v. 3, n. 10, 2023

Journal of
Agricultural
Sciences
Research

SPACE-TEMPORAL EVALUATION OF THE EFFECTS OF DROUGHT USING REMOTE SENSING ON PAYTUNA LAKE WATER IN MONTE ALEGRE FLUVIO-LACUSTRY COMPLEX, PARÁ, BRAZIL: IS IT POSSIBLE TO CULTIVATE FISH IN THIS AMAZONIAN ENVIRONMENT?

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DOI 10.22533/at.ed.9733102313076

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Abstract: The production of fish from fisheries and aquaculture for global food security in the 21st century is of paramount importance. Considering that the world production of fish in 2020 was 178 million tons and fisheries contributed with 51% of this total, while aquaculture contributed with 49%. However, in the Amazon region, fishing has an even greater representation in fish production, especially in the context of riverside populations that use this activity to guarantee their food and livelihood. In recent years, extractive fishing activity has been strongly affected by extreme weather events, such as severe droughts, causing ecological impacts, harming aquatic biodiversity, and social impacts, with the reduction of protein sources for the Amazonian population. Thus, the study proposes to evaluate the variability of the physical-chemical and nutrient conditions of Lake Paytuna during the dry season, as well as to analyze the occurrence of a tendency to decrease the lake's flooded area over the years. For this, limnological data were collected in the months of October, November and December between the years 2019 and 2021. In addition, satellite images were acquired for the months of October, November and December between the years 2000 and 2020 to calculate the area of the lake in the dry period using the Normalized Water Difference Index (NDWI). The results showed that the limnological variables did not present significant differences between the sampling stations, except for dissolved oxygen, which presented a lower value in a specific point characterized as a lotic environment. There was a trend towards a significant decrease (S = -80; p-value = 0.0104) in the area of the lake and we pointed out a greater attention to the years 2005 and 2015 than the dry seasons of smaller registered areas. Overall, Lake Paytuna appears to be in an oligotrophic state, with low concentrations of total phosphorus and chlorophyll-a. These results are important for aquaculture, as they indicate that the lake has good water quality for fish farming. Fish farming has been considered an alternative to increase the supply of aquatic animal protein and meet the demand of the local population.

Keywords: Amazonian lakes, El niño, EAC's monitoring

INTRODUCTION

The contribution of fisheries and aquaculture has been increasingly recognized for its essence to global food and nutrition security in the 21st century. Estimated world fish production in 2020 was 178 million tonnes, 1m tonnes less than the 2018 production record. Capture fisheries contributed 90 million tonnes (51%) and aquaculture 88 million tonnes (49%) (FAO, 2022).

The world's aquatic animal protein production indicates a "Blue Transformation" due to the growing role of fisheries and aquaculture in providing food, nutrition and employment.

In recent years, the Amazon basin has experienced a series of extreme weather events, with strong ecological and social impacts on the local population (TOMACELLA et al., 2010). The negative effects of climate change on wetlands in the Amazon affect mainly the aquatic biota, and involve not only the loss of biodiversity, but also of protein sources for the majority of the human population in this region (BARROS and ALBERNAZ, 2014).

With the frequent occurrences of strong variations in precipitation, the Amazon basin is affected by intense periods of flooding in rivers or extreme drought. Most of them being droughts, which can be characterized as severe droughts, and generally associated with the natural phenomenon El Niño, an event resulting from the strong connection between the Amazon and the temperature variability on the oceanic surface of the tropical Pacific (MARENGO, 2005; TOMASELLA et al., 2013).

Extreme droughts such as those of 1996 and 2005 were mentioned by local populations as largely responsible for the mortality of numerous aquatic species, death associated with hypoxia. In addition, the mobility of the population living in these areas is entirely dependent on the connection between the main river and the floodplain lakes, through the connecting channels, which are drained during severe droughts, causing impacts on the local economy, education and medicinal supply (TOMACELLA et al., 2010). The situation was no different in the great drought of 2010, considered more extreme than that of 2005 (MARENGO et al., 2011a; MARENGO et al., 2011b).

Considering the characteristic of the Amazonian population to have a greater preference for animal protein of aquatic origin, and the difficulty of fishing due to climate changes, the present study proposed to evaluate the spatial variability of the physical-chemical and nutrient variables in the dry season of Lake Paytuna, as well as also, calculate the area of the lake in the driest months between the years 2000 to 2020 using satellite images to analyze the occurrence of a tendency to decrease the flooded area of the lake, applying the index of the normalized water difference (NDWI) and thus verify the possibility of implementing fish farming for the subsistence of the local riverside population.

