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Autochthonous primary production in southern Amazon headwater streams: Novel indicators of altered environmental integrity

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ABSTRACT

The riparian forest reduces the amount of light entering streams, which limits autochthonous primary production. The aim of this study was to evaluate temporal variation of autochthonous primary production in pristine and altered streams, with the goal of identifying indicators of change in environmental integrity in the southern Brazilian Amazon. We evaluated free algal biomass in the water column, the presence of periphyton, and the richness and cover of aquatic herbaceous plants in 20 streams (10 pristine and 10 altered, i.e., with riparian deforestation) during the dry period, at the beginning of the rainy period, and at the end of the rainy period. In altered streams, we recorded the presence of macroscopic periphyton and the amount of algal biomass varied between the dry and flood seasons. Variations in hydrological periods did not contribute to changes in algal biomass in pristine streams; we did not observe the presence of macroscopic periphyton these streams. In altered streams, 23 aquatic herbaceous species were identified, versus only four in the pristine streams. Results showed that riparian deforestation contributes to increased autochthonous primary production, which is also influenced by different hydrological periods, with algae and aquatic herbaceous plants responding differently to dry and rainy periods. The responses of these primary producers confirm their role as important bioindicators of change in the environmental integrity of southern Amazonian streams.

1. Introduction

In headwaters, most of the energy enters the system via organic matter from the litter of terrestrial vegetation (mainly leaves) (Wantzen et al., 2008). In these environments, heterotrophic metabolism predominates (Cummins, 1975), with allochthonous primary production accounting for 90% of the input of organic matter to streams (Vannote et al., 1980). The riparian forest provides the organic material on which the food web depends, and thus influences the functional structure of stream ecosystems (Gregory et al., 1991; Wallace et al., 1997). It also limits the autochthonous primary production by shading (Davies et al., 2008), thus preventing significant growth of planktonic algae, periphyton, or aquatic plants (Begon et al., 2007). Thus, autochthonous primary productivity declines when the canopy above the stream intercepts the entry of sunlight (Hill et al., 2001).

On the other hand, the partial or total removal of riparian forest may increase or change primary production in streams (Davies et al., 2008). Among the effects of increased light input into streams are changes in functional groups, with palatable unicellular algae being replaced by filamentous green algae, which require more light (Bunn et al., 1999); moreover the abundance of aquatic herbaceous plants in streams may also increase (Fletcher et al., 2000), together with the productivity of periphyton (Neill et al., 2001). While light is a limiting factor for primary production in stream ecosystems, nutrients play an important secondary role, and must be present for biosynthesis to take place (Hill et al., 1995). Nutrient limitation may have a significant influence on aquatic primary production in situations where light is not the limiting factor (Davies et al., 2008).

If openings in the canopy occur or forests are replaced by pasture, the amount of light entering Amazon headwater streams will increase and may modify the primary productivity in these streams

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(Neill et al., 2001; Thomas et al., 2004). Thus, these changes in the riparian forest can lead to the loss or reduction of the environmental integrity of streams, and the primary aquatic producers (i.e., algae and aquatic herbaceous plants) may be good indicators for measuring these changes (Karr, 1991; Karr and Chu, 2000). These organisms respond quickly to conditions that are favorable to their development, whether it be an increase in insolation, or the availability of nutrients or substrate (Bleich et al., 2009; Calijuri et al., 2008; Camargo et al., 2003; Cardinale et al., 2002; Castro et al., 2008; Rodrigues et al., 2005; Wetzel, 2001).

Cardinale et al. (2005) suggest that changes in the productivity and diversity of streams can have a big impact on organisms sensitive to disturbances. Therefore, to understand the effects of changes in the riparian zone on the integrity of Amazonian streams, one must also know the responses of the autochthonous primary producers. However, there are no comprehensive studies done in Amazonian headwater streams, e.g. Neill et al. (2001) and Thomas et al. (2004), even though region has undergone important changes regarding land use (Soares-Filho et al., 2006; Trancoso et al., 2009). As deforestation is the main environmental impact in the huge network of rivers of various orders that cut across the Southern Brazilian Amazon, and the degradation in water bodies has been continuously increasing, we proposed use of a novel bioindicator of change in the environmental integrity of southern Amazonian streams, 'autochthonous primary production'. The hypothesis is that autochthonous primary production increases in altered streams and varies among hydrological periods. Altered and pristine streams classifications were based in the habitat integrity index, where altered streams presented median value of 0.52 and pristine streams, 0.98 (Bleich et al., 2014). To test this hypothesis, we quantified the autochthonous primary production (presence of macroscopic periphytic algae, free algal biomass in the water column, and the richness and cover of aquatic herbaceous plants) of a set of headwater streams with and without riparian deforestation, and its variation among hydrological periods. We determined the impact of the removal of riparian forest cover on autochthonous primary production in order to provide elements for environmental impacts assessment and the monitoring of these water bodies.

