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Preliminary analysis on the use of Trophic State Indexes in a brazilian semiarid reservoir

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ABSTRACT. The Carlson's (1977) Trophic State Index (TSI) is a widely employed tool to estimate the degree of eutrophication in a reservoir. In Brazil, the need of a classification system that would take into account regional characteristics employed adjusted indexes generated by data from reservoirs in the southeastern region of the country. Current research compares responses for Carlson's TSI (1977) and its derivations for Brazilian reservoirs from data collected in the Pereira de Miranda Reservoir (State of Ceará, Brazil), and analyzes the influence of local conditions on results and their applicability to reservoirs in the semiarid region. TSIs were calculated by data on total phosphorus, chlorophyll *a* and water transparency. The reservoir was estimated as mesotrophic based on the chlorophyll *a* variable, and between eutrophic and hyper-eutrophic when based on total phosphorus data and water transparency. Results showed the need to consider intrinsic factors in the discussion on the applicability of TSIs to reservoirs in the semiarid region since the peculiar hydro-climatic conditions and morphometric characteristics make them even more vulnerable to disturbance agents, such as winds which have a significant influence on processes that determine the trophic state.

Keywords: hydro-climatic conditions, eutrophication, limiting nutrient, phosphorus, nitrogen, chlorophyll *a*.

Análise preliminar sobre uso de Índices de Estado Trófico em um reservatório do semiárido brasileiro

RESUMO. O índice de estado trófico (IET) de Carlson (1977) é uma ferramenta muito utilizada para estimar o grau de eutrofização de reservatórios. No Brasil, a necessidade de um sistema classificatório que levasse em consideração as peculiaridades regionais resultou em derivações do índice original. O objetivo desta pesquisa foi comparar as respostas do IET de Carlson (clima temperado) e dos índices modificados para reservatórios do sudeste brasileiro (clima subtropical) originadas para dados do açude Pereira de Miranda e analisar a influência das condições locais sobre esses resultados, discutindo-se a sua aplicabilidade para a região semiárida do Brasil. Os índices de estado trófico foram calculados a partir dos valores de clorofila *a*, fósforo total e transparência da água. O estado trófico do açude foi estimado como mesotrófico, com base na variável clorofila *a*, e entre eutrófico e hipereutrófico, com os dados de fósforo total e de transparência da água. A partir dos resultados, observa-se a necessidade de considerar fatores intrínsecos na discussão sobre a aplicabilidade desses índices para os reservatórios do semiárido, especialmente quando as variáveis hidroclimáticas e morfométricas os tornam ainda mais vulneráveis a distúrbios, a exemplo do vento, que tem influência significativa sobre os processos que determinam o estado trófico.

Palavras-chave: condições hidroclimáticas, eutrofização, nutriente limitante, fósforo, nitrogênio, clorofila *a*.

Introduction

Climate conditions, hydrological regime and pollution loads from rural and urban anthropogenic activities are some of the factors which act in a peculiar way over the dynamics of limnological processes in semiarid region reservoirs. They have a significant influence on changes in the systems' trophic conditions, characterized by increase in nutrient concentrations and phytoplankton biomass (CHELLAPPA et al. 2008; CHELLAPPA; COSTA, 2003; SILVA, 2004; ESKINAZI-SANT'ANNA et al., 2007; FIGUEIRÊDO, et al., 2007; VIEIRA et al., 2009; ROLAND et al., 2012; MOLISANI et al., 2013; OLIVEIRA et al., 2015).

Several attempts to estimate the trophic state of lakes, reservoirs and rivers under qualitative and quantitative criteria are available in the literature (CARLSON, 1977; KRATZER; BREZONIK, 1981; TOLEDO JUNIOR et al., 1983; WALKER JUNIOR, 1984; CARLSON; SIMPSON, 1996; CUNHA et al., 2013) which highlights the technical and scientific importance of quantifying and understanding trophic conditions in continental aquatic systems. Accordingly, it is highly relevant to perform space-time studies of trophic conditions on Brazilian semiarid reservoirs to discuss their ecological functioning and to identify key cause and effect factors related to the eutrophication process.

Carlson (1977) adopted the algal biomass as basic reference to define the trophic state and formulate a numeric rating system from variables related to aquatic environment trophic conditions. The Trophic State Index (TSI), the name given for this classification system, has become widely used in natural lakes and reservoirs of several continents. Since the index was originally based on data obtained in glacial-origin lakes of temperate zones, its unrestricted use in other climatic regions has been criticized.

