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Effects of nutrients and organic matter inputs in the gases CO_2 and O_2: A mesocosm study in a tropical lake

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ABSTRACT

Lakes are important components in the carbon cycling and threatened by direct and indirect human activities, which ultimately affect metabolic processes. We analyzed the daily dynamics of the air-water CO_2 and O_2 fluxes over nine days in a mesocosm experiment to determine how the inputs of inorganic nutrients (+NUTRI) and allochthonous organic matter (+OM) affected the metabolic processes. The control, representing the original state of the lake, showed low coefficient of variability among the days sampled and a predominant FCO_2 to the atmosphere, but with mean values close to zero ($0.2 \pm 0.3\,mmol\,m^{-2}\,d^{-1}$). In +NUTRI and +NUTRI+OM treatments mesocosms, the FCO_2 and FO_2 showed similar response, where the FCO_2 was negative during all days (mean -1.8 ± 1.1 and $-1.9 \pm 1.2\,mmol\,m^{-2}\,d^{-1}$, respectively) and FO_2 was initially negative, becoming positive after day 4, and decreasing again after day 6. The +OM treatment intensified the FCO_2 to the atmosphere (mean $0.4 \pm 0.9\,mmol\,m^{-2}\,d^{-1}$) with highest values at day 7. The ecosystem in +NUTRI and +NUTRI +OM treatments showed a similar recovery (8 days), while +OM treatment mesocosm was similar to the control conditions. The models showed that nutrients promoted larger overall changes and higher daily variability in both FCO_2 and FO_2, leading to a CO_2 influx, followed by organic matter addition. In conclusion, this mesocosm experiment showed the fast response of the lakes to even small disturbances (e.g organic matter addition), which can intensify the sink or the source of carbon to the atmosphere and change the role of the lakes in the global carbon cycling.

1. Introduction

Aquatic environments play an important role in the global carbon cycle, by both degrading and producing organic matter (Cole et al., 2007; Tranvik et al., 2009). Natural lakes occupy 2.8% of the non-oceanic land (Downing et al., 2006), but still can be important sinks or sources of carbon dioxide (CO_2) to the atmosphere. A recent global estimate showed that CO_2 emissions from lakes and rivers are a disproportionately large (related to the area) when compared with CO_2 exchanges between the open ocean and atmosphere (Bauer et al., 2013). Climate changes observed in recent decades have affected the aquatic metabolic processes, influencing both physical-chemical and biological processes in the lakes. For instance, warming of the water column in Tanganyika Lake has prevent primary production, a very important process to support the food webs and biodiversity, consequently reducing fish production (Cohen et al., 2016).

It is commonly assumed that CO_2 supersaturation derives from net heterotrophy, which means that respiration is higher than primary production (Dodds and Cole, 2007). In general, this condition is supported in part by terrestrial organic matter (OM), despite other geochemical processes also contributing to the lake CO_2 supersaturation, for instance photodegradation, catchment productivity and carbonate weathering (Bertilsson and Tranvik, 2000; Marotta et al., 2010; Maberly et al., 2012; Marcé et al., 2015). Several studies have identified the factors related to the CO_2 saturation status, such as the influence of temperature (Kosten et al., 2010), organic carbon (Hanson et al., 2003),

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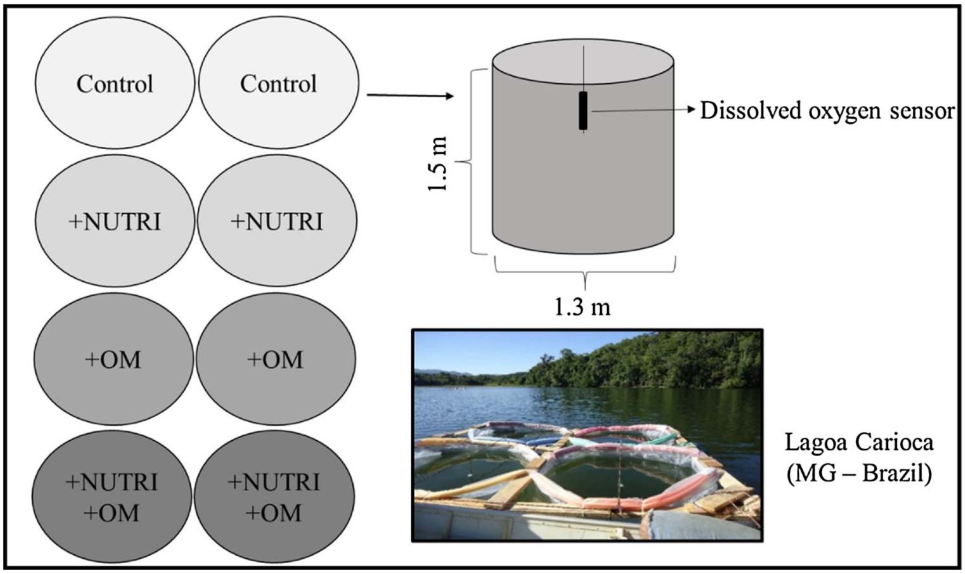

