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# Water Quality of Urban Lakes in the Central-Southern Region of Manaus, Amazon

Adriano Nobre Arcos[1], Aline Cristina Lima Amaral[2], Maria Arruda dos Santos[3], Cristiany de Moura Apolinário e Silva[4], Daiani Kochhann[5], Wanderli Pedro Tadei[6]

**Qualidade da água de lagoas urbanas da região centro-sul de Manaus, Amazonas. Diversos** ambientes aquáticos, dentre eles lagoas urbanas estão sendo eutrofizados devido à ocupação humana e esgotos. Essas modificações causam grandes problemas ambientais que afetam a saúde ambiental e humana, aumentando a perda da biodiversidade e dificuldades para a conservação. O objetivo deste trabalho foi avaliar a qualidade da água das duas lagoas nos períodos seco e chuvoso. Foram utilizados parâmetros para análise como: coliformes fecais, oxigênio dissolvido, temperatura, sólidos totais em suspensão, fósforo total, fitoplâncton e macrófitas. A lagoa do Bosque apresentou uma boa qualidade da água em relação à lagoa do Japiim, onde foi observado um alto grau de eutrofização. Os limites de coliformes fecais passaram do estipulado pela resolução CONAMA 274/2000, indicando este ambiente como poluído e podendo causar doenças aos seres humanos por meio do contato com esta água. Os parâmetros sólidos totais em suspensão e fosfato estavam fora dos padrões estipulados pela resolução CONAMA 357/2005, portanto, é essencial a realização de um monitoramento neste ambiente. Ao todo foram identificados cinco gêneros de macrófitas aquáticas nas duas lagoas, e elas são importantes indicadores e auxiliam na ciclagem e nutrientes nesses ambientes alterados. Vale salientar que a instalação de um sistema de tratamento de efluentes na lagoa do Japiim é necessária, visando à melhoria da qualidade da água e assim a melhora da qualidade ambiental e de vida dos visitantes.

**Palavras-Chave**: CONAMA, eutrofização, recursos hídricos, coliforme fecal.

## Abstract

Several aquatic environments, including urban lakes, are becoming eutrophic due to human occupation and sewers. These changes cause major environmental problems that affect environmental and human health, increasing biodiversity loss and conservation difficulties. The aim of this study was to evaluate the water quality of the two lakes in dry and rainy periods. We used the following as indicators for analysis: fecal coliforms, dissolved oxygen, temperature, total suspended solids, total phosphorus, phytoplankton, and macrophytes. The Bosque lake presented good water quality in relation to the Japiim lake, where a high degree of eutrophication was observed. Fecal coliforms surpass the limits stipulated by the CONAMA 274/2000 resolution, indicating that this environment is polluted and could cause diseases to humans who encounter this water. The total suspended solids and phosphate parameters were outside the standards stipulated by the CONAMA 357/2005 resolution, therefore, constant monitoring is essential in this

[1] Doutorando do Programa de Pós-Graduação em Ecologia e Conservação, Universidade Federal de Mato Grosso do Sul - UFMS, Av. Costa e Silva s/n, Cidade Universitária, 79070-900, Campo Grande, MS - Brasil. * autor correspondente e-mail: adriano.bionobre@gmail.com
[2] Bacharel em Ciências Biológicas, Faculdade Estácio do Amazonas, Av. Constantino Nery, 3693, Chapada, 69050-001, Manaus, AM - Brasil. e-mail: alineam.biologa@gmail.com
[3] Licenciada em Ciências Biológicas, Centro Universitário do Norte - UNINORTE, Av. Joaquim Nabuco, 1281, Centro, 69010-060, Manaus, AM - Brasil. e-mail: maria10dossantos@gmail.com
[4] Professora do Curso de Ciências Biológicas, UNINORTE, Av. Joaquim Nabuco, 1281, Centro, 69010-060, Manaus, AM - Brasil. e-mail: cristianysilva@yahoo.com.br
[5] Professora adjunta, Centro de Ciências Agrárias e Biológicas, Universidade Estadual Vale do Acaraú, Av. da Universidade, 850, 62040-370, Sobral, CE. e-mail: daia.kochhann@gmail.com
[6] Pesquisador do Laboratório de Malária e Dengue, Instituto Nacional de Pesquisas da Amazônia - INPA, Av. André Araújo, 2936, 69060-001, Manaus, AM - Brasil. e-mail: wptadei@gmail.com

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environment. Overall, we identified five genera of aquatic macrophytes in the two lakes, and they are important indicators and assist in cycling and nutrients in these altered environments. In addition, an effluent treatment system should be installed into the Japiim lake to improve water quality, the environment, and quality for the visitors.

