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Trophic assessment of four tropical reservoirs using phytoplankton genera

Avaliação trófica de quatro reservatórios tropicais usando gêneros fitoplanctônicos

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Abstract: Aim: Monitoring the trophic state of reservoirs requires indices that provide a quick report of the ecosystem to decision makers. This study aimed to develop a system of trophic status indicators for tropical mountain reservoirs using phytoplankton genera. **Methods:** Between 2004 and 2010, four reservoirs for water supply in Bogotá (Colombia), which have different trophic statuses and hydraulic management, were monitored. Samples were collected for the analysis of physical and chemical variables and phytoplankton community. Through multivariate analysis, the significance of the relationships between environmental variables and phytoplankton species and genera was established. Subsequently, trophic indices were proposed as relevant variables. The global trophic index was calculated as the sum of the partial indices. **Results:** Analysis of the main components showed that reservoirs varied chemically depending on trophic status. Phytoplankton were composed of 63 genera, 59% of which were present in the four reservoirs. Although the physical characteristics of water, such as temperature and total solids content, explained a large part of the variation in the genera, a significant relationship between the genera and variables related to trophic state was observed in each reservoir. The multivariate analyses grouping the data by genera showed a behavior similar to the analysis using information at the species level. Plankton indices of trophic state were developed for phosphorus (TP), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), and Secchi disk (SD) using data grouped by genera. The indices were significantly correlated with the values of each variable in each reservoir. Linear regression models showed a significant prediction of chlorophyll-a using TP, TKN, and SD indices in the three reservoirs with the highest trophic level. In addition, the global index showed a significant relationship with variables related to the trophic state. **Conclusions:** Phytoplankton data at the genus level can be used to assess trophic status. The models for SD, TP, and TKN could be used as indicators of the trophic status of the studied reservoirs.

Keywords: trophic index; ecological optimum; ecological indicator; phytoplankton; eutrophication.

Resumo: Objetivo: O monitoramento do estado trófico de reservatórios requer índices que forneçam um relatório rápido do ecossistema aos tomadores de decisão. Este estudo teve como objetivo desenvolver um sistema de indicadores de estado trófico para reservatórios de montanha tropical usando gêneros de fitoplâncton. **Métodos:** Entre 2004 e 2010, foram monitorados quatro reservatórios para abastecimento de água em Bogotá (Colômbia), que apresentam diferentes estados tróficos e gestão hidráulica. Amostras foram coletadas para análise de variáveis físicas e químicas e comunidade fitoplanctônica. Por meio de análise multivariada, estabeleceu-se a significância das relações entre variáveis ambientais e espécies e gêneros fitoplanctônicos. Posteriormente, os índices tróficos foram propostos como variáveis relevantes. O índice trófico global foi calculado como a soma dos índices parciais. **Resultados:** A análise dos principais componentes mostrou que os reservatórios variam quimicamente dependendo do estado trófico. O fitoplâncton foi composto por 63 gêneros, 59% dos quais estavam presentes nos quatro reservatórios. Embora as características físicas da água, como temperatura e teor de sólidos totais, explicassem grande parte da variação dos gêneros, observou-se em cada reservatório uma relação significativa entre os gêneros e as variáveis relacionadas ao estado trófico. As análises multivariadas agrupando os dados por gênero mostraram um comportamento semelhante à análise utilizando informações em nível de espécie. Os índices de estado trófico do plâncton foram desenvolvidos para fósforo (TP), nitrogênio Kjeldahl total (TKN), carbono orgânico total (TOC) e disco de Secchi (SD) usando dados agrupados por gêneros. Os índices foram significativamente correlacionados com os valores de cada variável em cada reservatório. Modelos de regressão linear mostraram um poder preditivo significativa de clorofila-a usando os índices TP, TKN e SD nos três reservatórios com maior nível trófico. Além disso, o índice global apresentou relação significativa com variáveis relacionadas ao estado trófico. **Conclusões:** Os dados do fitoplâncton em nível de gênero podem ser usados para avaliar o estado trófico. Os modelos para SD, TP e TKN podem ser utilizados como indicadores do estado trófico dos reservatórios estudados.

