Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Nutrient concentrations and trophic state of three Andean lakes from Junín, Perú

ARTICLES doi:10.4136/ambi-agua.2525

Received: 02 Feb. 2020; Accepted: 04 Jun. 2020

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ABSTRACT

The study assessed the trophic state of three lakes used as fish farms in the region of Junín-Peru, under different hydrological conditions. Surface water samples were collected from three points at each lake in 2018 during the rainy (March-April) and dry (June-July) seasons. Total phosphorus, turbidity, and chlorophyll-a (Chl-a) were measured. Trophic indexes (TSI Chl-a, and TSI TP) were also computed. The water trophic state categorization was performed by adapting and calculating the Trophic State Index (TSI). The TSI (TP) classified the three lakes in both seasons (rainy and dry) as mesotrophic ($30 < \text{TSI} \leq 60$). Pomacocha and Tipicocha were classified as eutropic ($60 < \text{TSI} \leq 90$) in the two seasons according to TSI (Chl *a*), while Tranca Grande was classified as mesotrophic (also two seasons). The results for TSI showed a predominance of eutrophic and mesotrophic conditions in all lakes used as fish farms.

Keywords: chlorophyll-*a*, lakes, Perú, total phosphorus, Trophic state index.

Concentração de nutrientes e estado trófico de três lagos andinos em Junín, Peru

RESUMO

O estudo tem como objetivo avaliar o estado trófico de três lagos utilizados com piscicultura na região Junín-Peru, sob diferentes condições hidrológicas. Amostras de água superficial foram coletadas em três pontos em cada lago em 2018 nas estações chuvosa (março-abril) e seca (junho-julho). Foram medidos fósforo total, turbidez e clorofila-a (Chl-a). Além disso, os índices tróficos (TSI chl-a e TSI TP) foram calculados. A categorização do estado trófico da água foi realizada por meio da adaptação e cálculo do Índice de estado trófico (TSI). O TSI (TP) classificou os três lagos em ambas as estações (chuvosa e seca) como mesotróficos ($30 < \text{TSI} \leq 60$). Pomacocha e Tipicocha foram classificados como eutrofóficos ($60 < \text{TSI} \leq$

90) nas duas estações de acordo com a TSI (Chl a), enquanto Tranca Grande foi classificada como mesotrófico (também duas estações). Os resultados para TSI mostraram predominância de condições eutróficas e mesotróficas em todos os lagos utilizados para a produção de peixes.

Palavras-chave: *clorofila-a*, fósforo total, índice de estado trófico, lagoas, Perú.

1. INTRODUCTION

Eutrophication is a complex process in which lakes, rivers and coastal waters receive enormous quantities of nutrients (especially phosphorus and nitrogen) and sediments that may cause accelerated growth of algae and other forms of plant life, which produces a disturbance in the aquatic system (Newman, 2005). It is mainly caused by agricultural activities, animal feedlots, sewage water, factories, air pollution and urban areas that release nutrients, which are washed into water ecosystems (Honkanen and Helminen, 2000). Fish farming is also considered an important nutrient source (Honkanen and Helminen, 2000). For example, Jia *et al.* (2015) showed that the use of fish feed and water-purification reagents introduced phosphorus and large quantities of sand-sized minerals such as quartz into the lake, which produced eutrophication. Nordvarg (2001) used predictive models for evaluating eutrophication effects of fish farms in lakes from Sweden and concluded that fish farms increased concentrations of dissolved and total phosphorus, total nitrogen, and chlorophyll. Likewise, Mustapha (2014) reported that eutrophication increased dissolved oxygen depletion, leading to negative impacts on fish growth and production and caused high mortality rates. Smith (2003) examined how eutrophication influences the biomass and species composition of algae in both coastal marine systems and freshwater, concluding that eutrophication causes predictable increases of biomass of algae in lakes, streams, rivers, wetlands, reservoirs, and coastal marine ecosystems.

In estuarine systems (lakes), the eutrophication process has been usually assessed through the determination of trophic state and their categorization into oligotrophic, mesotrophic, or eutrophic systems (Naumann, 1927). Common symptoms of additional nutrients include excessive growth of planktonic and benthic algaes, macrophytes, large pH changes, high turbidity, hypoxia and/or anoxia events, and brown or green water coloration (Adamovich *et al.*, 2019; Brugnoli *et al.*, 2019; Paula Filho *et al.*, 2020; Schindler *et al.*, 2008). The oligotrophic system is characterized by reduced content nutrients, low growth of algae, drinkable and clear water (Margalef, 1983). Mesotrophic systems present a medium level of nutrients with clear waters and the presence of submerged aquatic plants, while eutrophic systems present high levels of nutrients, representing a serious water-quality challenge (Carlson, 1977).

