assessing fish assemblages in southeastern Brazil (Araújo, 1998; Araújo et al., 2003; Bozzeti and Schulz, 2004; Casatti et al., 2009; Ferreira and Casatti, 2006; Pinto et al., 2006; Pinto and Araújo, 2007). However, a biological index based on fish community structure for aquatic environments in northern Brazil has only recently been created (Galuch, 2007).

Streams in the Central Amazonia (Manaus and nearby municipalities in northern Brazil) are under intense anthropogenic pressure as a result of recent measures proposed to stimulate economic development in the region. These government programs have resulted in increased deforestation, the extraction of natural resources and the disorderly growth of urban areas, all of which contribute to the degradation of streams (e.g., Couceiro et al., 2006, 2007). In the Amazon there is no evaluation of water quality in aquatic environments. Because of this, the environmental changes are generally perceived only when the streams are highly altered. We propose here a robust, easily applied index to evaluate the biological condition of low-order, black-water, sand-bed, upland streams in Central Amazonia, Brazil.

2. Materials and methods

2.1. Study area

The studied streams are distributed in the municipal area of Manaus, Amazonas, Brazil (03°06′25.89″S, 60°01′34.06″W; Fig. 1), located in a region known as "Central Amazonia." The streams can be classified as first- and second-order streams (Strahler, 1952), and were sampled during two seasons in the region (e.g., F.M. Oliveira et al., 2008), the dry period (11–12/2004) and the rainy period (05–06/2005).

Twenty-three streams were sampled, of which 20 were used to develop the index. Eight were classified as reference (undisturbed streams) and 12 as streams impacted by urban development (deforested and with contribution of sewage *in natura*). The other three streams with intermediate impacts (deforested but without sewage *in natura*), were used to test the applicability of the index in evaluating smaller impacts.

The reference streams were significantly different from the disturbed ones with respect to pH, dissolved oxygen, electrical conductivity, temperature, total nitrogen, total phosphorus, depth and flow (Table 1). Differences were also observed in terms of habitat availability, the disturbed streams being homogeneous, basically with sand bottoms and accumulations of organic debris derived from the sewage and from the deforested banks. While the reference streams had a greater variety of habitats (sand, leaves, trunks, etc.), streams with intermediate impacts differed significantly from the reference streams in terms of deforestation (%) and from the disturbed streams in terms of the total N and P concentrations and other abiotic variables related to sewage *in natura* (Table 1).

2.2. Sample of abiotic variables

The degree of deforestation in the area of each sampled stream was obtained from a 2003 Landsat satellite image classified into forested and deforested areas. The classification process consisted of image manipulation, identification of the classified areas, signature extraction, and accuracy assessment by comparison with the unclassified image that was used as a base. Deforestation degree for each stream was obtained for 100-m buffers around the geographical coordinates obtained for each sampled stream. Coordinates were obtained using a Garmin GPS.

The abiotic variables were sampled at 20-m intervals along a 60-m reach in each stream, totaling three samples for each variable. Water samples were collected in the water column using a polypropylene bottle (60 ml). The total N and P concentrations were obtained using the methodology of Valderrama (1981). The measurement of depth and width was done with a ruler. Water velocity was estimated by the time taken by a plastic float to move one meter. Electrical conductivity and pH were measured with a portable conductivimeter/potentiometer (Oakton, model pH/com 10 meter). Temperature and dissolved oxygen were measured near the bottom with a portable oxymeter (Oakton, model DO 110).

2.3. Macroinvertebrate collection and processing

Macroinvertebrates were collected from benthic substrates in the center and along the edges of stream channels, covering a large diversity of habitats. Mid-channel collections were made with a modified Petersen dredge (243 cm^2), while edge substrates were sampled with a D-shaped hand net (570 cm^2 surface area, 1 mm^2 net mesh), which was dragged along the bottom for 1 m. Each type of sample was collected at 20-m intervals along a 60-m reach in each stream, resulting in 3 dredge and 3 hand-net sub-samples per stream.

The sub-samples were placed in plastic bags and transported to the laboratory where stream water was replaced by 96% ethanol. These preserved samples were then stored until analysis under a stereo microscope. We identified specimens to genus level in the orders Ephemeroptera, Heteroptera, Megaloptera, Odonata, Plecoptera and Trichoptera, and in the Dipteran families Chironomidae and Simuliidae. Identifications were to family level for the remainder of the Diptera and for the order Coleoptera. All identifications were based on available taxonomic keys (e.g., Hamada et al., 2002; Hamada and Couceiro, 2003; Pes et al., 2005; Trivinho-Strixino and Strixino, 1995; Pereira et al., 2007). Taxa were classified into functional feeding groups according to Merritt et al. (2008).

The total number of macroinvertebrates collected in the six subsamples represents the macroinvertebrate abundance of each stream, and the values were later transformed to percent abundance (%). Taxa richness (#) was the total number of taxa that occurred in the six subsamples.

2.4. Selection of metrics

Twenty-one metrics related to macroinvertebrate richness, taxonomic composition, tolerance and ecological functions were evaluated (Table 2). These metrics have been used individually or in combination to characterize biotic communities in other regions (e.g., Barbour et al., 1996a,b, 1999; Karr, 1999; Baptista et al., 2007; Moya et al., 2007). Sensitive taxa were extracted from Couceiro et al. (2007).

The metrics were tested for range, temporal variability (stability), sensitivity in separating disturbed and reference areas, correlation with natural habitat variability of streams, correlation with the disturbance gradient and redundancy between metrics. The tests used were those proposed by Klemm et al. (2003), Hering et al. (2006), Stoddard et al. (2008) and R.B.S. Oliveira et al. (2008).