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Short term assessment of nutrients and physicochemical parameters considering different depths in a hypersaline lagoon – Araruama Lagoon –RJ

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RESUMO

A qualidade da água da laguna de Araruama tem se deteriorado em ritmo acelerado nas últimas décadas, principalmente devido ao aumento da ocupação urbana. O aumento da entrada de nutrientes pelos efluentes domésticos pode levar à eutrofização, o que pode causar episódios de proliferação de algas e mortalidade de peixes. O objetivo deste estudo foi avaliar a estratificação dos parâmetros hídricos em uma mesma campanha de coleta de amostras. Onze amostras de água foram coletadas na superfície, no meio e no fundo ao longo da laguna. Para cada amostra, foram analisados os seguintes parâmetros: demanda bioquímica de oxigênio (DBO_5), oxigênio dissolvido (OD), turbidez, carbono orgânico particulado (POC), nitrogênio e fósforo (dissolvido e particulado). A caracterização hidrodinâmica mostrou que independentemente da ligação com o oceano, grande parte da laguna é mais influenciada pelos ventos do que pelas marés. Em geral, os parâmetros apresentaram comportamento homogêneo ao longo da coluna d'água. Os resultados de DO e BOD_5 confirmaram que a laguna é altamente oxigenada. Altos valores de fósforo combinados com o resultado da razão das taxas de nitrogênio para fósforo (N: P) mostram que P é o fator limitante. As concentrações de DBO_5, nitrogênio total e fósforo total, clorofila-a e feopigmentos corroboram este resultado.

ABSTRACT

The Araruama lagoon water quality has deteriorated at an accelerated pace during the last decades, mainly due to an expansion of urban occupation. The nutrients input increased by domestic effluents could reach eutrophication, which may cause episodes of algal blooms and fish mortalities. The aim of this study was to evaluate the stratification of water parameters in the same sampling campaign. Eleven water samples were collected at the surface, middle, and bottom along the lagoon. For each sample, the following parameters were analyzed: biochemical oxygen demand (BOD_5), dissolved oxygen (DO), turbidity, particulate organic carbon (POC), nitrogen and phosphorus (dissolved and particulate). The hydrodynamic characterization showed that regardless the connection with the ocean, a large part of the lagoon is more influenced by winds than tides. In general, parameters showed a homogeneous behavior along the water column. The results of DO and BOD_5 confirmed that the lagoon is highly oxygenated. High phosphorus values combined with the result of the rates of nitrogen to phosphorus ratio (N:P) show that P is the limiting factor. The concentrations of BOD_5, total nitrogen and total phosphorus, chlorophyll-a and phaeopigments corroborate this result.

1. INTRODUCTION

Hypersaline coastal lagoons result from seawater entrance in semi-chocked geomorphologic depression associated with negative hydro-balance (KJERFVE *et al.,* 1996). Araruama Lagoon is an example of such ecosystem, located in the state of Rio de Janeiro, Brazil. Its region has a semi-arid climate with a strong interannual climate variability (TURCQ *et al.,* 1999) and it is adjacent to seasonal offshore upwelling (MOREIRA-TURCQ 2000). The seawater enters the lagoon through Itajuru Channel by tidal diffusion (KJERFVE; OLIVEIRA, 2004), but winds are the major responsible for hydrodynamics circulation (BRAGA *et al*., 2003), even with intense winds, water stratification can occur locally (KJERFVE *et al.*, 1996).

These environments tend to have high accumulation potential due to their limited exchange of water with the sea, being sensitive to anthropogenic impacts as pollution and eutrophication (SMITH, 1994). However, Araruama Lagoon does not present such high sedimentation because of its low precipitation and small drainage basin, but eutrophication process harms the lagoon's local communities and the environmental health (WASSERMAN, 2006). Organic nutrients can enhance and sustain marine algal productivity (FITZSIMONS *et al.*, 2020) and, when in excess, may promote eutrophication. Large quantities of fresh water, as well as domestic and industrial effluents discharged without appropriate treatment in the Araruama Lagoon, have overloaded the ecological system, with negative effects for the entire economy in the surrounding area (BERTUCCI *et al.*, 2016).

The evaluation of the water quality is a tool for the management of this ecosystem and for the understanding of the extent of the anthropogenic impacts. The present work is a first-time study of the stratification of quality parameters in the water column in Araruama lagoon. The hydrodynamics measurements using an Acoustic Doppler Current Profiler (ADCP) were also performed for the first time. The objective of this work was to identify stratification behavior of the nutrients and physicochemical parameters in the water column, linked with hydrodynamics characteristics and its possible relationship with primary productivity.

2. MATERIALS AND METHODS

2.1. STUDY AREA

Araruama Lagoon, in the state of Rio de Janeiro, Brazil, is a hypersaline coastal lagoon located between latitudes 22º50' – 22º57'S and longitudes 42º00' – 42º30'W. The hypersalinity of the lagoon is a result of semi-arid climatic conditions, a small drainage basin, a negative water balance and a choked entrance channel (Figure 1). Its surface area is 210 km^2 (including the sea connection channel) and it is considered as one of the largest perennial hypersaline coastal lagoon in the world (KJERFVE *et al.,* 1996). The northwest winds are dominant in most of the year, however during winter southwest winds are more frequent (CARVALHO, 2018). Salinity varied from 56 to 67 PSU in this study, but Mello (2007) measured salinity value of 37.3 PSU in summer 2006.

2.2. WATER SAMPLING AND PHYSICOCHEMICAL PARAMETERS ANALYSES

Current data and water samples were collected at different depths in the Araruama Lagoon on a two-days sampling campaign (February 12^{th} and 13^{th}, 2019). Water samples from surface, middle and bottom were collected with a Van-Dorn bottle in stations 2 to 9. Due to low depth, only surface water was collected from stations 1 and 11 and surface and bottom from station 10 (Figure 1). In each station, pH and Oxidation-Reduction Potential - ORP (mV) were measured with multi-probe Hanna® electrodes, dissolved oxygen with a multiparameter meter YSI, turbidity (NTU) with a Policontrol digital turbidimeter and the transparency of the water was obtained with a Secchi's disk.