MATERIAL AND METHODS

DESCRIPTION OF THE STUDY AREA

The municipality of Monte Alegre is located in the northwest portion of the state of Pará and is located on the left bank of the Amazon River. It belongs to the Lower Amazon Mesoregion, Microregion of Santarém, between the coordinates of

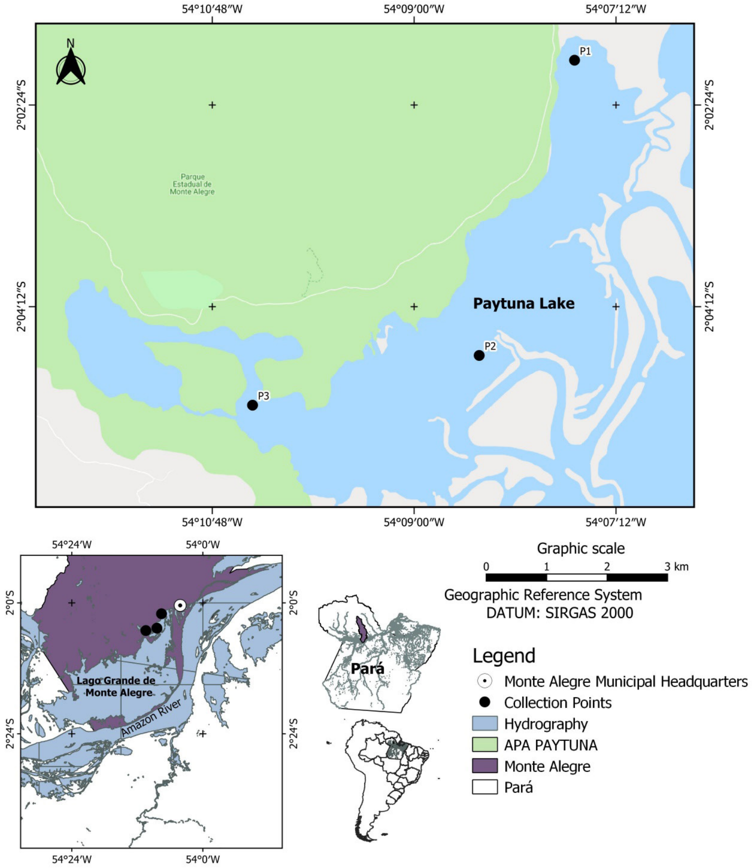

Figure 1 – Lake Paytuna located in the Paytuna Environmental Protection Area (APA) and respective collection stations.

Variables	Point 1	Point 2	Point 3
Depth (m)	1.78±0.59	2.2±064	1.57±0.13
Transparency (m)	0.20±0.03	0.21±0.04	0.18±0.04
Temperature (°C)	29.17±1.13	30.37±5.43	30.67±0.56
Condutivity (µ.S.cm^{-1})	45.10±6.27	37.27±13.26	39.43±12.52
Dissolved Oxygen (mg.L^{-1})	4.8±0.94	5.7±0.84	5.36±0.29
pH	6.23±0.16	6.51±1.18	6.3±0.16
Total Nitrogen (mg.L^{-1})	2.26±0.93	1.88±0.76	2.01±0.88
Silica (mg.L^{-1})	15.46±1.72	16.45±2.98	16.42±0.29
Chlorophyll-a (µg.L^{-1})	13.27±9.91	6.7±4.49	9.51±7.11
Total Phosphorus (mg.L^{-1})	0.005±0.002	0.009±0.005	0.008±0.002

Table 1 – Preliminary results of the limnological variables collected during the dry season of Lake Paytuna.

00º22’52” north latitude and 02º25’34” south latitude, and 53º41’10” east longitude and 54º54’13” west longitude (BRASIL, 2009). In the municipality, there is the Monte Alegre State Park (PEMA), with an area of 58 km² and a perimeter of 46,377 m, it is inserted in its entirety in the Environmental Protection Area (APA) Paytuna (see figure 1) (BRAZIL, 2009).