**Key-words**: CONAMA, eutrophication, water resources, fecal coliform.

## 1. Introduction

The Japiim and Bosque da Ciência lakes are attractions for tourists and city dwellers, for the landscape, sports, and leisure, i.e. contemplation of nature, family walks and picnics (SEMMAS, 2013; PASCOALOTO et al., 2014). Both are in the southern part of Manaus and considered urban lagoon environments.

According to Esteves (2011), a lake is considered a shallow water body where the solar radiation can reach the sediment, enabling the growth of aquatic macrophytes throughout its extension. Esteves also emphasizes that there are difficulties when differentiating a lake from a lagoon, therefore, depth of the basin and depth that light reaches are used for such differentiation.

Urban waters have suffered impacts generated by city development, since cities in Brazil grew very quickly and in a disorganized manner, as well as lacked infrastructure. According to Barbosa and Nascimento Júnior (2009), the disordered expansion of cities aggravates a sustainable society, the quality of urban space, and the quality of life itself.

Water is an essential element for life on earth, and can be a vector for various diseases, classified as water-borne diseases. Therefore, all factors that may harm human health due to lack of water quality must be addressed, both in relation to water for consumption, and the quality of final disposal, i.e. sewage or effluent (WALDMAN et al., 1997; SOARES et al., 2002; BARCELOS et al., 2006). Studies include the total coliform group, fecal coliforms, *E. coli* and *Enterococcus* as main indicators of the microbiological quality of water (SHIBATA et al., 2004). This group is known as an indicator of fecal contamination with potential for disease transmission (VON SPERLING, 1996).

The process of eutrophication causes increased growth of macrophytes and algae in aquatic environments due to the concentration of nutrients from natural sources and anthropogenic activities (FERREIRA et al., 2005; LI-NA et al., 2011). Environmental resolutions of the National Environment Council (Conselho Nacional do Meio Ambiente CONAMA) n° 274/2000 and n° 357/2005, as well as its updates n° 410/2009 and n° 430/2011, are very important because they set criteria and standards for categorization and classification of water bodies using microbiological, physical, and chemical indicators of water quality (BRASIL, 2000; BRASIL, 2005; QUEIROZ; RUBIM, 2016). These indicators provide us with information that specifies whether an aquatic environment is appropriate or unsuitable for various purposes.

Today, the search for information about environmental quality is of paramount importance because environmental and human health are intricately related, making it important to know the environmental quality of various urban spaces, especially those used for leisure that are in contact with nature. Thus, this study sought to evaluate the water quality of two urban lakes that are used for leisure in Manaus, by classifying the lakes according to standards established by the environmental resolutions using microbiological, physical, and chemical indicators of water quality.

## 2. Materials and Methods

### Study area

The samplings were carried out in two urban lagoons located in the central-southern region of the city of Manaus. The first lake is called Japiim (59°58'32 "W 03°37'08" S), located in the Japiim neighborhood, and the second is called Bosque da Ciência (59°59'09 "W 03°05'91 "S) lagoon, located within the area of the National Institute of Research of the Amazon - (Instituto Nacional de Pesquisas da Amazônia - INPA) (Figure 1).

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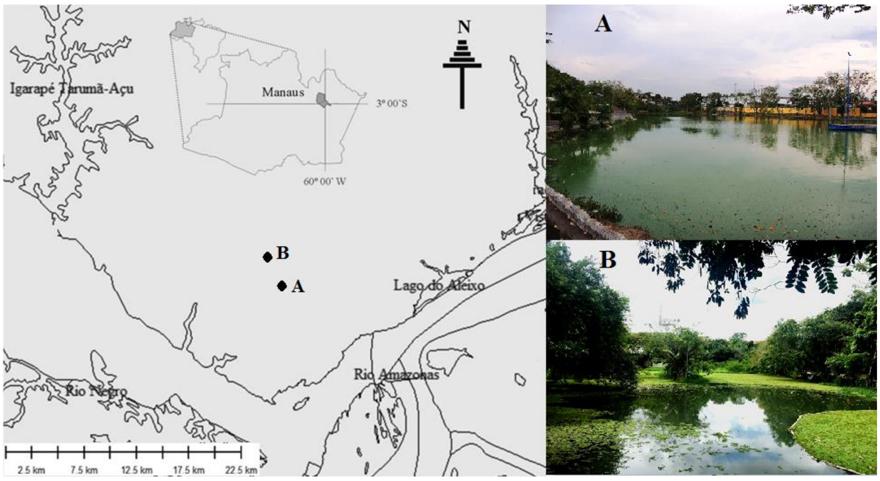


Figure 1. Study area with Japiim (A) and Bosque (B) lakes in the urban area of Manaus.

