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Hydrochemistry of oxbow lakes of the Chandless River, southwest Amazon

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ABSTRACT

This study investigated the hydrochemistry of three oxbow lakes and the Chandless River, within Chandless State Park (Acre, Brazil), during the dry season (June–July 2021). We tested whether oxbow lakes had lower nutrient concentrations than the river. Water samples were analyzed for cations and anions, alongside in situ measurements of pH, temperature, conductivity, and dissolved oxygen. Results showed higher pH, conductivity, and oxygen in the river, while lakes were more acidic with lower values. Contrary to the hypothesis, nutrient concentrations showed contrasting patterns among environments: Ca^{2+}, Na^{+}, and Mg^{2+} were higher in the river and Lake São João II, while SO_4^{2-} and NO_2^{-} dominated in Lakes Buião and São João I. The findings highlight distinct ionic profiles and the ecological uniqueness of each system—critical for managing the park's environmental diversity.

Keywords: aquatic ecosystems, floodplains, hydrochemistry, limnology.

Hidroquímica dos lagos em forma de ferradura do rio Chandless, sudoeste da Amazônia

RESUMO

O estudo investigou a hidroquímica de três lagos em ferradura e do Rio Chandless no Parque Estadual Chandless (Acre, Brasil) durante a estação seca (junho–julho de 2021). Testamos a hipótese de menores concentrações de nutrientes nos lagos. Amostras de água foram analisadas para cátions e ânions, além de medições *in situ* de pH, temperatura, condutividade e oxigênio dissolvido. O rio apresentou maiores valores de pH, condutividade e oxigênio. Contrariando a hipótese, as concentrações de nutrientes variaram. Ca^{2+}, Na^{+} e Mg^{2+} foram superiores no rio e no Lago São João II. SO_4^{2-} e NO_2^{-} dominaram nos lagos Buião e São João I. Os resultados destacam perfis iônicos distintos e a singularidade ecológica de cada sistema.

Palavras-chave: ecossistemas aquáticos, hidroquímica, limnologia, planícies aluviais.

1. INTRODUCTION

The Amazon Basin harbors exceptional biological diversity and provides crucial ecosystem services. Its aquatic systems range from small streams to large rivers bordered by floodplains that connect rivers, lakes, and forests, forming highly heterogeneous and ecologically dynamic landscapes (Melack and Coe, 2021). The hydrochemistry of Amazonian rivers reflects the geological and geomorphological features of their sub-basins, primarily influenced by the weathering of Andean-derived minerals (Moquet *et al.*, 2011). These physicochemical patterns are key to understanding biogeochemical cycles and guiding conservation efforts (Quesada *et al.*, 2010; Newman *et al.*, 2016).

During the dry season, groundwater influence increases, while the rainy season enhances inputs of organic matter and sediments, altering river water composition (Markewitz *et al.*, 2004; Rios-Villamizar *et al.*, 2017). Numerous studies have examined nutrient concentrations in various Amazonian aquatic systems using comparable sampling and analytical methodologies (Sousa, 2013; Li *et al.*, 2018; Drake *et al.*, 2021).

The Purus River and its tributaries, such as the Chandless River, are nutrient-rich, especially during the dry season, and feature a high density of oxbow lakes formed by river meandering and sediment dynamics (Ahmed *et al.*, 2019). These lakes connect to the main river channel during floods and become isolated in the dry season, which affects their limnological characteristics and associated biodiversity (Junk *et al.*, 2012; Güntzel *et al.*, 2020).

Given this context, the present study aimed to characterize the hydrochemistry of oxbow lakes and the main channel of the Chandless River, within the Chandless State Park (Acre, Brazil), during the dry season. We analyzed the concentrations of major cations and anions and key physicochemical parameters, testing the hypothesis that oxbow lakes in the southwestern Amazon develop hydrochemical profiles that diverge from those of the main river channel during the dry season. The absence of fluvial connectivity and the biomass of aquatic macrophytes generate distinct ionic signatures within each lentic system.

2. MATERIAL AND METHODS

2.1. Study Area

This study was conducted in three oxbow lakes formed by the Chandless River, located in the municipality of Manoel Urbano, Acre, within the geographic boundaries of the Chandless State Park (PEC). The PEC is a Strict Protection Conservation Unit, established by Decree No. 10,670 of September 2, 2004. It covers an area of 695,303 ha, spanning the municipalities of Sena Madureira and Santa Rosa do Purus (Acre, 2010) (Figure 1).