Considering some intrinsic factors mentioned by CASTAGNINO (1982), CUNHA et al. (2013), SALAS; MARTINO (1991) and TOLEDO JUNIOR et al. (1983), including the local climate and limnological peculiarities, Brazilian researchers identified the need of changes in methodological approaches for assessing the trophic state. Toledo Junior et al. (1983) were pioneers and proposed adjustments in the original Carlson's Index (1977) for use in tropical and subtropical reservoirs in the Brazilian southeastern region, also comprising an equation related to reactive soluble phosphorous. In comparison to the amount of data used previously by Toledo Junior et al. (1983), more recently Cunha et al. (2013) proposed adaptations to the Carlson's Index (1977) based on a larger set of data from reservoirs located in the Brazilian tropical/subtropical region.

However, within the attempts and evolution on trophic estimate propositions, none included data from reservoirs in the semiarid regions of Brazil, which are vulnerable to recurrent annual rainfall below historical averages and inter-annual periods of drought, with such consequences as water level reduction, increased residence time and physical instability on the water column caused by rainy years or the action of wind (CÂMARA et al., 2009; CHELLAPPA et al., 2009; VIEIRA et al., 2009; MOLISANI et al., 2010; BARBOSA et al., 2012; BITTENCOURT-OLIVEIRA et al. 2012; DANTAS et al., 2012; CHAVES et al., 2013).

Current research compares responses by Carlson's Trophic State Index (1977) and those of indexes adapted by Toledo Junior et al. (1983) and by Cunha et al. (2013) on data from the Pereira de Miranda reservoir in the semiarid region of the state of Ceará, Brazil, by analyzing the influence of local climatic conditions on these index results and making initial considerations about their applicability on reservoirs in the semiarid region of the Brazilian Northeastern region.

Material and methods

Description of area and its characteristics

The Pereira de Miranda Reservoir lies within the Curu river basin, in the municipality of Pentecoste, northern region of the state of Ceará, Brazil (Figure 1). The reservoir retains the water flow of the rivers Canindé and Capitão Mor, enabling flow control to human, agricultural and industrial supplies, as well as regulating the flow and flood control in the downstream stretch of the river Curu. Its storage capacity is 360 hm^3, with maximum depth reaching 19.8 m and average 7.2 m; basin area of 3,254 km^2; area 5,040 ha and hydraulic basin perimeter of 126 km. Since its construction in 1957, the reservoir storage capacity declined 9% (35.6 hm^3) which reflects the great volume of mineral and organic load from the watershed. Decrease reaches a dead volume of 9.3 hm^3 (CEARÁ, 2014).

Local climate is BSw'h' (KÖPPEN, 1948), characterizing the region as hot and semiarid with rains during summer and autumn. The rainfall regime is irregular in time and space, with scarcity of rainfall and periodic droughts of varying intensities. Owing to these conditions, runoff and tributary flows occur only during the rainy season (CEARÁ, 2014). The historical average precipitation is 781.2 mm (1974 to 2013) and the rainy season occurs between February and May (CEARÁ, 2013). The basin's soil features slight depth with vulnerability to water deficiency, salinization and erosion. Its predominant phytoecology unit is the Dense Shrubby Caatinga (CEARÁ, 2007).

Sampling and analytical procedures

Sampling was carried out monthly between 2012 and 2013, from 9h00 am to 3h00 pm at five sites (Figure 1) in the pelagic (P1), intermediate (P2 and P4) and fluvial (P3 and P5) regions. Water samples were collected with van Dorn bottles at 0.5 m below the surface and 0.5 m above the bottom. They were used to determine chlorophyll *a* (Chl *a*), total nitrogen (TN), total phosphorus (TP) and turbidity.

The laboratory analytical methods (Table 1) are described in Eaton et al. (2005). Variables were determined in the Laboratory of Effluents and Water Quality (EQUAL) of the Institute of Sea Sciences (LABOMAR) at the Universidade Federal do Ceará (UFC). Water transparency was measured with a secchi disc (Ø = 25 cm), while turbidity rates were obtained on the field with a portable turbidity meter immediately after each collection.

Concentrations of total nitrogen and total phosphorus obtained on the surface were used to estimate the limiting nutrient, while concentrations of chlorophyll *a* and total phosphorus on surface and water transparency rates were essential to calculate the trophic state indexes and to estimate the trophic conditions of the Pereira de Miranda Reservoir.

TN:TP ratio, limiting nutrient and trophic state indexes

Ratio mass determinations between total nitrogen and total phosphorus (TN:TP) and the nutrient limiting estimate to primary productivity in the Pereira de Miranda Reservoir were performed from TN:TP ratios established in the research conducted in temperate zones and adopted for subtropical and tropical regions (TOLEDO JUNIOR et al., 1983; SALAS; MARTINO, 1991; CUNHA et al., 2013).

