Chapter

Phytoplankton Biomass and Environmental Descriptors of Water Quality of an Urban Lagoon

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Abstract

The Jansen lagoon is a coastal system formed by damming the Ana Jansen Creek, which is located in the northwest of São Luís Island (northern Brazil) and is under high urban influence. The use of indexes to assess the water quality in aquatic systems is important because they show the degradation degree of an area and give support to measures for the sustainability and protection of aquatic life, consequently. For the seasonal and spatial analysis of environmental and biological variables, six bimonthly surveys between November 2011 and September 2012 were carried out at five sampling sites. In addition, indexes such as the index of minimum parameters for the protection of aquatic communities, Trophic State Index, and Aquatic Life Protection Index were applied to evaluate the water quality. High levels of dissolved oxygen (DO), pH, total phosphorus, and chlorophyll *a* were observed in the lagoon waters. In general, the water quality indexes showed that the Jansen lagoon has a poor water quality due to elevated DO and pH as well as high concentration of surfactants and phenols. These environmental conditions favored the intense process of eutrophication (hypereutrophy) and environmental degradation of the area, affecting the development of aquatic biota.

Keywords: coastal lagoon, water quality, aquatic life protection, eutrophication, pollutants

1. Introduction

Water quality is vital when it comes to determining how society uses and values aquatic environments associated with natural resources [1] and their monitoring provides empirical evidence to support decision-making on health and environmental issues [2]. Thus, water quality can be assessed through variables such as dissolved oxygen, temperature, pH, toxic substances (heavy metals, surfactants, and phenols) and others [3, 4].

Among the aquatic ecosystems, the coastal lagoons stand out for offering important environmental services (e.g., food production, nutrient cycling, recreational activities, and aquaculture). However, they have been degraded worldwide by human activities associated with rapid urbanization [5–8]. Therefore, coastal ecosystems need constant evaluation to provide the protection of the populations and the improvement of the quality of life.

Indexes and indicators of water quality work as tools that represent simplified models of the environmental structure, which makes it easy to understand the impacts and to present the results to the general public [9, 10]. Indicators are quantified information of environmental variables that help in the explanation of processes that undergo changes of anthropic or natural origins in time and space, thus allowing the dynamic monitoring of the real situation and identification of trends [11, 12].

The most complex indicator models integrate information from different ecosystem compartments, such as physical and chemical parameters of water, phytoplankton, zooplankton, benthos, submerged aquatic vegetation, macroalgae, sediments, etc. [13]. In this context, the indexes related to water quality are considered the most widely known water indicators in the world. They are represented by a dimensionless number, being the result of the aggregation of physical, chemical, and microbiological indicators obtained by specific methodologies [14].

The use of indexes to assess the quality of water becomes fundamental in the measurement of how and how much aquatic management is moving from the perspective of sustainability, observing the reflexes of the actions implemented in the aquatic environments as units of management of the water resources. Thus, the use of the aquatic life protection index (ALPI) is essential and therefore considers the physical-chemical quality of the water and its degree of enrichment regarding nutrients (phosphorus and nitrogen), as well as the degree of toxicity, and it can be used as an indicator of trophic status and pollution in aquatic ecosystems [9, 15].

In Brazil, studies that aim the measurement of the water quality through the application of indexes have been carried out mainly in reservoirs and rivers [16–18]. Considering the Brazilian coast, mainly in lagoon ecosystems such as the Jansen lagoon, these studies are still scarce, making the understanding of the behavior of this environment regarding the impacts that take place there evident. Thus, we propose to carry out an assessment of the water quality in the Jansen lagoon through the use of indexes and environmental descriptors as a way of assisting the management of local resources, as well as to subsidize the sustainability of this ecosystem in the global scope.

2. Brazilian coastal lagoons

Coastal lagoons are considered as depressions, with depths less than 10 meters, parallel to the coast, being connected to the sea temporarily or permanently by one or more channels and separated from it by a physical barrier [19, 20]. These coastal environments, although highly productive, are very fragile and subject to strong anthropogenic pressures, such as disordered population growth [21, 22].

In the Brazilian coast, it is possible to see lagoon complexes, as well as coastal lagoons impacted by man and in the stage of advanced eutrophication. Among them are the Mundaú-Manguaba lagoon complex, Jacarepaguá, Patos lagoon, Jacuném lagoon, Açu lagoon, and Rodrigo de Freitas lagoon that have the disposal of untreated sewage *in natura* directly into the water bodies as the main aggravating factor of water pollution [23–25].

The Jansen lagoon is the result of successive anthropic changes in the landscape. In the 1970s, the area was an estuarine region intersected by the Jansen and Jaracati streams with extensive mangrove forest represented by species such as *Rhizophora* *mangle*, *Avicennia germinans*, *Avicennia schaueriana*, and *Laguncularia racemosa*. However, the construction of roads altered the main drainage network of the Jansen stream with the sea leading to the salt water damming, forming consequently the lagoon [26].

The lagoon is located in the northwest of São Luís Island, between the coordinates 02°29′08″S and 44°18′02″W, northern Brazil (**Figure 1**). It covers 140 ha with an average depth of 1.5 m and is still surrounded in the east by a mangrove forest.

The lagoon is under a semidiurnal macrotidal system typical of the Amazon coastal zone [27], with amplitudes that can reach up to 7 m. It is connected with the sea and the water exchange occurs during the spring tides in the rainy season, when the freshwater supply ensures the flow toward the sea (115 m length and 3 m deep) [28]. According to the classification of Kjerfve [29] which is based on the geomorphological typology, the Jansen lagoon is classified as restricted (**Figure 2**), depending on fluctuations in sea level and rainfall.

