Ecological Indicators 91 (2018) 315–323

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Using multimetric indices to assess the effect of reduced impact logging on ecological integrity of Amazonian streams

Bruno da Silveira Prudente[a,c,*], Paulo Santos Pompeu[b], Luciano Montag[a,c,d]

[a] Programa de Capacitação Institucional, Coordenação de Zoologia, Museu Paraense Emílio Goeldi, Avenida Perimetral 1901, Terra Firme, 6677-530, Caixa Postal 399, Belém, Pará, Brazil

[b] Laboratório de Ecologia de Peixes, Departamento de Biologia, Universidade Federal de Lavras - UFLA, 37200-000 Lavras, Minas Gerais, Brazil

[c] Laboratório de Ecologia e Conservação, Instituto de Ciências Biológicas, Universidade Federal do Pará – UFPA, Rua Augusto Corrêa 01, Guamá, 66075-110, Caixa Postal 479, Belém, Pará, Brazil

[d] Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA

ARTICLE INFO

Keywords:
Biotic integrity
Habitat integrity
Fish assemblages
Forest management

ABSTRACT

Multimetric indices are considered a low-cost and rapid means of assessing ecological integrity in streams. The present study aimed to develop and validate multimetric indices that permit evaluation of reduced impact logging (RIL) effects on the ecological integrity of streams in the Eastern Amazon. We sampled 47 stream sites, 13 of them in reference areas and 11 in conventional logging (CL) areas, which were used to develop indices. The remaining 23 stream sites were sampled in RIL areas and used for validation of the developed indices. In each stream site we measured metrics relating to habitat structure and ecological features of fish assemblages, which were used to develop a habitat integrity index (HII), biotic integrity index (BII), and a general multimeric index (GMI). The values of the indices obtained for the RIL areas were compared and tested both in relation to the values observed in the reference and CL areas, and in relation to temporal gradients (i.e. time since logging) in RIL areas. All developed indices differed between RIL and CL, however only the HII differed between RIL and reference areas. We also detected a decrease in the GMI in recently logged RIL areas compared with streams in older RIL areas. The lack of distinction in GMI and BII indices between reference and RIL areas demonstrates the benefits of RIL practices for fish assemblages compared to conventional logging methods. However, the intermediate values obtained from these indices in RIL areas for all developed indices, the distinction of HII between reference and RIL, and the temporal variation of GMI in RIL areas can be considered as an important warning regards the possible impacts of RIL practices on ecological integrity in Amazonian streams. In summary, the multimetric indices were shown to be good indicators of ecological integrity in Amazonian streams subject to RIL. Even where the deleterious effects of logging are controlled by technical guidelines, indices presented a high sensitivity to anthropogenic disturbance, reinforcing their value as tools to evaluate and monitor ecological integrity of streams in human-modified tropical landscapes.

1. Introduction

Multimetric indices based on fish assemblages were first proposed by Karr (1981) and are considered a fast and relatively easy tool for the assessment of environmental disturbance in aquatic ecosystems. Subsequently, they have been developed, improved and applied in stream communities in many global regions (Lyons et al., 1995; Hughes et al., 1998; Kamdem-Toham and Teugels, 1999). Henceforth, physical habitat and biotic features of stream ecosystems began to be considered as important components of stream ecosystem health, and widely used by governmental programs in temperate regions to perform rapid assessment and monitoring of aquatic ecosystems (Clapcott et al., 2012; Faber-Langendoen et al., 2012a,b; Ruaro and Gubiania, 2013).

In tropical regions, multimetric indices have been used since the 1990's onwards to evaluate the influence of anthropogenic disturbance on the ecological integrity of stream habitats (Araújo, 1998; Kamdem-Toham and Teugels, 1999). However, in Brazil these indices have been predominantly proposed for Savanna and Atlantic Forest biomes (e.g. Terra and Araújo, 2011; Santos and Esteves, 2015; Carvalho et al., 2017), with few studies focusing on the Amazon biome (Nessimian et al., 2008; Couceiro et al., 2012; Chen et al., 2017). This lower number of studies may be attributed to the high diversity and

* Corresponding author at: Programa de Capacitação Institucional, Coordenação de Zoologia, Museu Paraense Emílio Goeldi, Avenida Perimetral 1901, Terra Firme, 6677-530, Caixa Postal 399, Belém, Pará, Brazil.

E-mail addresses: brunoprudente8@gmail.com (B.d.S. Prudente), pompeu@dbi.ufla.br (P.S. Pompeu), montag@ufpa.br (L. Montag).

https://doi.org/10.1016/j.ecolind.2018.04.020
Received 3 November 2017; Received in revised form 7 April 2018; Accepted 9 April 2018

environmental heterogeneity of the Amazon River Basin, due to its complex biogeographic history (Albert et al., 2011) and variability in soil type, relief, phytophysiology and hydrology (Abell et al., 2008). Considering this, careful development of multimetric indices is required before these indices can be widely applied or be considered as a useful tool for ecological integrity assessments in tropical streams.

In the Amazon, where small streams have a total area of influence almost three times greater than the area influenced by flood pulses of the large rivers (e.g. floodplains) (Junk and Furch, 1993), logging is known to be one of the main drivers of deforestation (Fearnside, 2017). Logging has also been considered a precursor for agricultural expansion and livestock activities in these areas (Geist and Lambin 2001), which are also harmful to stream ecosystems (Dias et al. 2010; Leal et al. 2016). Therefore, an alternative for Amazon logging expansion has been to replace conventional logging (CL), which does not require any type of planning (Asner et al., 2006), with reduced impact logging (RIL) practices, which requires a sustainable forest management plan (PMFS in Portuguese), including pre- and post-harvest planning (Putz et al., 2008; Sabogal et al., 2000).

