INFLUENCE OF RIPARIAN FOREST AND TEMPERATURE ON THE PRIMARY PRODUCTION OF TROPICAL STREAMS

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ABSTRACT

Oliveira, T. M., Wastowski, I. J. & Carneiro, F. M. (2023). Influence of riparian forest and temperature on the primary production of tropical streams. Braz. J. Aquat. Sci. Technol. 27(1). eISSN 1983-9057. DOI: 18352/bjast.v27n1. Primary production is a key feature for the functioning of aquatic ecosystems. The trophic state of streams reflects this primary production and is influenced by local limnological variables and the level of integrity of the watershed. In this study, the habitat integrity index (HII) and the physical, chemical, and biological parameters of tropical streams were sampled in two sub-basins, in order to understand the functioning of these ecosystems. We hypothesized that the limnological variables and the environmental integrity should determine the primary production in the streams, and that due to the similar land use in the sub-basins (i.e. agriculture and livestock) the streams would show similar limnological variables. To identify how the streams differed in relation to their limnological characterization and the HII, we performed Principal Component Analysis (PCA). The association between the variables was assessed by Pearson's correlation analysis. To identify the difference between the two basins, the Student's Test was performed. The best predictors of primary production were determined using multiple regression analysis with the Akaike selection criteria. The concentration of chlorophyll-a in the surface water indicated that the tropical streams sampled have, in general, low concentrations of nutrients, except at some more urban points. The variables that differed the most among the streams were blue-green cells/ml, pH, conductivity, and width of the riparian forest. Only redox potential and pH differed between the two watersheds. Temperature, blue-green cells/ml and width of the riparian forest were the variables that best predicted the primary production of phytoplankton in the watercourses in both watersheds. In this study, we emphasize the importance of temperature in aquatic productivity, particularly in the face of climate change which, along with deforestation, is increasing the amount of surface area that receives sunlight in the water courses, resulting in increased primary productivity and eutrophication.

Key Words: Blue-green Algae. Chemical Variables. Chlorophyll-a. HII. Phytoplankton.

INTRODUCTION

Eutrophication is the global problem of disordered growth of microalgae in freshwater environments due to the presence of excessive nutrients from agricultural, industrial, and urban activities. Eutrophication also reduces aquatic biodiversity, increases macrophyte biomass and biomass of consumer species, causes bloom of toxic algae species, reduces species diversity, causes oxygen depletion, and interferes in water turbidity (Smith 1983, Smith & Schindler 2009). The chlorophyll-a concentration in surface water is an indicator of phytoplankton biomass (Wetzel & Likens 2000, Ferrareze, 2012). Chlorophyll-a is a leading indicator of primary production in an aquatic environment and the consequent eutrophication events in the aquatic ecosystem (Reynolds 2006, Carpenter et al., 2009, Pinto & Antunes 2020).

Water quality can be assessed by analyzing the physical, chemical, and biological parameters of the aquatic environment. The hydrogenionic potential (pH) is used to identify whether the water is acid, neutral or basic (alkaline). The higher the amount of CO_2 in the aquatic environment, the greater the action of the heterotrophic organisms that produce it will be, resulting in higher acidity of the water. In turn, lower amounts of CO_2, conferred by autotrophic beings that consume it, provides a more alkaline water (Bucci & Oliveira 2014). Turbidity is a physical parameter of water that interferes with the penetration of sunlight into the water column, impairing the occurrence of photosynthesis (Esteves 1998, Araújo & Oliveira, 2013, Fornari et al., 2018). The electrical conductivity of the water is associated with the presence and concentration of ions (Esteves 1998, Araújo & Oliveira, 2013).

Besides the local limnological and biological variables cited above, other variables, such as riparian forest and land use in the catchment area, are also used to determine water quality and the consequent health of the ecosystem, and also change the primary production in the aquatic system. Headwater streams from the Amazon basin, where there is intense agricultural activity and no riparian forest, showed a more seasonal variation of the limnological and biological parameters (Jankowski et al., 2021). Agriculture increases the sediment input in tropical rivers, altering the pH (Antoneli et al., 2021). Riparian vegetation mitigates the impact of agriculture in tropical streams; thus, environments with greater presence of riparian vegetation have the best biotic integrity and habitat quality (Effert-Fanta et al., 2019, Hilary et al., 2021). A riparian forest of at least 15 m in width and 500 m in length preserves the water quality of tropical streams (Pusey & Arthington, 2003, Hilary et al., 2021).

The Habitat Integrity Index - HII represents local environmental quality, as well as broader landscape conditions (Brasil et al., 2020). Originally proposed by Karr (1981), it was later adapted by Nessimian et al. (2008) specifically for neotropical streams, aiming to assess the preservation of these sites. A high HII score indicates that sites are well preserved and has been associated with higher dissolved oxygen values, while lower HII scores represent more degraded sites with higher temperature, conductivity and pH values (Giehl et al., 2019, Veras et al., 2019, Viana et al., 2020). The HII is a useful biomonitoring tool, as it is simple to use in the field, requiring no special equipment or technical skills (Brasil et al., 2020).

This study sought to determine the interference of four variables: physical (turbidity), chemical (pH and conductivity), biological (blue-green cell density) and landscape (HII and Riparian Forest) in the phytoplankton primary production of tropical streams in an area dominated by agriculture and livestock farming. Given that the landscape variables influence the transport of nutrients to watercourses and the primary production (Carneiro et al., 2014), land use variables such as the HII (Habitat Integrity Index) and riparian forest can be used to determine the primary production in this system. As the two sub-basins sampled had similar land use, we expected that they would show similar limnological conditions. But despite the similar use of the two sub-basins, some of the streams sampled were better preserved than others, and showed different trophic status.

