



## Hydrological seasons fast identification applied to Jaitêua and São Lourenço lakes, Manacapuru, Amazonas State

### Identificação rápida de períodos hidrológicos aplicada aos lagos Jaitêua e São Lourenço, Manacapuru, estado do Amazonas

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**Abstract** This paper approaches the application of Hydrological Seasons Fast Identification procedure, proposed by Bittencourt & Amadio (2007), to floodplain lakes with no hydrometric history. For this, we used the correlation between the Solimões river water level, from January 1972 to December 2015, and the Jaitêua and São Lourenço lakes depths, collected from July 2006 to June 2007. Besides the usual results, seasons limits and its intensity and duration classes, we spotted differences between the river and lakes hydrological seasons, a phenomena normally associated with the environments connectivity. Most importantly, we would like to stimulate the debates about arbitraries and the development of better methodological standards for Amazon floodplains seasons identifications.

**Keywords:** Amazon, floodplain, hydrology, seasons.

**Resumo** Esse artigo aborda a aplicação da Identificação Rápida de Períodos Hidrológicos, procedimento proposto por Bittencourt & Amadio (2007), à lagos de várzea sem histórico hidrométrico. Para isso, usamos a correlação entre a cota linimétrica do rio Solimões, de 01/1972 a 12/2015, e a profundidade dos lagos Jaitêua e São Lourenço, medida entre 07/2006 e 06/2007. Além dos resultados habituais, limítrofes e suas classificações de intensidade e duração, foram observadas diferenças entre os períodos hidrológicos do rio e dos lagos, fenômeno normalmente associado ao tipo de conectividade entre os ambientes. Mais importante, gostaríamos de estimular os debates sobre a arbitrariedade e o desenvolvimento de melhores padrões metodológicos para identificação dos períodos hidrológicos na várzea.

**Palavras-chave:** Amazônia, estações, hidrologia, várzea.

## Introduction

Floodplain areas are marked by high biodiversity and habitat heterogeneity, as well as sensitivity to environmental changes (Bayley, 1995; Junk & Wantzen, 2004; Soares, Freitas & Oliveira, 2014). They are also a scenario for complex relationships of animals, plants and the environment (Isaac, Fabre, Silva, Ruffino & Saint-Paul, 2012). Effects of these environmental changes include the alteration of habitats, shifts in nutrient cycling patterns, and changes in temperature, oxygen levels, and other limnological variables (Kreibich, 2002; Esteves, 2011a; Almeida et al., 2014; Brito, Alves & Espirito-Santo, 2014). Under the influence of the environmental variation, many organisms, namely ichthyofauna, suffer direct effects of changes in community composition and food availability (Poff et al., 1997; Winemiller & Jepsen, 1998; Saint-Paul et al., 2000; Santos, Ferreira & Amadio, 2008).

Despite its importance, Amazon floodplain seasons delimitation are mostly arbitrary (Merona & Gascuel, 1993; Cunico, Graça, Veríssimo & Bini, 2002; Maciel, 2010; Maciel, Soares & Prestes, 2011), leading to comparison difficulties among different years studies. In attempt to establish a standard method, Bittencourt & Amadio (2007) proposed a statistical procedure to identify the Negro river hydrological seasons based in its a water level historical dataset. The aim of this paper is to demonstrate how this procedure can be extended to lakes without any hydrological history, such as Jaitêua and São Lourenço lakes, part of Grande lake system, next to Manacapuru city, Amazonas State.

## Materials and Methods

The depth of Jaitêua (coordinates S 3.28 W 60.72) and São Lourenço (coordinates S 3.24 W 60.75) lakes were measured monthly, from July 2006 to June 2007, always in the same location, using a metric tape with a sinker. The water level history for the Solimões River were obtained from the National Water Agency Hydrological Information System. We used the data from the hydrometric station code 14100000 (S 3.31 W 60.61), the closest to the lakes. This data set range from January 1972 to December 2015, totalizing 44 years of multiple daily measures. For the next analyses, we preferred the measures labeled as consistent and, for the data without it, the daily averages.

Firstly, to identify the Solimões River hydrological seasons, following the procedure described on Bittencourt & Amadio (2007), we used the averages and standard deviations of the minimum and maximum annual water level to estimate the dry season limit (the average minimum level plus its standard deviation) and the flood season limit (the average maximum level minus its standard deviation).