The park represents 4.23% of Acre's territory, distributed among the municipalities of Santa Rosa do Purus (161,630 ha – 24.12%), Manoel Urbano (445,208 ha – 66.44%), and Sena Madureira (63,296 ha – 9.45%) (Acre, 2010). Its boundaries begin at the international border between Brazil and Peru, near the headwaters of the Santa Rosa River, and extend to the municipalities of Feijó and Manoel Urbano.

The PEC is situated in one of the least-studied regions of the state in terms of biological richness: the Upper Purus region, encompassing the basins of the Purus and Chandless Rivers. Its borders are defined by the Alto Rio Purus Indigenous Land (north), Mamoadate Indigenous Land (south), the Republic of Peru and neighboring protected areas Alto Purus National Park and Purus Communal Reserve (west), and the Cazumbá-Iracema Extractive Reserve (east).

The park’s vegetation comprises a mosaic of forest types, including open ombrophilous forest without bamboo, open forest dominated by bamboo, forest with a mixture of bamboo and palms, and forest with palms and sparse bamboo. These areas are at different successional stages due to the death cycle of bamboo stands (Acre, 2010). The open forests with bamboo of the genus *Guadua*, locally known as *tabocais*, are rare in the Amazon but widespread in the southwestern portion of the basin (Nelson and Bianchini, 2005). The PEC is located at the core distribution area of *Guadua* spp. in the Amazon (McMichael *et al.*, 2014).