MATERIAL AND METHODS

Study area

The sampling was conducted in the Cerrado Biome of Central Brazil, in the city of Morrinhos - GO, in January 2019, during the rainy season. Ten sites in the Serra River sub-basin were selected for sampling, and nine sites in the Mimoso River sub-basin. This climate of the region is AW (Tropical Savanna Wet) with a dry winter; the coldest month has temperatures of ≥ 18°C and the rainfall in the driest winter month is < 25 mm (Alvares et al., 2014). Both sub-basins are part of the Paraná River basin; the Serra sub-basin is located northwest of Morrinhos and the Mimoso sub-basin is located south of the urban district of Morrinhos and north of Buriti Alegre-GO (Figure 1). Over 50% of the total area of both sub-basins is used for agriculture and livestock farming. In the Serra sub-basin, agriculture and livestock farming occupy 25% and 26% of the total area, respectively. Around 44% of this sub-basin is classified as having high erosion potential. In the Mimoso sub-basin, 55% of the area is used for agriculture and 23% for cattle farming. Unlike the Serra sub-basin, most of the Mimoso sub-basin has low susceptibility to erosion (Silva, 2016).

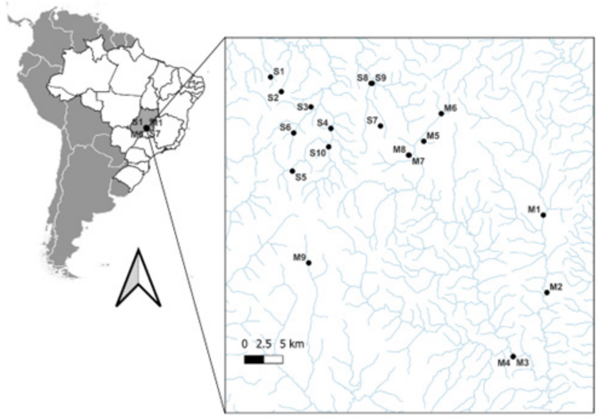

Figure 1 – Location of water collection points in the Parana River basin, sub-basins of Serra and Mimoso rivers - Morrinhos (Goiás State, Brazil).

Data collection

We followed the habitat assessment protocol to obtain the Habitat Integrity Index (HII; Nessimian et al., 2008). We conducted a visual assessment of the land use, riparian zone, stream bed and stream channel morphology to produce the HII. This protocol contains 12 environmental factors: 1) land use beyond the riparian zone; 2) width of the riparian forest; 3) state of preservation of the riparian forest; 4) condition of the riparian forest within a range of 10m; 5) retaining devices and sediment in the channel; 6) structure of the river bank; 7) excavation under the river bank; 8) riverbed; 9) areas of rapids; 10) potions or intricacies; 11) aquatic vegetation; and 12) debris. Each item was composed of four to six alternatives, ordered in relation to perceived aspect of habitat integrity. The HII score is the mean value of all these factors, and ranges from zero (most degraded to one (most preserved). The values were standardized in relation to the maximum value for each item (Nessimian et al., 2008).

The variables temperature (°C), pH, redox potential (RP – mV), electrical conductivity (Cond - µS/cm), blue-green algae (cells/ml), chlorophyll-a (chl-a; µg/l), rhodamine dye (Rhod - µg/l), dissolved oxygen (DO - mg/l) and turbidity (Turb – NTU) were obtained using a multiparameter Eureka probe (Manta 2/ Environmental Engineering). The probe was placed in the water near the riverbank at each sampling point. The results were automatically saved in the multiparameter probe and then stored on a computer. The chlorophyll-a, rhodamine, and blue-green algae (i.e.: phycocyanin) sensors of the Eureka probe are fluorometric, with each one tuned to slightly different wavelengths. The relationship between these parameters and chlorophyll-a concentration was analyzed, to characterize the environments.

Data analysis

The values of the limnological parameters obtained in the collection sites were compared to the standards established by CONAMA Resolution (National Council of the Environment-CONAMA) N. 357/2005, which classifies watercourses and establishes standard values for limnological parameters. The streams analyzed in this study were classified as class 2 freshwater environments because they are appropriate for human use, i.e., for human water supply, survival of aquatic organisms, irrigation, recreation and fish farming (Brasil, 2005). To identify the trophic status of these environments, the Trophic State Index - TSI of the sampled streams was obtained through the chlorophyll-a concentration values, following the Lamparelli (2004) methodology adapted from Carlson (1977). The Trophic State Index (TSI) is a scientific tool that is used as a basis for the development of actions to preserve aquatic ecosystems. It provides information on the conditions of watercourses. Six TSI categories are presented, in ascending order according to the increase in chlorophyll-a concentration in the aquatic environment: ultraoligotrophic, oligotrophic, mesotrophic, eutrophic, supereutrophic and hypereutrophic (Araújo et al., 2018). These categories are established based on ranges of chlorophyll-a concentration (Table 1).

Table 1 – Categorization of the Trophic Status Index (TSI) according to the chlorophyll-a (chl-a) concentration following Lamparelli (2004).

TSI	Chl-a (µg/L)
Ultraoligotrophic	Chl-a≤1.17
Oligotrophic	1.17< Chl-a≤3.24
Mesotrophic	3.24< Chl-a≤11.03
Eutrophic	11.03< Chl-a≤30.55
Supereutrophic	30.55< Chl-a≤69.05
Hipereutrophic	69.05< Chl-a

We analyzed whether the environmental variables were normally distributed. Then, the Student's t-test and HII were carried out to compare the limnological variables of the Serra and Mimoso sub-basins. Pearson's correlation was performed to check for any association between the limnological variables, using the software program PAST (Hammer et al., 2001). Principal component analysis (PCA) was performed (Legendre & Legendre, 1998) to project the collection sites in an ordination plane according to their limnological, biological and environmental variables. The data was log transformed (logx+1) before conducting the PCA, except for pH (which is already determined on the log scale), to standardized variables. The riparian forest width factor extracted from the HII was also analyzed in relation to the other parameters, using Pearson's correlation.