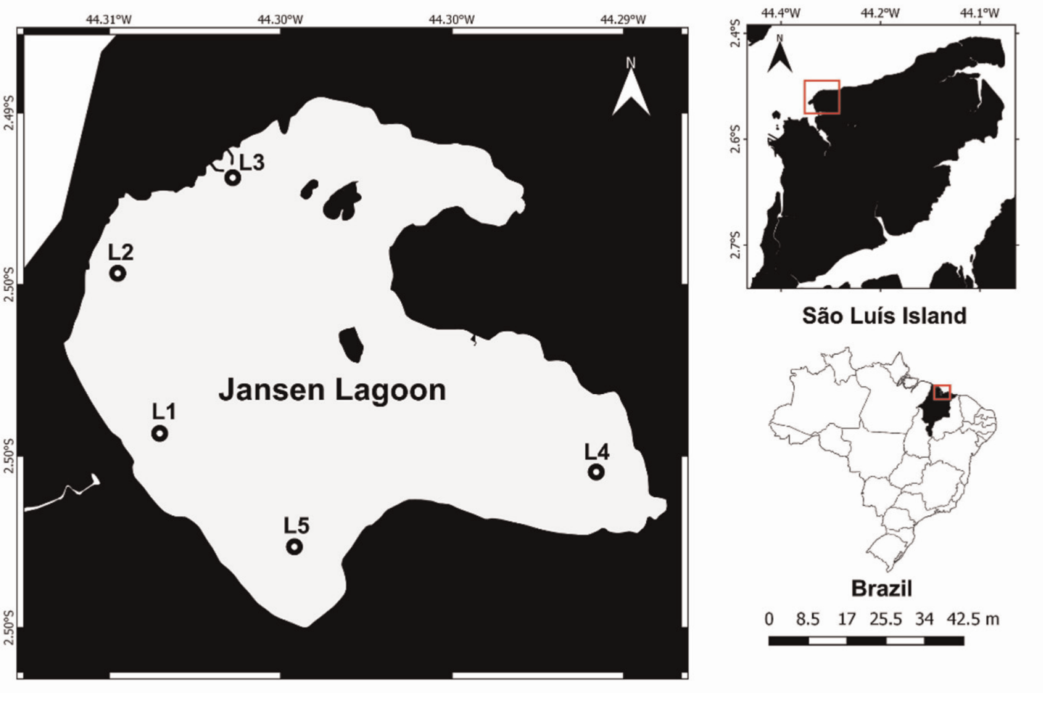

Figure 1.
Location of the study area with sampling points (L1–L5), Jansen lagoon, São Luís Island-Maranhão, Brazil.

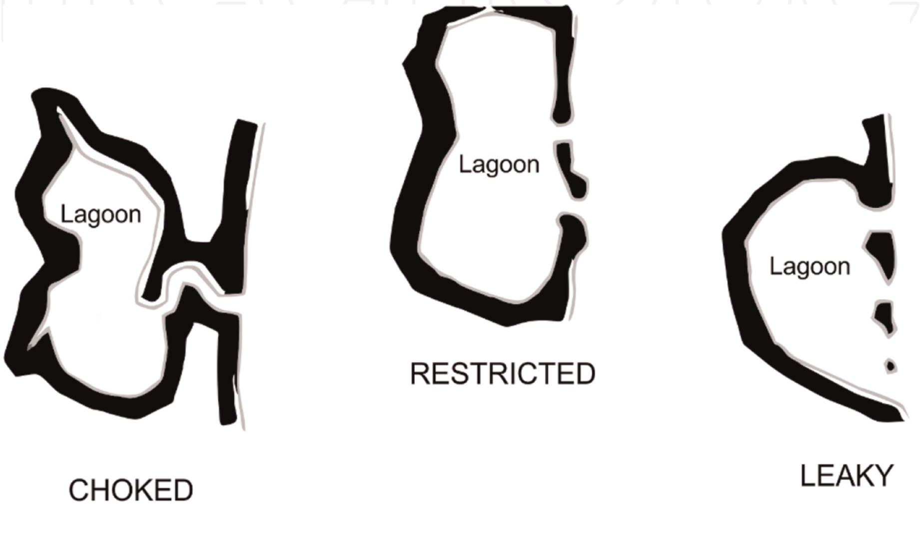

Figure 2.
Schematic representation of the types of coastal lagoons according to Kjerfve [29].

Regarding local climate, the region is hot and humid because it is situated in the equatorial belt with equatorial air mass influence originating in low-latitude regions where the southern boreal and trade winds converge. As a result, it has intrinsic characteristics such as high temperatures throughout the year as well as two well-defined seasonal periods strongly marked by precipitation: rainy season (January-June) and dry season (July-December).

The Jansen lagoon is a eutrophic environment, where most of the material found in it is of allochthonous origin, that is to say, originating from the release of fresh domestic sewage, which decisively influences the distribution of many nutrients, and consequently the biodiversity and water quality of the lagoon, with recurrent processes of eutrophication and algal blooms [26].

3. Material and methods

3.1 Sampling

From 2011 to 2012, samplings were carried out every 2 months, with a total of six surveys (November 2011–September 2012) performed at five sampling sites. In those samplings, tide (ebb tide and spring tide) and season (dry and rainy seasons) were considered. The rainfall data were obtained from the National Institute of Meteorology (INMET). Physical and chemical parameters are described in **Table 1**, considering the Federal Legislation of Classification of Water Bodies (CONAMA 357/05) [30] and the Aquatic Life Protection Index (ALPI).