The Japiim lake is about 170 meters long, 50 meters wide, and four meters deep, surrounded by shrubs, medium-sized trees, and grasses. Surrounding the lagoon are species such as *Clitoria fairchildiana* (Palheteira or Sombreiro), *Pseudobombax munguba* (Munguba), and *Cenostigma tocantinum* (Pau pretinho). The water of this lake is currently dark green, indicating massive phytoplanktonic proliferation due to organic matter from untreated sewage from the community at the bottom of the park. However, even with such visible pollution, animals such as turtles, fish, snails, and birds still live in the lake.

The Bosque da Ciência lake is commonly known as the "Amazonian Lake" and has vast plant cover, with Arecaceae as *Mauritia flexuosa* (Buritizeiro) and *Euterpe oleracea* (Açaizeiro) and other species such as *Clitoria fairchildiana* (Palheteira), *Ceiba pentandra* (Sumaúma), *Bambooa vulgari*s (Bamboo). This lake is approximately 140 meters long, 45 meters wide, and two meters deep, its water is lighter green compared to the Japiim lake with few signs of anthropic action. Therefore, the natural characteristics are preserved and there are animals as turtles, fish, amphibians, macroinvertebrates, and a great amount of aquatic macrophytes.

**Data collection**

Samplings from the two lakes were carried out in the second half of 2015 and the first semester of 2016, during the dry (October and November) and rainy (March and April) periods for five consecutive weeks, totaling 10 samplings in each lake and five in each season for the two lakes. The collections were carried out at three randomized points in each lake with sterile glass and polyethylene vials, that were labeled and sent to the Laboratório de Química Ambiental, Laboratório de Plâncton e Laboratório de Malária e Dengue at the Instituto Nacional de Pesquisas da Amazônia for analysis.

**Physical and chemical parameters**

During the sampling the following parameters were measured: pH, dissolved oxygen, and temperature using portable equipment (pH and oximeter), three times from random points at the edge of the lakes We also collected triplicates samples of 500 mL polyethylene vials for total suspended solids using the Gravimetric method and total phosphorus for analysis in Spectrophotometer (APHA, 1985).

**Multiple tubes technique**

This technique includes two tests: the 1st presumptive and 2nd confirmatory, which includes procedures I, II, and III. These tests quantify the most probable number (MPN) of total feces and coliforms in the water sample using the Hoskins table, (recommended by CONAMA through the resolution n°274/2000) which is based on the Standard Methods for Water and Wastewater examination (APHA, 1985; ARCOS et al., 2016). Procedure I, growth of coliforms; Procedure II, growth of the total coliform group; Procedure III, growth of the fecal coliform group.

**Phytoplankton and Macrophytes sample**

We collected phytoplankton for qualitative analysis using a 20cm x 30cm net (20 μm mesh opening). We trawled the water column

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near the edge of the lake for 10 minutes. The phytoplankton collected in the collector cup were stored in labeled vials. The samples were stored in a 40 mL glass vials and fixed in Transeau solution (6:3:1), in proportion 1:1 (50% of the sample and 50% of the solution). Phytoplankton was identified using inverted optical microscopy (BICUDO; MENEZES, 2006).

Macrophyte richness in the lakes was measured by collecting two samples of each plant, which we identified to the genus level through comparison with specialized literature (STODOLA, 1967; POTT; POTT, 2000; LORENZI, 2000; SOUZA; LORENZI, 2005).

**Data analysis**

We calculated the variance analysis of two ANOVA factors in the PAST version 2.17 software to test significant differences in fecal coliforms between the two lakes during the study periods (significance level = $p < 0.05$). The rainfall index (mm) was obtained directly from the automatic meteorological station installed in Manaus (A101) and obtained from the Meteorological Database for Teaching and Research – BDMEP/INMET.