Multiple regression analysis was performed to identify the main predictors of primary production in the sampled streams. The Akaike criterion was used because it indicates which model best predicts the concentration of chlorophyll-a through multiple regression. According to this criterion, the best model is the balance between the r^2-adjusted (higher values) and the number of predictor variables (a smaller number of variables). The models with $\Delta AIC < 2$ have substantial empirical support (Anderson & Burnham, 2002). This analysis was performed for each river basin separately, and for all the river basins together, in the R software (R Core Team 2021). Data from the river basins were log transformed, except for pH. In addition to the limnological variables, the width component of the riparian forest of the HII was included in this multiple regression analysis.

RESULTS

The sampled environments ranged from ultraoligotrophic to supereutrophic. Most of the environments were oligotrophic (1.17< chl-a < 3.24) (four sites in the Mimoso stream (M1, M2, M3, M7) and five in the Serra River (S1, S2, S4, S5, S9)), and ultraoligotrophic (chl-a <1.17) (three in the Mimoso stream (M6, M8, M9) and four in the Serra River (S3, S6, S7, S10)). Two environments of the Mimoso Stream were classified as mesotrophic (3.24 < chl-a <11.03; M4, M5) and one of the Serra as supereutrophic (30.55 < chl-a < 69.05; S8). Sites S2 and M5 presented higher cell/ml and rhodamine values, and site S8 presented higher temperature and trophic degree (classified as supereutrophic). The conductivity values ranged from 0.1 to 280 µS/cm, while turbidity was found to be higher in sites M3 and M6 of the Mimoso basin. Interestingly, site S2 exhibited a high value of Rhodamine and blue-green algae cells/mL, although its chlorophyll-a value was moderate. The Habitat Integrity Index (HII) values showed variation, ranging from 0.40 to 0.83. The best preserved one is highlighted in Table 2.

Table 2 – Longitude (Long), latitude (Lat), and limnological and biological variables in the sites sampled. Temperature (T), pH, redox potential (RP), conductivity (Cond), turbidity (Turb), dissolved oxygen (DO), rhodamine (Rh), green-algae cells/mL (Cell), chlorophyll-a (chl), Habitat Integrity Index (HII), width of Riparian Forest (Rip).

	Long	Lat	T	pH	RP	Cond	Turb	DO	Rh	Cell	Chl	HII	Rip
M1	-48.938	-17.815	24.4	5.9	336.1	16.1	13.07	7.0	1.97	48	1.88	0.83	17.5
M2	-48.934	-17.911	25.0	6.2	323.6	19.8	19.90	7.6	1.00	15	1.82	0.77	5
M3	-48.975	-17.990	24.9	6.4	340.6	62.0	103.80	7.6	2.07	21	1.18	0.61	17.5
M4	-48.976	-17.990	25.8	6.7	305.9	76.5	69.99	7.5	0.58	0.0	3.51	0.58	5
M5	-49.086	-17.724	27.5	5.9	190.5	17.2	22.87	5.6	0.64	28	7.68	0.61	17.5
M6	-49.064	-17.689	23.7	6.1	271.2	0.1	231.60	7.4	0.62	5	0.88	0.67	30
M7	-49.104	-17.741	26.1	6.9	265.3	148.1	24.95	5.6	1.69	9	2.28	0.61	5
M8	-49.105	-17.741	25.6	7.0	260.8	94.2	19.76	6.8	0.96	0.0	0.85	0.40	0
M9	-49.229	-17.874	26.2	6.3	220.4	5.7	9.53	6.9	0.62	0.0	0.47	0.45	5
S1	-49.276	-17.644	25.0	6.9	225.5	125.0	14.49	7.9	0.92	0.0	1.37	0.73	0
S2	-49.263	-17.662	24.7	5.9	202.0	9.9	18.93	6.3	24.0	271	2.00	0.59	17.5
S3	-49.226	-17.681	24.3	6.3	252.4	73.3	26.59	7.5	0.94	21	1.13	0.50	0
S4	-49.201	-17.708	25.7	7.1	249.4	132.0	29.79	7.7	1.02	0.0	1.29	0.66	5
S5	-49.249	-17.761	24.2	7.3	258.0	280.9	23.84	7.0	0.98	30	1.24	0.53	5
S6	-49.247	-17.713	25.7	7.2	225.3	149.4	43.08	7.0	1.31	8	0.81	0.76	5
S7	-49.140	-17.705	22.8	6.6	172.7	44.0	19.22	6.5	1.20	0.0	0.92	0.53	5
S8	-49.151	-17.652	26.4	6.8	224.5	83.3	22.11	6.7	2.11	103	42.7	0.48	0
S9	-49.150	-17.652	24.1	6.9	218.7	71.1	25.64	7.8	1.61	5	1.58	0.67	5
S10	-49.204	-17.731	24.5	7.0	190.8	131.3	14.93	7.6	0.75	2	0.78	0.67	5

The basins differed only in relation to redox potential (RP; $t = -3.06$; $p = 0.007$) and pH ($t = 2.33$; $p = 0.032$). The RP values were higher in the Mimoso sub-basin and pH was higher in the Serra sub-basin. The habitat integrity index (HII) did not differ between the river basins ($t = 0.03$; $p = 0.977$). The variables temperature, electrical conductivity, dissolved oxygen, HII, redox potential and pH presented data with normal and homoscedastic distribution, i.e., with equal variances for both sub-basins. Rhodamine and chlorophyll-a showed non-normality and homoscedasticity of the data for both sub-basins. In turn, blue-green cells/ml and turbidity showed non-normality in the Serra and Mimoso sub-basins, respectively.