Secondly, based on the limits above, the seasons could be classified as Low water (when the water level is below or equal the dry season limit), Rising water (when the water level is ascending between the dry and flood limits), High water (when the water level is above or equal the flood season limit) and Receding water (when the water level is descending between the dry and flood limits).

Thirdly, to classify the seasons intensity, we used the confidence interval ( $\alpha = 0, 05$ ) of the minimum and maximum annual water level. Thus, the Low water seasons were classified as weak (when the minimum water level of the year is above the confidence limits), strong (when the minimum water level of the year is below the confidence limits) or typical. Similarly, the High water seasons were classified as weak (when the maximum water level of the year is below the confidence limits), strong (when the maximum water level of the year is above the confidence limits) or typical.

Fourthly, to classify the seasons duration, we by its confidence interval ( $\alpha = 0, 05$ ), instead of the standard deviation as proposed by Bittencourt & Amadio (2007). We had to exclude the years when water level does not reached the dry or the flood season limit, since it was difficult to distinguish Rising and Receding water seasons. Thus, the four seasons were classified as short (when the duration was below the confidence limits), long (when the duration was above the confidence limits) or typical.

Lastly, to identify the hydrological seasons of the lakes, we used regression analysis (Nelder & Wedderburn, 1972; Hoffmann, 2016) to correlate its depths, measured from July 2006 to June 2007 as mentioned above, with the Solimões river water level. Thus, we could predict the lakes dry and flood season limits from the river's.

Distributions normality were verified by Shapiro-Wilk test (Yap & Sim, 2011; Noughabi & Arghami, 2011). All the analyses described above were supported by the R statistical software (R Core Team, 2017).

## Results

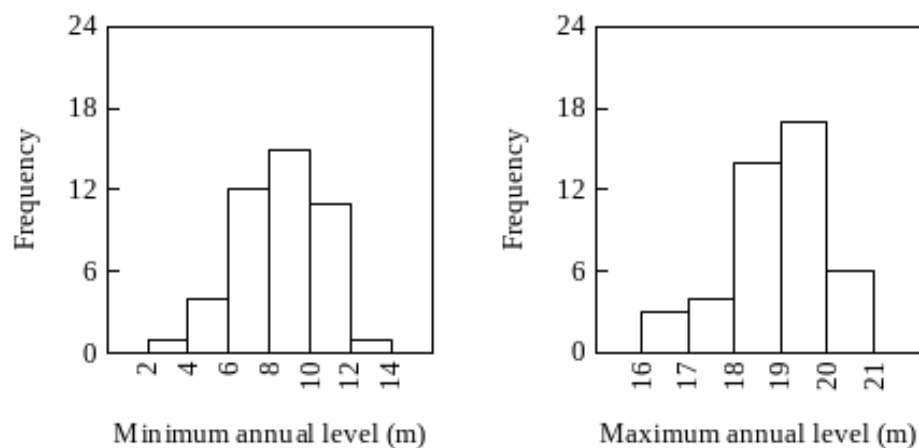
Solimões river minimum and maximum annual water level were, respectively,  $8.53 \pm 2.03$  and  $18.91 \pm 1.07$  m ( $n = 44$ ). Thus, we estimated the dry and flood season limits as 10.56 and 17.84 m, respectively, and classified the hydrological periods according to Table 1. The duration of the low, rising, high and receding water seasons were, respectively,  $72.86 \pm 30.13$ ,  $131.72 \pm 27.44$ ,  $98.10 \pm 31.12$  and  $62.55 \pm 16.69$  days ( $n = 29$ ). Through the confidence intervals, the seasons intensity and duration were classified according to Table 2. Normality assumption was valid for the maximum annual water level ( $p = 0.7228$ ,  $n = 44$ ), but not for the minimum ( $p = 0.0409$ ,  $n = 44$ ), as seen on Figure 1, and for the low, rising and high water season duration ( $p > 0.1177$ ,  $n = 29$ ), excepting the receding water ( $p = 0.0366$ ,  $n = 29$ ), as seen on Figure 2.

