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Selection of reference lakes and adaptation of a fish multimetric index of biotic integrity to six amazon floodplain lakes

Maria Letizia Petesse[a,*], Flávia Kelly Siqueira-Souza[b], Carlos Edwar de Carvalho Freitas[b], Miguel Petrere Jr.[c,d]

[a] Programa de Pós-graduação em Aquicultura e Pesca, Instituto de Pesca de São Paulo, Parque da Água Branca—Av. Francisco Matarazzo, 455 CEP, 05001-90, São Paulo, SP, Brazil
[b] Departamento de Ciências Pesqueiras—Universidade Federal do Amazonas, Av. Gen. Rodrigo Otávio, 3000, 69077-000, Manaus, AM, Brazil
[c] UFSCar, PPGPur, Programa de Pós-graduação em Planejamento e Uso de Recursos Renováveis, Rodovia João Leme dos Santos (SP 264), km 110, 18052-780, Sorocaba, SP, Brazil
[d] UNISANTA, Programa de Pós-Graduação em Sustentabilidade de Ecossistemas Costeiros e Marinhos, Rua Oswaldo Cruz, 277 (Boqueirão), 11045-907, Santos, SP, Brazil

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ABSTRACT

This study seeks to define a bioassessment tool for the floodplain lakes of the lower Solimões River (Amazonas, Brazil). We defined lakes in *pristine* condition as reference lakes and adapted a fish multimetric index of biotic integrity. The floodplain lakes analyzed were Baixio, Preto, Ananá, Araçá, Maracá and Poraqué, located 30–400 km from Manaus, the state capital. To select the reference lakes we adapted a rapid bioassessment protocol that analyzes satellite imagines from Google Earth. Landscape characteristics were investigated in two different screening phases: preliminary (presence/absence) and final (semi-quantitative). Each screening phase used two landscape scales: buffer-zone (a 6 km-diameter circle around each lake) and local (an area extending 500 m from the lake's shoreline). The landscape attributes selected in these screening phases allowed us to define an Environmental Gradient Index (EGI) that represented the effect of the human presence on the lakes. Lakes Araçá and Ananá, which had no or very few signs of anthropogenic disturbance, were classified in the high EGI category and selected as reference lakes. A floodplain-lake index of biotic integrity (FL-IBI) was developed from twenty candidate fish assemblage metrics, of which four were selected after range, sensitivity, responsiveness and redundancy tests for inclusion in the final index (total number of species, total number of individuals, total number of individuals with moderate-high vulnerability and percentage of carnivores). Metrics were scored continuously from 0 to 10. Final FL-IBI scores were calculated by adding the scores for each selected metric and dividing the result by the number of metrics. To facilitate comparison with other indices, this was weighted to range from 0 to 100. The FL-IBI proved to be able to distinguish well between reference and non-reference lakes. Index scores had wide seasonal and temporal variability, largely because of the major changes in habitat caused by the intensity, duration, frequency and occurrence of the Solimões flooding cycle. For the reference lakes, the lowest seasonal index variability (CV < 5%) was observed in the receding-water period, allowing us to consider this as the best index period for biomonitoring purposes. The greatest annual variability for the study period (2004–2007) was observed in 2005 (CV > 20%) and was associated with the severe drought occurred in that year. These results show that the fish assemblages in the lakes studied are highly resilient and perfectly adapted to the hydrological cycle of the Solimões River.

1. Introduction

The Amazon Basin is home to the largest tropical rainforest in the world, where the natural connectivity between rivers and floodplains is still generally preserved. The Amazon River floodplain is formed by a complex and highly dynamic system of islands, lakes, channels, holes, embayments and streams that contribute

* Corresponding author.
E-mail address: mlpetesse@gmail.com (M.L. Petesse).

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to its extraordinary biodiversity. The floodplain lakes are formed mainly by meanders (oxbow lakes) or by the occlusion of a stream mouth (dammed lakes) by sediments or macrophytes close to a main river channel (Soares, 1977). Most of the floodplain lakes are located along the Solimões and Amazon Rivers (Cox-Fernandes and Petry, 1991). The flood pulse, with its variable intensity, duration, frequency and occurrence, is the main natural force responsible for the productivity of the system and for the adaptation and survival strategies of organisms (Junk et al., 1989). In this context, fish distribution depends fundamentally on fishes' physiological requirements, behavioral characteristics and habitat complexity and availability (Wootton, 1998).

Since the 20th century there has been an ever-increasing human presence in this region, and the Amazon basin is becoming more and more vulnerable to anthropogenic transformation and disturbance. Deforestation, the construction of dams, mining, urbanization, agriculture and livestock practices are only some of the factors threatening the Amazon ecosystem (Castello et al., 2013). According to Costanza et al. (1997), an increase in anthropogenic pressure compromises important ecosystem services associated with aquatic environments, making development of tools to assess the integrity of aquatic systems essential for conservation and sustainable use of the ecosystems' resources. After it was first defined by Frey (1975), the concept of biotic integrity rapidly revolutionized the approach taken to assess aquatic resources, as anthropogenic disturbances interact in a complex way in the aquatic ecosystem and their effects are very difficult to assess using only physicochemical variables as indirect measures of biotic integrity. This became evident when evaluations based exclusively on the physicochemical characteristics of the water in aquatic ecosystems were unable to explain the degradation of these ecosystems after the objectives for chemical recovery of water quality had been achieved (Karr and Dudley, 1981; Barbour et al., 2000). Instead, the effects of anthropogenic disturbances need to be assessed using measures of the biotic components of aquatic systems (Fausch et al., 1990).