The Serra basin showed the maximum values of pH, conductivity, rhodamine, blue-green cells/mL and chlorophyll-a. The biological variables chlorophyll-a, Rhodamine and cells/mL exhibited high standard deviation within the basin (Table 3).

Positive and significant correlations were detected between chlorophyll-a and temperature ($r = 0.49$; $p = 0.03$), chlorophyll-a and blue-green cell/ml ($r = 0.46$; $p = 0.04$), conductivity and pH ($r = 0.79$; $p = 0.00004$), and blue-green cell/ml and rhodamine ($r = 0.63$; $p = 0.004$). A negative and significant correlation was also recorded between riparian width and pH ($r = -0.54$; $p = 0.01$), and riparian width and conductivity ($r = -0.62$; $p = 0.04$). The HII had no significant correlations (Figure 2).

Both axes of the Principal Component Analysis (PCA) explained 75.58% of the variation between the limnological factors of the basins. Axes 1 and 2 explained, respectively, 47.59% and 28.06% of the data variation. The variables that were best associated with the axes and different streams were cells/ml, pH, conductivity, and riparian forest width. The variables riparian forest width and cells/ml were positively associated with axis 1, while conductivity and pH were

Table 3 – Minimum (Min), maximum (Max), mean and standard deviation (SD) of the variables temperature (Temp), pH, redox potential (RP), conductivity (Cond), turbidity (Turb), dissolved oxygen (DO), rhodamine (Rh), blue-green cells/mL (Cell) chlorophyll-a (Chl), Habitat Integrity Index (HII), width of Riparian Forest (Rip) per river basin – Mimoso (Mim) and Serra.

Basin		Temp	pH	RP	Cond	Turb	DO	Rh	Cell	Chl	HII	Rip
Mim (N=9)	Min	23.70	5.95	190.50	0.10	9.53	5.64	0.58	0.00	0.47	0.40	0.30
	Max	27.50	6.96	340.60	148.10	231.60	7.66	2.07	48.29	7.68	0.83	30.0
	Mean	25.48	6.39	279.38	48.86	57.27	6.90	1.13	14.20	2.28	0.61	11.38
	SD	1.11	0.38	51.98	50.00	8.53	0.77	0.61	16.20	2.22	0.13	9.69
Serra (N=10)	Min	22.85	5.90	172.70	9.90	14.49	6.34	0.75	0.00	0.78	0.48	0
	Max	26.39	7.38	258.00	280.90	43.08	7.90	24.00	271.0	42.76	0.76	17.5
	Mean	24.75	6.85	221.93	110.02	23.86	7.22	3.48	44.04	5.39	0.61	4.75
	SD	1.01	0.47	27.52	74.44	7.30	0.56	7.22	85.68	13.14	0.10	5.06

negatively related to the same axis. Turbidity and forest width were negatively associated with axis 2 (Figure 3). The ordination of the points showed no distinction between the sub-basins. Most points were in quadrants I and III, i.e., lower riparian forest values and low blue-green cell density.

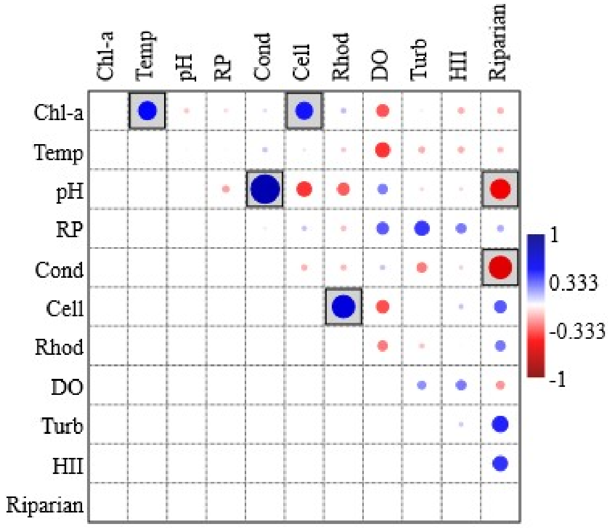

Figure 2 – Pearson's correlation between the physical, chemical, and biological variables of the sampled streams. Temperature (Temp), pH, redox potential (RP), electrical conductivity (Cond), blue-green cells/ml (Cell), chlorophyll-a (Chlo), rhodamina (Rhod), dissolved oxygen (DO), turbidity (Turb), categories of the average width of riparian forest (Riparian) and Habitat Integrity Index (HII). Significant values are outlined by a black square ($p<0.05$).

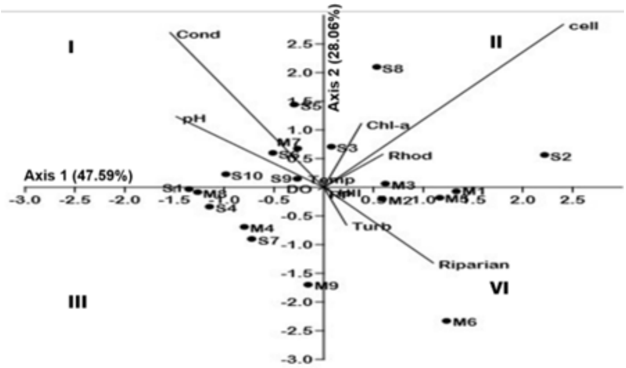

Figure 3 – Principal Component Analysis (PCA). The first axis explained 48.9% and the second 28.2% of the variation. Chlo (chlorophyll-a), Temp (temperature - °C), pH, RP (redox potential), Cond (conductivity), Rhod (Rodamina wt), DO (dissolved oxygen), Turb (turbidity), HII (Habitat Integrity Index), and Riparian (categories of average width of riparian forest).

