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A LITTLE ABOUT THE SCIENCE OF THE INLAND WATERS IN NORTHERN RIO DE JANEIRO STATE: CYANOBACTERIAL BLOOMS IN THE LOWER PARAÍBA DO SUL RIVER.

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Abstract: The 1993 inauguration of UENF (Universidade Estadual do Norte Fluminense Darcy Ribeiro) has made research on aquatic ecosystems in the northern region of Rio de Janeiro State a reality, most notably that pertaining to the lower Paraíba do Sul River (PSR) and associated ecosystems (e.g. mangroves, coastal lagoons and coastal zone). These researches were, in part, leveraged by the scientific training provided by Dr Francisco Esteves. Within the municipality of Campos dos Goytacazes, the PSR has been monitored with biweekly samplings since 1994 by UENF in a long-term project highlighting the river's role in supplying water for 90% of the municipality's population. However, potamological conditions such as low outflow and eutrophication have fostered episodic cyanobacterial blooms, especially during the dry season. One such event caused water supply interruptions in the municipalities located in the lower PSR basin, a fact that highlights the importance of pluriannual monitoring of its hydrochemical conditions.

Keywords: Eutrophication; water outflow; dry period; river damming.

Rivers, *sensu* Thorp *et al.* (2006), form biocomplex networks across space and time, connecting terrestrial, lentic, wetland and oceanic systems in a complex mosaic of habitats and environments. Amidst this complexity, the ecological aspects of riverine phytoplankton are poorly known when compared to their lentic and marine counterparts (Wu *et al.* 2014, Dokulil 2015, Abonyi *et al.* 2021). Limnologists consider phytoplankton of reduced importance to riverine food webs, particularly when compared to the more significant quantities of allochthonous organic matter inputs from watersheds (Welker & Walz 1999). Studies regularly show that phytoplankton abundance in rivers is comparable to moderately productive lentic systems because of regulation factors (Qu *et al.* 2018). Growth rates can be inhibited by low light availability due to the attenuation caused by high concentrations of suspended particulate matter, resulting in very low photosynthetic production. Therefore, phytoplankton production and abundance in rivers is regulated, especially by hydrological processes such as discharge and water residence time, light availability, limited nutrients, sedimentation and biotic interactions that include grazing and competition (Kim *et al.* 2019). In tropical zones these variables can change seasonally because hydrological cycles are closely linked to highly defined rainy and dry seasons (Hunt *et al.* 2012, Granado & Henry 2014).

One example of an unusual pattern found in tropical areas is the Paraíba do Sul River (PSR). The PSR is a medium-sized river that is 1,145 km

long with a 55,400 km^2 drainage basin. It traverses the three most developed states in Brazil: São Paulo, Minas Gerais and Rio de Janeiro and flows into the Atlantic Ocean. The PSR represents the main source of water supply for more than 22 million people living in the metropolitan area of Rio de Janeiro and other cities such as Campos dos Goytacazes. Despite its importance, this river has been used for effluent disposal by a very large number of industries and municipalities along its course, especially in the middle basin where considerable population growth and intense and varied industrial development have taken place in recent decades, resulting in negative consequences with regard to water quality (Lima *et al*. 2016, CEIVAP 2020)

Previous studies carried out along the PSR have indicated that the Funil and other smaller reservoirs represent traps for a portion of the material carried by the PSR, retaining particles and carrying nutrients and metals to the bottom compartment (Araújo *et al*. 2011) and improving the water quality downstream (Pacheco *et al*. 2017). The lower portion of the PSR (100 km of extension and 22,000 km^2) is a wide alluvial plain located in the north of Rio de Janeiro State whose landscape is occupied by almost 200,000 ha of sugar-cane crops and pastures. The main tributaries of the lower PSR are the Pomba, Dois Rios and Muriaé Rivers (CEIVAP 2020).

In Campos dos Goytacazes, the largest city located in the lower PSR, the LCA/UENF (Laboratório de Ciências Ambientais of the Universidade Estadual do Norte Fluminense Darcy Ribeiro) has maintained a program to monitor the hydrochemical parameters of the Paraíba do Sul River since 1994, mostly at biweekly intervals. Until 2014, when a prolonged period of drought began, the PSR presented water outflows ranging from 111 to 7,500 $m^3 s^{-1}$ with a median value of 587 $m^3 s^{-1}$. Values above 3,000 $m^3 s^{-1}$ are rare and associated with very high wet season flooding; however, values above 1,000 $m^3 s^{-1}$ frequently occur during the rainy season (November to March). Average water outflow is 425 $m^3 s^{-1}$ during the dry season (characteristically between April and October each year) and minimum values vary around 120 $m^3 s^{-1}$. During these dry periods, dry sand banks accumulate in sedimentation areas of the fluvial channel, fragmenting it and restricting waterflow where lentic characteristics develop along the river.