Palavras-chave: índice trófico; ótimo ecológico; indicador ecológico; fitoplâncton; eutrofização.

1. Introduction

Phytoplankton is widely used to assess changes in the trophic state of ecosystems, either through the study of algal community structure (e.g., Becker et al., 2010a; Horn et al., 2011; Seeligmann & Tracanna, 2009) or by using trophic indices (Carvalho et al., 2013; Lyche-Solheim et al., 2013; Rodrigues et al., 2019). The routine study of phytoplankton in reservoirs involves many hours of work under a microscope, resulting in observations made by different technicians. The phytoplankton count is performed using an inverted microscope; therefore, identification is usually very difficult, complicating the harmonization of the species found. This causes difficulties in the standardization of algal morphotypes found during monitoring.

The simplification of algal communities to understand the relationship between phytoplankton and the environment usually considers a functional approach. The shape of algae is strongly related to their ecological requirements; therefore, morphology-based groups can be predicted based on environmental conditions (Kruk et al., 2011; Rocha et al., 2020). Genus-level data have also been tested for European and tropical south American ecosystems (Carneiro et al., 2010; Peng et al., 2021; Phillips et al., 2013; Souza et al., 2019).

Phytoplankton respond to a set of environmental factors, including the physical stability of the water column and the concentration of nutrients (Reynolds, 2006; Yang et al., 2016). Although physical stability is important for regulating the distribution of phytoplankton, the main interest during the monitoring of lentic systems is the effect of phosphorus on lake eutrophication (Carvalho et al., 2013). Nitrogen is also an essential nutrient for algal productivity because its limitation in water has been related to cyanobacterial dominance (Lewis Junior, 2000; Reynolds, 1997), but the relationship between N and P is not linear (Lv et al., 2011); and P has mainly been associated with changes in the algal community. However, organic carbon availability in the water can indirectly affect the productivity and composition of phytoplankton (Cahyonugroho et al., 2022; Engel et al., 2019). Light availability can also control the growth of algae in planktons (Reynolds, 2006). Water transparency is mainly affected by inorganic and organic materials suspended in the water column (Margalef, 1983).

Reservoirs are ecosystems of anthropic origin that differ from rivers in their lower water flow and from lakes in their high relative depth, high sedimentation rate, and high hydrological variability (Straskraba & Tundisi, 1999). These factors cause reservoirs to have a high nutrient retention and a high possibility of eutrophication. Eutrophication events in tropical and subtropical reservoirs have been well-documented (Burford et al., 2007; Chellappa et al., 2009; Sotero-Santos et al., 2008; Tundisi et al., 2008). Eutrophication has been widely reported (Huszar et al., 2000; Leigh et al., 2010), and can trigger the development of harmful algae (Becker et al., 2010b; Bouvy et al., 2010; Douma et al., 2010). The management of reservoirs for water supply requires permanent monitoring of eutrophication and contamination from different sources, because of the difficulty in treating water after problems appear (Steffensen, 2008).

Trophic indices can be very useful for reservoir managers because they allow quick measurement of the state of the system. Phytoplankton-based indices are mainly used to evaluate the trophic state of lakes by studying the relationship between algae and the concentrations of phosphorus and chlorophyll-a (e.g., Phillips et al., 2013). The ecological traits of phytoplankton, considering their response to the environment, can help develop a system of indicators in reservoirs. Even so, the use of phytoplankton-based indices that explain the trophic aspects of tropical reservoirs is scarce. The main difficulty in developing indices is the lack of knowledge on the relationship between the aquatic environment and phytoplankton and limited knowledge on the taxonomy of algal groups. Considering this context, the objective of the present study was to develop a trophic status system for four tropical mountain reservoirs using phytoplankton genera. We hypothesized that approximation at the genus level will allow us to determine ecological relationships with the environment so that trophic state indices can be constructed. The morphological and evolutionary traits of algae may indicate their responses to environmental filters (Kruk et al., 2011). Because most traits are conserved within the taxonomic range of the genus, species within the same genus would tend to present acceptably similar ecological responses. Here, we compared the response of phytoplankton identified at the species level with the response at the genus level to build a simplified index that allows monitoring of phytoplankton in tropical mountain reservoirs.