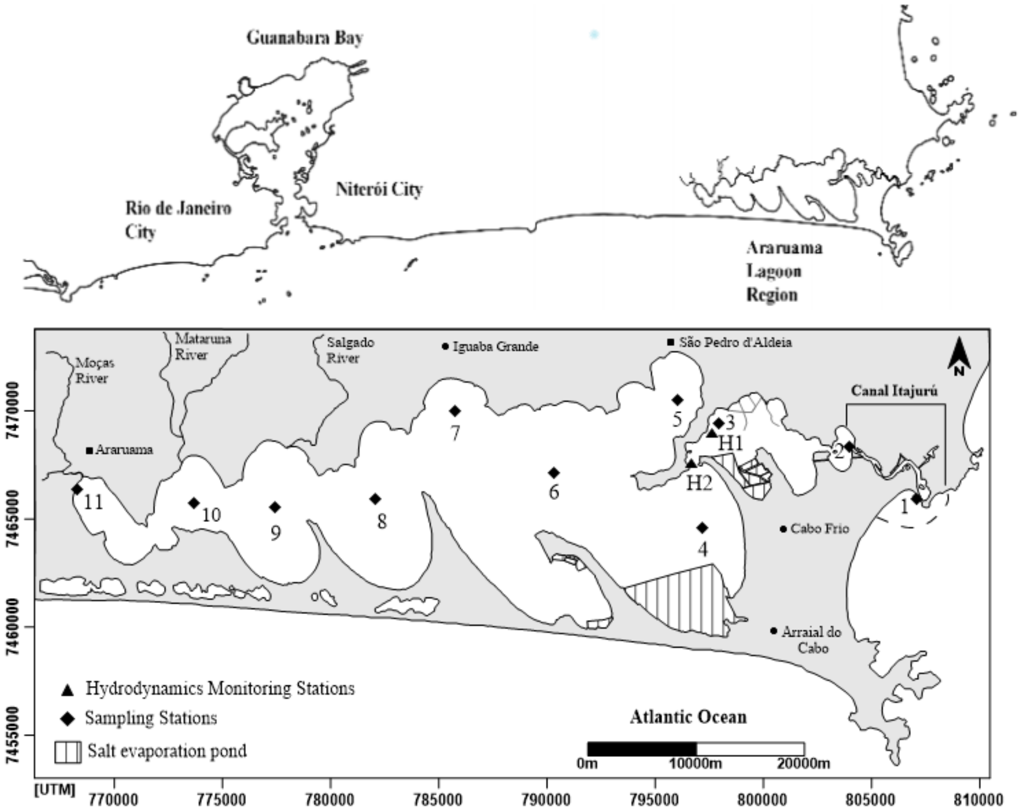

Figure 1

Study Area location: Araruama Lagoon, Rio de Janeiro, Brazil.

LEGEND: ●1 Sample stations; * H1 ADCP hydrodynamic monitoring points

Volumes of approximately 200 mL of the sample were filtered *in situ* using a manifold filtration system for 47 mm Whatman TM GF/C glass microfiber filters and a manual vacuum pump. The filters were packed in holders and frozen until the analysis of the concentration of suspended particulate matter (gravimetry, chlorophyll-a, phaeopigments, particulate nitrogen, particulate phosphorus and particulate organic carbon). Filtered water was analyzed for phosphate and ammonium according to Grasshoff (1983), nitrite by Shinn (1941) and by Bendschneider and Robinson (1952) and nitrate according to Zhang and Fischer (2006). Particulate nitrogen and phosphorus were analyzed by oxidation of the filtered material with a persulfate solution. The resulting nitrate was analyzed after Zhang and Fischer (2006) and the resulting phosphate was analyzed after Grasshoff (1983). Chlorophyll-a, phaeopigments and particulate organic carbon were analyzed after Strickland and Parsons (1972). The Detection Limit (DL) for the analysis was: ammonium (0.17 µmol L^{-1}), nitrite (0.04 µmol L^{-1}), nitrate (1.29 µmol L^{-1}), phosphate (0.08 µmol L^{-1}), particulate nitrogen (0.21 µmol L^{-1}), particulate phosphorus (0.09 µmol L^{-1}).

Samples were collected for the analysis of BOD_5 and were kept refrigerated and in the dark (stabilizing the biochemical processes). In the same sampling day, the water was taken to the laboratory, where it was placed in an incubator at 20°C, for 5 days. At the end of the period, the samples were measured for the concentrations of oxygen. BOD_5 is given by the concentration before incubation (measured in the field), subtracted from the concentration after incubation according (STRICKLAND; PARSONS 1972).

2.3. CTD and ADCP (Salinity and Temperature Profile Measurements)

Salinity and water temperature profiles were measured in all eleven stations with a Castaway CTD from SonTek – YSI. This equipment allows the construction of salinity and temperature stratification in the water column. An Acoustic Doppler Current Profiler (ADCP) was installed in two stations (Figure 1), in order to evaluate current velocities and directions. The equipment used was a SonTek/YSI ADP prepared to take measurements every 20 cm starting at 0.65 m (shadow area) to a depth of 2.9 m. Measurements were made every 2 minutes, starting on 02/12/2019 at 10:25:23 and ending at 20:41:23, local daylight-saving time totaling 10 hours and 36 minutes. On 02/13/2019, measurements were also made every 2 minutes, starting at 11:07:23 and ending at 14:31:23 local daylight-saving time, in a total of 3 hours and 24 minutes of measurements.

3. RESULTS AND DISCUSSION

3.1. HYDRODYNAMIC MEASUREMENTS

In the Araruama Lagoon it is expected a small tidal influence and measurements and simulations indicate an insignificant tidal variation in most part of the lagoon, due the morphology of the Itajuru Channel (SILVA *et al.*, 2020). On the other hand, as shown in Figure 2A, winds should have a preponderant role in current cell formation (SILVA; ROSMAN 2016). Figure 2B demonstrates that despite the fact that the only force is the wind, the current velocities are quite elevated, which occurs due to the fact that the measuring station is located in a bottleneck between two coves in the lagoon (Figure 1). On 12th February, winds moved from West and South (3 m s^{-1}), after a short period of northeast wind blowed (around 9 m s^{-1}). The continuous changing lead currents to go South (when Northeast is predominant) and go North (when Southwest is blowing stronger). However, it seems that there is a lag of time between the response in terms of current in the surface and in the bottom. This is the reason why most of the measurements of currents vary significantly within the water column.