Variable	Symbol	Units	Methods and equipment
Temperature	Water temp.	°C	Multiparametric Probe/Hanna 9828
Salinity	Sal.	—	
Dissolved oxygen	DO	mg L^{-1}	Sodium azide used in the Winkler method
pH	pH	—	Multiparametric Probe/Hanna 9828
Phenol	Phen.	μg L^{-1}	**USEPA SW 846-8270D e 3510C, *SMWW 6410B
Total phosphorus	TP	mg L^{-1}	Ascorbic acid method/SMEWW 4500
Surfactants	***LAS	mg L^{-1}	POP PA023/*SMWW 5540C
Cadmium	Cd	μg L^{-1}	POP PA038 *SMWW 3125 B **USEPA 6020
Lead	Pb	μg L^{-1}	
Copper	Cu	μg L^{-1}	
Chrome	Cr	μg L^{-1}	
Manganese	Mn	μg L^{-1}	
Nickel	Ni	μg L^{-1}	
Zinc	Zn	μg L^{-1}	
Chlorophyll-a	Chla	μg L^{-1}	Spectrophotometry

**SMWW, standard methods for water and wastewater [31].*
***USEPA, United States Environmental Protection Agency.*
****LAS, linear alkylbenzene sulfonate.*

Table 1.
Physiochemical parameters applied to the determination of the aquatic life protection index (ALPI) in Jansen lagoon, São Luís-Maranhão.

3.2 Aquatic life protection index (ALPI)

The Aquatic Life Protection Index (ALPI) is one of the most complete indexes for the assessment of the quality of aquatic ecosystems. It allows analyzing the water quality differently from other indexes, taking into account the presence and concentration of contaminants and their effects (toxicity), comprising two indexes: IMPAC (Index of Minimum Parameters for the Protection of Aquatic Communities) and TSI (Trophic State Index), which provide information on water quality and degree of trophy [32].

The IMPAC, proposed by Zagatto et al. [17] is composed of two groups of parameters: toxic substances (copper, zinc, lead, chromium, mercury, nickel, cadmium, surfactants, and phenols) and essential parameters (dissolved oxygen, pH and toxicity analyzes). For each parameter, three different levels were set, with numerical weightings of 1, 2, and 3. Weighting 1 corresponds to the water quality standards established by the Brazilian legislation [30] and weightings 2 and 3 consider the American and French legislations [33, 34], respectively, which establish maximum permissible limits of chemical substances in water to avoid chronic and acute effects on the aquatic biota.

Environmentally speaking, these weightings mean the following:

a. **Weighting 1**: waters with suitable characteristics of maintaining survival and reproduction of organisms;

b. **Weighting 2**: waters with suitable characteristics for the survival of aquatic organisms, but reproduction may be affected in the long term;

c. **Weighting 3**: waters that may compromise the survival of organisms.

The IMPAC is calculated as follows (Eq. (1)):

$$\mathbf{IMPAC} = \mathrm{PE} \times \mathrm{ST} \tag{1}$$

where PE = value of the highest weighting in the group of essential parameters; ST = average value of the three highest weightings in the group of toxic substances.

If the value of the toxic substances is an integer, the following rounding criterion is considered: values smaller than 0.5 will be rounded down and values greater than or equal to 0.5 will be rounded up. Using this methodology, the value of the index can vary from 1 to 9. For the water classification, the IMPAC was subdivided into four levels (**Table 2**).

Toxicity tests followed the regulation ABNT/NBR 15088 [35] adapted for the euryhaline species *Poecilia sphenops* [36], considering salinity variation between sampling sites in the Jansen lagoon.

Quality	Color Scale	Weighting
Good		1
Regular		2
Bad		3-4
Very Bad		> 6

Table 2.
Water quality according to the index of minimum parameters for the protection of aquatic communities (IMPAC) by Zagatto et al. [17].

The TSI, used to determine the trophic levels of the Jansen lagoon, followed the standards proposed by Carlson [37], modified by Toledo et al. [38], who updated the original formula using the water parameter transparency, phosphate, ortho-phosphate, and chlorophyll *a* for tropical environments.

In this study, the calculation of the ALPI considered the Trophic State Index for phosphorus-TSI (TP) and the Trophic State Index for chlorophyll *a*-TSI (Chl), modified by Lamparelli [18], established for lotic environments, according to the equations (Eqs. (2) and (3)):

$$\text{TSI (TP)} = 10 \times (6 - ((0.42 - 0.36 \times (\ln \text{TP}))/\ln 2)) - 20 \tag{2}$$

$$\text{TSI (Chl)} = 10 \times (6 - ((-0.7 - 0.6 \times (\ln \text{Chl}))/\ln 2)) - 20 \tag{3}$$

where TP: total phosphorus concentration measured at the water surface ($\mu g\ L^{-1}$); Chl: chlorophyll *a* concentration measured at the water surface ($\mu g\ L^{-1}$) ln: natural logarithm.

Regarding the TSI, the result shown in the tables is the simple arithmetic mean of the indexes related to the total phosphorus and chlorophyll *a*, expressed in the following equation (Eq. (4)):

$$\text{TSI} = [\text{TSI}_{\text{TP}} + \text{TSI}_{\text{Chl}}]/2 \tag{4}$$

According to Lamparelli [18], the different values of TSI lead to the following water classification (**Table 3**):

Based on the data obtained and associated by IMPAC [17] and the Trophic State Index (TSI) as shown in **Table 4**, the ALPI (Aquatic Life Protection Index) was calculated according to the following equation (Eq. (5)):

$$\text{ALPI} = (\text{IMPAC} \times 1.2) + \text{TSI} \tag{5}$$

Quality	Color Scale	TSI	Weighting
Ultraoligotrophic	(blue)	TSI ≤ 47	0.5
Oligotrophic	(green)	47< TSI ≤ 52	1
Mesotrophic	(yellow)	52< TSI ≤ 59	2
Eutrophic	(orange)	59 < TSI ≤ 63	3
Supereutrophic	(red)	63 < TSI ≤ 67	4
Hypereutrophic	(purple)	TSI > 67	5

Table 3.
Water quality according to the state trophic index (TSI) by Carlson [37] modified by Toledo et al. [38].