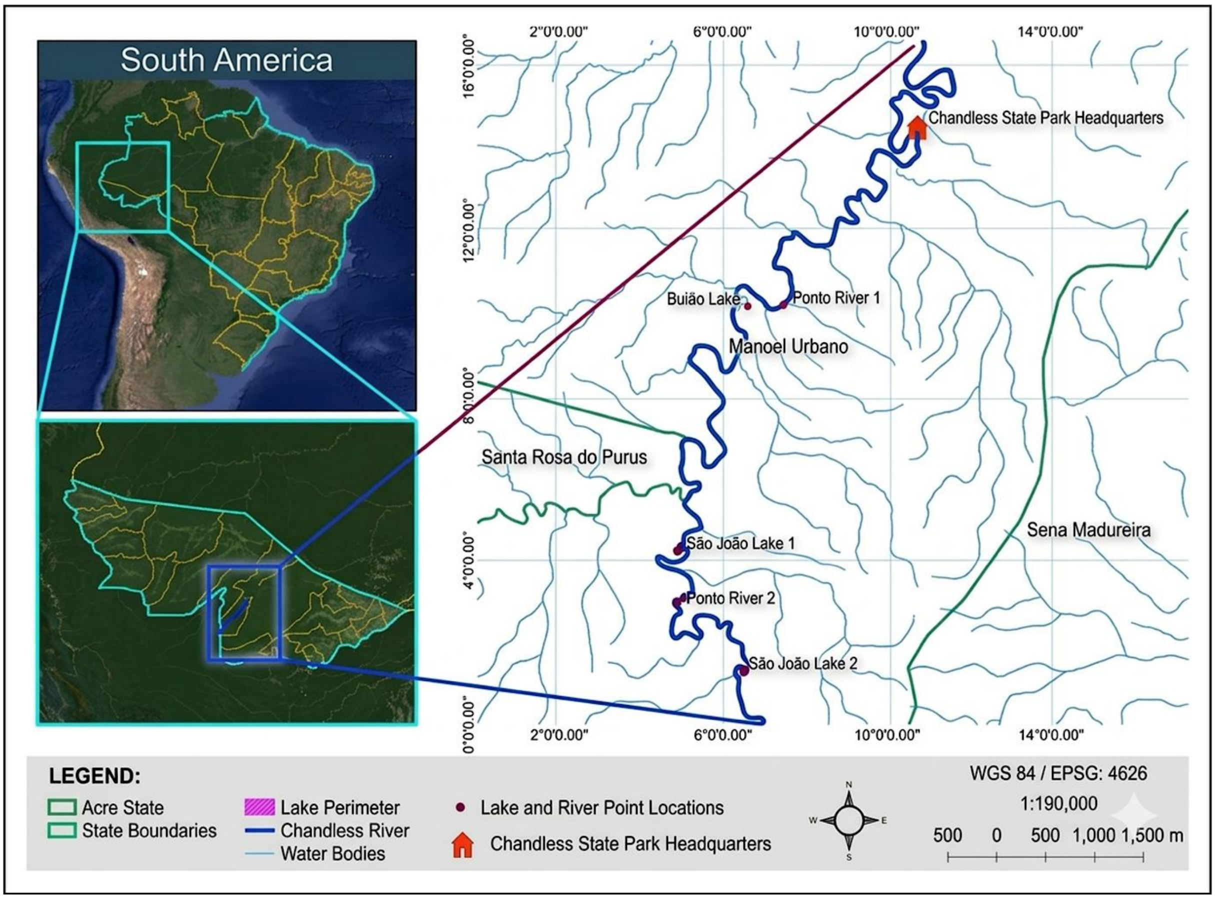

Figure 1. Map showing the location of Chandless State Park and the Chandless River, as well as the sampled lakes.
Source: Author.

The study area encompasses the lower reach of the Chandless River, characterized by a meandering channel and active floodplains. The regional relief is marked by low elevations and extensive planated surfaces. Sampling was conducted in sectors directly influenced by erosional and depositional processes typical of the southwestern Amazon. The Chandless River is part of the Purus River Basin, a transboundary basin spanning the states of Amazonas and Acre, as well as parts of Peru and Bolivia. Its drainage area within Acre covers approximately 19,686 km² (Acre, 2017). The Purus basin experiences a seasonal rainfall regime, with a rainy season from November to March, a dry season from May to September, and transitional periods in April and October (Silva *et al.*, 2008).

According to Sioli's (1984) classification, the Chandless River is a whitewater river, with high suspended solids content, water transparency between 30 and 60 cm, near-neutral pH, and high electrical conductivity—characteristics typical of Andean whitewater rivers influenced by seasonal variability (Junk *et al.*, 2012; Rios-Villamizar *et al.*, 2013; Röpke *et al.*, 2016). The regional hydrochemistry is directly influenced by the Solimões Formation, a Miocene geological unit composed predominantly of fine-grained sediments and carbonates. The weathering of these materials releases ions such as Ca^{2+} and Mg^{2+}, which helps explain the concentrations observed in the Chandless River.

2.2. Data Collection
2.2.1. Water Sampling
Sampling was carried out in three oxbow lakes and the Chandless River during the dry season (June–July 2021) within the boundaries of the PEC. Two sampling points were selected in each lake (Buião, São João I, and São João II), and two points were sampled in the Chandless River one upstream of Lake Buião, near the PEC headquarters, and one downstream of Lake São João II. In total, eight sampling points were analyzed: six in the lakes and two in the main river channel. At each point, a 1-liter water sample was collected using PET bottles and kept on ice until filtration. Samples were filtered using a vacuum pump at the PEC headquarters. Two 60 mL aliquots (duplicate samples) were taken from each point, filtered through cellulose acetate membranes (0.45 µm pore size), and preserved with 6 mg of thymol for ion concentration analysis. Sixteen aliquots were processed and sent to the Laboratory of Biology and Cultivation of Freshwater Fish (LAPAD) at the Federal University of Santa Catarina.

2.2.2. Limnological Variables
At each sampling site, limnological parameters were measured using portable probes. Water pH and temperature (°C) were measured with an Orion 290Aplus portable pH meter, and electrical conductivity ($\mu S.cm^{-1}$) was measured with a VWR 2052 conductivity meter. Dissolved oxygen (DO) concentration ($mg.L^{-1}$) was assessed using a YSI 55 oximeter. Measurements were taken by submerging the electrodes approximately 50 cm below the surface until values stabilized. Depth and transparency (in cm) were recorded using a Secchi disk. GPS coordinates, time, and photographic records were also taken at all sampling points.

2.2.3. Ion Analysis
Cation concentrations (sodium, magnesium, potassium, and ammonium) and anions (chloride, sulfate, nitrite, and nitrate) were determined using ion chromatography with ion suppression, with a Dionex DX-500 system. This method involves injecting the sample into a mobile phase that passes through an ion-exchange column (stationary phase), with detection based on electrical conductivity. Analytical columns used were IonPac AS14HC (4 mm) for anions and CS12A (4 mm) for cations. Concentrations were calculated by comparison with known standards (Leite, 2004).