## 3. Results and Discussion

### Most probable number of fecal coliforms

We observed a high number of fecal coliforms in the Japiim lake during the dry and rainy period, with 1500 and 1200 MPN/100 ml. In the Bosque lake fecal coliforms were below 500 MPN/100 ml in the two periods (Fig. 2 and 3). The quantity of coliforms showed significant variation between the two lakes ($F = 25.80$ and $p < 0.01$), pointing out that the Bosque lake did not exceed the limit of 1000 MPN/100 mL (stipulated by resolution CONAMA 274/2000) (BRASIL, 2000) during the five consecutive weeks. However, the Japiim lake receives untreated sewage, which directly influences the water quality due to contamination by fecal coliforms and resulted a concentration of fecal coliforms above the level stipulated by the environmental resolution. It is worth mentioning that this resolution is mainly used to evaluate the balneability of aquatic environments, and values above 1000 are classified as unsuitable. However, it is also used as the basis for several works involving evaluation of a water body.

Studies using these indicators to monitor and evaluate water quality are being carried out in the Northern region (CAMPOS; CUNHA, 2015), since they measure the microbiological quality of water and health risks for populations that have direct contact with these environments. High concentrations of coliforms are mainly found during dry periods in natural and altered environments (TENORIO et al., 2011; SILVA; SÁ-OLIVEIRA, 2014; ARCOS et al., 2016) due to low water volume, which prevents dilution of coliforms in the aquatic environment.

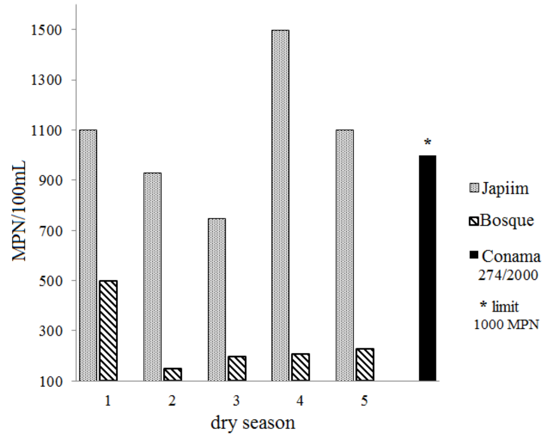


Figure 2. Most probable number of fecal coliforms present in Japiim and Bosque lakes for five consecutive weeks in the dry season (*limit of coliform stipulated by CONAMA for classification of proper).

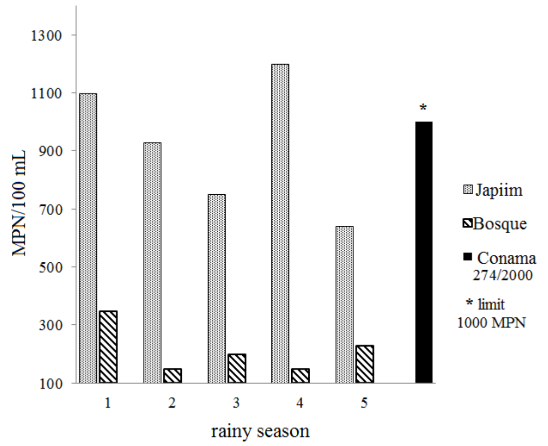


Figure 3. Most probable number of fecal coliforms present in Japiim and Bosque lakes for five consecutive weeks in the rainy season (*limit of coliform stipulated by CONAMA for classification of proper).

### Physical and chemical indicators

In the Japiim and Bosque lakes the pH values remained within the standards established to maintain aquatic life (6.0 – 9.0) according to resolution CONAMA 357/2005 (BRASIL, 2005)

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in both periods, as shown in Table 1. It is noteworthy that in addition to pH other limnological parameters are important and that their association guarantees the maintenance of aquatic life. There is another standard for environments with domestic sewage, ranging from 6.7 to 8.0 (VON SPERLING, 2005), which includes Japiim lagoon.

Pascoaloto et al. (2015) studied these same urban lakes and verified pH values within the same range that we found in this study. This may indicate that this is a local characteristic, or that there were no changes in the characteristics of these environments during this period. Similar pH values (close to neutral) have been found in shallow eutrophic urban lakes or those in the process of eutrophication (BEM et al., 2013). Such results can be explained by the buffer effect that occurs in waters with sewage intake (ARAÚJO et al., 2016) and high pH values attributed to increased photosynthetic activity in aquatic environments (PEDROZO; ROCHA, 2007).

