EXTREME DROUGHT EVENTS INCREASE PHYTOPLANKTON BIOMASS IN THE BARRA BONITA RESERVOIR

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ABSTRACT

We used satellite imagery to estimate the Chl-a concentration from 2014 to 2020 using the Slope Index (NRMSE of 18.92% and bias of -0.20 mg m^{-3}). Ancillary data such as precipitation, water level and air temperature from the same period were also used. Drought events were identified using the standardized precipitation index (SPI). In addition, we computed the probability of future drought events. The highest correlation was observed between Chl-a concentration and SPI (-0.97) in 2014, while Chl-a had had the highest correlation with water level (-0.59) in 2020. These results provide new insights into the influence of extreme drought events on the Chl-a concentration in the BBHR and their relationship with other climate variables and reservoir water levels.

***Key words** — Extreme events, algae bloom, inland waters body.*

1. INTRODUCTION

Phytoplankton biomass can be identified through a proxy, the chlorophyll-*a* (Chl-*a*) concentration, which is commonly monitored by water quality programs. Notably, phytoplankton blooms have been reported regularly in lakes, reservoirs, coastal areas, and oceans worldwide [1].

Temporal and seasonal variations in phytoplankton is known as phenology, which responds much more quickly to meteorological and climatic forces than to terrestrial vegetation. Phenological responses to environmental changes include: 1) shifts in the timing of phytoplankton blooms [2], 2) changes in phytoplankton biomass [3], 3) changes in their growth rates [4], and 4) changes in overall biodiversity [5].

Monitoring aquatic systems is important because climatic extremes such as drought, is severely threatening aquatic ecosystems globally [6]. However, understanding the potential effects of climate variability on aquatic systems is challenging because of the multitude of responses in the entire watershed. The chemical, biological, and physical responses of aquatic systems are affected by climate extremes [7]. Drought have recently increased in frequency, intensity, and duration resulting in the occurrence of intense and long dry periods [8]. In Brazil, drought periods have become increasingly frequent, resulting in episodes of water deficit leading to water crises in southeastern Brazil [9]. Extreme drought is mostly related to lower-than-usual precipitation rates, resulting in high soil moisture depletion and lower rates of evapotranspiration.

Intensification (in space and time) of algal growth in inland waters has been linked to eutrophication and climate variability; however, there is little empirical evidence that this trend is universal [10]. Ho et al. [11] used three decades of Landsat-5/Thematic Mapper imagery to investigate long-term trends in intense summertime near-surface phytoplankton blooms in 71 large lakes worldwide. This study found that the summertime bloom intensity increased in 68% of the studied lakes. In contrast, [12] analyzed a global dataset extracted from the Harmful Algal Event Database and Ocean Biodiversity Information System for the period 1985–2018 and found no uniform global trend for harmful marine algae. These studies suggest that future research should focus on regional rather than global trends.

The lack of time-series analysis limits the understanding of the relationship between the observed increase in Chl-*a* in the Barra Bonita reservoir and drought events. To address this knowledge gap, this current study evaluated the relationship between the Chl-*a* concentration and precipitation, air temperature, water level, and drought time series (from 2014 to 2020). Our goal was to understand phytoplankton responses to drought events in eutrophic subtropical aquatic systems.

2. MATERIALS AND METHODS

2.1 Study site

Barra Bonita reservoir is a storage-type system (flooded area of 310 km^2, volume of 3.62×10^6 m^3), and is in the middle course of the Tietê River, São Paulo State, Brazil (Figure 1). The average depth of water is 25 m with a retention time ranging from 37 to 137 days [13].

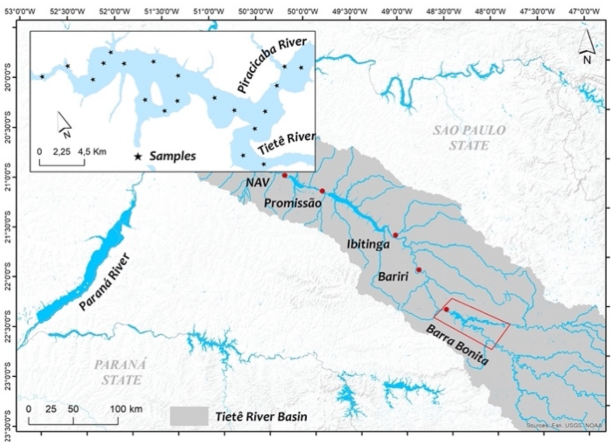

Figure 1. Location of Barra Bonita Hydroelectric Reservoir in São Paulo State, Brazil and sampling distribution.

The methodological approach was summarized in a fluxogram as shows in Figure 2.