2.3. Data Analysis
To test the hypothesis that oxbow lakes have lower nutrient concentrations than the main river channel, chemical and limnological variables were compared between environments. Oxbow lakes and the Chandless River channel were considered predictor variables, and average distances were used as response variables.

Mean concentration values between the two groups (lakes and river) were compared using a t-test with 1000 permutations. Differences among individual environments (Lakes Buião, São João I, São João II, and Chandless River) were analyzed via one-way ANOVA. Normality was assessed using the Shapiro-Wilk test.

A Principal Component Analysis (PCA) was performed to explore data grouping. The PCA configuration was tested using permutational multivariate analysis of variance (PERMANOVA) with 1000 permutations and dispersion analysis via PERMDISP. Pearson correlation analysis was also conducted to examine relationships between nutrient concentrations across environments. All statistical analyses were conducted using R software, version 3.0.3 (Oksanen *et al.*, 2013; R Core Team, 2018).

3. RESULTS AND DISCUSSION

The results revealed that the average depth was 143 cm among the sampling points, with the two points in the Chandless River being shallower, and the oxbow lakes reaching depths of up to 200 cm (Table 1). The average water transparency was 60 cm, with Lake Buião exhibiting the greatest transparency, followed by the Chandless River, Lake São João II, and São João I. Among the directly measured parameters, water temperature was stable across environments, with an average of 25.3°C and greater variation between the Chandless River points, as collections were conducted on different days (Table 1).

Table 1. Results of limnological parameters and nutrient analyses from oxbow lakes and the main channel of the Chandless River, Chandless State Park, Acre.

POINT/SAMPLE	DIRECT MEASUREMENTS						ION ANALYSIS										
	Limnological Variables						Cations (µmol)					Anions (µmol)					
	Depth (cm)	TRANSP. (cm)	TEMP. (°C)	DO (mg L^{-1})	pH	COND. (µS cm^{-1})	Sodium (Na^+)	Ammon. (NH_4^+)	Potass. (K^+)	Calc. (Ca^{2+})	Magnes. (Mg^{2+})	Fluoride (F^-)	Chlor. (Cl^-)	Nitrite (NO_2^-)	Nitrate (NO_3^-)	Sulfate (SO_4^{2-})	Phosphate (PO_4^{3-})
Chandless River - P1/A	100	60	27.9	6.7	7.299	674	237.10	2.28	36.46	492.51	132.73	0.38	1.04	2.30	0.29	3.99	0.83
Chandless River - P1/B							225.79	0.23	18.74	495.13	105.70	0.38	0.87	2.34	0.22	3.98	0.85
Chandless River - P2/A	100	80	23.5	7.4	7.228	694	274.85	0.26	22.78	553.79	119.20	0.37	0.95	3.26	0.49	3.79	0.97
Chandless River - P2/B							264.41	0.94	25.39	589.64	157.00	0.38	0.93	3.19	*	3.77	0.80
Lake São João - P1/A	150	30	27.1	3.05	6.091	302	309.39	0.03	31.96	269.91	53.80	0.59	0.93	8.60	0.17	62.88	0.57
Lake São João - P1/B							118.00	0.94	20.61	320.43	80.94	0.60	1.26	6.15	0.17	62.86	0.63
Lake São João - P2/A	200	30	27	5.55	6.167	301	112.04	1.21	9.74	284.63	80.94	0.56	0.84	5.28	0.20	84.49	0.60
Lake São João - P2/B							121.53	1.23	19.02	299.77	74.32	0.56	0.90	4.95	0.17	84.62	0.52
Lake São João II - P1/A	100	40	24.4	4.31	6.917	416	135.14	0.69	21.30	407.83	112.45	0.69	2.34	9.41	0.20	156.45	0.64
Lake São João II - P1/B							134.01	1.70	20.76	417.56	108.67	0.69	1.24	5.43	0.17	156.47	0.60
Lake São João II - P2/A	200	40	24.9	4.75	6.891	412	122.61	0.66	16.90	385.00	100.69	0.66	1.07	4.93	0.19	160.10	0.83
Lake São João II - P2/B							119.18	1.93	17.26	385.27	100.36	0.68	1.21	5.19	*	159.75	0.46
Lake Buião - P1/A	150	100	24.1	2.75	6.222	199	258.41	0.34	58.02	220.78	31.79	0.72	1.63	9.69	0.22	257.08	2.60
Lake Buião - P1/B							97.08	0.56	20.76	239.24	69.96	0.71	1.57	9.65	0.22	259.14	1.96
Lake Buião - P2/A	150	100	24	1.67	6.236	204	102.00	0.73	14.37	233.53	51.53	0.74	1.77	11.71	0.46	269.05	1.07
Lake Buião - P2/B							79.20	0.64	32.99	236.65	68.89	0.73	1.69	11.56	0.48	270.90	1.06