The Trophic State Indexes (TSIs) and qualitative criteria applied in current study were derived from Carlson (1977), Carlson and Simpson (1996), Toledo Junior et al. (1983), Toledo Junior (1990) and Cunha et al. (2013). The resulting rates of these indexes were used to prepare the chart of differences between the TSI for Chl *a* and the TSIs for TP and SD, and the amplitude variation analysis between the indexes.

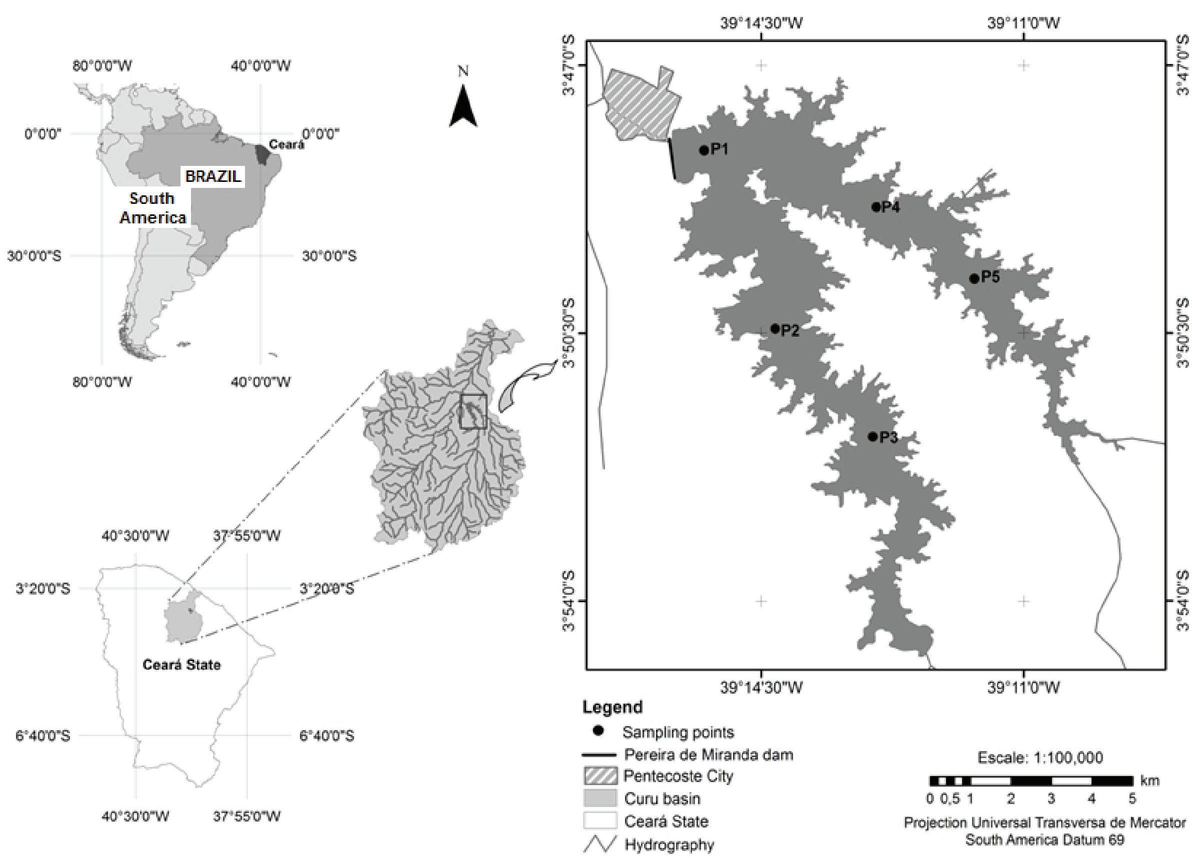

Figure 1. Geographical location of the Pereira de Miranda Reservoir (Pentecoste, Ceará, Brazil) and the sampling stations. Source: Researcher, 2014.

Table 1. Analytical methods used to determine total nitrogen (TN), total phosphorus (TP) and chlorophyll a (Chl *a*).

Variable	Method	Reference
Total Nitrogen	Persulfate digestion; cadmium column	4500-P J.; 4500- NO_3 E.
Total Phosphorus	Persulfate digestion; Ascorbic acid	4500-P J.; 4500-P E.
Chlorophyll *a*	Spectrophotometric; extraction with acetone	10200 H.

Source: Researcher, 2014.

Hydro-climatic data

Monthly rainfall and monthly historical average data were provided by the Fundação Cearense de Meteorologia – FUNCEME, while stored volume, average depth and residence time were calculated by the Companhia de Gestão de Recursos Hídricos do Estado do Ceará – COGERH. The hydro-climatic analysis was retrieved up to 2009 to better understanding the temporal variability acting on the Pereira de Miranda basin in the Ceará's semiarid region.