		IMPAC				
	Weighting	1	2	3	4	5 a 9
TSI	0.5	1.7	2.9	4.1	5.3	7.7-11.3
	1	2.2	3.4	4.6	5.8	8.2-11.8
	2	3.2	4.4	5.6	6.8	9.2-12.8
	3	4.2	5.4	6.6	7.8	10.2-13.8
	4	5.2	6.4	7.6	8.8	11.2-14.8
	5	6.2	7.4	8.6	9.8	12.2-15.8

Table 4.
Calculation of the ALPI integrating the values of the TSI and IMPAC. Where: excellent (blue), good (green), regular (yellow), bad (red), and very bad (purple).

		IMPAC				
	Weighting	1	2	3	4	5 a 9
TSI	0.5	1.7	2.9	4.1	5.3	7.7-11.3
	1	2.2	3.4	4.6	5.8	8.2-11.8
	2	3.2	4.4	5.6	6.8	9.2-12.8
	3	4.2	5.4	6.6	7.8	10.2-13.8
	4	5.2	6.4	7.6	8.8	11.2-14.8
	5	6.2	7.4	8.6	9.8	12.2-15.8

Table 5.
Water quality according to the aquatic life protection index (ALPI) by Zagatto et al. [17] modified by CETESB [32].

The classification of the waters can be represented according to the ALPI index values, being divided into five categories as described below (**Table 5**):

Phytoplankton was analyzed in terms of chlorophyll *a*. Water samples for chlorophyll *a* (μg L^{-1}) determinations were filtered through Whatman GF/F glass fiber filters, and a pigment extraction was performed with 90% acetone. To obtain the fractional values of chlorophyll, sub-samples were passed through a 20 μm mesh and then filtered. Pigment concentration was measured by spectrophotometry [39, 40] and the calculations were done according to Strickland and Parsons [41].

4. Results and discussion

4.1 Climatological scenario and environmental descriptors

During the sampling period, an atypical pattern was observed, with annual rainfall amounts ranging from 995 mm (2012) to 2530 mm (2011), which was the result of a combination of the effects of the El Niño–Southern Oscillation (ENSO) [42].

The characteristics of the estuarine waters of the Jansen lagoon are summarized in **Table 6** and **Figure 3**, with significant differences in environmental variables occurring between the rainy and dry seasons.

The water temperature is typical of environments near the equator, and regarding the salinity values, the waters of Jansen lagoon during the study period were

Variables	Units	CONAMA 357/05	Dry	Rainy	Anova	KW
			Mean ± SD	Mean ± SD		
Dissolved oxygen	(mg L^{-1})	>4	3.73 ± 1.43	7.05 ± 2.61	0.000*	—
pH	—	6.5–8.5	8.89 ± 0.56	8.54 ± 0.40	0.075	—
Salinity	—	0.5–30	28.34 ± 5.82	24.50 ± 8.91	—	0.120
Water temperature	(°C)	—	28.60 ± 1.07	28.53 ± 1.64	0.906	—
Total chlorophyll *a*	(μg L^{-1})	—	74.64 ± 55.69	71.61 ± 96.74	—	—
Total phosphorus	(μg L^{-1})	0.186	5.73 ± 3.67	6.05 ± 4.26	—	0.917
Phenols	(mg L^{-1})	0.003	0.24 ± 0.22	0.42 ± 0.39	—	—
Surfactants (LAS)	(mg L^{-1})	0.2	0.81 ± 0.59	1.15 ± 0.41	—	—

**Variables with significant difference.*
KW = Kruskal-Wallis.

Table 6.
Seasonal variation of environmental variables in Jansen lagoon, São Luís-Maranhão.