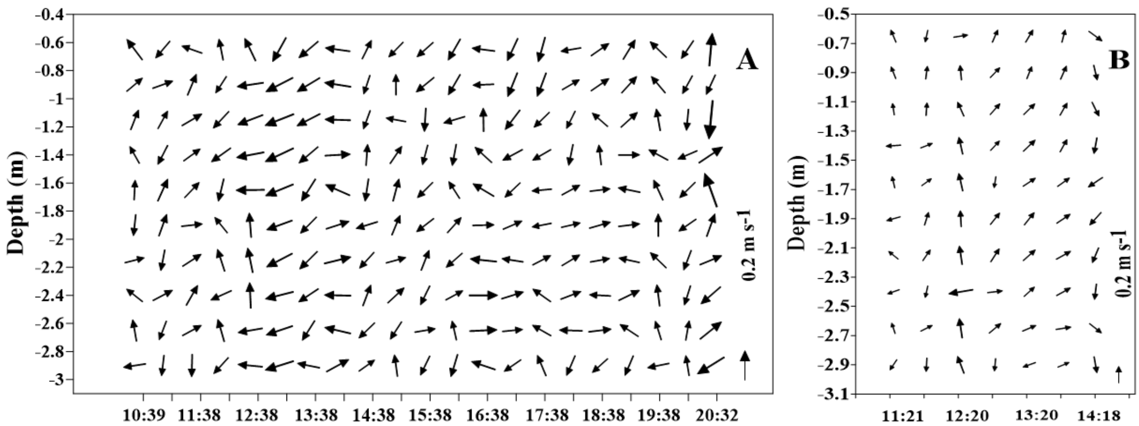

Figure 2

Current speed and direction of stations H1 (A) and H2 (B), 02/12/2019 and 02/13/2019 respectively – Araruama Lagoon. The vertical arrow at the right bottom corresponds to a 0 degree and a speed of 0.2 m s^{-1}.

3.2. SALINITY AND TEMPERATURE PROFILES

Due to the low depth, the salinity and temperature profiles in stations 1 and 11 were not measured (Table 1). Station 1 is a control point, located out of the lagoon in the open ocean and therefore it was expected to represent values of the Southeast Brazilian coastal waters. This station represents the salinity of the water that enters through the Itajuru Channel, connecting the ocean with Araruama Lagoon. Station 2 is strongly influenced by mixing processes of oceanic and hypersaline waters of the lagoon. On the other hand, station 11, in the opposite extreme of the lagoon, presented the highest salinity values for the system, influenced by the intense evaporation process.

Table 1 – Salinity and Temperature surface measurements in the Araruama Lagoon.

Stations	Time	Depth (m)	Temperature (°C)	Salinity (PPS)
1 – Forte Beach	13/02/2019 17:38	0.60	25.4	35.50
11 - Hospício	13/02/2019 20:00	0.40	28.6	67.01

It is interesting to note that although a marked stratification of salinity and temperature profiles at station 2 (Figure 3) were expected, promoted by hypersaline waters (denser) underlying seawaters (colder, but less dense), the tidal current turbulence apparently promotes an intense mixing zone (YE *et al.* 2017), justifying the lack of salinity and temperature stratification. As shown in the results of the currents above (Figure 2A), station 3 is located in an area that is more propitious for water column stratification, because the wind fetch is shorter and tidal currents are not strong enough (SILVA; ROSMAN 2016, VICENTE *et al.*, 2021). This location displays an inverted stratification pattern, with colder water overlying hotter, which is explained by the lower salinity of the colder water, resulting in lower density. The salinity differences between surface and bottom are almost three salinity units, and temperature approximately 1°C. Station 4, located in the Tucuns cove, presented a homogenous profile. Regardless the fact that this is the deeper station (12.5 m), the strong wind intensity produces an effective water mixing condition (KJERFVE *et al.*, 1996).

Stations 5, 6, 7 and 8 also presented homogenous salinity and temperature profiles, even at deeper sites, like stations 6 and 8 (9.92 and 8.36 meters respectively) (Figure 4). For these profiles, salinity variations were always smaller than one salinity unit, while the temperature presented variations of 1.5°C. Temperature tends to present a small decrease with depth, while surface waters are in general warmer due to solar radiation during the day-light (DE LA FUENTE, 2014). Intense wind at the central lagoon area favors water turbulence, consequently, allows a more effective mixing water process, resulting in homogenous profiles. Different from central area, stations 9 and 10 presented a slightly bigger stratification trend, with a salinity increase of 1.5 units below 2 meters depth. This lagoon area presented lower hydrodynamics intensity and slightly higher freshwater input, through Mataruna and das Moças rivers (SILVA; ROSMAN 2016). The freshwater input promotes a density decrease in surface water, associated with a less effective mixing process and, therefore, salinity and temperature stratification (GRODSKY *et al.*, 2014).

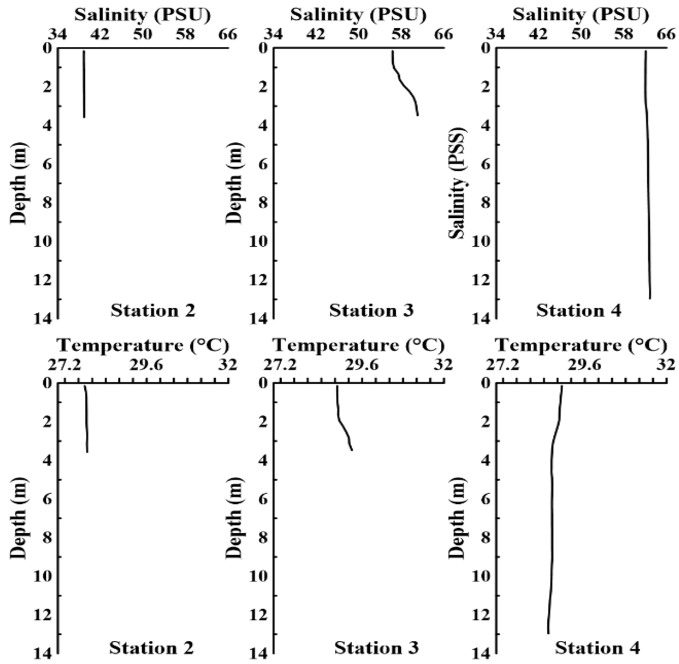

Figure 3
The salinity and temperature profiles of stations 2, 3 and 4 in the Araruama Lagoon.
Legend: PSU=Practical Salinity Unit