Statistical analyses

Pearson's correlation analysis was carried out to better understand the nature and strength of the relationship between total phosphorus, total nitrogen, chlorophyll *a*, turbidity and transparency of water. The pairs of variables with statistically significant correlation ($p < 0.05$) underwent linear regression analysis. Prior to regression analysis, the data were log transformed and analyses were done with the Statistica 8.0 by using the entire data set collected during the biennium 2012-1013.

Results

Hydro-climatic data

Limnological dynamics in the Pereira de Miranda Reservoir was influenced by a rare hydro-climatic scenario structured between 2009 and 2013. During this 5-year period, the third largest annual rainfall (1460.7 mm; 2009) and the third (301.7 mm; 2012) and fourth (418.2 mm; 2010) greatest drought in the last 39 years were observed. In 2011, it rained 1045.1 mm, which was higher than the annual historical average (781.2 mm), with a default behavior in the wettest months (February to May); however, the rainy season came earlier, in January (174.1 mm).

Whereas between April and July 2009, the volume of the Pereira de Miranda Reservoir exceeded the maximum quota, with water overflow in December 2013, corresponding to the final sampling period, its storage capacity was close to 5% (18.01 hm^3). During the period under analysis, the theoretical residence time ranged from 27.1 days in May 2009 to 1121.3 days in December 2013, while the average depth ranged from 7.2 m (July 2009) to 2.2 m (December 2013).

Nutrients, ratio TN:TP, chlorophyll *a* and water transparency

The initial proposal was to perform limnological studies over two years with data obtained in five sample stations. However, since October 2013, the water level in the Pereira de Miranda Reservoir decreased so much that it became impossible to collect samples on the fluvial region (P3 and P5). Hence, between October and November 2013, it was not possible to collect samples or compare data obtained in the fluvial and other regions.

There were similar concentrations of nutrients and chlorophyll *a* between the surface and the bottom. Their monthly variation was also similar during the research period (2012 and 2013). The monthly variation of total phosphorus (Figure 2a) and total nitrogen (Figure 2b) had a similar pattern among the five collection points, including heavy increments of total phosphorus (December 2012) and total nitrogen (October 2012 and June 2013).

TP concentrations ranged between 0.023 mg L^{-1} (January 2013; P2) and 0.275 mg L^{-1} (December 2012; P3). The largest concentrations were detected in the fluvial region (P3 and P5), while the lowest amplitude among the monthly variations was observed at the deepest sites (P1, P2 and P4). This behavior was not evident for TN, which had its maximum rate (6.722 mg L^{-1}) observed in October 2012, next to the dam (P1), and minimum rates in April 2013, at P3 and P4 (0.199 and 0.293 mg $L^{-1,}$ respectively).

Most results showed chlorophyll *a* concentrations with less than 10 μg L^{-1}, varying little in spatial and temporal scales (Figure 2c). Although increased algal biomass occurred in June during the two years of research, maximum rates were recorded in the intermediate region (P2 and P4) in October 2013.

Water transparency rates decreased during the sampling period, with a maximum of 1.30 m in April 2012 (P1) and a minimum of 0.10 m in April and October 2013 (P4 and P5). The highest rates were obtained on the lacustrine region (P1) and lower rates were on the fluvial region (P3 and P5), as shown in Figure 2d. Taking the five sites into account, the highest monthly average occurred between January and July 2012 (0.70 to 0.90 m) and the lowest from February 2013 (0.20 to 0.40 m). Spatial and temporal variation of turbidity rates (Figure 2e) showed an inverse pattern observed on water transparency, or rather, greater in the fluvial region and increasing during the research, especially in 2013.

Monthly distribution pattern of total nitrogen and total phosphorus mass ratios (Figure 2f) was similar on the sampling stations, with peaks in March 2012, October 2012 (maximum value in P1), January and June 2013 (very close rates) and September 2013. In February and April 2013, the ratio TN: TP was often less than 20:1, with lower rates in P4 (intermediate region) and P3 and P5 (fluvial region). Based on NT: TP stoichiometric proportions, results have indicated phosphorus as a possible limiting nutrient most of the year in the Pereira de Miranda Reservoir.

Trophic state indexes

Table 2 summarizes results from Trophic State Index (TSI) by Carlson (1977), TSI adapted by Toledo Junior et al. (1983) and TSI adapted by Cunha et al. (2013). The magnitude of rates on Carlson's TSI and its adaptations resulted in a mesotrophic estimate according to Chl *a* concentration, disagreeing with eutrophic, supereutrophic and hypereutrophic estimates results from TSIs to TP and SD.