**Table 1.** Solimões river hydrological seasons delimitation

Season	Water level
Low water	Below or equal 10.56 m
Rising water	Ascending between 10.56 and 17.84 m
High water	Above or equal 17.84 m
Receding water	Descending between 17.84 and 10.56 m

**Table 2.** Solimões river seasons intensity and duration classes

Season	Intensity		
	Weak	Typical	Strong
Low water	Above 9.13 m	Between 7.93 and 9.13 m	Below 7.93 m
High water	Below 18.60 m	Between 18.60 and 19.23 m	Above 19, 23 m
Season	Duration		
	Short	Typical	Long
Low Water	Less than 61 days	Between 61 and 84 days	More than 84 days
Rising Water	Less than 121 days	Between 121 and 142 days	More than 142 days
High Water	Less than 86 days	Between 86 and 110 days	More than 110 days
Receding Water	Less than 56 days	Between 56 and 69 days	More than 69 days



**Figure 1.** Histogram of the Solimões river minimum and maximum annual water level

The correlation between the lakes depths and Solimões river water level produced the linear models described by Equations 1 ( $r^2 = 0.8081$ ,  $p = 0.0002$ ,  $n = 11$ ) and 2 ( $r^2 = 0.9268$ ,  $p < 0.0001$ ,  $n = 9$ ). The dispersion plots can be seen on Figure 3. Applying the Solimões river season limits, 10.56 and 17.84 m, on these equations we estimated the dry and flood season limits for the Jaitêua lake, 2.23 and 6.40 m, and for the São Lourenço lake, 3.49 and 7.71 m. By these limits, we could define the hydrological periods as seen in Table 3. Although these equations cannot predict the seasons duration, it can be used to classify the seasons intensity, applying the Solimões river confidence limits (see Table 2), as shown in Table 4.

$$Z_{Jai} = 0.5715 \cdot h_{Sol} - 3.8022 \quad (1)$$

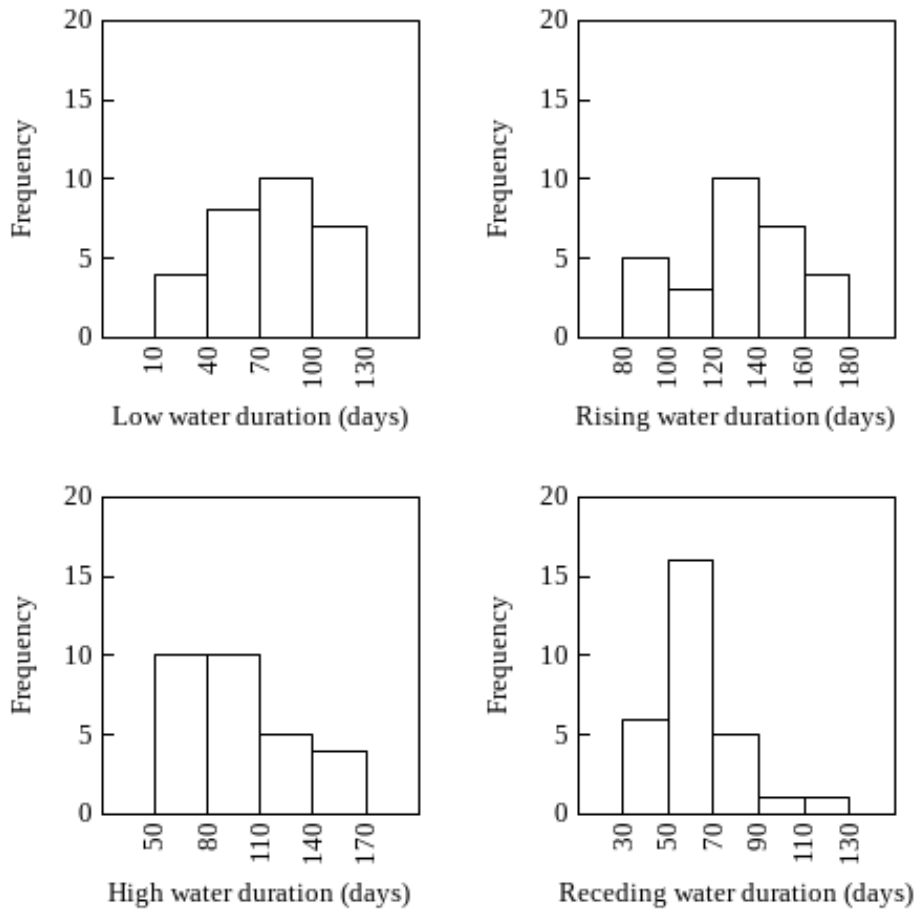
$$Z_{Lou} = 0.5791 \cdot h_{Sol} - 2.6274 \quad (2)$$

When:

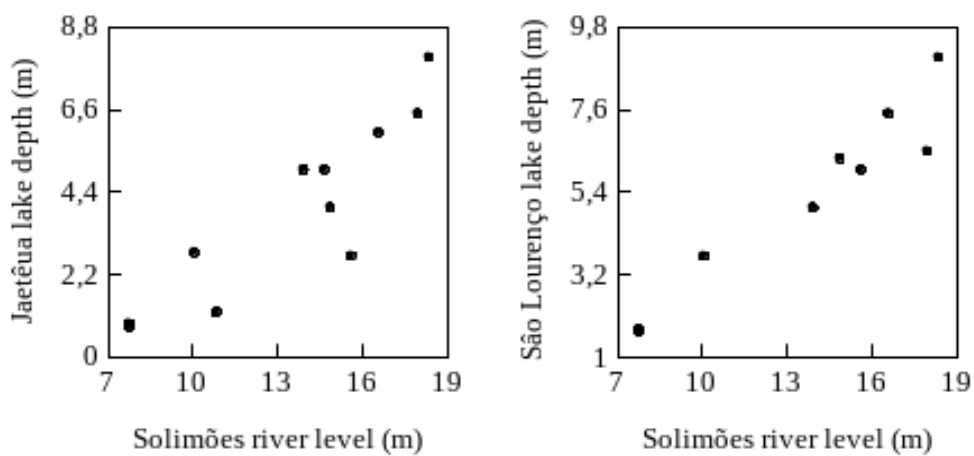
$Z_{jai}$  is the Jaitêua lake depth, in meters

$Z_{lou}$  is the São Lourenço lake depth, in meters

$h_{sol}$  is the Solimões river water level, in meters



**Figure 2.** Histogram of the Solimões river seasons duration



**Figure 3.** Dispersion plot of the correlation between Jaitêua and São Lourenço lakes depth and Solimões river water level

**Table 3.** Jaitêua and São Lourenço lakes hydrological seasons delimitation

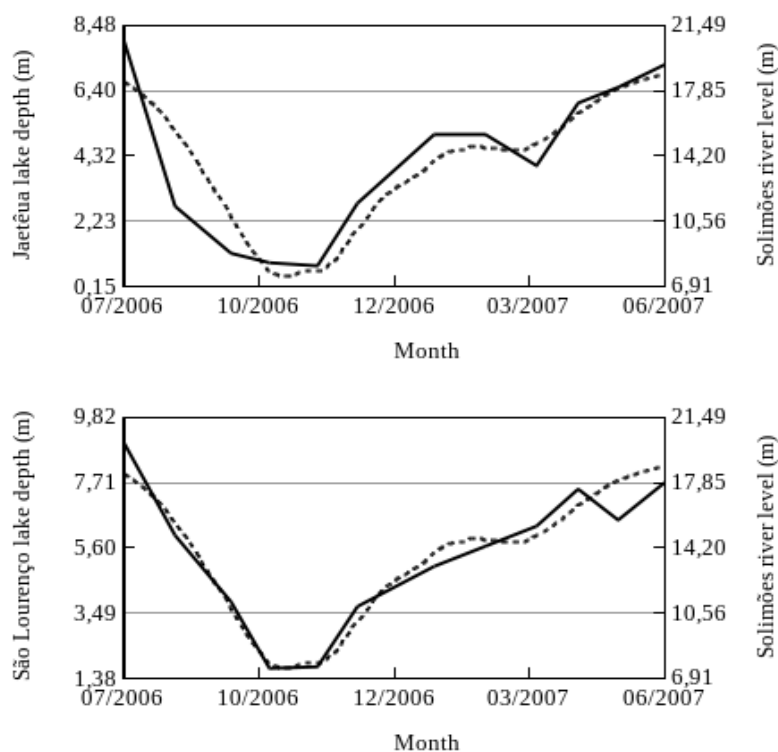
Lake	Season	Water level
Jaitêua	Low water	Below or equal 2.23 m
	Rising water	Ascending between 2.23 and 6.40 m
	High water	Above or equal 6.40 m
	Receding water	Descending between 6.40 and 2.23 m
São Lourenço	Low water	Below or equal 3.49 m
	Rising water	Ascending between 3.49 and 7.71 m
	High water	Above or equal 7.71 m
	Receding water	Descending between 7.71 and 3.49 m

**Table 4.** Jaitêua and São Lourenço lakes seasons intensity classes

Lake	Season	Intensity		
		Weak	Typical	Strong
Jaitêua	Low Water	Above 1.41 m	Between 0.73 and 1.41 m	Below 0.73 m
	High Water	Below 6.83 m	Between 6.83 and 7.19 m	Above 7.19 m
São Lourenço	Low Water	Above 2.66 m	Between 1.96 and 2.66 m	Below 1.96 m
	High Water	Below 8.14 m	Between 8.14 and 8.51 m	Above 8.51 m

Superposing Solimões river and the lakes season limits, we produced the Figure 4 to illustrate the differences of the water fluctuation between the environments. Table 5 presents the monthly seasons delimitation, during July 2006 and June 2007. Here we note some differences in the environments seasons: compared to Solimões river, Low water season starts earlier in Jaitêua lake and is shorter in São Lourenço lake. We can also see that São Lourenço lake does not reach the flood season limit in 2007.