3.3. WATER COLUMN PHYSICOCHEMICAL PARAMETERS

The pH demonstrated a light increment trend westward, in the opposite direction of the sea (Figure 5A). This increment should be associated with salinity and primary production increase (PEREZ *et al.*, 1994). However, the expected higher primary production at the

superficial samples practically does not affects pH stratification, even at sites presenting high stratification, as in station 3. This behavior is attributed to the buffer effect of the high salinity, compensating for the enrichment in CO_2 originated from primary producers. Similar values of pH were found in South Lagoon of Tunis, but the increase from east to west was due to evaporation and hydrodynamic regime (ABIDI *et al.,* 2018). Diamantopoulou *et al.* (2008) studied Korissia Lagoon and values of pH varied from 8 to 8.4 in summer.

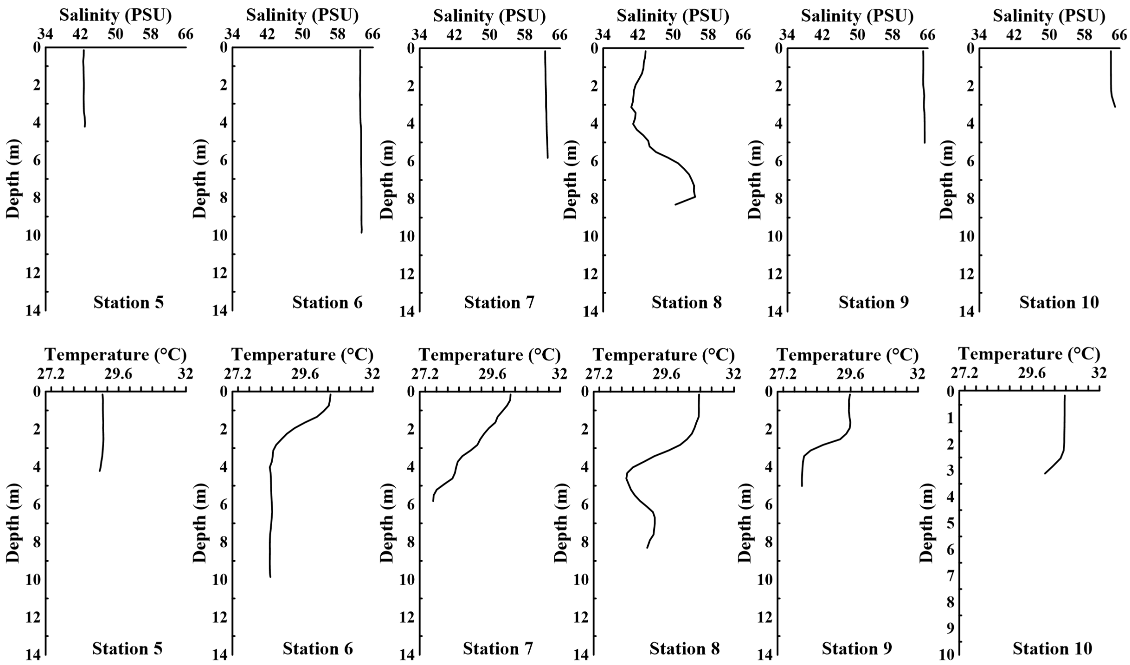

Figure 4
The salinity and temperature profiles of stations 5, 6, 7, 8, 9 and 10 in the Araruama Lagoon.
Legend: PSU=Practical Salinity Unit

3.3. WATER COLUMN PHYSICOCHEMICAL PARAMETERS

The pH demonstrated a light increment trend westward, in the opposite direction of the sea (Figure 5A). This increment should be associated with salinity and primary production increase (PEREZ *et al.*, 1994). However, the expected higher primary production at the superficial samples practically does not affects pH stratification, even at sites presenting high stratification, as in station 3. This behavior is attributed to the buffer effect of the high salinity, compensating for the enrichment in CO_2 originated from primary producers. Similar values of pH were found in South Lagoon of Tunis, but the increase from east to west was due to evaporation and hydrodynamic regime (ABIDI *et al.,* 2018). Diamantopoulou *et al.* (2008) studied Korissia Lagoon and values of pH varied from 8 to 8.4 in summer.

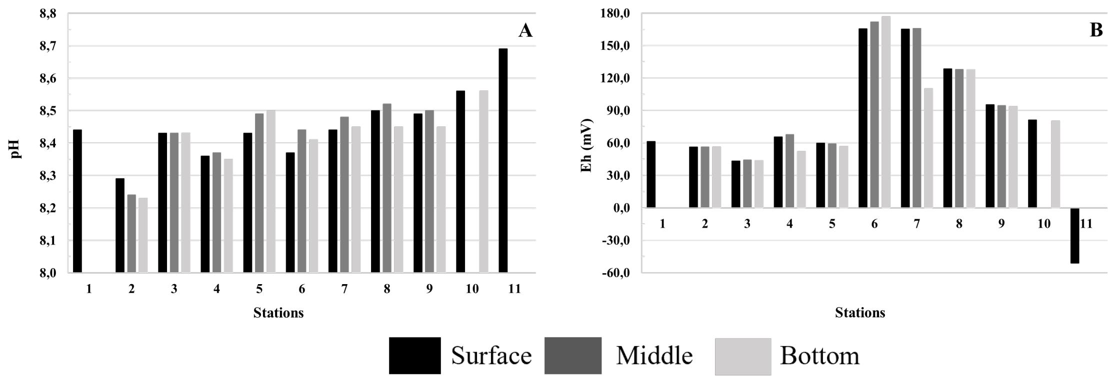

Figure 5
The pH (A) and Eh (B) for surface, middle and bottom depths - Araruama Lagoon.