The differences between TSI for Chl *a* and TSIs for PT and SD are shown in Figure 3 and were restricted to the same chart area formed by axes in which negative rates of Chl *a* TSIs were smaller than those observed on TSI for TP and SD.

Statistical analysis

In 2012 and 2013, Pearson's correlation analysis revealed significant ($p < 0.05$) correlations (Figure 4) to the same variables between the surface and the bottom data. Considering the total of data from surface and bottom in 2012 and 2013, there was a significant correlation ($p < 0.05$) between total phosphorus, turbidity and water transparency, and between total nitrogen and chlorophyll *a*.

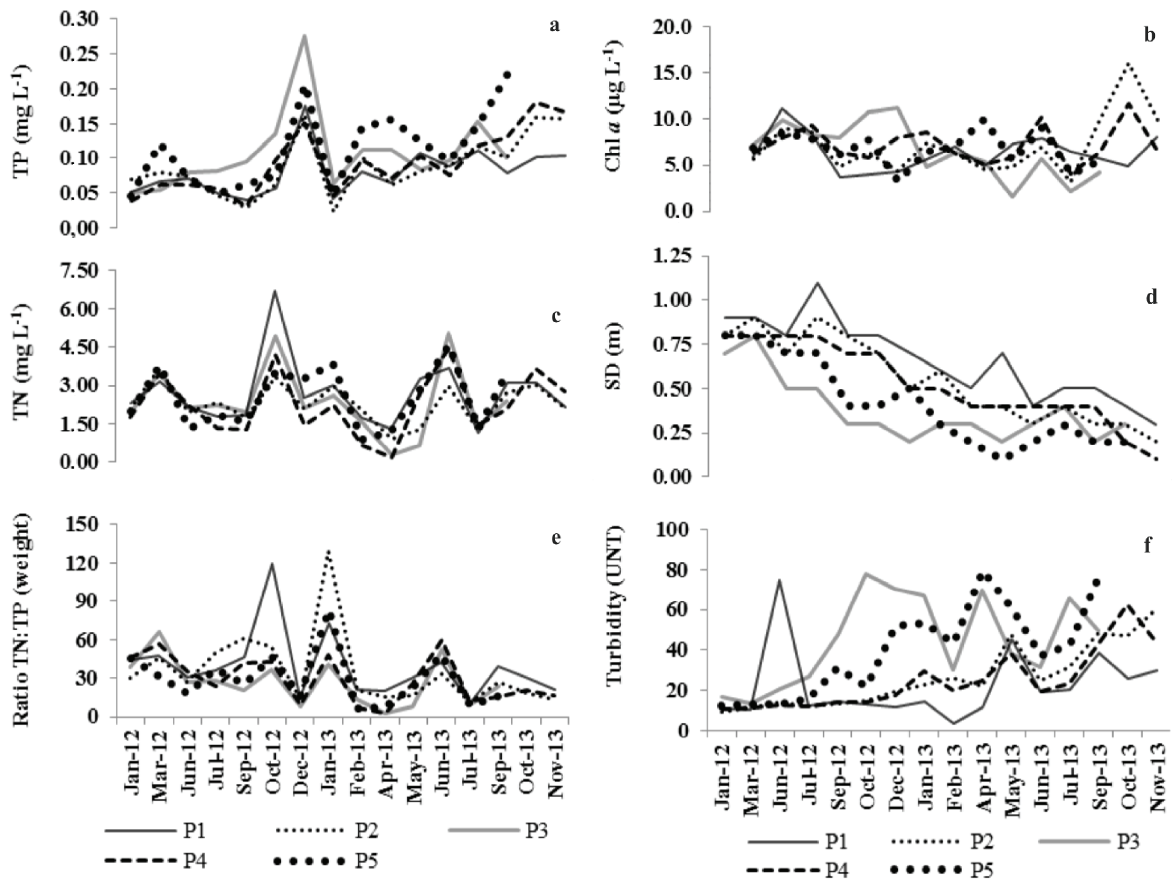

Figure 2. Monthly variation of total phosphorus, PT, (a), total nitrogen, NT, (b), chlorophyll *a*, Chl *a*, (c), (d) water transparency, SD, turbidity (e) and ratio TN:TP (f), corresponding to the surface of the five sites, Pereira de Miranda Reservoir (Pentecoste, Ceará, Brazil), 2012 and 2013. Source: Researcher, 2014.