Environmental factors, such as dissolved inorganic nutrients (nitrite, nitrate, orthophosphate, ammonium), algal biomass (chlorophyll-a) and water-transparency status are frequently used to describe eutrophication process (Brugnoli *et al.*, 2019). Likewise, the trophic condition can be assessed by means of unimetric and/or multimetric indexes based on the arithmetical combination of these factors. Unimetric indexes use factors related to water-quality monitoring, employing algorithms or a reference previously established. Nonetheless, multimetric indices provide a better approximation to assess both spatial or temporal aspects of trophic state, and are recommended because they consider biomass production, nutrient enrichment, and oxygen content as factors reflecting the main effects and causes of the eutrophication. The Trophic State Index (TSI) has been used for assessing trophic states on different lakes of South America, Europe, North America, and Asia.

Because of the above, this study assessed the nutrient- and current trophic status of three lakes used to breed rainbow trout and the need for conservation actions.

2. MATERIALS AND METHODS

2.1. Study area

Three lakes that were used as fish farms: i) Pomacocha Lake (473139 E, 8697593 N); ii) Tranca Grande Lake (474549 E, 8703971 N), and iii) Tipicocha Lake (475976 E, 8701280 N) (Figure 1). Table 1 presents some parameters of each lake in the study.

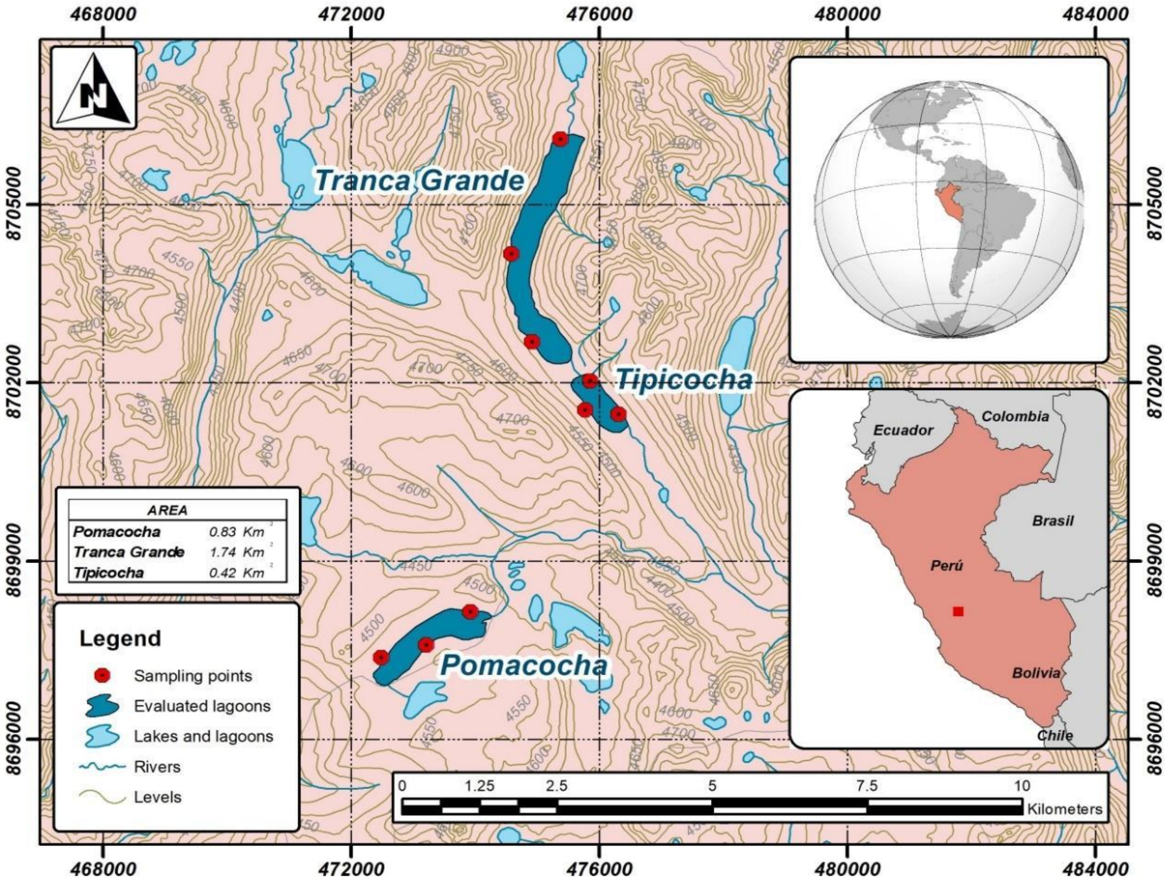

Figure 1. Locations of three lakes used as fish farms. Red points symbolize sampling place.

Table 1. Main parameters of lakes used as fish farms in the Region Junin Peru.

Parameters	Pomacocha	Tranca Grande	Tipicocha
Height (m.a.s.l)	4310	4351	4333
Area (Ha)	120	164	90
Depth (m)	9	25	10

The catchment areas of all of the assessed lakes are used by farmers to breed sheep, cattle, and camelids. In addition, in 1996, rainbow trout farming began in floating cages. The trout are fed with pelletized food. Therefore, both food waste and fecal residue from animals contribute an important quantity of nutrients for each lake system, producing eutrophication (Mariano *et al.*, 2010).

2.2. Sample collection and processing

In total, eighteen samples were collected at the different points set with GPS in two campaigns carried out in 2018: nine samples (three samples at each lake) during the dry season