The oxidizing characteristics (positive values) are dominant in all stations. Figure 5B shows remarkably high potential redox values which are, nonetheless, homogenously in the water column. Station 6 presented the higher redox potential values, probably associated with the wind incidence at the central part of Araruama Lagoon. Only station 11, in the extreme west, presented reducing values. The reduced hydrodynamic characteristic at this point is probably responsible for this behavior (COUTURIER *et al*., 2016). Besides, Mataruna and das Moças rivers discharge a considerable amount of organic matter and nutrients at this site, making this region an important spot for microbial degradation (LUO *et al*., 2019). In this western portion, it is expected a higher oxygen content and other electron acceptor consumption by aerobic and anaerobic bacteria, collaborating for the reducing characteristic (SILVA, 2019).

In this work, the DO (Figure 6A) was similar to those collected by the State Environment Institute (INEA) in the summer of 2010/2011 and summarized by Vicente (2018), higher than those found at Vermelha Lagoon (LAUT *et al.*, 2017), a hypersaline lagoon close to Araruama Lagoon and connect to it by a small anthropic channel. If compared to other worldwide lagoons, DO values were higher than in South Lagoon of Tunis and similar values for the Korissia Lagoon. The first one is an eutrophicated environment which presented smaller values for DO in July 2013 (summer) because of its high rate of bacterial degradation, and oversaturated values in February 2014 (winter) due to its wind mixing and decrease of its biomass production (ABIDI *et al.*, 2018). The second lagoon is a hypersaline body of water in Greece and showed similar values in later winter of 2006 to those of the Araruama Lagoon. For this European lagoon the higher values were possibly result of an increased of freshwater input and lower temperatures (DIAMANTOPOULOU *et al*., 2008).

The high values of DO in the water column of Araruama Lagoon are prone to readily supply the BOD_5 from domestic effluent discharges (ROSENQUIST *et al.*, 2013). These two parameters were relatively homogenous in the water column all over the lagoon and no significant spatial or vertical stratification was identified. The BOD_5 (Figure 6B) is very low, however normal for Araruama Lagoon, due to high oxygen diffusion rate by wind incidence in water (KJERFVE *et al.*, 1996). Values for summer of 2010 (VICENTE *et al.*, 2021) were smaller than these observed in this work.

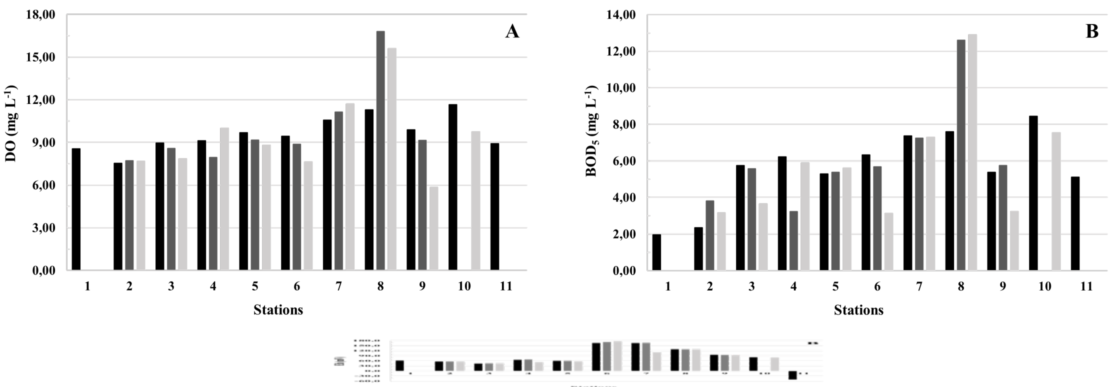

Figure 6
The Dissolved Oxygen (A) and Biochemical Oxygen Demand (B) or surface, middle and bottom depths - Araruama Lagoon.

The Araruama Lagoon exhibits a spatial trend in turbidity with higher values westwards (Figure 7A) and the opposite behavior for depth of Secchi's disc, Figure 7B. This is an expected bias considering that the more suspended material in water column, the lesser is the depth of Secchi's disk. The POC presented the same spatial behavior of turbidity, also increasing westwards (Figure 8A) and it is the same behavior of Total Suspended Solids, Figure 8B. These trends should also be related to reduced hydrodynamic (high water residence time), organic matter and nutrient input by Mataruna and das Moças Rivers (CARPENTER *et al.,* 1998). The relationship between these parameters demonstrates the autochthone primary production process as the most relevant for water transparency and primary production.