Legend: (*) - invalid or missing sample; (P) - Point; A and B – aliquots of water samples collected at each point. **Source:** Prepared by the author.

Dissolved oxygen (DO) levels ranged from 7.4 to 1.6 mg·L^{-1}, with an average of 4.5 mg·L^{-1}. The highest DO concentrations were recorded in the Chandless River, followed by Lakes São João II, São João I, and Buião. pH levels followed a similar pattern to DO, with the Chandless River having the highest mean pH of 7.263. The oxbow lakes were more acidic in comparison, with an average of 6.420, and Lake São João I showing the lowest average pH of 6.129 (Table 1).

Electrical conductivity was the parameter with the greatest variation among the sampling points, both in the oxbow lakes and in the main river channel. The Chandless River showed the highest mean conductivity (684 µS·cm^{-1}), followed by Lake São João II (414 µS·cm^{-1}), São João I (301 µS·cm^{-1}), and Buião (201 µS·cm^{-1}).

Regarding nutrient concentrations, the most abundant cations were calcium (Ca^{2+}) (364.48 ± 120.22 µmol), sodium (Na^{+}) (169.42 ± 76.89 µmol), and magnesium (Mg^{2+}) (90.56 ± 32.57 µmol). Among anions, sulfate (SO_4^{2-}) (124.96 ± 100.51 µmol) was the most prevalent (Table 1).

The lowest concentrations were observed for potassium (K^{+}) (24.19 ± 11.38 µmol) and ammonium (NH_4^{+}) (0.90 ± 0.63 µmol) among cations; and for fluoride (F^{-}) (0.6 ± 0.1 µmol), chloride (Cl^{-}) (1.2 ± 0.42 µmol), nitrite (NO_2^{-}) (6.48 ± 3.17 µmol), nitrate (NO_3^{-}) (0.26 ± 0.12 µmol), and phosphate (PO_4^{3-}) (0.94 ± 0.56 µmol) among anions (Table 1).

Analyses of directly measured limnological parameters in oxbow lakes and the Chandless River indicated no significant differences in depth, DO, pH, and temperature. However, transparency and conductivity differed among sampling points ($\chi^2 = 627.61$, $P < 0.0001$). These differences are likely due to varying concentrations of suspended particulate matter between sites. Significant correlations were found between pH and conductivity (Pearson's $r = 0.92$, $t = 3.36$, $P = 0.001$); DO and conductivity ($r = 0.90$, $t = 3.34$, $P = 0.001$); and DO and pH ($r = 0.76$, $t = 5.24$, $P = 0.01$). Transparency showed negative, non-significant correlations with temperature ($r = -0.61$) and DO ($r = -0.28$).

Nutrient analysis indicated significant differences in cation concentrations for Ca^{2+} ($t = -7.0713$, $df = 8.2739$, $P < 0.0001$) and Na^{+} ($t = -4.7177$, $df = 13.895$, $P < 0.0001$). Among anions, SO_4^{2-} ($t = 6.8465$, $df = 11$, $P < 0.00001$), F^{-} ($t = 14.855$, $df = 11.071$, $P < 0.0001$), and NO_2^{-} ($t = 6.1051$, $df = 13.056$, $P < 0.0001$) also differed significantly. Cl^{-}, NO_3^{-}, and PO_4^{3-} showed no significant differences and had low concentrations relative to other anions.

The PCA explained 68.8% of the total variance and showed clear separation in cation and anion concentrations between oxbow lakes and the Chandless River (PERMANOVA $F = 13.621$, $P < 0.0001$; PERMDISP $F = 3.439$, $P > 0.05$). Differences in Ca^{2+}, Na^{+}, Mg^{2+}, and SO_4^{2-} primarily accounted for this separation (Figure 2).