2. Materials and methods

2.1. Study area

This study was conducted in 2010 and 2011 in streams in the southern Brazilian Amazon (9°30′28″–10°17′07″ S; 55°59′59″–56°44′37″ W), between 238 and 296 m above sea level in the Baixo Teles Pires River sub-basin, Alto Tapajós River, in the northern region of the state of Mato Grosso (Fig. 1). The watershed of the Teles Pires river traverses the land area of the Cerrado, followed by the Amazon–Cerrado transition area, and reaches the Amazon Forest area in the northern region of the state of Mato Grosso, Brazil. In this geographical region, rainfall shows two well-defined seasons throughout the year, with June, July, and August being the driest months (SEPLAN, 2000).

2.2. Sampling design

We assessed the presence of macroscopic periphytic algae, the free algal biomass in the water column, and the richness and cover of aquatic herbaceous plants in 10 sites selected based on their spatial location (Fig. 1). At each site, we selected two headwater streams, one located in an area with preserved riparian vegetation (pristine streams) and the other with riparian deforestation (altered streams). Each sampling site consisted of a 50 m stretch of a chosen stream. We sampled stretches during three periods between July 2010 and May 2011: dry period (July and August 2010; mean rainfall = 5 mm), beginning of the rainy period (i.e., rain/begin; November and December 2010; mean rainfall = 363 mm), and end of the rainy period (i.e., rain/end; April and May 2011; mean rainfall = 158 mm).

Table 1
Median values of the riparian zone characteristics of pristine (P) and altered (A) streams of Southern Brazilian Amazon, from linear buffer zones of varying width (50, 100, and 200 m) surrounding each stream stretch.

Riparian zone (%)	50 m width		100 m width		200 m width	
	P	A	P	A	P	A
Forest	96.03	0.00	94.71	0.00	93.15	3.79
Secondary forest	0.00	9.53	0.00	7.03	0.00	2.51
Gap	3.49	0.00	3.48	0.00	2.62	0.29
Pasture	0.00	81.36	0.00	81.38	0.00	84.56
Exposed soil/roads	0.00	4.13	0.67	4.79	1.84	3.48

Stream riparian zones were evaluated regarding their proportional forested area, canopy gap density, surrounding pasture, secondary forest, and exposed soil. We analyzed Spot-5 satellite images (Satellite Probatoire Pour l'Observation de La Terre) from 2009 for linear buffer zones vectorization of varying width (50, 100, and 200 m) along each 150 m stream stretch using ArcGis 9.3 (ESRI, 2006). Altered streams have median values of pasture above 80% in buffer zones, while pristine streams do not present pasture cover at the 50 m and 100 m buffer zones, with only minor alterations at the 200 m buffer zone (Table 1).

The presence of macroscopic periphytic algae was determined by surveying a 50 m stretch of the stream. The free algal biomass in the water column (mg/L) was determined by extracting chlorophyll *a*, for which three water samples were collected from each stream, then packed in bottles protected from light by aluminum foil and kept refrigerated until filtering and early extraction (which occurred within 12 h of collection). For water filtration (2000 mL), we used fiberglass filters (52 mm GF/C Whatman) that was previously calcined in a muffle furnace at 450 °C for 4 h. Chlorophyll *a* was extracted with 90% ethanol heated to 78 °C and a concentration reading was conducted according to Nush (1980) and using a spectrophotometer (Quimis, Q798U2M model).

The richness and cover of aquatic herbaceous plants were evaluated by identifying species over a stretch of 50 m following the course of the stream and 1 m wide on each bank. Fertile specimens were collected, recorded, and incorporated into the Herbarium of the National Institute for Amazonian Research (Instituto Nacional de Pesquisas da Amazônia, INPA, collector ME Bleich 247406–247505). Taxonomic identification was performed at the INPA herbarium and species scientific names and families were updated according to the Angiosperm Phylogeny Group III system (APG III, 2009); these species names and their authors were confirmed using the Tropicos (2013) database from the Missouri Botanical Garden, USA. The coverage of aquatic herbaceous plants was measured as the percentage of coverage for a given length of stretch evaluated: 0% (no aquatic herbaceous plants), 0.1–2% in up to 1 m of stretch evaluated, 2.1–20% in up to 10 m of stretch, 21–50% in up to 25 m of stretch, 51–70% in up to 35 m, and 71–100% in up to 50 m of stretch. Classification of the lifeforms of aquatic herbaceous species was conducted according to Cook (1996).

Canopy openness (CO) was estimated with three equidistant digital photographs of the canopy per stretch (50 m) using an Olympus FE-120 (6.3–18.9 mm) camera, which were converted to monochromatic (black and white) images using an image editor (ArcGis 9.3) (ESRI, 2006). CO (%) was calculated as the mean of the proportion of white pixels from the total amount of pixels per image (Bunn et al., 1999; Mendonça et al., 2005).