**Figure 4.** Annual water level fluctuation of Jaitêua and São Lourenço lakes (continuous lines) and Solimões River (dashed lines)



**Table 5.** Solimões River and Jaitêua and São Lourenço lakes monthly seasons

Environment	2006						2007					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mai	Jun
Solimões	Hi	Re	Re	Lo	Lo	Lo	Ri	Ri	Ri	Ri	Hi	Hi
Jaitêua	Hi	Re	Lo	Lo	Lo	Ri	Ri	Ri	Ri	Ri	Hi	Hi
São Lourenço	Hi	Re	Re	Lo	Lo	Ri	Ri	Ri	Ri	Ri	Ri	Ri

Hi: High water season; Re: Receding water season; Lo: Low water season; Ri: Rising water season

Finally, Table 6 summarizes the annual minimum and maximum water levels, seasons intensity and duration classes for Solimões River.

**Table 6.** Solimões River annual seasons intensity and duration classes

Year	Season intensity				Season duration							
	Low water		High water		Low water		Rising water		High water		Receding water	
1972*	10,66	We	19,23	St								
1973*	11,45	We	19,22	Ty								
1974*	12,51	We	19,09	Ty								
1975	10,03	We	19,72	St	23	S	136	T	135	L	71	L
1976	8,84	Ty	19,99	St	66	T	118	S	127	L	55	S
1977*	11,15	We	19,09	Ty								
1978*	10,95	We	18,75	Ty								
1979	7,89	St	18,7	Ty	102	L	96	S	70	S	97	L
1980*	8,45	Ty	16,27	We								
1981*	7,74	St	17,45	We								
1982	8,76	Ty	19,44	St	57	S	150	L	95	T	63	T
1983*	7,48	St	17,13	We								
1984	9,91	We	18,57	We	59	S	156	L	73	S	78	L
1985*	10,3	We	16,6	We								
1986*	11,81	We	18,59	We								
1987	8,49	Ty	18,63	Ty	79	T	138	T	69	S	79	L
1988	8,26	Ty	18,33	We	72	T	179	L	54	S	61	T
1989	9,38	We	19,94	St	11	S	100	S	140	L	114	L
1990	6,7	St	18,57	We	93	L	126	T	79	S	67	T
1991	6,83	St	18,62	Ty	85	L	140	T	77	S	63	T
1992*	8,28	Ty	16,23	We								
1993	10,05	We	19,55	St	20	S	157	L	114	L	74	L
1994*	11,01	We	19,79	St								
1995*	5,52	St	17,77	We								
1996	9,41	We	19,11	Ty	51	S	167	L	90	T	58	T
1997	4,95	St	19,52	St	107	L	103	S	107	T	48	S
1998	5,57	St	18,28	We	110	L	149	L	50	S	56	T
1999	7,49	St	20,03	St	93	L	96	S	132	L	44	S
2000	8,58	Ty	19,14	Ty	53	S	137	T	93	T	83	L
2001	7,44	St	18,86	Ty	82	T	122	T	96	T	65	T
2002	8,01	Ty	19,56	St	41	S	158	L	109	T	57	T
2003	9,86	We	19,02	Ty	41	S	178	L	90	T	56	T
2004*	10,22	We	17,58	We								
2005	5,08	St	18,72	Ty	113	L	127	T	65	S	60	T
2006	7,48	St	19,27	St	82	T	137	T	86	T	60	T
2007	8,08	Ty	18,76	Ty	73	T	161	L	75	S	56	T
2008	8,72	Ty	19,06	Ty	64	T	154	L	84	S	64	T
2009	7,68	St	20,46	St	80	T	87	S	156	L	42	S
2010	2,89	St	18,50	We	117	L	131	T	62	S	55	S
2011	6,98	St	18,97	Ty	122	L	120	S	80	S	43	S
2012	6,72	St	20,73	St	100	L	80	S	141	L	45	S
2013	9,85	We	20,17	St	35	S	128	T	136	L	66	T
2014*	10,79	We	20,33	St								
2015	6,91	St	20,78	St	82	T	89	S	160	L	34	S
n	44		44		29		29		29		29	
AVR	8,53		18,91		72,86		131,72		98,10		62,55	
SD	2,03		1,07		30,13		27,44		31,12		16,69	
CL	7,93 –		18,60 –		61,90 –		121,74 –		86,77 –		56,48 –	
	9,13		19,23		83,83		141,71		159,43		68,63	