2. Materials and Methods

2.1. Study area

The studied reservoirs (Chisacá, Regadera, San Rafael, and Chuza) are located in the eastern Cordillera of Colombia (Figure 1). Reservoirs present differences in bathymetry, altitude, reservoir volume, and nutrient concentrations (Table 1). Chuza Reservoir is the largest and is located at a higher altitude. The basin of Chuza Reservoir is inside a national natural park with dominant herbaceous and shrubby vegetation typical of *Páramo* ecosystems. The basins of Chisacá, La Regadera, and San Rafael are poorly protected, with extensive crop fields and nearby human settlements. The San Rafael reservoir mainly receives water from the Teusacá River, but through a 25 km tunnel it also receives water from the Chuza reservoir. Chisacá and La Regadera are the oldest reservoirs, with more intensive land use in the basin and connected in a cascade.

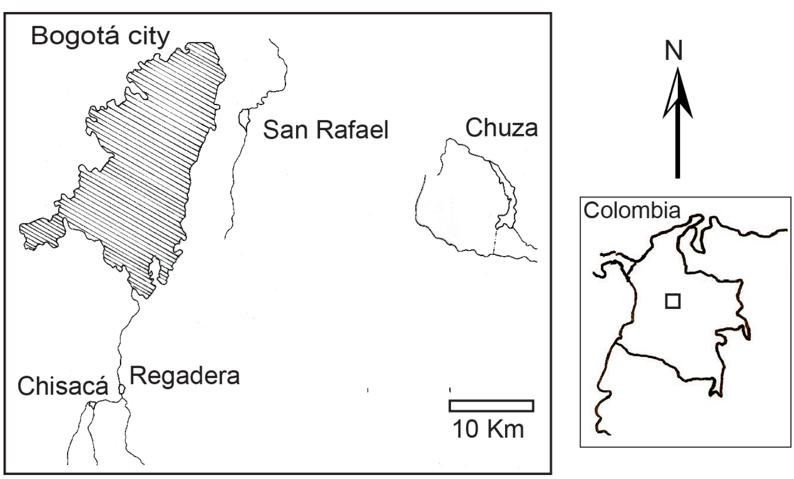

Figure 1. Location of the reservoirs studied in Colombia. Details of the location of the studied reservoirs were described by León et al. (2012).

Table 1. Summary of geographic and morphometric data of the four studied reservoirs.

	Chisacá	La Regadera	San Rafael	Chuza
Location	4° 23’ 47.7”N 74° 8’ 32.4”W	4° 23´4.9”N 74° 10´11.9”W	4° 42’ 10.2”N 73° 59’ 14.6”W	4° 34’ 22.7”N 73° 42’ 16.8”W
Altitude (m.a.s.l.)	3146	2997	2777	2990
Maximum volume (m^3)	7 072 183	4 000 000	50 000 000	250 000 000
Area (ha)	53	41	371	580
Maximum depth (m)	24	26	50	85
Relative depth (%)	2.9	3.6	2.3	3.1
Water renewal rate (d^{-1})	0.009	0.042	0.002	0.007

2.2. Sample collection and analysis

Sampling was carried out monthly to quarterly between January 2004 and December 2010, depending on the reservoir. The number of sampling points in each reservoir depended on the size of each reservoir: Chisacá was sampled at one point (33 samples), La Regadera at two (43 samples), and San Rafael (183 samples) and Chuza (93 samples) at four points. A total of 352 samples were used in this study.