Table 2. Number of data (N), mean, trophic class, standard deviation (SD), minimum and maximum values of index trophic state (Chl *a*, SD and PT) generated from data obtained in the Pereira de Miranda Reservoir, (Pentecoste, Ceará, Brazil), 2012 and 2013.

Authors (Date)	TSI/Variable	N	Mean	Trophic Class	SD	Min.	Max.
Carlson (1977); Carlson and Simpson (1996)	TSI (Chl *a*)	71	48.8	M	3.8	34.7 (O)	57.8 (E)
	TSI (SD)	81	71.4	H	8.0	56.2 (E)	93.2 (H)
	TSI (TP)	81	68.1	E	6.9	49.5 (E)	85.2 (H)
Toledo Junior et al. (1983); Toledo Junior (1990)	TSI (Chl *a*)	71	49.2	M	3.9	34.8 (O)	58.5 (E)
	TSI (SD)	81	62.1	E	8.0	47.0 (M)	84.0 (H)
	TSI (TP)	81	60.7	E	6.9	42.1 (O)	77.7 (H)
Cunha et al. (2013)	TSI (Chl *a*)	71	54.6	M	1.4	49.4 (U)	57.9 (E)
	TSI (TP)	81	58.5	S	1.9	53.3 (M)	63.2 (H)

Ultraoligotrophic (U); Oligotrophic (O); Mesotrophic (M); Eutrophic (E); Supereutrophic (S); and Hypereutrophic (H).

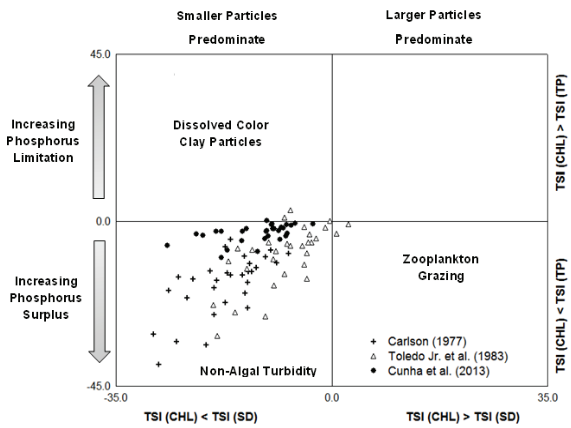

Figure 3. Graphic showing differences [TSI (Chl *a*) - TSI (TP)] versus [TSI (Chl *a*) - TSI (SD)] and possible interpretation on deviations of rates of the Trophic State Index (TSI) of Carlson (1977), Toledo Junior et al. (1983) and Cunha et al. (2013) from data obtained in the Pereira de Miranda Reservoir (Pentecoste, Ceará, Brazil), 2012 and 2013. Source: Adapted from Carlson and Havens (2005).

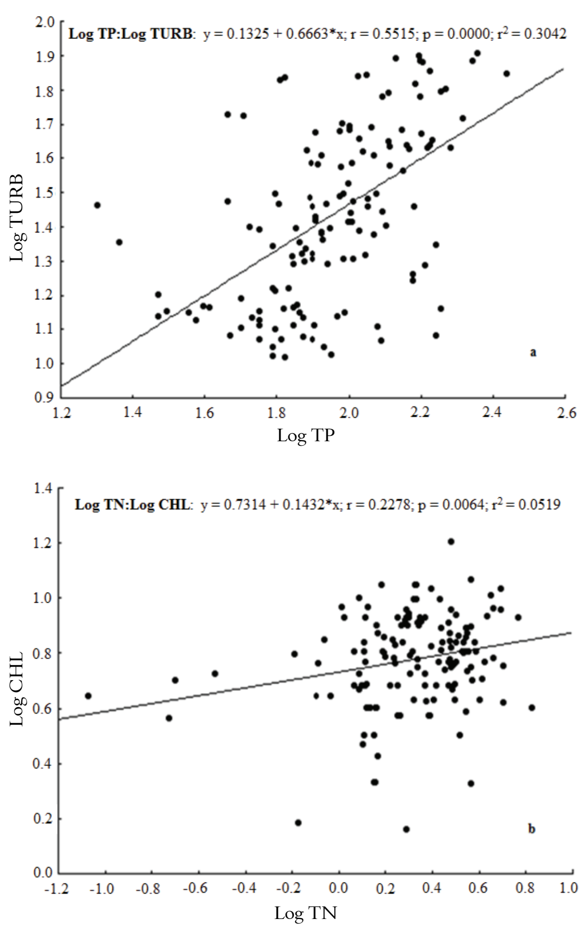

Figure 4. Linear regression analysis for significant correlationships ($p < 0.05$) between log-transformed data from turbidity and total phosphorus (a) and chlorophyll *a*, and total nitrogen (b) from data obtained in the Pereira de Miranda Reservoir (Pentecoste, Ceará, Brazil), 2012 and 2013. Source: Researcher, 2014.