The best model to predict primary productivity (chlorophyll-a) in the sampled streams included the variables blue-green cell density (cells/ml), temperature, and forest width. These three variables explained 40.5% of the chlorophyll-a variation in streams (Table 4), and were present in the second and third best models. The second-best model included turbidity, and the third best model included RP and turbidity.

Table 4 – Best predictors of chlorophyll-a according to the Akaike criterion (delta AIC<2). Temp (temperature in °C), Cell (blue-green cell density/ml), Riparian Forest (categories of average width of riparian forest), Turb (turbidity), RP (redox potential). Delta AIC - Akaike scores; adjusted coefficient of determination (r^2adj).

Model	Variables	AIC	ΔAIC	r²adj	P
1	Temp, Cell, Riparian Forest	48.07	0	0.405	0.012
2	Temp, Cell, Turb, Riparian Forest	46.87	1.2	0.388	0.025
3	Temp, RP, Cell, Turb, Riparian Forest	46.20	1.87	0.386	0.039

In the best model, temperature, blue-green cell density and riparian forest width, analyzed together, better predicted chlorophyll-a. However, when analyzed separately, only temperature and blue-green cell density increased, generating significantly higher chlorophyll-a values (Table 5). Thus, environments that present concomitantly higher temperature and blue-green cell density values, and lower percentages of riparian forest, presented higher chlorophyll-a values. It is natural that more preserved streams (with higher levels of riparian forest) will have lower primary production, due to the shading conditions (lower light input) of the aquatic environments.

Table 5 – Estimated coefficient and standard error (SE) associated with the best chlorophyll-a prediction model in streams. Values with $p < 0.05$ are shown in bold.

	Estimated	SE	t	P
Intercept	-10.726	4.802	-2.234	0.041
Temperature	7.860	3.383	2.323	0.035
Cells	0.227	0.084	2.700	0.017
Riparian forest	-0.197	0.137	-1.435	0.172

DISCUSSION

The sampled environments had different trophic levels, and the HII scores varied from degraded to preserved streams. These results are similar to those found by Giehl et al. (2019). As was expected, when the sampled points were grouped by sub-basins, they showed similar limnological conditions, except for the redox potential (RP), which was higher in the Mimoso sub-basin, and pH, which was higher in Serra sub-basin. The sub-basins sampled have similar land-use, but differ in terms of potential erosion. The Serra sub-basin has more erosive processes than the Mimoso sub-basin (Silva, 2016). The high pH value is associated with a high algal biomass in freshwater (Reynolds, 1994, Wilhelm et al., 2004). The redox potential is a vital indicator of water quality in surface water; low RP values indicate the presence of a reducing agent (ammonia, nitrites, organic substances), while high RP values indicate the presence of oxidizing agents (Mn, Cr, oxygen) (Goncharuk et al., 2010, APHA, 2017).

The sampling points closer to urban areas were the most productive, and had higher temperatures and blue-green cells counts per ml. The variables blue-green cells/ml, pH, conductivity, and riparian forest width were the best variables to characterize the limnological conditions of the tropical streams studied. These variables are influenced by the transport and deposition of sediments in the water courses, which result in degradation of riparian forest and soil (Rocha et al., 2014). Riparian forest was also an important factor in determining the environmental differences among headwater streams in the USA (Effert-Fanta et al., 2019). The few local variables measured here were sufficient to determine the water quality of these environments. Another, larger-scale study reinforces the importance of local environmental variables for explaining the chlorophyll-a concentration in lakes (Marcionilio et al., 2016).

The best model to predict primary productivity (chlorophyll-a) in the sampled streams included blue-green cell density/ml, temperature, and forest width. These three variables were also present in the other two best models. Thus, environments that present concomitantly higher temperatures and blue-green cell densities and lower percentages of riparian forest presented higher chlorophyll-a values. As we previously expected, the blue-green cells/ml predicted the primary production, due to the presence of chlorophyll-a in the blue-green cells. Cyanobacteria (blue-green cells) was highlighted as the most efficient primary producer of the tropical streams (Branco et al., 2017). A study demonstrates that increasing temperature results in smaller phytoplankton and a greater abundance of more efficient primary producers such as cyanobacteria (Rasconi et al., 2015). The effect of agriculture in the primary production mediated by the abundance of cyanobacteria was demonstrated by the glyphosate input, which promotes the dominance of picocyanobacteria and an increase in primary production (Pérez et al., 2007).

Temperature changes have an immediate effect on protozoa and microalgae, and consequently on aquatic productivity (Wang et al., 2019). Identifying the interaction between temperature and the primary production of microalgae, which contributes approximately 50% of global primary production, is critical to predict the impacts of climate change (Litchman et al., 2015). Temperature affects populations of autotrophic and heterotrophic organisms and their interactions, which in turn, affects the productivity of the aquatic systems (Wang et al., 2019). Therefore, temperature influences the diversity of primary producers, as well as the production of organisms that make up the food chains (Striebel et al., 2012). Climate change effects the rainfall cycle, and temperature increases can amplify the consequences of chemical and ecological variations on water quality. The impact of climate changes on water quality increases from groundwater via head-water streams, rivers, lakes, estuaries, and coastal water (Rozemeijer et al., 2021). A microcosm experiment on eutrophication in tropical aquatic ecosystems also found a positive relationship between temperature and chlorophyll-a concentration (Moura et al., 2017). In rivers, warming of 1.5°C can increase the GPP (Gross Primary Production) from 7% to 9%. This study highlights the more critical situation in shallower rivers, like the ones studied here (Zoboli et al., 2018).