\*Year excluded from the season duration analysis;

We: weak intensity; St: strong intensity; Ty: typical intensity; S: short duration; L: long duration; T: typical duration  
n: sample size; AVR: average; SD: standard deviation; CL: confidence limits ( $\alpha = 0,05$ )



## Discussions

Contributing to standardize in the hydrological periods delimitation, this study expands the procedure described by Bittencourt & Amadio (2007) and demonstrate how a simple data collection can provide reliable models (see Equations 1 and 2) to identify the seasonal changes in a lake without any hydrometric history (see Tables 3, 4 and 5). We believe this approach can be especially useful for floodplain studies, due the flood pulse social and ecological importance (Poff et al., 1997; Bayley, 1995; Johnson, Richardson & Naimo, 1995; Junk & Wantzen, 2004; Alho, 2008; Lopes & Caliman, 2008; Almeida et al., 2014; Soares, Freitas & Oliveira, 2014) combined with the lack of permanent hydrometric monitoring programs in most of these environments (Ramalho et al., 2005).

Regarding the asymmetry of some distributions (see Figures 1 and 2), as the range of the data history increases, future studies may generate more precise estimations. In comparison, the data set used in this study, of 44 years, have less than a half of the range used by Bittencourt & Amadio (2007), that was 101 years. Nevertheless, we cannot rule out the possibility that there is a real asymmetry in these distributions, either due to natural phenomena or climate changes (Cunico, Graça, Veríssimo & Bini, 2002; Bonnet et al., 2008; Ramalho et al., 2005; Araujo & Rocha, 2010; Freitas et al., 2012; Sousa & Rocha, 2015; Ropke et al., 2017). In example, the Mamirauá lake hydrometric history, presented by Ramalho et al. (2005), also shows a slight increase in the maximum water level along 1990 to 2009, 19 years, which is expected to cause a negative skewness in the frequency distribution of maximum annual water level.

Concerning the differences between the lakes and the river seasons (see Figure 4 and Table 5), this is not uncommon phenomena. In fact, beside the distance, its usually associated with the environments connectivity (Centofante & Melo, 2012; Brito, Alves & Espírito-Santo, 2014), an important feature for its ecology and biodiversity (Freitas & Sousa, 2004; Fantin-Cruz, Loverde-Oliveira & Girard, 2008; Hurd et al., 2016). In example, the isolated Camaleão lake, located inside the Marchantaria Island, Amazonas state, has a fluctuating water level which follows the Solimões river from Rising to Receding and stabilizes during Low water season despite a severe reduction in the river level (Kreibich, 2002). Close to Camaleão, the Catalão lake is connected to both Negro and Solimões rivers, from the north and the south respectively, receiving more limnological influence of the first during Rising and of the last during High water season (Brito, Alves & Espírito-Santo, 2014), meaning a different level of connectivity between them.

The Grande lacustric complex, where Jaitêua and São Lourenço lakes are located, is believed to be originated by the damming of the Manacapuru river with sediments carried by the Solimões river. This process normally is associated with the genesis of elongated dendritic lakes (Esteves, 2011b), a geomorphological class with remarkable productivity (Souza, 2000). As these floodplain lakes are subject to structural changes over time, we suspect the depth might not be the best measure for this kind of study. In example, Almeida et al. (2014), studying mercury contamination in Puruzinho lake, mentions the transport of this substance through sediments suspension and deposition. Thus, we believe a fixed staff gauge could prevent errors from sediments accumulation and bottom depth changes, generating more accurate results.

## Conclusions

We extend the methodology proposed by Bittencourt & Amadio (2007) to the lakes, where normally there are no hydrometric monitoring, and demonstrated how to delimit a lake hydrological seasons by correlating its depth, collected in a short period of months, with the main river water levels, provided there is a hydrometric history dataset available. In the process, we also spotted differences between the Solimões river hydrological seasons and Jaitêua and São Lourenço lakes.

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