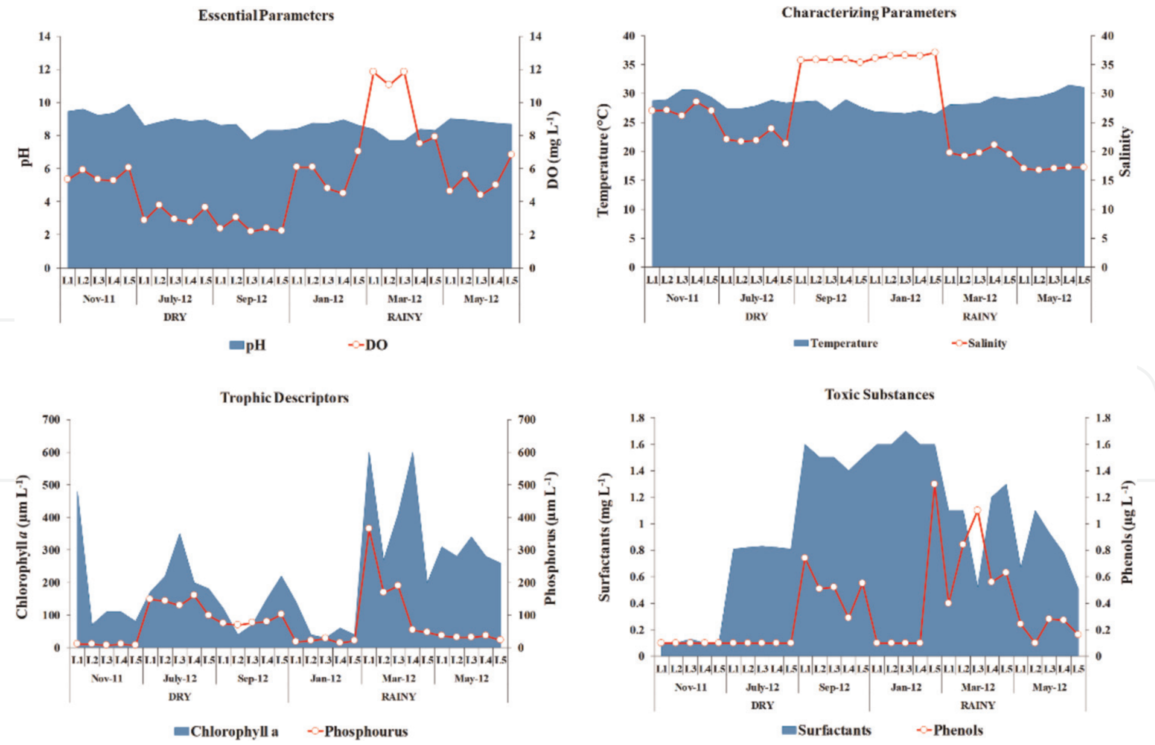

Figure 3.
Seasonal variation of environmental variables during the study period in Jansen lagoon, São Luís-Maranhão.

classified as brackish waters. Total chlorophyll *a* concentrations showed higher values in the dry season. The TP showed higher values in the rainy season. For toxic substances, phenol and surfactants also showed higher values in the rainy season.

The water samples from the Jansen lagoon did not show any acute effect for the *Poecilia sphenops* juveniles during 96 hours of exposure, without water renewal and in stable physicochemical conditions (temperature, salinity, oxygen, and pH), considering 100% of survival during acute toxicity tests.

4.2 Water quality indexes

4.2.1 Index of minimum parameters for the protection of aquatic communities (IMPAC)

According to the results obtained for the essential parameters and the toxic substances, the IMPAC was calculated for the Jansen lagoon waters with weightings ranging from 2 to 9, being 5.13 during the dry season and 3.3 in the rainy season. In general, the quality of the water in Jansen lagoon was considered bad in 56.66% (**Figure 4**).

Regarding the seasonal variation of IMPAC, the waters had the pattern shown in **Table 7**. During the study period, the presence of dead fish was not observed. However, some species that are possibly the ones that could adapt and remain in that environment were observed.

Due to the decomposition of the organic matter in the lagoon, the bad smell from the release of the hydrogen sulfide gas was constant. Besides that, blooms of indicator phytoplankton (*Microcystis aeruginosa*) and *Ruppia maritima* specimens were observed at the study area, resulting in a mass of greenish-dark coloration [26, 43].

The surfactants were the main toxic substances that determinate the classification of water quality in the Jansen lagoon. July 12 was the period in which the lagoon had the lowest water quality. In that period, all sampling sites were classified as very bad where dissolved oxygen and surfactants reached the highest weightings, indicating that the whole environment was very much compromised.

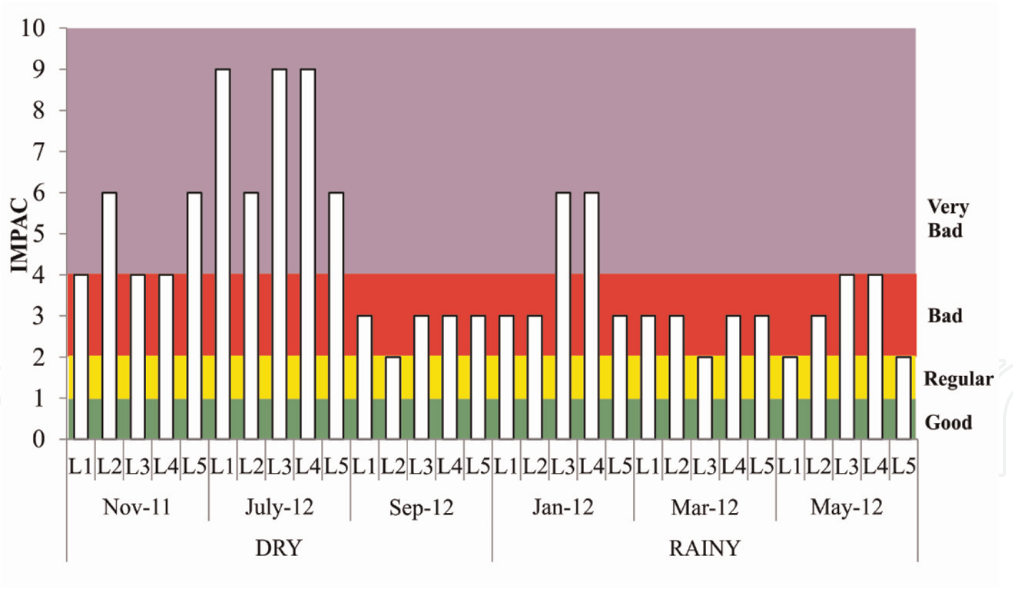

Figure 4.
Representation of the index of minimum parameters for the protection of aquatic communities (IMPAC) in Jansen lagoon, São Luís-Maranhão.