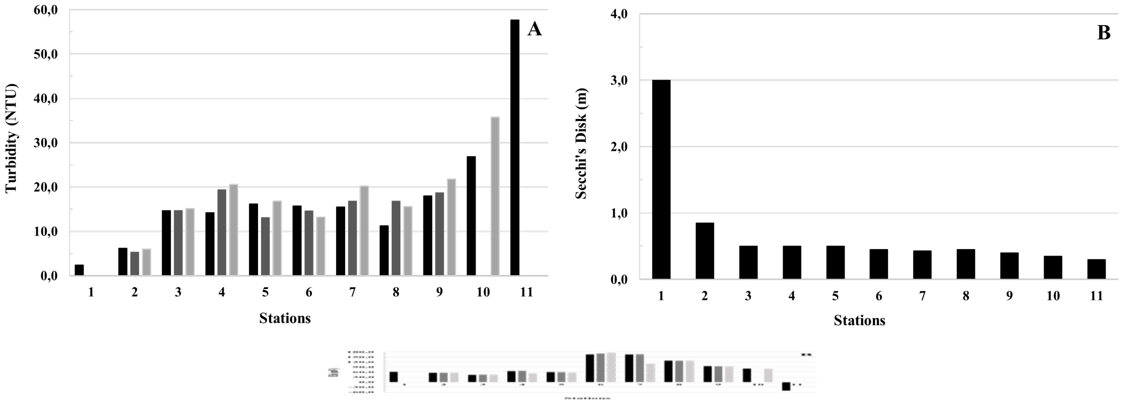

Figure 7
The Turbidity (A) and depth of Secchi's disk (B) for surface, middle and bottom water samples in the Araruama Lagoon.
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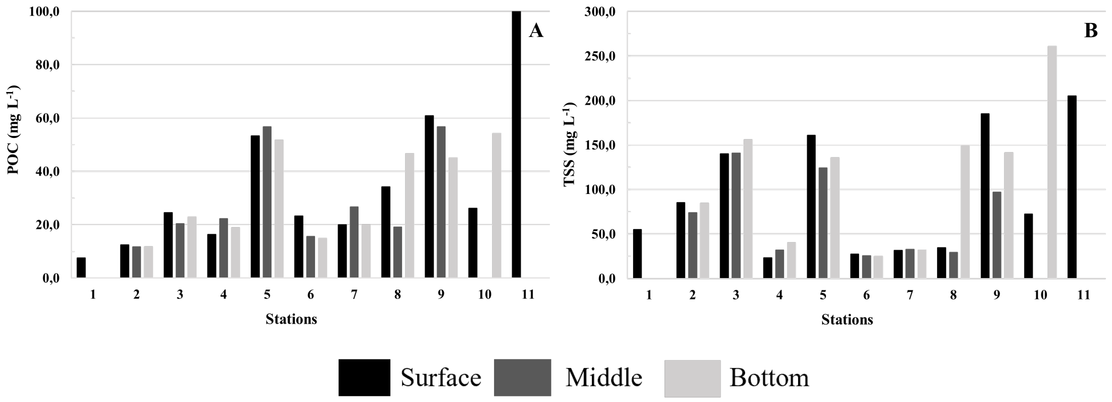

Figure 8
The Particulate Organic Carbon (POC) (A) and Total Suspended Solids (TSS) (B) for surface, middle and bottom water samples in the Araruama Lagoon.

Table 2 shows pH, salinity, Do and turbidity for Araruama Lagoon and two other worldwide lagoons. Ammonium (NH_4^+) indicates relatively fresh sewage inputs in the water column (COSTODIO, *et al.,* 2006). These concentrations of this contaminant in Araruama Lagoon are extremely low, even smaller than those presented by Vicente *et al.* (2021). It also seems that, apparently, the domestic effluent inputs are rapidly oxidized to other forms of nitrogen (Figure 9A). NH_4^+ oxidation process leads to nitrite (NO_2^-) formation, an intermediate dissolved inorganic nitrogen form. The NO_2^- is the most unstable form of inorganic nitrogen and in the Araruama oxidizing system, it readily changes to nitrate (ELSER *et al.,* 2007) (Figure 9B). This is probably why NO_2^- presented extremely low concentration in all stations in different depths This work presented smaller values than those reported by Vicente *et al.* (2021) . It is interesting to note homogenous low concentrations of NO_2^-, along the Lagoon, except only in stations 1 and 2, due to the effective seawater mixing. This trend is also observed in Korissia Lagoon (DIAMANTO-POULOU *et al.*, 2008) and in South Lagoon of Tunis (ABIDI *et al*., 2018).

Nitrate (NO_3^-) is the dominant form of dissolved inorganic nitrogen, presenting concentrations almost twice as high as NH_4^+ and reaching 20 times that of NO_2^- (Figure 9C) (KRUSCHE *et al.,* 1997). The nitrification process due high oxygenated water also happens in the South Lagoon of Tunis (ABIDI *et al.,* 2018). All over the lagoon, it is possible to observe homogenous concentrations in the water column (no stratification). This behavior is not evident in station 3 which presented a significant stratification, probably due to less important turbulence in the water column, as discussed in topic 2.3. in this work nitrate concentrations are higher than those values for summer 2011/2012 reported by Vicente *et al.* (2021) despite both being in the rainy season.

Opposite behavior was observed in Korissa lagoon, where dominant form of dissolved nitrogen was ammonium, and nitrate was found only in well water samples indicating the presence of fertilizer contaminants (DIAMANTOPOULOU *et al.*, 2008).

Table 2 - Parameters comparison among lagoons Araruama, Korissia and South Lagoon of Tunis.

Parameters/Lagoon	pH	Salinity (PSU)	DO (mg L^{-1})	Turbidity (NTU)	References
Araruama Lagoon	8.24-8.69	56-67	5.8-16.8	11.3-57.7	This study, summer 2019 (excluding endpoint and Itajuru Channel)
	7.3-8.6	NA	4.4-10.0	NA	(VICENTE *et al*., 2021), summer 2010/2011
Korissia Lagoon	8.0-8.4	>50	4.6-7.7	NA	(DIAMANTOPOULOU *et al.*, 2008), late summer 2005
South Lagoon of Tunis	8.48-8.94	48.3-49.1‰	2.9-4.4	8-20	(ABIDI *et al.,* 2018), summer 2013