The PCA for individual environments (Lakes Buião, São João I, São João II, and the Chandless River) showed distinct clustering likely due to their unique concentration profiles (PERMANOVA $F = 17.508$, $P < 0.0001$; PERMDISP $F = 0.2972$, $P > 0.05$). These results suggest differences in hydrochemical composition between sampled environments. Comparisons among the oxbow lakes themselves revealed that Ca^{2+} and SO_4^{2-} differed significantly ($\chi^2 = 7.5868$, $P < 0.01$ and $\chi^2 = 44.581$, $P < 0.0001$, respectively), indicating their role in shaping the hydrochemical identity of each lake.

This study showed that the evaluated oxbow lakes and the Chandless River present distinct physicochemical characteristics, despite the data being based on single-time sampling with a relatively small number of sites. Directly measured variables revealed that the Chandless River exhibited higher pH, electrical conductivity, and dissolved oxygen, similar to what was reported for the Purus River—its main tributary—by Salimon *et al.* (2013) and Sousa (2013). The elevated pH and conductivity during the dry season are associated with the influx of groundwater rich in dissolved salts, which increases concentrations of bicarbonate (HCO_3^{-}), Ca^{2+}, Na^{+}, Mg^{2+}, and SO_4^{2-}, while the dilution capacity is reduced due to lower discharge volumes (Quesada *et al.*, 2011; Cunha and Sternberg, 2018).

Figure 2. PCA results for cation and anion concentrations between treatments (oxbow lakes vs. Chandless River), Chandless State Park, Acre.
Source: Author.

Higher levels of dissolved oxygen may be explained by increased light penetration into the water column during the dry season, as suspended particulate matter is reduced, thus enhancing primary productivity (Forsberg *et al.*, 2017). Conversely, the evaluated oxbow lakes displayed more acidic waters, lower conductivity, and reduced oxygen levels. Transparency varied among lakes, indicating environmental heterogeneity, as also observed by Cabral *et al.* (2021).

Beyond the expected differences between lentic and lotic systems, Amazonian oxbow lakes experience extreme abiotic conditions during the dry season—becoming shallower and warmer, with high decomposition rates and altered biological interactions that negatively affect the environment (Thomé-Souza and Chao, 2004; Fantin-Cruz, 2008; Miranda, 2011; Virgílio *et al.*, 2021).

The hypothesis that oxbow lakes would have lower nutrient concentrations than the main river channel was rejected. Our study indicates that the hydrochemical profiles of the Chandless River and the oxbow lakes (Buião, São João I and II) are not solely determined by nutrient concentrations. The rejection of the initial hypothesis indicates that lake isolation during the dry season generates autonomous chemical signatures. The high concentrations of SO_4^{2-} and NO_2^- in Lakes Buião and São João suggest decomposition of organic matter and macrophytes under low-flow conditions. The mineralization of these detrital materials likely replaces the direct influence of the main river channel.

Cations such as Ca^{2+}, Na^+, and Mg^{2+} were more concentrated in the Chandless River and

Lake São João II, likely due to the more basic geochemical nature of the Purus Basin waters (Salimon *et al.*, 2013). On the other hand, SO_4^{2-} and NO_2^- anions were more concentrated in Lake Buião and São João I, probably due to sediment deposition, presence of macrophytes, and the decomposition of riparian and aquatic plant material—all of which influence hydrochemical dynamics (Cole *et al.*, 2020; Gayer *et al.*, 2021).

Although the Chandless River showed higher concentrations of Ca^{2+}, Na^+, Mg^{2+}, and K^+ compared to the lakes—as expected—these values were lower than those reported in other Purus Basin tributaries such as the Caeté River (Ca^{2+} = 536.96±188.47 µmol; Na^+ = 590.01±198.46 µmol; Mg^{2+} = 520.61±167.02 µmol; K^+ = 112.33±17.90 µmol) and even the Purus River itself (Ca^{2+} = 541.44±207.98 µmol; Na^+ = 575.23±87.05 µmol; Mg^{2+} = 390.02±18.50 µmol; K^+ = 88.20±11.71 µmol) (Sousa, 2013). This pattern of lower ion concentrations was also seen for anions.