Among other functions, riparian forest stabilizes the temperature of watercourses, influences in the physical, chemical and biological conditions of these environments, and reduces the inflow of pollutants to the river (Tambosi et al., 2015). In addition, the more extensive the riparian forest, the greater the protection of these environments in terms of carrying nutrients able to increase primary production. By filtering the waste carried to the watercourses, riparian forest helps maintain the balance of the aquatic community (Ramos-Filho et al., 2015). Riparian forest acts as a buffer to pollution from agricultural activity (Jankowski et al., 2021) and is an effective tool for mitigating such pollution and improving aquatic ecosystems in tropical streams (Effert-Fanta et al., 2019). For instance, when the riparian forest cover alongside an agricultural stream is increased, the total phosphorus, organic matter, and nitrification rate decrease (Kreiling et al., 2021). Riparian forest can also mitigate the impact of temperature increases in streams (Turunen et al., 2021). As we found in our study, the riparian forest has strong influences on environmental differences among streams (Effert-Fanta et al., 2019, Jankowski et al., 2021).

The variable turbidity, included as a predictor in the second and third best models, and the redox potential, present in the third best model for chlorophyll-a prediction, could also explain the primary production in the environments analyzed. The negative relationship between turbidity and chlorophyll-a was as expected, as light penetration is essential for the photosynthetic activity and consequently, for primary production. Light is one of the most important factors that limits algae development in streams (Hill et al., 2009). Loss of riparian forest results in changes in sunlight on the stream (Warren et al., 2008). Turbidity was important for predicting chlorophyll-a concentrations in tropical reservoirs (Carneiro et al., 2014) and rivers (Figueroa-Nieves et al., 2006, Aboim et al., 2020).

CONCLUSION

The variables that best predicted chlorophyll-a concentration of the tropical streams sampled in the two river basins studied were temperature, blue-green cells/ml, and with of the riparian forest, emphasizing the importance of temperature for aquatic productivity, in the face of climate changes. This study also highlights the importance of riparian forest in the limnological conditions of tropical streams, evidencing its influence on the increase in primary productivity, which may result in algae bloom and eutrophication processes. It is important to highlight that we measuring only riparian width at the collection site to represent the vegetation cover information. Nonetheless, this variable was an important predictor of the primary production of these environments. The use of simple local variables to determine the chlorophyll-a concentration may guide the conservation of aquatic ecosystem in tropical streams.

Most of the streams sampled have reduced primary productivity, except for a single watercourse that has been classified as supereutrophic. However, our study indicates that this condition may change due to temperature increases on a global scale and the constant deforestation that is occurring in the region. As a result, these environments may soon show changes in their primary production, with the consequent eutrophication of other environments.

REFERENCES

American Public Health Association (APHA). 2017. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, D.C.: APHA.

Aboim, I.L.; Gomes, D.F. & Mafalda Junior, P. O. 2020. Phytoplankton response to water quality seasonality in a Brazilian neotropical river. Environ Monit Assess. 192(70):1-16. DOI: 10.1007/s10661-019-7882-5

Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Moraes Gonçalves, J.L. & Sparovek, G. 2014. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift. 22(6):711–728. DOI:10.1127/0941-2948/2013/0507

Anderson, D.R. & Burnham, K.P. 2002. Avoiding Pitfalls When Using Information-Theoretic Methods. J Wildlife Manage. 66(3):912-918. DOI:10.2307/3803155

Antoneli, V.; Pulido-Fernández, M.; Bednarz, J.A.; Brandes, L.; Vrahnakis, M.; Kazoglou, Y.; Lozano-Parra, J. & García-Marín, R. 2021. Changes in Water Quality of the River das Antas as It Passes through Rural and Urban Areas. Urban Sci. 5(1):22. DOI:10.3390/urbansci5010022

Araújo, M.C. & Oliveira, M.B.M. 2013. Monitoramento da qualidade das águas de um riacho da Universidade Federal de Pernambuco, Brasil. AMBIAGUA. 8(3), 247-257. DOI: https://doi.org/10.4136/ambi-agua.1192

Araújo, F.G., Melão, M.G.S., Santos, J.E. dos, Araújo, R.G.O., & Figueiredo-Barros, M.P. 2018. Classification of Brazilian Reservoirs Using the Trophic State Index Based on Chlorophyll-a Concentration. Braz. J. Aquat. Sci. Technol., 22(3), e1278. doi:10.21477/1984-5333-2018-1278

Branco, C.C.Z.; Riolfi, T.A.; Crulhas, B.P.; Tonetto, A.F.; Bautista, A.I.N. & Necchi Júnior, O. 2017. Tropical lotic primary producers: Who has the most efficient photosynthesis in low-order stream ecosystems? Freshw Biol. 62(9):1623–1636. DOI: 10.1111/fwb.12974

Brasil. 2005. Resolução CONAMA N°357, de 17 de março de 2005. Diário Oficial da União, Brasília, Brasil.