Table 1. Mean values of the limnological parameters found in the Japiim and Bosque lakes for five consecutive weeks in the dry and rainy season.

| Lakes | Season | pH | DO mg/L | Temp. ºC | TSS mg/L | P mg/L |
|---|---|---|---|---|---|---|
| Japiim | Dry | 7.8 | 4.1 | 27.0 | 507 | 0.30 |
| Japiim | Dry | 7.7 | 4.0 | 30.1 | 461 | 0.11 |
| Japiim | Dry | 7.9 | 4.6 | 30.0 | 348 | 0.25 |
| Japiim | Dry | 7.8 | 4.4 | 29.7 | 625 | 0.13 |
| Japiim | Dry | 7.7 | 5.0 | 29.1 | 573 | 0.42 |
| Bosque | Dry | 6.0 | 6.1 | 29.3 | 64 | 0.10 |
| Bosque | Dry | 6.1 | 6.3 | 28,8 | 102 | 0.09 |
| Bosque | Dry | 5.9 | 5.0 | 27.5 | 67 | 0.06 |
| Bosque | Dry | 6.2 | 5.7 | 28.9 | 44 | 0.15 |
| Bosque | Dry | 6.0 | 6.5 | 27.2 | 51 | 0.18 |
| Japiim | Rainy | 7.5 | 6.9 | 26.6 | 423 | 0.17 |
| Japiim | Rainy | 7.4 | 6.0 | 27.2 | 210 | 0.10 |
| Japiim | Rainy | 6.3 | 6.3 | 26.7 | 186 | 0.17 |
| Japiim | Rainy | 7.1 | 6.2 | 26.9 | 341 | 0.20 |
| Japiim | Rainy | 7.5 | 6.5 | 27.5 | 195 | 0.09 |
| Bosque | Rainy | 6.2 | 7.0 | 27.1 | 48 | 0,09 |
| Bosque | Rainy | 6.6 | 7.1 | 26.1 | 23 | 0.05 |
| Bosque | Rainy | 6.5 | 6.9 | 26.3 | 48 | 0.10 |
| Bosque | Rainy | 6.8 | 6.4 | 27.0 | 22 | 0.03 |
| Bosque | Rainy | 6.4 | 6.3 | 26.5 | 37 | 0.04 |

In the two lakes, dissolved oxygen varied between 4.1 and 6.5 mg/L in the dry period and 6.0 and 7.1 mg/L in the rainy period, as seen in Table 1. This parameter is important because it expresses the quality of life in the aquatic environment, since fish death is related to low amounts of oxygen available for biota. The CONAMA 357/2005 (BRASIL, 2005) resolution establishes that dissolved oxygen values of such waterbodies should not be less than 4.0 mg/L, demonstrating that the values we obtained in our analyses are within the standard.

An important characteristic we observed was the phytoplankton "bloom", which consists of the accelerated growth of algae biomass (IGNATIADES, 1994), that ended up increasing photosynthesis and oxygen production in the Japiim lake during the dry period. This bloom was responsible for the oxygen concentration in the lake but may hinder some organisms that need cleaner and clearer waters. In addition, Pascoaloto et al. (2015) related precipitation to oxygen concentration in these two lakes. In the present study we observed increased oxygen in the rainy period due to wind action and inlet of rainwater (Figure 3).

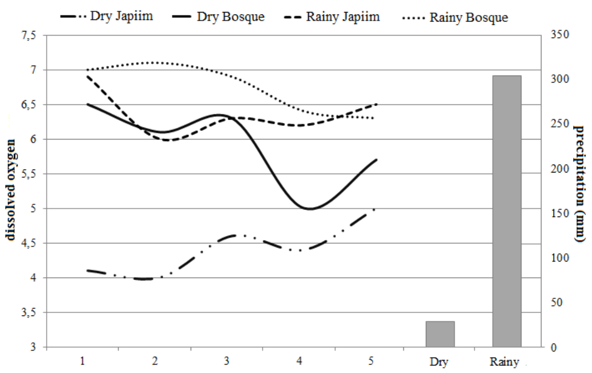


Figure 3. Observed relation of the oxygen content in the water of the lakes with total rainfall in the dry (October and November - 2015) and rainy (March and April - 2016) periods.