Discussion

Underwater radiation and nutritional conditions are among the main factors controlling photosynthetic production and phytoplankton growth (HENRY et al., 2006). If nutrients are available, the largest primary productivity occurs in periods of physical stability observed in the summer on temperate zone lakes and between seasonal events of wind and rainfall in subtropical and semiarid tropical zones (BOUVY et al., 2003; CHELLAPPA et al., 2009; CHAVES et al., 2013), especially in periods of greater water volume or in the lacustrine region of reservoirs (MOLISANI et al., 2013).

Nonetheless, frequent instabilities in the water column may be verified naturally in reservoirs due to external factors (rain and wind) (DANTAS et al., 2008; CHELLAPPA et al., 2009; FREIRE et al., 2009; CHAVES et al., 2013; MOLISANI et al., 2013), operational (as water release regime) (RANGEL et al., 2012) and internal processes (stratification and water mass circulation) (BITTENCOURT-OLIVEIRA et al., 2012; DANTAS; BITTENCOURT-OLIVEIRA E MOURA, 2010; DANTAS, MOURA E BITTENCOURT-OLIVEIRA, 2011; DANTAS et al., 2008; CHELLAPPA et al., 2009; DANTAS et al., 2012). These factors may act together by restricting or triggering primary productivity of the systems.

In some Brazilian semiarid regions, annual variation in trophic status indicators is associated with seasonal fluctuations in hydrological regime, led by rains during the first half of the year (BOUVY et al., 2003; CHAVES et al., 2013; CHELLAPPA; COSTA, 2003). In the second half, this variation is associated with stronger winds; in addition, it is increased by the lower average depth in reservoirs at this time of year (BRAGA et al., 2015; ESKINAZI-SANT'ANNA et al., 2007; FREIRE et al., 2009; DANTAS et al., 2012).

In the Pereira de Miranda Reservoir, inexpressive water contribution during the rainy season associated with anthropogenic consumption demands and high potential evapotranspiration resulted in significant water level reduction, with an increase in residence time. These factors intensify vulnerability on physical (turbulent mixing), chemical (internal inputs of nutrients) and biological (greater abundance of cyanobacteria) factors in Brazilian semiarid reservoirs (BOUVY et al., 2003; FIGUEIRÊDO et al., 2007; FREIRE et al., 2009; BARBOSA et al., 2012).

In this scenario, limnological conditions in the Pereira de Miranda Reservoir resulted from climatic conditions other than those in which rains in the first half have a strong influence on water transparency, nutrient intake and changes on phytoplanktonic community structure. (BOUVY et al., 2003; CHELLAPPA; COSTA, 2003; CHELLAPPA et al., 2009).

The drought between 2012 and 2013 in the Pereira de Miranda Reservoir region gave rise to hydraulic and morphometric characteristics that favored wind as a factor of disturbance, particularly during the second half of the year. The establishment of these conditions is acknowledged as one of the main determining factors for the re-suspension of bottom sediments and the consequent internal load of nutrients, besides decreasing the optical quality of the water column (SOUSA et al., 2008; FREIRE et al., 2009; FREITAS et al., 2011). This hypothesis was strengthened by a significant correlation between turbidity and total phosphorus variables when all data from the two years of study are taken into account.

Continuous reduction of water transparency observed in periods of drought (FREIRE et al., 2009) and chlorophyll *a* concentrations below the expected with regard to phosphorus availability reinforces the existence of physical instability conditions in the Pereira de Miranda Reservoir. Therefore, weak correlation between 'TP and Chl *a*' and between 'SD and Chl *a*' may have been the result of limnological conditions established by hydro-climatic factors intensified during drought, common in Brazilian semiarid regions.

After studying limnological conditions on 136 lakes and 56 reservoirs in many countries, Huszar et al. (2006) concluded that climatic conditions may interfere in TP-Chl *a* relationship. The authors identified the correlation between the two variables obtained in tropical and subtropical aquatic systems as lower and more variable than those in temperate zones. Thus, the climatic peculiarities of the Brazilian semiarid region may increase amplitude variation in limnological variables, such as those observed in the Pereira de Miranda Reservoir.

As a consequence of weak co-relationship between expressive 'TP and Chl *a*' and 'SD and Chl *a*', the rates generated by Trophic State Indexes of chlorophyll *a*, total phosphorus and water transparency were different from each other, resulting in distinct trophic classification for each variable. The above was valid for TSIs by Carlson (1977), by Toledo Junior et al. (1983) and by Cunha et al. (2013). From Chl *a* concentration, the mesotrophic estimate - in disagreement with eutrophic, supereutrophic and hypereutrophic estimates - resulted in TSIs for TP and SD, reinforcing that assumptions established by Carlson (1977) from exclusive correlations between 'TP and Chl *a*' and 'SD and Chl *a*' were not observed in the Pereira de Miranda Reservoir.