Fig. 1. Design of the mesocosm study performed in Carioca Lake. Control represents the lake original state regarding nutrients and organic carbon. +NUTRI represents the additions of dissolved inorganic nitrogen and phosphorus, +OM represents the addition of allochthonous organic matter and +NUTRI+OM represents the combined nutrients and organic matter additions.

geographical location (Lazzarino et al., 2009), weather (Kelly et al., 2001), and trophic status (Trolle et al., 2012). Temperature influences all the biological processes, where in warmer conditions, as the observed in tropical lakes, the organisms typically exhibit higher primary production and respiration rates (Brown et al., 2004) mirrored by high rates of nutrient and carbon cycling. After a 20–25 °C threshold, however, temperature generally influences respiration more than primary production (Yvon-Durocher et al., 2012). The increase of nutrients has, usually a strong effect on primary production in aquatic ecosystems (Palmer et al., 2013; Staehr et al., 2016), where nitrogen and phosphorus inputs enhance primary production and may cause CO_2 depletion, changing the balance between primary production and respiration (Cole et al., 2000). Finally, inputs of OM directly enhance the activity of the heterotrophic communities and indirectly reduces the autotrophic activity by reducing the light available (Granéli, 2012; Thrane et al., 2014).

Precipitation events and human influence can impact directly the aquatic ecosystems through OM and nutrients inputs. In both cases, these inputs can be considered as disturbances or perturbations since they affect the stability of the communities and the ecosystems processes (Pimm, 1984; Carpenter et al., 2001). The development of the physical and biological changes can be followed daily until the ecosystem reaches a new equilibrium status or returns to the original conditions (Scheffer and Carpenter, 2003). The degree to which an environmental variable changes following a perturbation is called resistance, and how fast a variable returns towards its equilibrium following a perturbation is the resilience (Pimm, 1984). Addressing the resistance and resilience of the system can be important to understand how adaptive the ecosystems are in maintaining the ecosystem functions (Carpenter et al., 2001).

Knowledge about the coupling between environmental perturbations (climate change, eutrophication, deforestation) and limnological conditions (eg. levels of nutrients and organic matter) have been investigated in many lakes (Jeppesen et al., 2014, 2015). However, considerably less is known about how these conditions affect the daily dynamics of the metabolic processes (Trolle et al., 2012; Fontes et al., 2015) especially in tropical lakes (Brighenti et al., 2015; Tonetta et al., 2016). Such knowledge is fundamental to improve the understanding about the importance of lakes for carbon cycling since inputs of nutrients and organic matter can lead to contrasting effects in the carbon cycling, the first promoting increases in O_2 and the second increases in CO_2. Scofield et al. (2016) studied different Amazonian aquatic systems and observed that high inputs of organic matter occurred during rainfall season supporting higher CO_2 emissions. On the other hand, Almeida et al. (2016) studied a tropical eutrophic lake which showed that despite the high primary production, the system was a stronger CO_2 source.

In this study, we tested the effects of inorganic nutrients and allochthonous OM addition on the daily variability of air-water fluxes of CO_2 and O_2 over nine days in a tropical lake. Additionally, we explored the resistance and resilience of the ecosystem. We hypothesized that day-to-day variability in FCO_2 and FO_2 would increase with additions of inorganic nutrients and OM. These manipulations were however, expected to have mirrored effects, with more CO_2 for OM addition versus more O_2 for addition of nutrients. Additionally, we expect that responses to OM and addition of nutrients will change over time as nutrients become depleted and the pool of carbon changes.

2. Material and methods

2.1. Mesocosm setup

A mesocosm experiment was carried out at the tropical freshwater Carioca Lake (19°45′26.0′′S; 42°37′06.2″W), an environment protected from direct human impacts, located in the Rio Doce Park in the Atlantic Forest, south-east Brazil. The weather is well-defined with a dry season during May–September and rainy season during October–March. Carioca Lake is a small (perimeter: 1718 m, area: 0.14 km^2, volume: 6.71×10^5 m^3, maximum depth: 11.8 m, mean depth: 4.8 m; Bezerra-Neto et al., 2010) and warm monomictic lake, with a stable thermal stratification period beginning in September and lasting until May and a mixing period from June to August (Brighenti et al., 2015).

The mesocosms were deployed in the pelagic area of the lake (7–8 m depth) and were filled with water pumped from the lake with no sediment inside the mesocosms. The pumping was slow and at the same depth in the lake, in order to avoid damages to the biological community and to keep the same biological composition in all replicates. Each treatment mesocosm (control, +NUTRI, +OM and +NUTRI +OM) was replicated twice, totaling eight mesocosms (Fig. 1), and the quarters were deployed less than 50 m from each other. Mesocosms experiments can provide an important knowledge about the biological complexity of natural systems and can contribute to test, at ecosystem level, the response to different environmental conditions even under low replication. In this study we were able to manipulate some conditions of the lake and compare with the control, but without disturbing the entire lake ecosystem. In this sense, we are able to obtain valuable