Oxygen concentrations below 4.0 mg/L are characterized as a dangerous condition of hypoxia and may cause fish death. According to Kozlowsky-Suzuki and Bozelli (2002), hypoxia occurs through the deleterious effects of eutrophication, caused by nutrient pollution such as ammonium, phosphates, and nitrates

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(DANTAS-SILVA; DANTAS, 2013). In urban lakes, low dissolved oxygen content is attributed to sewage inlet into the environment (ARAÚJO et al., 2016), which we observed in the Japiim lake, that had worse environmental conditions compared to the Bosque lake.

Water temperatures in lakes remained within acceptable norms for lentic environments, with lower temperatures in the rainy period (Table 1). Temperatures between 25-35 °C are great for bacterial activity (METCALF; EDDY, 1991), with temperature increases in a water body related to the dumping of untreated sewage (CETESB, 2017). The Japiim lake presented higher temperatures, mainly in the dry period, due to the presence of sewage. Carvalho et al. (2000) identified the existence of a significant relationship between the increase in water temperature and suspended solids with the electrical conductivity in the water, which can occur from reactions triggered by aquatic fauna as temperature increases. The temperature in the water body also influences the oxygen consumption and the ability to carry oxygen in the water (GOLOMBIESKI et al., 2003). In addition, natural climatic variations and industrial sewage dumps can cause an increase in water temperature.

Total suspended solids were higher in the Japiim lake in relation to the Bosque lake, with higher values in the dry period that were above the limit of the standards established by the CONAMA 357/2005 (BRASIL, 2005) resolution, which stipulates values below 500 mg/L (Table 1). Lower TSS values (average of 7.7 mg/L) were found in lagoons and natural dams that have been modified for various purposes in the peri-urban area of Manaus (ARCOS, 2012; FERREIRA et al., 2015). The input of particulate material in the Japiim lake originates from the superficial runoff from rains and the organic material from sewage. However, in the Bosque lake this material is mainly derived from superficial runoff and this entrance of the total suspended solids in the aquatic environment favors silting over time.

We observed high values of total phosphorus in both lagoons in the two collection periods (dry and rainy). Environmental resolution nº 357/2005 established different values of total phosphorus for water bodies in Classes 1 to 4 (BRASIL, 2005), where the value stipulated for lentic environments varies from 0.02 to 0.05 mg/L, not meeting the resolution, with clear signs of eutrophication. However, for environments polluted by direct release of untreated sewage, the values of this nutrient vary from 4 to 15 mg/L (VON SPERLING, 2005). The classification assembles a series of definitions based on the natural aptitude of the watercourses, observing their quality, capacity, among other specific characteristics. And based on inspection, the lower the number of the class in which the body of water is located, the more rigid is the inspection and penalty when it is applied. This resolution fits both large rivers and small bodies of water, such as ponds and lakes.

Studies about urban lakes in Brazil have identified high concentrations of nutrients as total phosphorus and nitrogen compounds (THEBALDI et al., 2017), indicating a high trophic degree in these aquatic environments, as we observed in the lakes in Manaus. Many nutrients such as phosphorus are washed away with rains and the discharge of untreated domestic and industrial effluents to the lagoons, which we observed mainly in the Japiim lake. This process causes eutrophication of these environments, which over time become unfit for aquatic life and end up affecting the quality of life for human populations that live in the surrounding areas.

These studies and information on the quality of water bodies, especially in the lagoons studied in Manaus, are important for designing plans for the conservation and recovery of environments in the process of environmental degradation, where the quality of the environment and the health of the population are benefited.

**Aquatic macrophytes**

During the study, we identified five genera of aquatic macrophytes. In the Japiim lake we found *Cyperus* sp., distributed along the margin, classified as an emerging macrophyte type, which fixed its root into the soil in contact with the water and had most of its structure outside of the water. We also found *Brachiaria* sp. in the Japiim lake, and was clustered in large quantities in the background, in direct contact with the largest concentration of organic matter from the sewage. In the Bosque laake we observed a large amount of floating macrophytes of *Pistia* sp. and *Salvini*a sp. throughout the entire lagoon and *Hymenachne* sp. in regions near the edges.