(June-July), and nine samples (three samples at each lake) during the rainy season (March-April). Samples were collected, refrigerated at 4°C (ANA and MINAGRI, 2016), and transferred to the Water Research Laboratory of the National University of Peru. Total phosphorus concentration (TP), chlorophyll-a (Chl-a) content and turbidity (NTU) were measured.

2.3. Laboratory analysis

Turbidity (NTU) of the samples was measured using a Hanna 93702 portable turbidimeter. Chlorophyll *a* (chl *a*)concentrations (µg/L) were measured by spectrophotometry after extraction in 2:1 chloroform-methanol according to American Public Health Association (APHA) method 10,200 H (APHA *et al.*, 2017) using a FluorPen FP 110 digital fluorometer equipped with two blue and red LED emitters that offer intensities up to 3000 mol (photon)/$m^{-2}.s^{-1}$. Prior *to the* measurement of fluorescence emission, the instrument parameters were set and calibrated. Subsequently, the average of the results was determined by the trophic state index – Chlorophyll *a* TSI (Chl *a*) of each lake was determined. Determination of total phosphorus (TP) was determined by ascorbic acid following current APHA procedures using a LOVIBOND Maxidirect MD600 digital photometer at 660 nm with detectable test range of 0.02 – 1.1 mg/L. The average obtained of these measurements were used posteriorly to calculate the trophic state index – total phosphorus TSI (TP) for each lake.

2.4. Determination of Trophic state index (TSI) for water samples

Trophic state index was computed to determine the trophic state. The trophic index applied was the trophic state index (TSI) proposed by Carlson (1977), considering trophic state index – Chlorophyll *a* TSI (Chl *a*) (µg L^{-1}) in and trophic state index – total phosphorus TSI (TP) (µg L^{-1} P) using Equations 1 and 2, according to Carlson and Simpson (1996). The values of both indexes were determined and categorized according to Table 2.

$$TSI\ (Chl\ a) = 9.81 * ln\ ln\ (Chl\ a) + 30.6\ (range\ Chl\ a = 0.04 - 1180\ \mu g L^{-1}) \tag{1}$$

$$TSI\ (TP) = 14.42 * ln\ ln\ (TP) + 4.15\ (range\ TP = 0.75 - 768\ \mu g L^{-1} P) \tag{2}$$

Table 2. Trophic state index (TSI) scale according (Carlson, 1977).

Chl a (µg L^{-1})	Total phosphorus (µg L^{-1})	TSI	Trophic state
0.04 - 0.94	0.75 - 6	TSI ≤ 30	Oligotrophic
2.6 - 20	12 - 48	30 < TSI ≤ 60	Mesotrophic
56 - 427	96 - 384	60 < TSI ≤ 90	Eutrophic
1183	768	TSI > 100	Hypertrophic

The R Project free software was employed for data analysis (R Team Core, 2019). To examine interlake differences, the t-test and one-way Analysis of Variance (ANOVA) and Tukey post-hoc test were used, to a confidence interval of 95%.