DATA SURVEY

Limnological data collection

The collections take place in the months of October and November between the years 2019 and 2021 in the dry season. The environmental variables measured in situ were: Depth (m) measured with the aid of an echo probe – GAMIM ECHO 150, water transparency (m) with the aid of a Secchi disk, pH, Dissolved Oxygen (mg.L-1), Conductivity (μS.cm-1) and Temperature (°C) which were measured with the aid of the multiparameter probe AKSO model AK88. Turbidity (NTU) was measured using a Policontrol series AP 2000 benchtop turbidimeter. The variables Total Nitrogen (mg.L-1), Total Phosphorus (mg.L-1), Silicate (mg.L-1) and Chlorophyll-a (μg.L-1) were analyzed in the laboratory using analytical methods recommended in the international manual Standard Methods for the Examination of Water and Wastewater (APHA, 2012).

Image acquisition

The images were obtained from the Landsat 5 sensor TM, Landsat 7 sensor ETM+ and Landsat 8 sensor OLI satellites with a spatial resolution of 30 meters, made available in the freely accessible image database of the United State Geology Service-USGS (Source: https://earthexplorer.usgs.gov/). Images will always be selected in the months between October, November and December between the years 2000 to 2020 that characterize the dry period for the region. As many elements can interfere with the spectral response of water as dense cloud cover over the study area, the images were selected according to the minimum cloud cover.

Acquisition of climatological data

The climatological data used were indices based on different atmospheric and oceanic variables. Among these variables, two indices of the El Niño-Southern Oscillation (ENSO) phenomenon were obtained: Oceanic Niño Index (Oceanic Niño Index) of the Niño 3.4 region; The Multivariate ENSO Index (MEI). Another index based on sea surface temperature in the Tropical North Atlantic Ocean (Tropical Northern Atlantic Index - TNA). These data were obtained from the freely accessible database of the atmospheric sciences course at the ``Universidade Federal de Itajubá`` - UNIFEI and is available at https://meteorologia.unifei.edu.br/teleconexoes/. The data were processed by calculating the averages between the months of October, November and December for each year of the studied time series.

Data processing

For the enhancement of water fragments in Lake Paytuna and characterization of this lake in the dry season, the Normalized Water Difference Index (NDWI) will be applied using reflectance data from the bands corresponding to 0.86μm and 1.24μm, respectively. The images obtained by the database belong to the Landsat Collection 2 Level-2 catalog, this USGS product provides the images converted from Digital Number to Physical Values Surface Reflectance.

The NDWI calculated by equation (1) for Landsat 5 and 7, and equation (2) for Landsat 8, both use the wavelengths of reflected radiation in the green range (0.52 – 0.60μm), the radiation reflected in the near-infrared range (0.76 – 0.90μm) from the sensors aboard the Landsat satellite. The NDWI value ranges from -1 to 1. McFeeters (1996) defined zero as the threshold. That is, the type of cover is water if NDWI ≥ 0 and there is no presence of water on the surface if NDWI ≤ 0 (BRUBASCHER and GUASSELLI, 2013).

$$NDWI = \frac{(Band\ 2 - Band\ 4)}{(Band\ 2 + Band\ 4)} \quad (1)$$

$$NDWI = \frac{(Band\ 3 - Band\ 5)}{(Band\ 3 + Band\ 5)} \quad (2)$$

After applying the NDWI on the time series of images, the lake area will be calculated for each month in which the smallest water area occurred. To test the occurrence of trends in area decrease over 20 years of data, the Mann-Kendall (MK) test will be used. This tool, as it is a non-parametric method, does not require normal distribution for data analysis. An analysis of variance (ANOVA) was performed to test the occurrence of significant differences in the limnological variables between the three collection stations and a posteriori the Tukey test. The above analyzes were tested at a significance level of 5%. For the above procedures, we used the free software QGIS 3.16 for image processing and PAST 4.06 for statistical analyses.

RESULTS AND DISCUSSION

In Table 1, it presents the average results of the physical-chemical variables and nutrients of the campaigns carried out in the dry season of the region, these limnological variables did not present significant differences ($p>0.05$) between the three collection stations, with the exception of dissolved oxygen ($p<0.05$) where we highlight the lowest value in point 1, which characterizes a lotic environment. Despite not showing spatial variation, we highlight the average values of Chlorophyll-a and Total Phosphorus that point to an apparently oligotrophic environment. However, for such a statement, it is necessary to carry out other studies that include collections in the rainy season in order to elucidate the trophic state of the lake.