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Studies highlight that macrophytes are structural components for the metabolism of South American ecosystems and their intense growth can alter water quality and interfere with multiple uses of the water (POMPÊO, 2008). Macrophytes can accumulate and accelerate nutrient cycling (BROCK et al., 1983), observed in the two lakes, in addition to serving as a substrate for algae (WEHR; SHEATH, 2003). In shallow environments such as lakes, macrophytes influence water chemistry and sustain the food chain through detritus and herbivory (WETZEL, 1981). According to Vargas and Roman (2008), the species *Brachiaria plantaginea* is considered weedy, being spontaneously present in an area with human occupation or interference. And this genus was found in greater density mainly near the more polluted region of the Japiim lake.

**Phytoplankton**

We found 22 species distributed in 17 phytoplankton genera in the two lakes. Chlorophyta (1) was the most frequent with 45.4%, followed by Euglenophyta (2) with 27.2%, Bacillariophyta (3) and Cyanoprocariophyta (4) with 13.6% each (Table 2).

Phytoplankton richness was higher in the Bosque lake. The presence of these groups is important for the entire environment, because they are sources of oxygen through photosynthesis, as well as parts of the food chain in the aquatic environment. The relationship of the largest richness and largest group found in the Bosque lake was also observed in monitoring work conducted in Manaus (PASCOALOTO et al., 2015).

The Cetesb (2008) points to phytoplankton as an indicator of trophic state, since some species can compromise the quality of the water in large quantities, especially algae that are potentially toxic. Study conducted in Manaus found cyanobacteria in these lakes (PASCOALOTO et al., 2015), emphasizing the process of eutrophication that has been occurring.

According to Oliveira and Valle (2010), the multiplication of cyanophyte algae is favored with in natura sewage dumping, and due to their cluttered growth end up suffocating the zooplankton and other aquatic invertebrates and vertebrates, releasing foul-smelling gases. We identified two cyanobacteria from the Japiim lake, which were responsible for the phytoplanktonic bloom. Such blooming behavior of phytoplankton is especially observed in the summer (GARCÍA-SOTO, 2006), when phosphorus is the main limiting factor for permanent cyanobacterial floras (FERNANDES et al., 2009b). Therefore, the reservoirs constructed by man favor the expansion of cyanobacterial flora, since they are generally shallow, easily eutrophied, and have a long water retention time (SANT'ANNA et al., 2008). Such characteristics are observed in the Japiim lake, which is considered the most impacted. The floras of this cyanobacteria cause changes in the organoleptic aspects of water, such as bad appearance and unpleasant odor, causing ecological damage and threatening human health (FERNANDES et al., 2009a).

Table 2. Qualitative determination of the phytoplankton collected in the urban lagoons of Japiim and Bosque.

| **Division** | **Species** | **Lakes** | |
|---|---|---|---|
| | | **Japiim** | **Bosque** |
| 1 | *Coelastrum* sp. | x | x |
| 1 | *Cosmarium depressum* | x | - |
| 1 | *Desmodesmus cf. communis* | - | x |
| 1 | *Desmodesmus* sp. | x | - |
| 1 | *Eudorina elegans* | x | - |
| 1 | *Kirchneriella lunaris* | - | x |
| 1 | *Pediastrum duplex* | x | x |
| 1 | *Scenedesmus acuminatus* | - | x |
| 1 | *Scenedesmus* sp. | x | - |
| 1 | *Tetrallantos lagerheimii* | - | x |
| 2 | *Euglena acus* | - | x |
| 2 | *Euglena oxyuris* | x | x |
| 2 | *Phacus longicauda* | - | x |
| 2 | *Phacus* sp. | x | x |
| 2 | *Trachelomonas* sp. | x | - |
| 2 | *Lepocincles* sp. | x | x |
| 3 | *Aulacoseira cf. italica* | - | x |
| 3 | *Eutonia* sp. | x | x |
| 3 | *Gomphonema* sp. | - | x |
| 4 | *Planktothrix cf. agardi* | x | - |
| 4 | *Microcystis wesenbergii* | x | - |
| 4 | *Microcystis* sp. | - | x |

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## 4. Conclusion

We observed characteristics of eutrophication in both lakes, but at different levels. The physico-chemical and microbiological indicators indicated higher pollution in the Japiim lake compared to the Bosque lake, which was classified as unsuitable for several purposes. Seasons directly influenced the water quality of these lakes, especially the rainy season. A treatment plant for the sewage that flows into the Japiim lake would greatly change the current state of the water and help maintain the aquatic life and the quality of life of visitors. The preservation of these environments inserted in the big cities is of great importance, because it houses an expressive number of fauna and flora, besides contributing with the environmental quality and landscape in the cities.

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