3. RESULTS

Table 3 presents the quality parameters of the water measured at each lake during the dry and wet seasons. Pomacocha Lake showed slightly higher concentrations of TP, Chl *a*, TSI (Chl *a*), and TSI (TP) in the dry season than the rainy season. In contrast, only Chl *a* and TSI (Chl *a*) showed slightly high concentrations during the dry season in Tranca Grande Lake. In Tipicocha Lake, most parameters (except turbidity) showed higher concentrations during the dry season than during the rainy season. The TSI (Chl *a*) and TSI (TP) for the three lakes showed no significant differences ($p<0.05$) for both seasons (Table 3).

Table 3. Water-quality parameters of Lakes Pomacocha, Tranca Grande, and Tipicocha according to the sampling season.

Lake/water quality parameter	Rainy Season	Dry Season
Pomacocha (473139 E - 8697593 N)		
Temperature (°C)	9.3 ± 0.8 a **(A)**	15.5 ± 0.4 b **(A)**
pH	8.9 ± 1.4 a **(A)**	7.3 ± 0.4 a **(A)**
Conductivity (µS/cm)	24.7 ± 4 a **(A)**	4.6 ± 1.3 b **(A)**
TP (ug L^{-1})	21 ± 8.4 a **(A)**	24 ± 2 a **(A)**
Chl a (ug L^{-1})	29.5 ± 3.1 a **(A)**	35 ± 2.0 b **(A)**
Turbidity (NTU)	10.18 ± 0.81 a **(A)**	7.3 ± 1.61 b **(A)**
TSI (Chl *a*)	63 ± 5.1 (eutrophic) a **(A)**	64 ± 5.0 (eutrophic) a **(A)**
TSI (TP)	47 ± 5.1 (mesotrophic) a **(A)**	50 ± 5.8 (mesotrophic) a **(A)**
Tranca Grande (474549 E - 8703971 N)		
Temperature (°C)	13.1 ± 0.8 a **(B)**	16.6 ± 0.9 b **(B)**
pH	7.7 ± 0.2 a **(B)**	9.2 ± 0.1 b **(B)**
Conductivity (µS/cm)	119 ± 28 a **(B)**	4.7 ± 3.1 b **(A)**
TP (ug L^{-1})	20 ± 1 a **(A)**	22 ± 1 a **(A)**
Chl a (ug L^{-1})	6 ± 0.5 a **(B)**	6.5 ± 1.2 a **(B)**
Turbidity (NTU)	9.63 ± 1.1 a **(A)**	7.7 ± 1.01 b **(A)**
TSI (Chl a)	49 ± 5.5 (mesotrophic) a **(B)**	50 ± 5.8 (mesotrophic) a **(B)**
TSI (TP)	47 ± 5.13 (mesotrophic) a **(A)**	47 ± 5.1 (mesotrophic) a **(A)**
Tipicocha (475976 E - 8701280 N)		
Temperature (°C)	11.9 ± 1.4 a **(B)**	15.6 ± 0.5 b **(A)**
pH	8.9 ± 0.4 a **(B)**	8.0 ± 0.3 a **(A)**
Conductivity (µS/cm)	112 ± 29 a **(B)**	4.9 ± 1.5 b **(A)**
TP (ug L^{-1})	21 ± 3 a **(A)**	23 ± 2 a **(A)**
Chl *a* (ug L^{-1})	18.5 ± 0.7 a **(C)**	23.5 ± 0.6 b **(C)**
Turbidity (NTU)	9.83 ± 0.4 a **(A)**	7.8 ± 3.1 b **(A)**
TSI (Chl a)	59 ± 5.5 (eutrophic) a **(A)**	61 ± 5.5 (eutrophic) a **(A)**
TSI (TP)	47 ± 5.1 (mesotrophic) a **(A)**	51 ± 5.5 (mesotrophic) a **(A)**

TP: total phosphorus; Chl *a*: chloropyll *a*; TSI (chl a): trophic state index of chlorophyll *a*; TSI (TP): trophic state index of total phosphorus. aValues (t-test) on each horizontal line followed by the same letter do not differ significantly ($p<0.05$). (A) Values (ANOVA test) on each vertical line followed by the same letter do not differ significantly ($p<0.05$).