Deforestation in the riparian areas of the watershed is the primary cause of siltation processes in the fluvial channel. The native vegetation of the PSR has been modified by diverse forms of human occupation and land use which resulted in erosion leading to siltation processes in the river channel. However, currently the most documented and harmful source of pollution to the PSR watershed is domestic sewage and the solid residues produced by the cities located along its course (Rosa 2012). More than 1 billion liters of domestic sewage are released daily into the PSR catchment (CEIVAP 2006).

As a result of this environmental degradation, abnormal episodic growth of phytoplankton communities has become common in the lower PSR, especially during low outflow periods (Ovalle *et al*. 2013, LCA/UENF database – 35 events with chlorophyll-*a* > 5.0 $\mu g.L^{-1}$ from January 1999 to September 2013) contrasting with often undetectable values for phytoplankton biomass during periods of high outflow (Nov to Mar – summer season). The synergistic conditions of low outflow combined with constant and high solar incidence and high temperatures present in this region, even during the winter (classified as tropical semi-humid climate), high nutrient availability and increases in water transparency (the result of lentic characteristics which allow for deeper penetration of solar radiation in the water column) have resulted in frequent phytoplanktonic blooms during dry seasons.

As observed in lentic systems, the frequencies of cyanobacterial blooms have increased (Chorus & Welker 2021). In October of 2002 and October of 2007, when values of riverine outflow had been calculated as approximately 190 $m^3 s^{-1}$ and 115 $m^3 s^{-1}$, cyanobacterial blooms with the predominance of *Dolichospermum* cf *circinale* were recorded in Campos dos Goytacazes. The first event (chlorophyll-*a* and *D. circinale* density up to 36 $\mu g.L^{-1}$ and 21,000 $ind.mL^{-1}$, respectively) resulted in water supply interruptions in the municipalities of Campos dos Goytacazes (15 km distant from the estuary) and São João da Barra (located at the estuary of the PSR) lasting three days. This water supply interruption was related to the production of organoleptical substances,

probably geosmin, giving drinking water an unpleasant odor and taste. The inability to collect water from the PSR represented a serious problem for the municipality of Campos dos Goytacazes, where around 90% of the population is dependent on the river's water supply. During the second event in 2007, while the algae bloom did not produce any perceivable substance, the values of chlorophyll-*a* and the density of *D. circinale* reached 42 $\mu g.L^{-1}$ and 28,000 $ind.mL^{-1}$. Both events caused increases in the pH of the water, which rose from its normal range of 6.8-7.0 to a maximum of 9.2. The concentrations of dissolved inorganic nutrients largely remained stable (NID ~30 µM; ~0.3 PID µM) before and during the blooming events, but an increase in NOD and POD values (> ~25%) was detected during the blooms. Due to the water outflow (low residence time), the blooms were quickly dispersed (in three days for the first event and four days for the second), indicating the high ecological resilience of the PSR. However, in September-October 2016 a more persistent *Raphidiopsis raciborskii* bloom was observed, which fortunately was not associated with toxin production. During that event, chlorophyll-*a* and the *R. raciborski* density values reached 10 $\mu g.L^{-1}$ and 7,300 $ind.mL^{-1}$. Researchers have often warned of filamentous cyanobacterium that can form persistent and resilient blooms in eutrophic ecosystems (*e.g.* Bonilla *et al.* 2012, 2016), especially in lentic ones. Again, the PRS presented low values of water outflow, from 126 to 200 $m^3 s^{-1}$, although no significant variations in the values of dissolved and total nutrients were observed at the time.

Notwithstanding the rarity of the cyanobacterial blooms observed in Campos dos Goytacazes, algae blooming events, including those with populations that present the potential for the production of organoleptical and toxic compounds, represent a threat in the near future due to the observation of more frequent minimum outflows and the persistence and/or increase of domestic effluents and farm and industrial discharge into the PSR basin. It should be noted that the lower PRS region continues to be affected by the consequences of a prolonged drought period that began in 2014. Since then, only at the end of 2019 have two consecutive events (biweekly intervals) been observed with outflow values greater than 1000 $m^3 s^{-1}$. Therefore, these conditions will probably favor the development of phytoplanktonic populations whenever they encounter physical (*i.e.* optical, mechanical) and chemical (especially nutrients) conditions favorable to their proliferation.

The Funil Reservoir, a component of the continuous system where frequent cyanobacterial blooms formed by *D. circinale* and *C. raciborskii have been* observed (Rangel *et al.* 2016, Domingues *et al.* 2017), can represent a consistent source of cyanobacterial inocula for the lower PSR. This section of the PRS provides conditions favorable to the development of inocula, such as low turbulence and the availability of light and nutrients. Controlling eutrophication and cyanobacterial blooms in water supply ecosystems is one of the greatest challenges for water resource management (Chorus & Welker 2021). A major warning has been emitted by Brazilian fluvial system authorities because, concomitant to the cyanobacterial blooms in the PSR, the Doce and São Francisco rivers (two other important medium-sized rivers in Brazil) also presented harmful blooms in October 2007, leading to massive fish deaths, which were probably caused by cyanotoxin production, as reported on Brazilian TV and in large circulation newspapers. Thus, in municipalities dependent on the rivers for water supply, public policies to control the emission of effluents throughout the entire river basin should be a priority.

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