NA= Not available

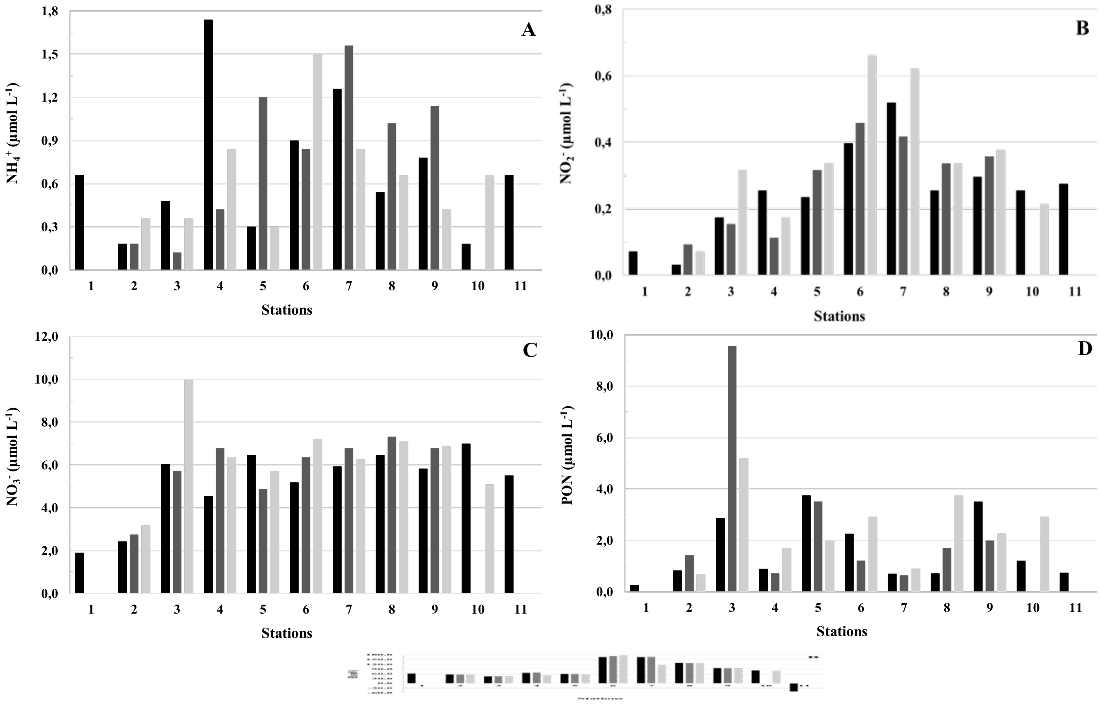

Figure 9
The Ammonium (A), Nitrite (B), Nitrate (C) and Particulate Organic Nitrogen (D) for surface, middle and bottom depths in the Araruama Lagoon.

The particulate organic nitrogen (PON) (Figure 9D) represents the nitrogen concentrations in dendritic and/or biomass particles (PARSONS, 1970). In the Araruama Lagoon a major part of the PON is related with phytoplankton, because the dendritic inputs are small, due to the reduced watershed and low freshwater input (SOUZA *et al.,* 2003). The PON concentration was relatively low, even smaller than dissolved nitrogen forms, indicating that phytoplankton production is not able to consume all nitrogen in the water column. The limited supply of phosphates is the most probable explanation, as it has been discussed in the literature and as it will also be discussed further in this work. An outlier value was observed at station 3 (middle water column sample). However, no reasonable explanation could justify this observation, emphasizing the importance of further studies about this subject in the Araruama Lagoon.

The phosphate (PO_4^{3-}) concentration was relatively high (Figure 10A) for a compound that is considered a limiting factor for primary production. The maintenance of PO_4^{3-} concentrations in the water column indicates a low phytoplankton metabolism efficiency (KJERFVE *et al*., 1996; SOUZA *et al*., 2003). The water transparency can be considered the limiting factor, thus in greater depths the primary production can be less effective in consuming PO_4^{3-}. In general, the bottom water samples presented higher PO_4^{3-} concentrations, it is also reasonable that phosphorus is supplied from the sediment to the water column, mainly in the western stations. Phosphate in this work was slightly higher than values for summer of 2011/2012 (VICENTE *et al*., 2021). PO_4^{3-} values are smaller than in South Lagoon of Tunis, which reach concentrations around 2.5 mg L^{-1} (ABIDI *et al.,* 2018) in summer, while the Araruama Lagoon presents values from 0.2 to 1.2 mg L^{-1}. Korissia Lagoon presented values around 0.3 µg L^{-1} (DIAMANTOPOULOU *et al.,* 2008).

The particulate organic phosphorus (POP) (Figure 10B) were quite homogenous, however station 3 shows a slightly higher concentration in the middle of the water column. Station 10 also presented high values for POP in the bottom sample, probably due to Mataruna River nutrient inputs, associated with lower hydrodynamic circulation, consequently higher water residence time (SILVA; ROSMAN, 2016). At station 11, where the transparency was very low, the concentrations of POP and PON were also very low. These characteristics in this lagoon area are probably related to Das Moças River dendritic material input, at this point responsible for transparency decrease.

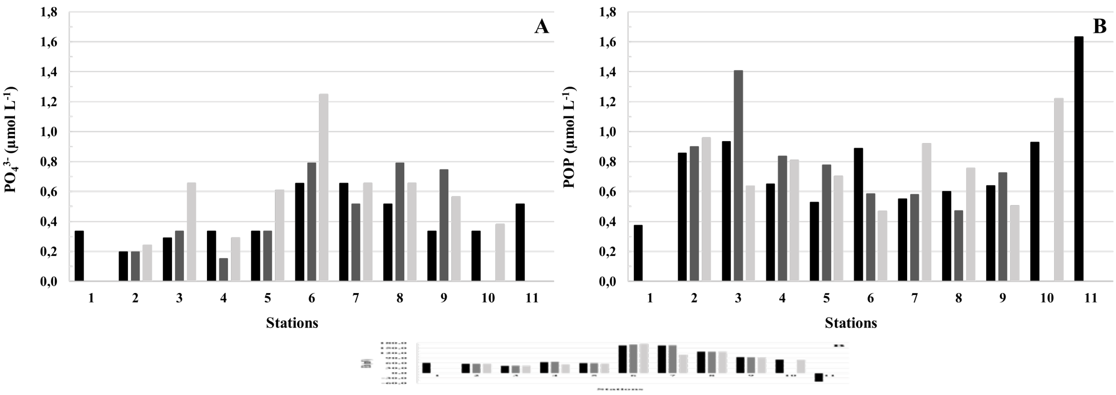

Figure 10
The Phosphate (A) and Particulate Organic Phosphorus (B) for surface, middle and bottom water samples in the Araruama Lagoon.

In almost all sampling stations the N:P ratio is high, indicating that P is potentially the limiting for primary production (Figure 11). In environments where phosphorus is less expressive, phytoplankton can access dissolved organic phosphorus to enhance its P uptake. In addition, this process may be the result of different changes in the macronutrients availability (FITZSIMONS *et al*., 2020). Korissia Lagoon also presents phosphorus as limiting factor (DIAMANTOPOULOU *et al*., 2008) but South Lagoon of Tunis presents nitrogen as the limiting nutrient (ABIDI *et al.,* 2018). At the control station, in the ocean (station 1) althoug no drop in water temperature was observed, a lower N:P ratio is related to the occurrence of the upwelling phenomenon which is extensively registered in this area (CARBONEL, 2003). Thus, this sampling station presented remarkable characteristic of this region marine waters. The low N:P ratio was also observed at Station 10 and in this case P input is probably related to the polluted Mataruna River.