At each sampling point, 3-L water samples were collected at a depth corresponding to half of the transparency of the Secchi disk depth using a van Dorn bottle (Rivera-Rondón & Zapata, 2009). Samples were homogenized, and smaller volumes were collected for chemical analyses and study of phytoplankton. Phytoplankton samples were preserved in 1% Lugol's solution (Wetzel & Likens, 2000).

Water transparency was estimated using SD. The conductivity and pH were measured *in situ* at each sampling point using a HACH probe. The following parameters were analyzed following the method of APHA (2005): alkalinity (H_2SO_4 titration), turbidity (nephelometric), silicates (Si, colorimetric molybdosilicate method), TP (colorimetric stannous chloride protocol 4500-P), TKN (H_2SO_4 titration), ionic concentration (ICPlasma), and TOC (combustion-infrared 5310-B). Chlorophyll-a concentrations were measured using the spectrometer method and applying the trichromatic formula of Jeffrey and Humphrey, according to APHA (2005). The hydraulic characteristics of the reservoir were described by León et al. (2012).

Phytoplankton were quantified using sedimentation chambers (Utermöhl, 1958), and at least 200 individuals of the most frequent taxon were counted under an inverted microscope at 800× magnification. Algal densities were calculated according to the methods described by the Intergovernmental Oceanographic Commission of UNESCO (IOC UNESCO, 2010). Algae were identified to the lowest possible taxonomic level (species or morphotypes) using specialized taxonomic keys. However, as this study was oriented to facilitate the work of different analysts, specimens were grouped at the genus *sensu lato* or Family level. For example, *Anabaena* includes *Dolichospermum*; *Scenedesmus* includes *Desmodesmus* (the grouping of genera/family is shown in the Table 2).

2.3. Data analysis

Patterns of environmental variables were studied using principal component analysis (PCA).

Table 2. Most frequent (>2%) species and groups (genera/family) used in the study.

Species	group
Anabaena constricta (Szafer) Geitler	Anabaena
Ankistrodesmus sp1	Ankistrodesmus
Ankyra sp1	Ankyra
Aphanothece sp	Aphanothece
Asterococcus sp1	Asterococcus
Botryococcus braunii Kützing	Botryococcus
Botryococcus terribilis Komarek & Marvan	Botryococcus
Ceratium furcoides (Levander) Langhans	Ceratium
Chlamydomonas sp1	Chlamydomonas
Chlorococcales sp2	Chlorococcales
Chroococcus sp1	Chroococcus
Closteriopsis sp1	Closteriopsis
Closterium aciculare T. West	Closterium
Closterium sp4	Closterium
Coelastrum sp1	Coelastrum
Cosmarium venustum (Brebisson) Archer	Cosmarium
Cosmarium contractum O.Kirchner	Cosmarium
Cosmarium margaritiferum Menegh. ex Ralfs	Cosmarium
Cosmarium sp3	Cosmarium
Cosmarium sp5	Cosmarium
Cosmarium sp6	Cosmarium
Cosmarium sp8	Cosmarium
Cosmarium sp9	Cosmarium
Crucigenia sp1	Crucigenia
Crucigeniella sp1	Crucigeniella
Cryptomonas sp1	Cryptomonas
Cryptomonas sp2	Cryptomonas
Cryptomonas sp3	Cryptomonas
Cyclotella sp1	Cyclotella
Cyclotella sp2	Cyclotella
Encyonema silesiacum (Bleisch in Rabenhorst) D.G. Mann	Cymbella
Desmodesmus communis (Hegewald) Hegewald	Scenedesmus
Dictyosphaerium sp1	Dictyosphaerium
Dinobryon divergens O.E.Imhof	Dinobryon
Dinobryon sp2	Dinobryon
Discostella stelligera (Cleve & Grunow) Houk & Klee	Cyclotella
Dolichospermum solitarium (Kleb.) Wacklin, L.Hoffm. & Komárek	Anabaena
Elakatothrix gelatinosa Wille	Elakatothrix
Euastrum sp1	Euastrum
Eudorina elegans Ehrenberg	Eudorina
Euglena sp1	Euglena
Euglena sp2	Euglena
Euglena sp3	Euglena
Eunotia cf. *bilunaris* (Ehrenberg) Schaarschmidt	Eunotia
Eutetramorus sp1	Eutetramorus
Chlamydomonas sp2	Chlamydomonas
Fragilaria sp1	Fragilaria
Gomphonema lagenula Kützing	Gomphonema
Gomphonema olivaceum (Hornemann) Brébisson	Gomphonema
Gomphosphaeria sp1	Gomphosphaeria
Gymnodinium sp1	Gymnodinium
Gymnodinium sp2	Gymnodinium