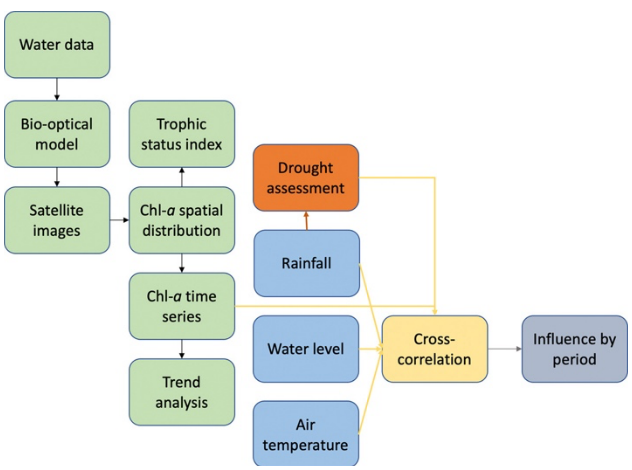

Figure 2: Fluxogram summarizing the methodological approach.

3. RESULTS

3.1 Drought assessment

Drought occurred during two periods of extreme dryness, in: 1) January and February of 2014, and 2) April and May of 2020 (Figure 3). In addition, severe dry conditions were observed for the following periods: 1) July and November of 2014; 2) March of 2017; 3) February and May of 2018, and 4) January of 2019. Notably, the two extreme dry periods occurred during Austral summer in 2014 and the austral autumn in 2020.

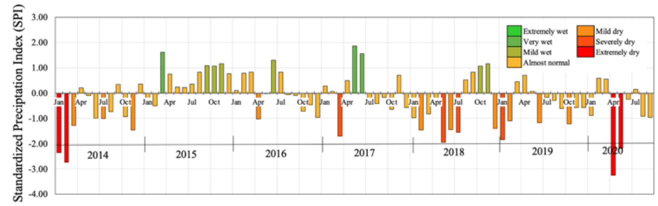

Figure 3: SPI time series from 2014 to 2020.

3.2. Phytoplankton biomass

To better understand the variability in Chl-*a* from 2014 to 2020, we display a boxplot that used all 50 images (Figure 5). In summer, Chl-*a* concentrations tend to be high. The Chl-*a* concentration during the extreme drought in January 2014 ranged from 9 to 1068 mg m^{-3}, and in April 2020, the Chl-*a* concentration ranged from 3 to 902 mg m^{-3}. Since no cloud-free satellite images were available after January 2014, only Chl-*a* data for September were analysed (Chl-*a* ranged from 2 to 724 mg m^{-3}). However, after April 2020, the next available image was for July (Chl-*a* ranged from 3 to 755 mg m^{-3}).

Notably, the three highest Chl-*a* concentrations were found in March 2017 (austral autumn) (Chl-*a* ranged from 2 to 1625 mg m^{-3}), August 2018 (austral winter) (Chl-*a* ranged from 3 to 1463 mg m^{-3}), and August 2020 (austral winter) (Chl-*a* ranged from 2 to 1267 mg m^{-3}). The SPI for March 2017, August 2018 and August 2020 were 0.50 (almost normal), 0.53 (almost normal) and -0.92 (almost normal) respectively. The air temperature and rainfall values were 21.5℃ (122 mm), 19.15℃ (89 mm) and 19.92℃ (33 mm) respectively. Lastly, the water level and useful volume were 451.14 m (95.73%), 449.65 m (78.81%) and 450.06 m (83.35%) respectively.

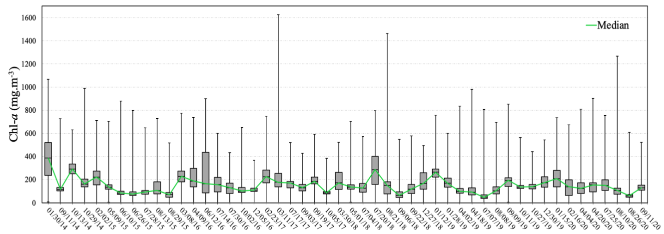

Figure 4. Boxplot showing the distribution of Chl-*a* concentration from 2014 to 2020.

Figure 5 shows a set of 16 selected processed images for the study site during this period. The regions where high values (red) were next to the dam and the Piracicaba River.

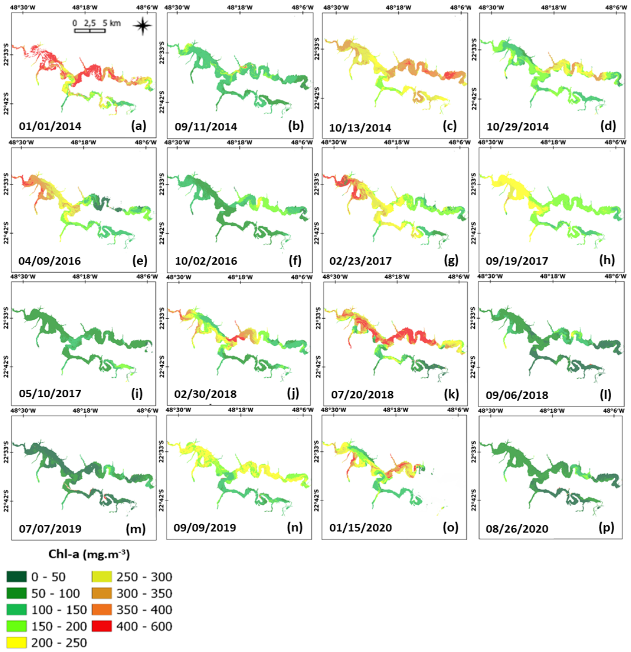

Figure 5. Selected Chl-*a* maps showing the spatial distribution within the Barra Bonita reservoir between 2014 to 2020.