Such lower ionic values compared to other studies may reflect geological conditions and local biogeochemical cycles within Chandless State Park, which influence aquatic chemical composition (Neu *et al.*, 2016). Additionally, rainfall patterns, sedimentary rock prevalence, and seasonality can, depending on sampling timing, cause whitewater rivers to present intermediate characteristics more akin to blackwater systems (Rios-Villamizar *et al.*, 2020).

Regarding other ions, the presence of ammonium, nitrite, and nitrate stood out. In aquatic ecosystems, nitrogen can also occur as ammonia (NH_3), but nitrate and ammonium are the primary nitrogen sources for primary producers. In the euphotic zone, ammonium is typically low, making nitrate the main nitrogen source for aquatic plants (Esteves, 1988). This pattern may explain the high nitrate concentrations in Lake Buião, which harbored the most macrophytes among the studied oxbow lakes. The lower concentrations of ammonium, nitrite, and nitrate in the Chandless River may reflect the fact that rivers primarily receive nitrogen from rainfall, allochthonous organic and inorganic materials, and molecular nitrogen fixation within the aquatic system (Tundisi and Tundisi, 2008; Weathers *et al.*, 2015)—factors with limited influence during the dry season (Marengo and Espinoza, 2016).

The oxbow lakes showed hydrochemical differences both among themselves and compared to the Chandless River, yet they still share core properties of Amazonian whitewater systems (Junk *et al.*, 2012). Cabral *et al.* (2021), in their study on macrophytes and limnological variables affecting cladoceran communities in Chandless oxbow lakes, showed that changes in water chemistry and macrophyte dominance influenced the abundance and composition of phytophilous cladocerans.

Abiotic and biotic features of oxbow lakes in the Purus Basin—such as macrophyte presence, lake size, faunal composition (fish, amphibians, reptiles), lake age, and connectivity with the river—collectively shape the unique properties of each lake and can shift with time and seasonal variation (Ramalho *et al.*, 2016; Virgílio *et al.*, 2021; 2022).

This study focused on dry-season conditions, when oxbow lake dynamics are not influenced by the flood pulse. Seasonality, particularly the alternation between dry and rainy seasons, and the formation of floodplains, is one of the main drivers of changes in physicochemical characteristics in Amazonian ecosystems (Junk *et al.*, 2012). In the case of oxbow lakes, seasonal dynamics and connectivity with the river during water level rises are vital to maintaining both abiotic and biotic conditions (Silva *et al.*, 2013; Röpke *et al.*, 2016; MacKinnon *et al.*, 2016). Over time, seasonal variations and river course shifts form oxbow lakes, whose conditions depend on how long they've been isolated or connected to the main channel (Rodrigues *et al.*, 2002; Stoffels *et al.*, 2015; Penha *et al.*, 2017; Cunha and Sternberg, 2018; Lynch *et al.*, 2019).

Studying river and lake hydrochemistry during the dry season, in the absence of flood influence, helps reveal each environment's intrinsic characteristics (Gayer *et al.*, 2021). Our results show that the sampled oxbow lakes have distinct hydrochemical patterns, shaped by multiple factors documented in the literature but not directly measured in this study.

4. CONCLUSION

Each aquatic system within Chandless State Park exhibits a distinct chemical identity, shaped by the interaction between regional geology and local biological processes. Bedrock weathering of the Solimões Formation regulates the ionic inputs to the Chandless River, whereas decomposition processes and lake morphometry drive the differentiation of the isolated oxbow lakes.

These findings establish an essential scientific baseline for environmental monitoring and the conservation of water resources in this strategically important region of the Amazon. This study provides the first detailed hydrochemical dataset for the interior of Chandless State Park, revealing pronounced environmental heterogeneity in a priority conservation area that remains largely underrepresented in limnological records.

In conclusion, the evaluated oxbow lakes display distinct ionic compositions, both among themselves and relative to the Chandless River, underscoring the unique and heterogeneous nature of each aquatic environment. This pattern is not only of scientific significance but also fundamental for the effective management of Chandless State Park. Recognizing this environmental mosaic supports improved decision-making and the development of strategies aimed at safeguarding the park's natural resources.

Further research incorporating variables such as floristic and faunal composition, regional geology, and seasonal hydrological dynamics is required to better understand the lakes and the Chandless River, in order to achieve a more comprehensive understanding of the limnological and ecological dynamics of these aquatic ecosystems.

5. DATA AVAILABILITY STATEMENT

Data availability not informed.

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