Brasil, J.; Santos, J.B.O.; Sousa, W.; Menezes, R.F.; Huszar, V.L.M. & Attayde, J.L. 2020. Rainfall leads to habitat homogenization and facilitates plankton dispersal in tropical semiarid lakes. Aquat Ecol. 54(1), 225–241. DOI: 10.1007/s10452-019-09738-9

Bucci, M.H.S & Oliveira, L.F.C. 2014. Índices de Qualidade da Água e de Estado Trófico na Represa Dr. João Penido (Juiz de Fora, MG). AMBIAGUA. 9(1):130-148. DOI: 10.4136/ambi-agua.1290

Carlson, R.E. 1977. A trophic state index for lakes. Limnol Oceanogr. 22(2): 361-369. DOI:10.4319/lo.1977.22.2.0361

Carneiro, F.M.; Nabout, J.C.; Vieira, L.C.G.; Roland, F. & Bini, L.M. 2014. Determinants of chlorophyll-a concentration in tropical reservoirs. Hydrobiologia. 740(1):89–99. DOI:10.1007/s10750-014-1940-3

Carpenter, S.R.; Brock, W.A.; Cole, J.J. & Pace, M.L. 2009. Leading indicators of phytoplankton transitions caused by resource competition. Theoretical Ecology:2(3), 139–148. DOI:10.1007/s12080-009-0038-4

Effert-Fanta, E.L.; Fischer, R.U. & Wahl, D.H. 2019. Effects of riparian forest buffers and agricultural land use on macroinvertebrate and fish community structure. Hydrobiologia. 841(1):45–64. DOI:10.1007/s10750-019-04006-1

Esteves, F.A. 1998. Fundamentos de Limnologia. 2ª Ed. Rio de Janeiro: Interciência, 602p.

Ferrareze, M. 2012. The effect of the land use on phytoplankton assemblages of a Cerrado stream

(Brazil). Acta Limnol Brasil. 24(1):43-51. DOI: 10.1590/S2179-975X2012005000025

Figueroa-Nieves, D.; Royer, T. V. & David, M.B. 2006. Controls on chlorophyll-a in nutrient-rich agricultural streams in Illinois, USA. Hydrobiologia 568(1):287–298. DOI:10.1007/s10750-006-0114-3

Fornari, M.R.; Camotti-Bastos, M.; Medeiros-Silveira, F.; Vargas, J.P.R.; Fernandes, G.; Santos, M.A.S. & Santos, D.R. 2018. Efluentes urbanos na água do Rio Marau (Brasil). Qualidade da água no Rio Marau. Bitácora Urbano Territ. 28(3):121-130. DOI:10.15446/bitacora.v28n3.68152

Giehl, N.F.S.; Brasil, L.S.; Dias-Silva, K.; Nogueira, D.S. & Cabette, H.S.R. 2019. Environmental Thresholds of Nepomorpha in Cerrado Streams, Brazilian Savannah. Neotrop Entomol. 48:186–196. DOI:10.1007/s13744-018-0632-5

Goncharuk, V.V.; Bagrii, V.A.; Mel'nik, L.A.; Chebotareva, R.D. & Bashtan, S. Y. 2010. The use of redox potential in water treatment processes. J Water Chem Techno. 32(1):1–9. DOI:10.3103/S1063455X10010017

Hammer, Ø., Harper, D.A.T., & Ryan, P.D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol. Electron., 4(1), 1-9. doi:10.26879/876

Hilary, B.; Chris, B.; North, B.E.; Angelica Maria, A. Z.; Sandra Lucia, A. Z.; Carlos Alberto, Q.G.; Beatriz, L.G.; Rachael, E. & Andrew, W. 2021. Riparian buffer length is more influential than width on river water quality: A case study in southern Costa Rica. J Environ Manage. 286:112132. DOI:10.1016/j.jenvman.2021.112132

Hill, W.R.; Fanta, S.E. & Roberts, B.J. 2009. Quantifying phosphorus and light effects in stream algae. Limnol Oceanogr. 54(1):368–380.

Jankowski, K.J.; Deegan, L.A.; Neill, C.; Sullivan, H.L.; Ilha, P.; Maracahipes-Santos, L.; Marques, N. & Macedo, M.N. 2021. Land use change influences ecosystem function in headwater streams of the lowland amazon basin. Water-Sui. 13(12). DOI: 10.3390/w13121667

Kreiling, R.M.; Bartsch, L.A.; Perner, P.M.; Hlavacek, E.J. & Christensen, V.G. 2021. Riparian Forest Cover Modulates Phosphorus Storage and Nitrogen Cycling in Agricultural Stream Sediments. Environ Manage. 68(2):279–293. DOI: 10.1007/s00267-021-01484-9

Lamparelli, M. C. 2004. Grau de trofia em corpos d`água do estado de São Paulo: avaliação dos métodos de monitoramento. Doctoral thesis. Instituto de Biociências da Universidade de São Paulo. 207p.

Legendre, P. & Legendre, L. 1998. Numerical ecology. 2nd edition. Elsevier Sci-ence BV, Amsterdam, 853p.

Litchman, E.; de Tezanos Pinto, P.; Edwards, K.F.; Klausmeier, C.A.; Kremer, C.T. & Thomas, M.K. 2015. Global biogeochemical impacts of phytoplankton: A trait-based perspective. J Ecol. 103(6):1384–1396. DOI:10.1111/1365-2745.12438

Marcionilio, S.M.L.O.; Machado, K.B.; Carneiro, F.M.; Ferreira, M.E.; Carvalho, P.; Vieira, L.C.G.; Huszar, V.L.M. & Nabout, J.C. 2016. Environmental factors addecting chlorophyll-a concentration in tropical floodplain, Central Brazil. Environ Monit Assess. 188(11):611. DOI: 10.1007/s10661-016-5622-7

Moura, M.E.P.; Rocha, L.S. & Nabout, J.C. 2017. Effects of global climate change on chlorophyll-a concentrations in a tropical aquatic system during a cyanobacterial bloom: a microcosm study. AMBIAGUA. 12(3):390-404. DOI: 10.4136/1980-993X