In his initial proposition, Carlson (1977) acknowledged the restrictions of his index to greater instability conditions, such as the ones commonly observed in the shallow reservoirs of the Brazilian semiarid regions (BOUVY et al., 2003; CHELLAPPA et al., 2009; BARBOSA et al., 2012). According to Carlson (2007), high non-algal turbidity in shallow reservoirs interferes in the results of other variables and may cause distinction between the index results. Toledo Junior et al. (1983), Walker Junior (1984) and Cunha et al. (2013) also credited limited algal biomass production to non-algal turbidity.

Differences between TSI for Chl *a* and TSIs for TP and SD in data of the Pereira de Miranda Reservoir may be partially explained by turbidity influence as a controlling factor of algal biomass due to limited underwater radiation. According to Carlson and Haven (2005), similar scenarios are related to light limitation caused by non-algal turbidity, (inorganic and/or organic) and increased concentrations of total phosphorus, as observed in the Pereira de Miranda Reservoir mainly during the period of lowest average depth and greater wind action.

Hence, due to regional particularities, including climatic, hydrological and environmental factors, the correlation degree between limnological variables have been assessed on the adequacies of the original Carlson's Trophic State Index (1977), aiming to reduce the TSI amplitude results obtained from each variable. As noted (Figure 3), the adjustments made by Cunha et al. (2013) resulted in a smaller amplitude on differences between TSI for Chl *a* and TSI for TP. The above suggests that adjustments made by these authors included part of the data variability observed in the Pereira de Miranda Reservoir.

Although Carlson (1977) has considered chlorophyll *a* as a primary algal biomass estimator and TSI for Chl *a* as a priority to estimate the trophic state of aquatic systems, the unique correlation between 'TP and Chl *a*' and 'SD and Chl *a*' may not occur under limnological conditions in the Pereira de Miranda Reservoir mainly in the inter-annual drought period.

Nevertheless, phosphorus and chlorophyll *a* are still variables listed as best suited to estimate the trophic state of aquatic systems, recognizing phosphorus as an indicator variable of potential eutrophication and chlorophyll *a* as a response variable resulting from the interaction of limnological factors (CARLSON, 1977; TOLEDO JUNIOR et al., 1983; CUNHA et al., 2013).

Phosphorus use is recommended in case it is the primary limiting nutrient to algal biomass production in periods of system instability, when the phytoplankton is limited by other factors over phosphorus availability and/or in the absence of chlorophyll *a* data (CARLSON, 1977). Although all these requirements have been observed in the Pereira de Miranda Reservoir, total phosphorus is a secondary estimator of algal biomass used to define the trophic state.

Other variables not included in Carlson's (1977) correlations may show strong relationship with the algal biomass estimator. Total nitrogen at the Pereira de Miranda Reservoir provided significant co-relationship with chlorophyll *a*. Inclusion of total nitrogen in the Trophic State Index was proposed by Kratzer and Brezonik (1981) for systems with limited primary production by total nitrogen.

The choice of the most suitable variable to estimate the trophic conditions in environments with high physical instability and temporal variation on limnological variables will depend on the analysis of multiple factors involved. In tropical and subtropical aquatic systems, Huszar et al. (2006) found that Chl *a* concentration were not related to light extinction caused by mineral turbidity predominant in algal turbidity, although, Chl *a* concentration had been smaller than total phosphorus availability would allow.

When nutrient concentrations are above limiting levels, other factors beyond light limitation may limit or co-limit primary production in reservoirs, such as zooplankton grazing, decrease in residence time (RANGEL et al., 2012), exporting organisms and nutrients downstream during periods of high discharge (CHELLAPPA et al., 2009). In this direction, new surveys are being conducted to examine possible influences of these factors on algal production in the Pereira de Miranda Reservoir.

Conclusion

The TSI's used currently may be restricted to climatic regions to which they were initially proposed. The indexes adapted to Brazilian reservoirs have not included data from semiarid reservoirs; therefore, they do not include the variation range of limnological variables between rainy and dry periods, as observed for the Pereira de Miranda Reservoir. In order to advance in the initial considerations raised in this paper, further research will require more representative data climatic conditions on semiarid reservoirs for more detailed discussions on trophic conditions and adjustments or formulation of trophic state indexes more consistent with local conditions should be undertaken.

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