Currently, RIL has been considered a more sustainable form of timber extraction in tropical forests (Putz et al., 2012). For this reason, this type of forest management has been authorized in approximately one million hectares of Sustainable Use Conservation Units in the Brazilian Amazon (SFB, 2017). However, the inherent complexity of ecological communities and processes (Barlow et al., 2011), and limited knowledge of biodiversity in this region (Peres, 2005; Hubbell et al., 2008), has made it extremely difficult to design ecological models and indicators that provide accurate assessment of the effects of forest management on the biodiversity and ecological integrity in the Amazon (Kormos and Zimmerman, 2014; Bicknell et al., 2015).

In stream ecosystems, knowledge about the effects of forest management (e.g. RIL) on aquatic biodiversity is extremely limited (Dias et al., 2010, Nogueira et al., 2016; Prudente et al. 2017). For this reason, there are no current technical guidelines for RIL that focus explicitly on streams (Sabogal et al., 2000). The maintenance of permanent 30-m wide preservation areas along the margins of water courses, provided in the Brazilian Forestry Code, law n° 12.651, is the only regulation aiming to maintain the ecological integrity of stream ecosystems. However, existing legislative frameworks focusing on protecting riparian vegetation has been demonstrated to be insufficient in maintaining the integrity of instream physical habitat and fish assemblages (Leal et al., 2017).

In this context, the present study aimed to develop and validate multimetric indices based on the stream habitat and fish assemblages features that allow the rapid and efficient evaluation and monitoring of the effects of RIL on stream ecological integrity in the Eastern Amazon. These indices were also evaluated in relation to their ability to discriminate possible changes in ecological integrity across temporal gradients in RIL activity (i.e. time since logging event). Considering that RIL aims to minimize the deleterious effects of logging on biodiversity and ecosystem services provided by tropical forests, we expected that streams in RIL areas would present intermediate values of ecological integrity when compared with streams in reference and conventional logging areas.

2. Material and methods

2.1. Study area

This study was conducted in the middle portion of the Capim River basin, between coordinates 03°42′33″S/48°33′40″W and 02°57′56″S/47°44′12″W, in the Eastern Amazon, Brazil (Fig. 1). In the southernmost part of this region is located a heavily-forested area of approximately 209,000 ha, owned by the Cikel Brasil Verde Madereira group, representing a mosaic of undisturbed forest areas (here denominated reference area), and managed forest fragments that are subject to reduced impact logging (RIL). Undisturbed forest patches include areas of high conservation value and legal reserves, as well as forest stands designated for future logging activity which were considered as reference areas in this study.

In the northernmost part of this region, we selected forest fragments that are subject to conventional logging (CL), which has been carried out without any pre- or post-logging event planning to reduce impacts of logging on forest biodiversity. This logging method is permitted by Brazilian environmental law in the case of forest suppression for alternative land use or non-commercial logging carried out on rural properties, or by traditional populations. However, inefficient control of this activity has contributed to its illegal expansion in most Amazon forest fragments.

The spatial distribution of the sampled stream sites is related to the history of logging expansion in the region. Initially, conventional logging techniques were predominantly used in forested areas near roads (Barros and Verissimo, 2002). Later, large companies were interested in the ecological and, consequently, the economic advantages of forest management. They implemented RIL in forested areas with more restricted access, where we also found undisturbed areas that were used as reference condition sites (Putz et al., 2008). However, all stream sites belong to the same hydrographic basin, freshwater ecoregion, present similar species pools and similar ecological conditions (e.g. hydrology, relief and phytophysiognomy features) (Abell et al., 2008).

The RIL sites included in this study area have been certified by the Forest Stewardship Council (FSC) since 2001, totaling 16 years of logging activity. However, in the present study, only areas logged between 2001 and 2011 were sampled. The RIL areas are subdivided in Annual Production Areas (APA) ranging from 2000 to 5000 ha. Each APA has a 35-year cutting cycle and provides a mean logged volume of approximately 25 $m^3\ ha^{-1}\ year^{-1}$, representing approximately three trees per hectare per year (Holmes et al., 2002). In addition to FSC certification, the forest management applied in the region occurs according to the Brazilian Forestry Code, which establishes the maintenance of a permanent 30 m-wide preservation area (APP – *Área de Preservação Permanente* in Portuguese), beginning at the margins of watercourses.

The topography of the region ranges from flat to smoothly undulating terrain, with dense submontane ombrophilous vegetation (Veloso et al., 1991). The climate is classified as wet tropical, of subtype "Af" according to the Köeppen classification scheme adapted by Peel et al. (2007), with a well-defined dry season between August and October. The mean annual temperature is 27.2 °C, with mean annual rainfall of 1,800 mm (Watrin and Rocha 1992). The area studied is limited by the Capim River to the North, and by the Surubiju River to the South, drained through by many headwater streams.

2.2. Sample design

We sampled 47 stream sites (1st and 2nd order *sensu* Strahler, 1957), of which 24 were used to develop the habitat and biotic indices. Of these streams, 13 stream sites were sampled in reference areas, and 11 in areas of CL. The 23 remaining stream sites were sampled in RIL areas and used to validate the developed indices and assess their performance in determining the ecological integrity of streams in forest areas under differing levels of anthropogenic disturbance in the Eastern Brazilian Amazon.

2.3. Data Collection

For each stream site we set a 150-meter sampling stretch according to the wadeable stream habitat protocol proposed by Peck et al. (2006) adapted to tropical streams by Callisto et al. (2014). Each stretch was subdivided into eleven cross-sections (named A to K, in the downstream/upstream direction), resulting in ten 15-meter longitudinal sections. Equivalent sampling designs have been used in previous studies of Amazonian streams and were sufficient to detect patterns in fish