Nessimian, J.L.; Venticinque, E.M.; Zuanon, J.; Marco Jr, P.; Gordo, M.; Fidelis, L.; Batista, J.D. & Juen, L. 2008. Land use, habitat integrity, and aquatic insect assemblages in Central Amazonian streams. Hydrobiologia. 614 (117):117–131. DOI: 10.1007/s10750-008-9441-x

Pérez, G.L.; Torremorell, A.; Mugni, H.; Rodriguez, P.; Rodriguez, R.; Vera, M.S.; Nascimento, M.; Allende, L.; Bustingorry, J.; Escaray, R.; Ferraro, M.; Izaguirre, I.; Pizarro, H.; Bonetto, C.; Morris, D.P. & Zagarese, A.H. 2007. Effects of the herbicide roundup on freshwater microbial communities: a mesocosm study. Ecol Appl. 17:2310–2322.

Pinto, J.F. & Antunes, S.C. 2020. Biomanipulação para o controlo da eutrofização. Ver Ciência Elem. 8(1):1-5. DOI:10.24927/rce2020.010

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ramos-Filho, M.; Menezes, L.; Saroba, C. & Thomé, M. P. 2015. Descrição do processo de recuperação da mata ciliar de um riacho no município de Varre-Sai-RJ. REINOEC. 1(11):143-286. DOI: 10.20951/2446-6778/v1n1a11

Rasconi, S., Barbone, È., Marañón, J. C., & Vespoli, M. T. M. V. S. 2015. Increased temperature alters the structure and functioning of freshwater lake food webs. Glob Change Biol, 21(6), 2274-2288. doi:10.1111/gcb.12834

Reynolds, C.S. 2006. The Ecology of Phytoplankton. 1st Ed. Cambridge University Press. 552p.

Reynolds, C.S. 1984. The Ecology of Freshwater Phytoplankton. 1st Ed. Cambridge University Press. 396p.

Rocha, C.H.B.; Freitas, F.A. & Silva, T.M. 2014. Alterações em variáveis limnológicas de manancial de Juiz de Fora devido ao uso da

terra. RBEAA. 18(4):431–436. DOI: 10.1590/S1415-43662014000400011
Rozemeijer, J.; Noordhuis, R.; Ouwerkerk, K.; Dionisio Pires, M.; Blauw, A.; Hooijboer, A. & van Oldenborgh, G.J. 2021. Climate variability effects on eutrophication of groundwater, lakes, rivers, and coastal waters in the Netherlands. Sci Total Environ. 771. DOI: 10.1016/j.scitotenv.2021.145366
Silva, C.L. 2016. Análise morfológica, física e química de duas ocorrências erosivas lineares de grande porte no Município de Morrinhos (GO). Master Dissertation. Universidade Estadual de Goiás. 119p.
Smith, V.H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science. 221(4611): 669-671.
Smith, V.H. & Schindler, D.W. 2009. Eutrophication science: where do we go from here? Trends Ecol Evol. 24(4):201–207. DOI:10.1016/j.tree.2008.11.009
Striebel, M.; Singer, G.; Stibor, H. & Andersen, T. 2012."Trophic overyielding": Phytoplankton diversity promotes zooplankton productivity. Ecology. 93(12): 2719-2727. DOI: 10.2307/41739628
Tambosi, L.R.; Vidal, M.M.; Ferraz, S.F.B. & Metzger, J.P. 2015. Funções eco-hidrológicas das florestas nativas e o Código Florestal. Estud av. 29(84): 151-162. DOI: 10.1590/S0103-40142015000200010
Turunen, J.; Elbrecht, V.; Steinke, D. & Aroviita, J. 2021. Riparian forests can mitigate warming and ecological degradation of agricultural headwater streams. Freshw Biol. 66(4): 785–798. DOI: 10.1111/fwb.13678
Veras, D.S.; Castro, E.R.; Lustosa, G.S; Azevêdo, C.A.S. & Juen, L. 2019. Evaluating the habitat integrity index as a potential surrogate for monitoring the water quality of streams in the cerrado-caatinga ecotone in northern Brazil. Environ Monit Assess. 191:562. DOI:10.1007/s10661-019-7667-x
Viana, C.; Campos, I.; Veras, D. &Lustosa, G. S. 2020. Environmental gradients as filters on the composition of aquatic insect of the Cerrado-Caatinga, Brazil. Acta Brasil. 4:142-148. DOI: 10.22571/2526-4338362.
Wang, Q.; Lyu, Z.; Omar, S.; Cornell, S.; Yang, Z. & Montagnes, D.J.S. 2019. Predicting temperature impacts on aquatic productivity: Questioning the metabolic theory of ecology's "canonical" activation energies. Limnol Oceanogr. 64:1172–1185. DOI:10.1002/lno.11105
Warren, D.L.; Glor, R.E. & Turelli, M. 2008. Environmental niche equivalency versus conservatism: Quantitative approaches to niche evolution. Evolution. 62(11):2868–2883. DOI: 10.1111/j.1558-5646.2008.00482.x
Wetzel, R.G. and Likens, G.E. 2000. Limnological Analysis. 1st. Ed. Springer Science & Business Media. 429p.
Wilhelm, C.; Becker, A.; Toepel, J.; Vieler, A. & Rautenberger, R. 2004. Photophysiology and primary production of phytoplankton in freshwater. Physiol Plantarum.120:347-357.
Zoboli, O.; Schilling, K.; Ludwig, A.L.; Kreuzinger, N. & Zessner, M. 2018. Primary productivity and climate change in Austrian lowland rivers. Water Sci.Techn. 77(2), 417–425. DOI: 10.2166/wst.2017.553

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