IMPAC							
Sampling point	**Dry**			**Rainy**			**Spatial average**
	Nov-11	**July-12**	**Sep-12**	**Jan-12**	**Mar-12**	**May-12**	
L1	4	9	3	3	3	2	**4**
L2	6	6	2	3	3	3	**4**
L3	4	9	3	6	2	4	**5**
L4	4	9	3	6	3	4	**5**
L5	6	6	3	3	3	2	**4**
Temporal average	**5**	**8**	**3**	**4**	**3**	**3**	

Table 7.
Spatiotemporal distribution of IMPAC mean values according to Zagatto et al. [17] in Jansen lagoon, São Luís-Maranhão.

This scenario was favored by the season. In the beginning of the dry season, the confined waters presented a typical oxygen profile of that environmental scenario and the increase of surfactants could be expected due to the fact that it is a holiday season, which means that people will stay longer in their residences and consequently there will be a greater use of cleaning products, which are sources of these substances, and that will be released to the sewage system.

The quality of the lagoon waters ranged from regular to very bad. For this index, the most important elements for classification of the Jansen lagoon were the dissolved oxygen in the group of essential parameters, and the surfactants in group of toxic substances. These parameters presented high values, being above the allowed by CONAMA Resolution 357/05 [30], evidencing a high degree of pollution caused by the disordered occupation that occurs in the area and by problems of sanitary sewage that still persist.

The heavy metals were detected in small quantities; however, even when quantified above the limit allowed by the federal legislation, their weightings did not have the same weighting as the other indicators in the calculation and final values of IMPAC.

4.2.2 State trophic index (TSI)

With the TSI based on two partial indexes (TSI-TP and TSI-Chl *a*), the trophic state of Jansen lagoon showed a variation of 190.69 μg L^{-1} in the dry season and 191.04 μg L^{-1} in the rainy season, and Jansen lagoon was classified as hypereutrophic (**Figure 5**). When the parameters are analyzed individually, the environment is classified as very eutrophic, and when they are aggregated for the final calculation of this index, the result obtained corroborates this pattern, with a weighting of 5.

Combining the two partial indexes, it was possible to observe that the TSI-TP showed higher weighting with regard to the increase of the degree of eutrophication in Jansen lagoon, considering that the total TSI showed an intermediate quantification in relation to the one observed in the TSI-TP and in the TSI-Chl *a*; however, all of them had the same weighting and classification. When that happens, it is inferred that the system is already under eutrophication, since the trophic state indicated by the TSI-TP coincided with TSI-Chl *a*.

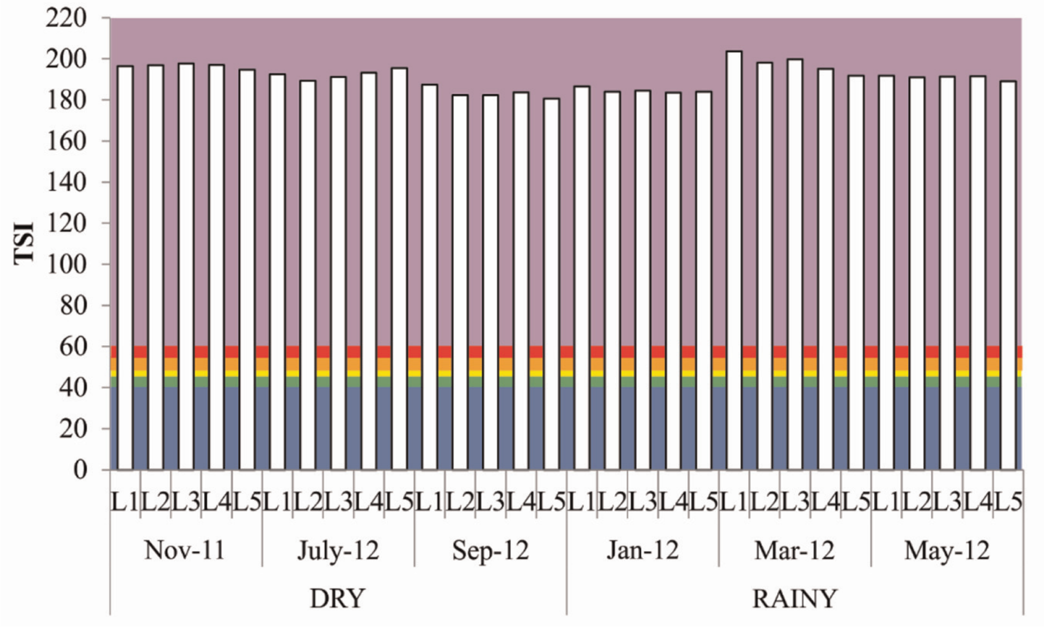

Figure 5.
Representation of the trophic state index (TSI) in Jansen lagoon, São Luís-Maranhão: ultraoligotrophic (blue), oligotrophic (green), mesotrophic (yellow), eutrophic (orange), supereutrophic (red), and hypereutrophic (purple).

TSI							
	Dry			Rainy			
Sampling point	**Nov-11**	**July-12**	**Sep-12**	**Jan-12**	**Mar-12**	**May-12**	**Spatial average**
L1	196	192	187	187	204	192	193
L2	197	189	182	184	198	191	190
L3	198	191	182	185	200	191	191
L4	197	193	184	184	195	192	191
L5	195	195	181	184	192	189	189
Temporal average	197	192	183	185	198	191	

Table 8.
Spatial-temporal means of TSI values according to Lamparelli [18] in Jansen lagoon, São Luís-Maranhão.

Comparing the values obtained in the final TSI, it was possible to observe a small variation in the degree of eutrophication. In this perspective, in a general average for the sites, L1 was considered the most eutrophic and L5 as the less eutrophic (**Table 8**). Regarding the sampling campaigns, Mar-12 was the most eutrophic because it had maximum values of the TSI (TP) and the TSI (Chl *a*) and the least eutrophic was set/12 because it had high values for the TSI (TP) only.