Among the lakes and for both seasons, Pomacocha (RS: 63 ± 5.1 and DS: 64.00 ± 5.0) presented higher concentration values of TSI (Chl *a*) than Tranca Grande (RS: 49 ± 5.5 and DS: 50.00 ± 5.8) and Tipicocha (RS: 59 ± 5.5 and DS: 61.00 ± 5.5). No significant differences ($p<0.05$) were found for both seasons and for the three lakes for TSI (TP) values. In contrast, a significant difference ($p>0.05$) was observed between Tranca Grande and the other lakes (Pomacocha and Tipicocha) during both seasons for TSI (Chl *a*) concentrations (Table 3).

The Peruvian Environmental quality standard (ECA) from the Ministry of Environment (MINAM) set a value of 8.0 µg L^{-1} for chlorophyll-*a* in lakes and lagoons (category 4: conservation of the aquatic environment) (Peru, 2017). In Table 3, it is observed that Pomacocha Lake (64 µg L^{-1}) and Tipicocha Lake (60 µg L^{-1}) both exceed the ECA value (8.0 µg L^{-1}). In contrast, it is noted that Tranca Grande Lake (6.25 µg L^{-1}) does not exceed the value established by ECA.

4. DISCUSSION

Water temperature among the lakes and seasons varied slightly. Temperature ranged from 9.3°C to 16.6°C. These small differences can be explained by different locations and altitudes.

Similarly, pH varied slightly in lakes and seasons. Pomacocha and Tranca Grande Lakes showed lower pH values in the dry season (pH=7.3) and rainy season (pH=7.7). Turbidity (NTU) was measured to describe water clarity. Surface turbidity values in all three lakes ranged from 9.63 to 10.18 NTU in the rainy season and from 7.3 to 7.8 NTU in the dry season. Higher values in the rainy season can be explained because during this season algae development is limited by the dilution of algal particles in the water column because of rainfall. Likewise, mean surface conductivity ranged from 24.7 µS/cm to 119 µS/cm in the rainy season, and from 4.6 µS/cm to 4.9 µS/cm in the dry season. Rainy season lixiviated a lot of minerals from soil, which were discharged in water ecosystems.

Phosphorus concentrations in all lakes and during both seasons ranged from 20 to 24 µg/L (Table 3). Likewise, no significant differences ($p < 0.05$) were observed among lakes and seasons. Phosphorus (P) is an essential nutrient for plant and animal life, but when there is too much of it in aquatic environments it can accelerate eutrophication. Mariano *et al.* (2010) for the period 2002 to 2007 reported similar phosphorus concentrations for Tranca Grande (27 ± 2.05 µg/L), but higher phosphorus concentrations for Pomacocha (98 ± 34 µg/L) and Tipicocha (146 ± 5.0 µg/L) Lakes. In our study, the minor concentration of phosphorus found in both lakes may be attributed to the fact that both lakes were not used as much for farming fish in floating cages because there was a massive mortality of trout in Tipicocha (Peru, 2005). Likewise, when surface water samples were collected, abandoned floating cages were observed in Pomacocha by the researchers. Other factors that could have influenced phosphorus decrease may be natural restoration, sample collections far from the floating cages, and reduction in the external phosphorus load. Janssen *et al.* (2019) reported that restoration of deteriorated lakes critically depends on heterogeneity in nutrient loading and hydrology, with nutrient reduction being more effective. Likewise, Copetti *et al.* (2017) found restoration of Lake Pusiano (Southern Alps) as a consequence of external phosphorus load reduction.

A study carried out by Robertson *et al.* (2003) in Muskellunge Lake, Wisconsin, reported that phosphorus concentrations ranged from 20 to 80 µg/L. Vystavna *et al.* (2017) reported a long-term variation of total phosphorus concentrations measured over 53 years (1963-2015) in the Slapy Reservoir, Czechia, which ranged 10 to 118 µg/L. Soil erosion is considered a main contributor (especially during floods) of phosphorus to streams, lakes, or other water bodies (Eger *et al.*, 2018). However, agricultural activities, organic wastes in sewage, industrial discharges, cattle manure, construction sites, and urban areas can also contribute phosphorus (Reid *et al.*, 2018).

Lower phosphorus concentrations compared to both works described above may be attributed to the fact that livestock such as sheep and camelids are found around these places. Likewise, soil erosion and fish feed probably influenced phosphorus concentrations. For example, Jia *et al.* (2015) reported that fish feed introduces phosphorus into the water ecosystem.