The high values for chlorophyll-a indicate an elevated primary production in the Araruama Lagoon, mainly in the central part (Figure 12A). The low phaeopigment values, ten times smaller, suggest a photosynthetic active and freshly produced biomass (Figure 12B). It is important to note the inverse proportion of chlorophyll-a and phaeopigment, corroborating the concept that as biomass gets senescent, it shifts to phaeopigments. Almost all stations presented a prominent chlorophyll-a stratification. The surface primary production was more relevant in stations 1 and 4, which has presented the same trend described by (SILVA *et al*., 2017) in Conceição Lagoon. Very low values were found in South Lagoon of Tunis for chlorophyll-a and phaeopigments, around 1 to 3 µg L^{-1} and 4 to 9 µg L^{-1} respectively with opposite distribution at the lagoon. The role of intense UV radiation in the superficial water may also be important in reducing the primary production in the level of the water column (CARVALHO *et al.,* 2006)

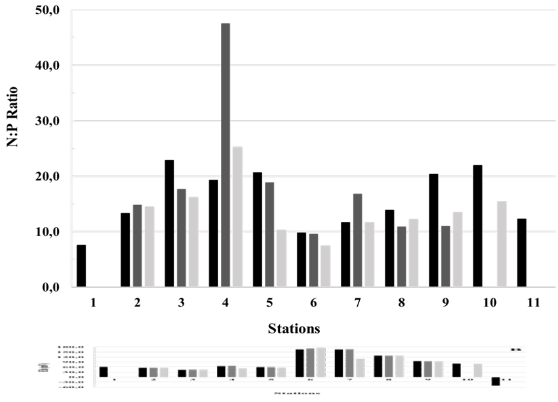

Figure 11
The N:P ratio calculated for surface, middle and bottom water samples in the Araruama Lagoon.

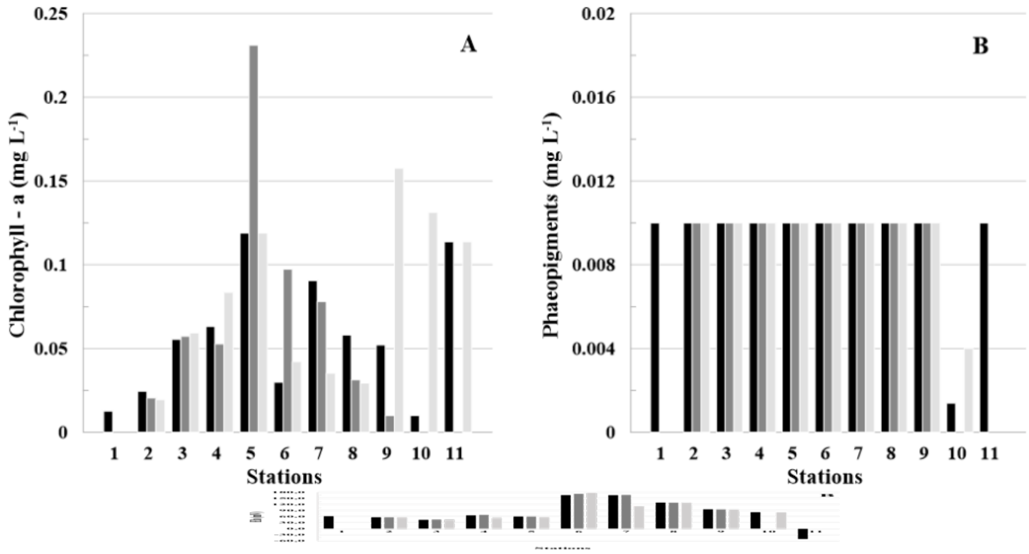

Figure 12
Chlorophyll-a (A) and Phaeopigments (B) for surface, middle and bottom depths in the Araruama Lagoon
.

In the other stations subsurface production relevance increased westwards. At stations 9 and 10, the subsurface primary production concentration is three times higher than surface samples. In this area a small stratification in temperature and salinity was observable (see Salinity and Temperature Profiles in Figure 4). The water density may be playing an important role for primary production water column position in this area of Araruama Lagoon. The increase in nutrient cycling, caused by anthropic changes, has led to a higher primary production in the water column. The lagoon system was changed from mesotrophic to eutrophic with a shift on organisms assemblage with predominance of benthonic over planktonic assemblages (Mello 2007). According to Regis (2020) Araruama Lagoon can be classified by TRIX index as a mesotrophic to eutrophic environment. The lagoon was classified as eutrophic/hypertrophic for the present work according to Organization for Economic Co-operation and Development (OECD) values of chlorophyll-a, total P and Secchi's disk (CASPERS, 1984). Despite this trophic state, high DO and low BOD_5 are favorable for life.

4. CONCLUSION

This work presented the first-time current measurements in the Araruama Lagoon, which is associated with wind estimations, proving the intrinsic relationship between these two parameters. The wind is preponderant for hydrodynamics circulation and probably controls current velocity and direction. The Araruama Lagoon is characterized by a small water column stratification. The intense winds in the whole lagoon area promotes an effective water mixing, resulting in homogenous profiles. In the eastern part, a more intense stratification results from seawater entrance and reduced wind fetch, depending on tides and, in the western region, on freshwater inputs - depending probably on the season.

In general, the physicochemical parameters suggest a water quality decrease westwards. Therefore, it was shown that the west part is the most critical one, presenting the highest values for turbidity, POC and reaching negative potential redox values. However, DO and BOD_5 presented favorable values for aquatic life development. Regardless of the common belief, it is unlikely that previous fish mortality episodes were linked with anoxia events.

The nutrients presented low concentrations in all stations. However spatial and vertical differences could be identified mainly in the western portion. It is interesting to note, precisely in stations 9 and 10, higher bottom water sample values of POP, chlorophyll-a and POC. The water stratification in these areas suggests spatial differences in the Araruama Lagoon biogeochemical cycle. However, the process responsible for this behavior remains unclear and further studies are indicated on this specific subject. One interesting point is the sudden events of oligotrophy, when transparency of the lagoon can increase intensely for a few days and then it goes back to its regular eutrophication, as reported by the riverain. Further studies of these oligotrophic events are necessary to understand the processes behind it, then giving clues on the behavior of the nutrients in the Araruama Lagoon.

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