3.3. *Trophic Status Index versus SPI*

The TSI was calculated from the Chl-*a* derived from satellite images, and a boxplot of the TSI for each SPI class was plotted (Figure 6). For mildly wet conditions, only one median value of TSI was identified. However, an increase in TSI from almost normal to extremely dry conditions was evident. In general, mildly wet, mildly dry, severely dry, and extremely dry events resulted in TSI being classified as eutrophic while almost normal events meant that TSI was classified as hypereutrophic. The rule was that $54 < TSI \leq 74$ indicated eutrophic waters and $TSI > 74$ indicated hypereutrophic waters.

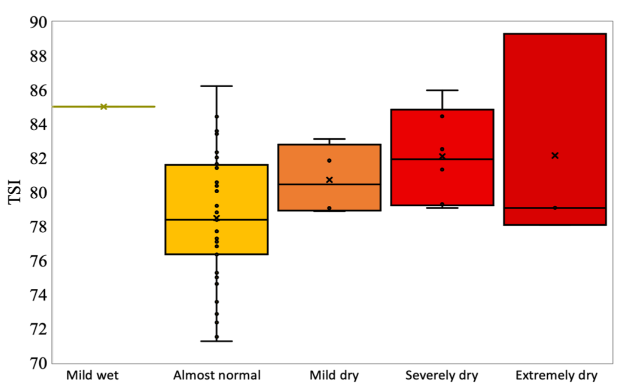

Figure 6. Boxplot of TSI based on the Chl-*a* estimated by satellite images by SPI class.

4. DISCUSSION

Climate variability has altered rainfall regimes, affecting reservoir storage, stream flow, soil moisture, and water availability in southeastern Brazil. The Tietê River where the BBRH was located, had its water storage capacity reduced to approximately 3% owing to the most severe drought in 2014 [14]. During this period, the water flux at the dam was controlled and the water retention time increased, making the reservoir a suitable place for phytoplankton growth

Compared to the drought in 2020, the extreme drought in 2014 was more positively correlated with air temperature; however, a positive pattern was also observed in 2020. This indicates that an increase in air temperature has increased phytoplankton biomass, whereas a decrease in the SPI will increase phytoplankton biomass. Increasing air temperature also affects primary productivity, solubility, nutrient biogeochemical cycling, reaction rates, soil moisture, and other factors related to water quality.

Barra Bonita reservoir was classified as a eutrophic-hypertrophic waterbody (Figure 7), which confirms that eutrophication in the reservoir was a result of several processes, such as land-use land cover changes in the watershed, diffuse and specific pollution, and hydropower operation (high water retention time). Salk et al. (2022) used an experiment on eutrophication in lakes and showed that increases in water temperature associated with climate change can lead to earlier and larger phytoplankton blooms. Therefore, the use of meteorological and climatological data should always be considered in the assessment and modelling of water quality, and this includes the use of the maximum air temperature.

Cyanobacterial harmful algal blooms (cHABs) are a serious public health issue worldwide because of their ability to form dense biomass-producing toxins. cHABs toxins can cause gastrointestinal distress, dermatitis, liver failure, and death in domestic and livestock animals. This is an important finding for Barra Bonita because the São Paulo State Environmental Agency (CETESB) annual reports (CETESB 2011–2015) showed that BBHR was mostly dominated by cyanobacteria, including potential cHAB toxin producers. The 2014 and 2020 droughts started as meteorological events that led to hydrological droughts. A meteorological drought is associated with periods of low rainfall, high temperatures and high evaporation rates. Meanwhile, water shortages are caused by hydrological droughts and such droughts can increase water retention time. In addition, the increasing of air temperature due to climate change can influence the heating and cooling of aquatic systems, altering water column mixing and stratification patterns and increasing the potential of algal blooms.

5. CONCLUSION

High concentrations were observed during the summer in Barra Bonita reservoir, especially in January and February. The same period that experienced extreme drought events in 2014 was also confirmed using the SPI time series analysis. The Chl-*a* concentration was positively correlated (r=0.79) with air temperature and negatively correlated with SPI (r=-0.97) in 2014. These results indicate an increase in algal biomass due to high air temperatures and low SPI. In 2020, another extreme drought event was observed, where the Chl-*a* concentration was positively correlated with air temperature (0.54) and negatively correlated (-0.59) with water level. Our results suggest an unexpected dynamic for the occurrence of phytoplankton blooms, which are usually associated with the transport of nutrients from agricultural land to aquatic systems via rainfall. Therefore, our findings show the need for further investigation, especially for the identification of phytoplankton species, to improve water quality monitoring, especially with climatic variability. Lastly, this assessment was supported by the recurrence probability of drought events, which meant that such similar events may occur once every 50 years.

6. REFERENCES

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