The results obtained for Total Phosphorus are well below the limit established by CONAMA (National Council for the Environment) Resolution 357/2005, which is 0.030 mg/L for lentic environments. Chlorophyll-a values are below the standard established by CONAMA (National Council for the Environment) Resolution 357/2005, which is up to 30 μg/L in class 2 freshwater bodies (MMA, 2005). These results point to an oligotrophic state for the lake, According to Esteves (2011), the trophic state for freshwater environment can be classified with the concentration of Total Phosphorus and to classify the oligotrophic state it must be within a range of 3.0 to 17.7 μg/L.

For aquaculture, the water quality of a reservoir such as a lake must have a value lower than 30 μg/L of total Phosphorus to be considered good or excellent for fish farming (SÁ, 2012).

Aquaculture has been a growing activity in Pará for some decades now as an alternative to increase the supply of animal protein of aquatic origin (SOUZA, 2002). In the state of Pará, the aquaculture activity, as in the north of the country, is fish farming, distributed in several regions of the state, fish farming exhibits a diversity of producers from strictly subsistence farming to the large producer focused on commercialization (LEE; SARPEDONTI, 2008).

The average area of the lake analyzed throughout this study was 3877196.72±1932905.09 m^2 (Table 2), the smallest area recorded was in the dry season of 2010, and the largest area occurred four years later in the dry season of 2014. In Figure 2, a significant decreasing trend can be observed (S

= -80; p-value = 0.0104), based on the Mann-Kendall test, we point out a greater attention to the years 2005 and 2015 than other years. dry seasons of smaller areas recorded.

	Area	Unit
Minimum	1520027.48	m²
Average	3877196.72	m²
Maximum	8032437.05	m²
Standard Deviation	1932905.10	m²
Coefficient of Variation	53.76	%

Table 2 - Descriptive statistics of the Paytuna Lake area between the years 2000 to 2020.

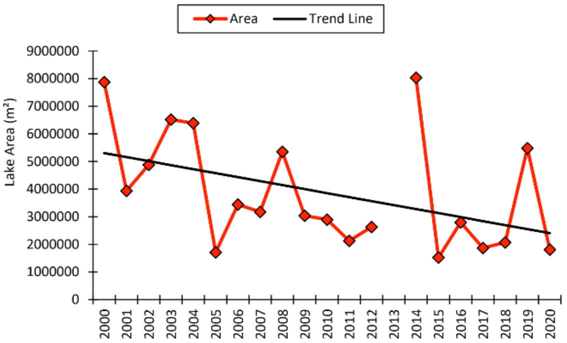

Figure 2 – Historical series of measurement of the area of the Paytuna logo between the years 2000 to 2020. No data was recorded in 2013, as this year presented excessive cloud cover.

By associating the years with the smallest areas with the strong El Niño years (Figure 3), it can be seen that in the year with the highest peak of the Oceanic Niño Index in the Niño region 3.4 with a value of 1.67 in the month of November 2015, which coincides with the year 2015 that had the lowest lake water coverage in Paytuna. Between the decades of 2000-2010 and 2011 to 2020, three extreme droughts (2005, 2010 and 2015-2016), caused by El Niño, hit the Amazon region and the last drought was the most severe in the Amazon biome (ERFANIAN et al., 2017; ARAGÃO et al., 2018). The maximum climatological water deficit (a measure of dry season intensity) for the region peaked at -448 mm, the highest deficit in the 19-year record, this climatological water deficit remained negative for 8 months, 2 months longer than the normal (BERENGUER et al, 2021).

The results mapped from the NDWI index demonstrated that the study area comprises the presence of dry regions, allowing the establishment of a standardized visualization of the water bodies analyzed. Comparing the year 2014, which had the largest area among dry seasons with NDWI values ≥ 1, it was possible to clearly highlight areas with greater presence of water (see Figures 4). On the other hand, a year later, the smallest area recorded in this study occurred in the dry season of 2015, with a predominance of NDWI values ≤ 1, such results allowed us to have a clear spatial view of the drastic reduction of the wet plain of the Lake Paytuna lake complex (see Figure 4). It can be noted that in the same year there was a long period of strong ``El Niño`` (see Figure 3) that intensified in the last three months of the year, we believe that this fact may be strongly associated with the large retreat in the flooded areas, resulting in the smallest area recorded in that year. study.