In the United States, concern about the deterioration of the aquatic ecosystem was formally recognized by the passage of the lean Water Act (1972), which aimed to "restore and maintain the chemical, physical and biological integrity of the Nation's waters". In 1981, Karr, responding to the mandatory requirements of the Clean Water Act, created the Index of Biotic Integrity (IBI), a multimetric index in which the metrics are ecological attributes of the biotic assemblages that change in a predictable way in the presence of anthropogenic disturbances (Karr et al., 1986, 1987). To be effective, the index needs reference conditions against which the level of impairment can be judged. The great versatility of the index makes it possible to adapt it to various aquatic contexts (streams, great rivers, lakes, reservoirs and estuaries) and organisms (phytoplankton, periphyton, macroinvertebrates, fish and macrophytes) (Borja et al., 2008; Delpech et al., 2010; Drake and Valley, 2005; Furse et al., 2006; Launois et al., 2011; Marchant et al., 2006; Roset et al., 2007). Currently, adaptations of the IBI are used in the six continents, making it one of the most popular tools for aquatic bioassessment. In South America, however, the development of multimetric indices is still incipient (Jaramillo-Villa and Caramaschi, 2008). In Brazil, adaptations first appeared at the end of the 20th century and beginning of the 21st with Araújo (1998) and Araújo et al. (2003), since when interest among the Brazilian scientific community has increased steadily. The main changes in the Brazilian adaptation are related to fluvial systems, as described in Bozzetti and Schulz (2004), Ferreira and Casatti (2006), Pinto et al. (2006) and Terra et al. (2013), but adaptations for reservoirs can be found in Petesse et al. (2007,2014) and Terra and Araújo (2010). The incipient status of bioassessment in Brazil can be explained by the fact that, unlike in other countries (USA, EU, Canada and Australia), there is no legal requirement for biological monitoring of aquatic systems.

In the present study, a fish multimetric index of biotic integrity was adapted for the floodplain lakes of the lower Solimões River by *a priori* classification of the reference lakes. Lakes were classified in *pristine* or almost *pristine* condition using easily detectable landscape attributes.

2. Material and methods

2.1. Study area

The Solimões River floodplain is almost completely preserved and strongly dependent on the river's hydrologic cycle, which is regulated by local rainfall and the annual melting of snow in the Andes. The hydrologic cycle is marked by four seasons, defined for the Central Amazon as rising water (January–April), high water (May–July), receding water (August–September) and low water (October–December) (Bittencourt and Amadio, 2007). During the high-water season, the lakes remain connected to the main river channel and to each other, while during the low-water season these connections disappear and the lakes become isolated. In the rising-water and receding-water seasons, the lakes may or may not be connected depending on the water level. In the course of a complete hydrologic cycle, the depth of the floodplain lakes may vary by as much as 15 m, creating a complex, rich and highly dynamic ecosystem. Junk et al. (2011) described the floodplain lakes of the Solimões River as "wetlands with oscillating water levels" and, more specifically, lakes in "floodplains of high fertility (whitewater river floodplains)".

In this study, six floodplain lakes located between the towns of Iranduba and Coari, which are almost 30 km and 400 km from the state capital Manaus, respectively, were analyzed. In upriver-to-downriver order, the floodplain lakes studied were Poraqué, Maracá, Araçá, Ananá, Preto and Baixio (Fig. 1). Basic geographic data for the lakes are shown in Table 1. All the data included in the study were collected as part of the PIATAM (Potenciais Impactos e Riscos Ambientais da Indústria do Petróleo e Gás no Amazonas – Potential Environmental Impacts and Risks from the Oil Industry and Gas in Amazonia) project (PIATAM, 2008) run by the Federal University of Amazonas in Manaus (UFAM).

2.2. Selection of reference lakes

The procedure for selecting the reference lakes was adapted from a rapid bioassessment protocol (Barbour et al., 1999; Roth et al., 2000). Initially we analyzed satellite images from Google Earth to identify landscape characteristics in two different screening phases: preliminary (presence/absence) and final (semi-quantitative). Each screening phase in turn had two landscape scales: buffer-zone and local. For the buffer-zone scale, following Uzarski et al. (2005) and Pinto et al. (2006), we considered a six km-diameter circle around each lake, while for the local scale an area extending 500 m from the lake's shoreline was examined.

2.2.1. Preliminary screening phase – presence/absence

The objective of this phase was to quickly define the landscape attributes that could be used to select the reference lakes. First, a list of 20 attributes (10 on the buffer-zone scale and 10 on the local scale) was defined based on the knowledge of experts familiar with the study area. Each landscape attribute was evaluated using the exclusion criterion (1 = presence; 0 = absence). In this way, attributes with no variability among lakes were eliminated in this step. The attributes selected were classified as positive if they contributed to an increase in environmental quality (e.g., native forest)