This scenario is explained by the high concentration of total phosphorus available in the system and because it has not been considered as a limiting element for photosynthetic organisms, since even though it was being consumed, there was still a large amount of it.

Regardless of the sampling site or campaign, Jansen lagoon was classified as hypereutrophic, because according to the classification of Lamparelli [18], all sites obtained a weighting of 5, which equals TSI values above 67.

The trophic level observed in this study through the use of the TSI showed to be very high, being even higher than what is reported for other environments that also suffer from cultural eutrophication as verified by Knoppers et al. [44] in six coastal lagoons in Rio de Janeiro (Brazil), Herrera-Silveira et al. [45] in three coastal

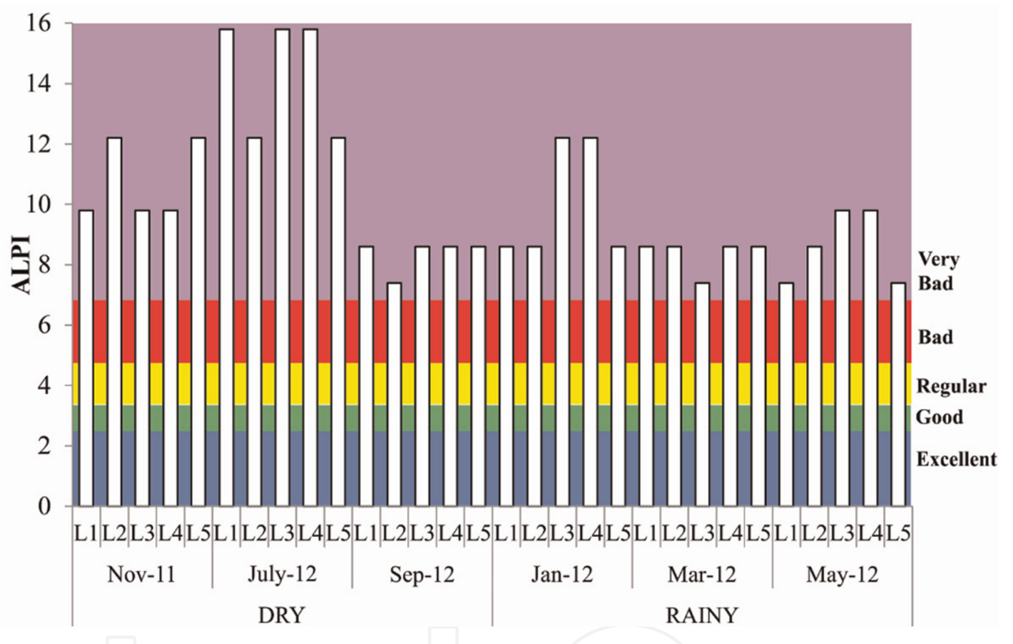

Figure 6.
Representation of the aquatic life protection index (ALPI) at Jansen lagoon, São Luís-Maranhão.

ALPI							
Sampling point	Dry			Rainy			Spatial average
	Nov-11	July-12	Sep-12	Jan-12	Mar-12	May-12	
L1	9.8	15.8	8.6	8.6	8.6	7.4	9.8
L2	12.2	12.2	7.4	8.6	8.6	8.6	9.6
L3	9.8	15.8	8.6	12.2	7.4	9.8	10.6
L4	9.8	15.8	8.6	12.2	8.6	9.8	10.8
L5	12.2	12.2	8.6	8.6	8.6	7.4	9.6
Temporal average	10.8	14.4	8.4	10.0	8.4	8.6	

Table 9.
Mean values of the aquatic life protection index (ALPI) according to Zagatto et al. [17] modified by CETESB [32] in Jansen Lagoon, São Luís-Maranhão.

lagoons in Yucatán (México), and Fia et al. [46] in Mirim lagoon (Brazil). These authors also observed that cultural eutrophication plays an important role in the determination of water quality, besides influencing the self-purification capacity of the environment, leading to loss of water quality and intensification of the eutrophication process.

Therefore, the use of these waters for any secondary contact activity (recreation and amateur fishing-subsistence) is not appropriate, as for these purposes, the acceptable trophic state in environments such as lakes is mesotrophic or even slightly eutrophic [15].