On the other hand, we deduced that sediment contributions to the lake can occur in two ways: The first contribution would be via the Amazon River, since this lake is connected to the great lake of Monte Alegre, which in turn also has a connection with the Amazon river. Over the years, both lakes receive contributions during the flood season. The second contribution comes from the region where Lake Paytuna is located. The soil of this region is composed of rocks from the Precambrian to the most recent Cenozoic. Among these rocks, there are sandy terrains and metamorphosed shales from the Paleoproterozoic, gneiss and granitic rocks originated by magmatism and sedimentation in the Mesoproterozoic, as well as clayey, sandy and gravel sediments

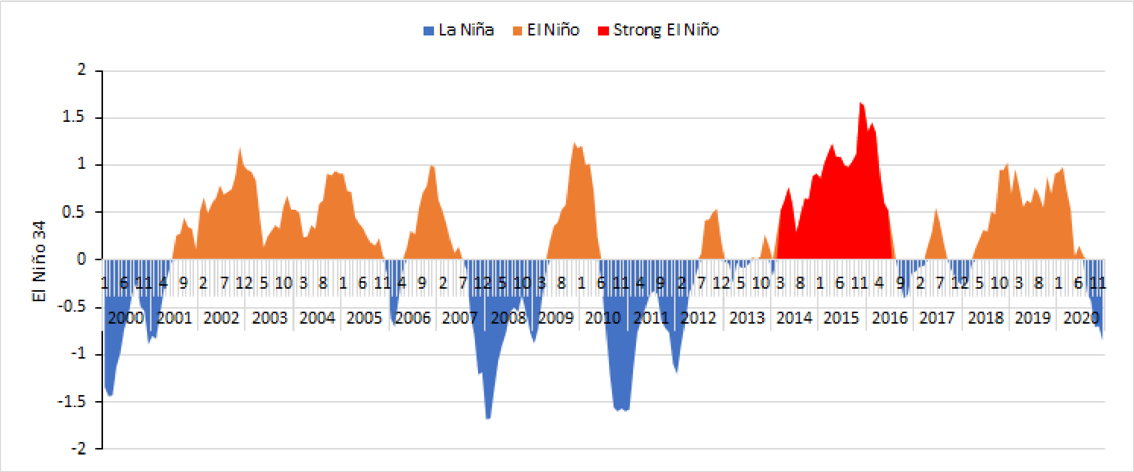

Figure 3 – Oceanic Niño Index of the Niño region 3.4 for the historical period studied, series in red represents Strong El Niño year.

Source: UNIFEI available at: https://meteorologia.unifei.edu.br/teleconexoes/.