Pomacocha Lake (RS: 29.5 ± 3.1 µg/L and DS: 35.0 ± 2.0 µg/L) presented higher Chlorophyll *a* (Chl *a*) concentrations than Tranca Grande (RS: 6.0 ± 0.5 µg/L and DS: 6.5 ± 1.2 µg/L) and Tipicocha Lakes (RS: 29.5 ± 3.1 µg/L and DS: 29.5 ± 3.1 µg/L) for both seasons. Also, significant differences ($p > 0.05$) were found among lakes and seasons. Chlorophyll (chlorophyll *a*, algal biovolume, organic weight, organic carbon, ATP, total dry weight, and turbidity) is the main estimator of phytoplankton biomass (Carlson, 2007). Phytoplankton growth in lakes is basically restricted by light conditions and the quantity of nutrients (Li *et al.*, 2017). Therefore, the higher chl *a* concentration found in Pomacocha is probably related to elevated nutrient concentration (total phosphorus) (Table 3). Filstrup and Downing (2017) reported an increase of Chl *a* when total phosphorus concentration was increased (positive correlation, $r^2 = 0.84$). Similarly, Magumba *et al.* (2013) suggested that the concentration of Chl *a* could be controlled by controlling the concentration of TP. Turbidity estimates the density of algal particles contained in water ecosystems. As seen in Table 3, Pomacocha also presented higher values of turbidity compared to Tranca Grande and Tipicocha Lakes. Likewise, an increase of turbidity in the rainy seasons was noted. An increase in water levels does not cause dilution of nutrients such as phosphorus. According to the literature, nutrient enrichment during flood periods was observed in shallow lakes (Rennella and Quirós, 2014; Sosnovsky and Quirós, 2006), high Andean lakes (Aranguren-Riaño *et al.*, 2018; Baigún *et al.*, 2006) and other water bodies (Chamoglou *et al.*, 2018; Newman, 2005). Elevated concentrations of phytoplankton caused the water to appear turbid, causing decreased water clarity and posteriorly occasioning eutrophic lakes.

Arbuckle and Downing (2001), reported that livestock kept on the shores of lakes contributed to an increase in chlorophyll-a, while Jeppesen *et al.* (1999) mentioned that when water volume falls, the internal load of phosphates and the rate of mineralization increase, but hydric balance is negative. This phenomenon is more noticeable during the dry season, where higher concentrations of nutrients and algae biomass are presented. In contrast, lower concentrations from nutrients and algae biomass occur during the rainy season.

Human activities also increase substantially in the lakes, affecting and varying physical, chemical, and biological parameters. This may partially explain the difference found in phosphate and chlorophyll-a concentrations measured in the lentic resources studied. Since a higher concentration of phosphorus allows higher production of algae biomass; therefore, chlorophyll concentration will be greater (Sheffer *et al.*, 1993).

The TSI (TP), classified all lakes during both seasons as mesotrophic, while TSI (Chl *a*) classified Pomacocha and Tipicocha for both seasons as eutrophic and Tranca Grande as mesotrophic (during both seasons). Previous studies reported differences in the Trophic State Index (TSI) when computed with two (TP and Chl *a*) or more variables (TP, Chl *a*, and Secchi disk) (Brugnoli *et al.*, 2019; Coelho *et al.*, 2007). Carlson and Simpson, (1996) noted that TSI values calculated with two or more variables caused discrepancies when establishing the trophic state in a water ecosystem. Coelho *et al.* (2007) and Rakocevic-Nedovic and Hollert (2005) reported differences in TSI values in the lakes of Foz de Almargem (Algarve, South Portugal) and Skadar (Montenegro, Balkan), respectively. In our case, the TSI (Chl *a*) being higher than TSI (TP) would indicate a system with a limiting factor for TP. In this case, chlorophyll *a* may be considered a better predictor of algal biomass than either of the other indices.

5. CONCLUSION

This study assessed the trophic states of three lakes used as fish farms using the Trophic State Index (TSI). Mesotrophic and eutrophic states were found among the lakes. TSI (TP) showed mesotrophic state for all lakes during the two seasons studied, while TSI (Chl *a*) showed two lakes in eutrophic states (Pomacocha and Tipicocha), while Tranca Grande maintained a mesotrophic state.

Fish farming can have a negative impact on lake ecosystems, because of the accumulation of organic matter from excreta and phosphorus from fish food, among other things.

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