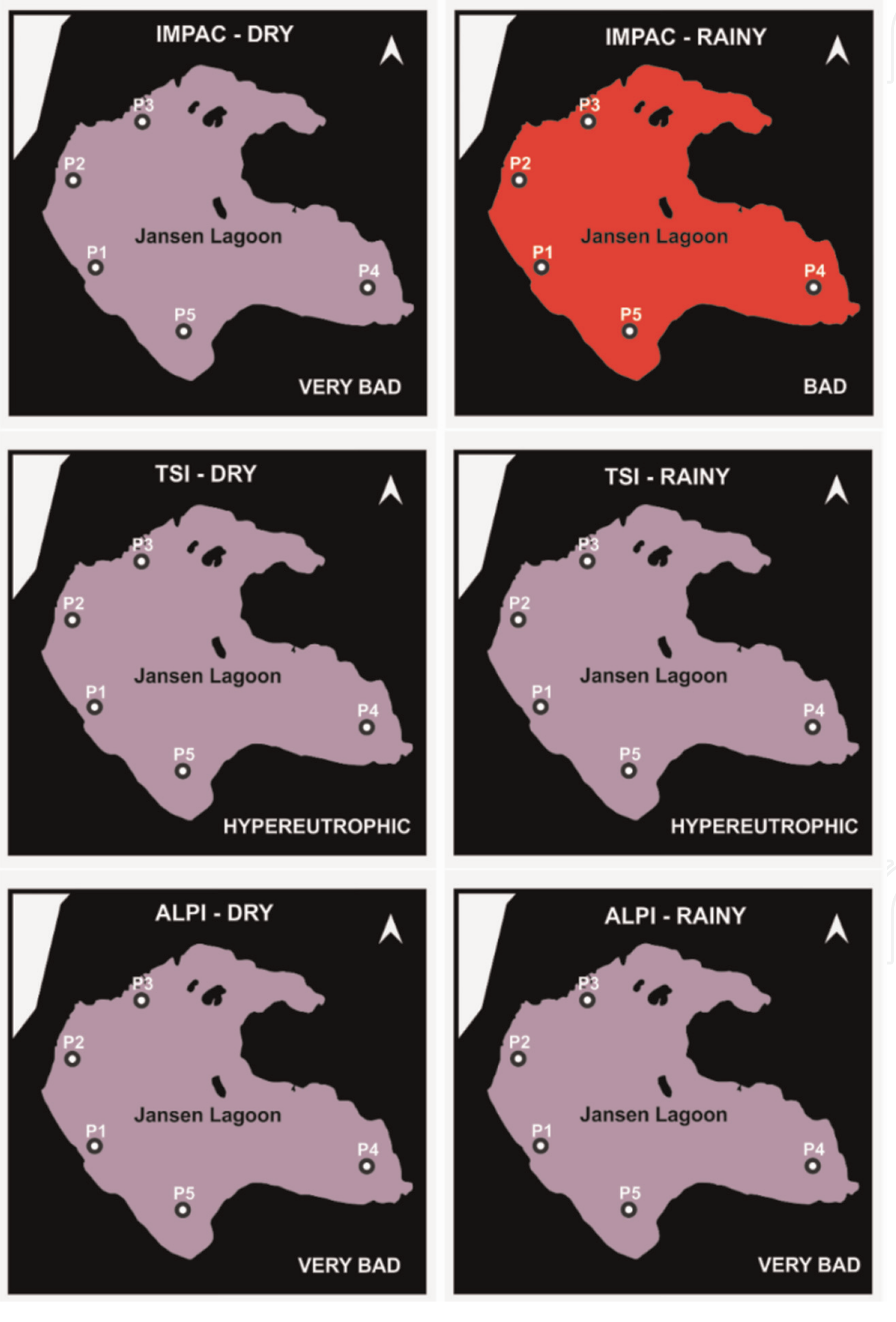

Figure 7.
Representation of IMPAC (index of minimum parameters for the protection of aquatic communities), TSI (state trophic index), and ALPI (aquatic life protection index) classification categories at Jansen Lagoon, São Luís-Maranhão.

4.2.3 Aquatic life protection index (ALPI)

The general characterization of water quality in the Jansen lagoon from the ALPI interpretation was classified as bad, with values of 11.16 in the dry season and 9.0 in the rainy season (**Figure 6**).

Knowing that the first two indexes have already shown that water quality in Jansen lagoon is not suitable for the activities indicated for class 2 brackish waters, according to CONAMA 357/05 [30], it is confirmed by the ALPI which classifies this environment as inappropriate. The weightings obtained from the ALPI calculation were above 6.8 resulting in a very bad classification. It can be observed that the poor water quality was more critical at the site L4 and in the July-12 campaign, with average weightings of 10.8 and 14.4 (**Table 9**), respectively.

Comparing the weightings obtained from the first two indexes with the weightings obtained from the ALPI calculation, it was observed that the higher IMPAC weightings were responsible for raising the weightings of the ALPI in 30% of the sites monitored, mainly in July-12, being again the campaign with a higher degree of impairment of water quality. Thus, it was verified that the worst weightings defined the final value of the index [9]. The result obtained through the ALPI index for the Jansen lagoon was much higher when compared to the environments studied by Coelho [47] and Barbosa [9]. Besides, they do not have a constant classification pattern in relation to the TSI as verified in this study.

Based on CONAMA Resolution [30], which was used to classify the waters of the Jansen lagoon, the preponderant conditions verified through the application of the indexes and the limits established for each environmental parameter analyzed showed that this lagoon environment is very much affected by a loss of water quality and decreased protection of aquatic life.

In this scenario, the application of IMPAC and TSI showed that the renewal of the water of Jansen lagoon by the spring tides is not enough to improve its quality. According to Schettini [48], this deterioration in coastal lagoons is favored by their morphometry that makes them more susceptible mainly due to the exchange with the ocean and the increase in the time of renovation; for this environment, the ideal would be around 90% every 28 days if all polluting sources were eliminated. In view of this situation, the Jansen lagoon does not have a spatial and temporal difference, with poor water quality, subject to the conditions of the environmental descriptors, trophic degree, and toxic substances (**Figure 7**).

5. Conclusion

The ALPI showed that the Jansen lagoon has a very high degree of deterioration reflecting poor water quality that could endanger the local aquatic biota, with inappropriate conditions for reproduction, stages of development, and the permanence of aquatic organisms, reflecting a framework of environmental degradation of the area.

The use of IMPAC and TSI to obtain the ALPI was an effective tool for the quantification and representation of the degree of deterioration of water quality and, consequently, in the evaluation of the extreme conditions that the aquatic biota that inhabit in the lagoon is subjected to, besides showing the importance of the tides for the underestimation of the detected values for each parameter analyzed, being an important auxiliary element in the self-purification of this environment.

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