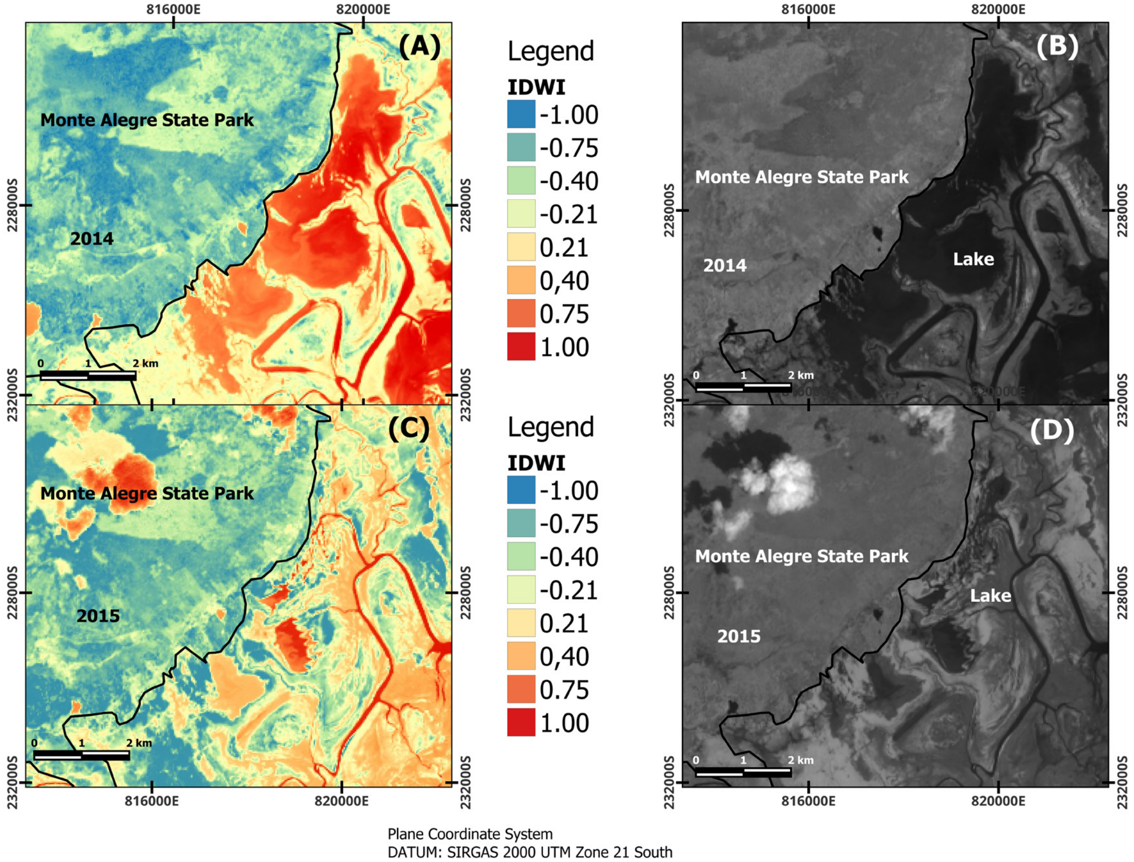

Figure 4 – Normalized Water Difference Index (NDWI): (A) year of largest area measured in dry seasons and (C) year of smallest area measured in dry seasons for Lake Paytuna. (B) Image extracted from the Near Infrared (NIR) band of the Lantsat 7 ETM+ satellite for the year 2014 and (D) Image extracted from the NIR Landsat 8 OLI for the year 2015.

Figure 5 - Characteristic effects of the dry season on Lake Paytuna, changing the landscape with the emergence of semi-arid plains.

Source: Author personal archive

from the Paleozoic and Mesozoic (PARÁ, 2015). To elucidate the deductions of the two ways mentioned above, it will be necessary to carry out studies with a greater focus on the origin of the sediments deposited in the lake.

Intense reductions in the areas of the aquatic surface of Lake Paytuna, as a result of increasingly severe droughts in recent years, may cause harmful effects on the landscape in the floodplain of the fluvial-lacustrine complex, which may extend not only to the study area, as well as for other lakes along the Amazon basin (LIMA et al, 2021). We can mention other drastic consequences such as the reduction of the water surface that causes the death of organisms that are not tolerant to high temperatures and progressive reduction in the level of dissolved oxygen (LAKE 2003, TOMACELLA et al 2010, HURD et al 2016). These negative effects affect not only the aquatic biota, but also harm human populations in this region in obtaining protein sources from these environments (BARROS; ALBERNAZ, 2014). For this reason, it is common for local residents to report high fish mortality in these environments (TOMACELLA et al 2010).

The low water level and changes in limnological variables such as dissolved oxygen, make us look for an alternative to implement fish farming, even at low stocking density, in order to guarantee the food security of this population.

The NDWI showed fragmentation of the lake with difficult access to some areas of the lake, and with the emergence of vast semi-arid areas of bare soil and fragmentation of the lake with the decrease in flow; the isolation of fragments of difficult-to-access lakes, which are still suitable for fishing (TOMACELLA et al 2010; BARROS and ALBERNAZ 2014). The significant reduction of the water surface area of the lake, turning the landscape into an extensive semi-arid plain, but with adaptive strategies of the local population, as can be seen in figure 5.

CONCLUSIONS

Lake Paytuna has been showing a tendency to reduce its area, mainly in the years most affected by El Niño. Despite the reduction of its total area, it presents water quality data within the accepted standards for fish farming. Thus, this study observed that there is the possibility of cultivating fish at low stocking density, aimed at food security, in a two-phase cultivation system, where the lake can be used in the second phase of cultivation in the period of flood and flood, moment of greater depth of the lake.

More studies in the flood period will be necessary to evaluate the limnological data in the deepest portion of the lake in order to observe possible stratification profiles of the lake in the rainy season.

ACKNOWLEDGMENT

To the Campus Universitário Monte Alegre da Universidade Federal do Oeste do Pará and the Provost for Research, Graduate Studies and Technological Innovation Universidade Federal do Oeste do Pará.

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