Table 2. Continued...

Species	group
Hannaea arcus (Ehrenb.) R. M. Patrick	Hannaea
Mallomonas sp1	Mallomonas
Mallomonas sp2	Mallomonas
Mallomonas sp3	Mallomonas
Monoraphidium sp1	Monoraphidium
Mougeotia sp1	Mougeotia
Navicula sp1	Navicula
Nephrocytium limneticum G.M.Smith	Nephrocytium
Nephrodiella sp1	Nephrodiella
Nitzschia cf. acicularis (Kützing) W.Smith	Nitzschia
Nitzschia sp1	Nitzschia
Ochromonas sp1	Ochromonas
Oocystis cf. *lacustris* Chodat	Oocystis
Oocystis sp2	Oocystis
Oocystis sp3	Oocystis
Oscillatoria sp5	Oscillatoria
Pandorina sp1	Pandorina
Peridinium limbatum (Stokes) Lemmermann	Peridinium
Peridinium spp	Peridinium
Phacus longicauda (Ehrenberg) Dujardin	Phacus
Phacus sp1	Phacus
Pinnularia sp1	Pinnularia
Plagioselmis lacustris (Pascher & Ruttner) Javorn	Plagioselmis
Pseudanabaena sp2	Pseudanabaena
Pseudanabaena sp3	Pseudanabaena
Pseudosphaerocystis sp1	Pseudosphaerocystis
Quadrigula sp1	Quadrigula
Scenedesmus cf. *arcuatus* (Lemmermann) Lemmermann	Scenedesmus
Scenedesmus disciformis (Chodat) Fott & Komárek	Scenedesmus
Scenedesmus sp1	Scenedesmus
Scenedesmus sp4	Scenedesmus
Scenedesmus sp5	Scenedesmus
Sphaerocystis cf. *schroeteri* Chodat	Sphaerocystis
Spondylosium sp1	Spondylosium
Staurastrum cf. *limneticum* burmense	Staurastrum
Staurastrum cf. *longipes* f. maius	Staurastrum
Staurastrum rotula Nordst.	Staurastrum
Staurastrum leptocladum Nordst.	Staurastrum
Staurastrum sp2	Staurastrum
Staurastrum quadrangulare Brebisson	Staurastrum
Stauridium cf. *tetras* (Ehrenberg) E.Hegewald	Pediastrum
Staurodesmus cf. *convergens* (Ehrenb.) Teiling	Staurodesmus
Staurodesmus dejectus (Brébisson) Teiling	Staurodesmus
Staurodesmus cf. *extensus*	Staurodesmus
Staurodesmus cf. *lobatus var. ellipticus* (F.E.Fritsch & Rich) Teiling	Staurodesmus
Staurodesmus cf. *mamillatus* (Nordst.) Teiling	Staurodesmus
Staurodesmus cf. *phimus* (W.B.Turner) Thomasson	Staurodesmus
Staurodesmus lobatus (Børgesen) Bourr.	Staurodesmus
Staurodesmus octocornis (Ehrenb. ex Ralfs) Stastny et al.	Staurodesmus
Staurodesmus sp5	Staurodesmus
Staurodesmus sp6	Staurodesmus

Table 2. Continued...

Species	group
Staurodesmus sp7	Staurodesmus
Stauroneis sp2	Stauroneis
Synura sp1	Synura
Tabellaria fenestrata (Lyngbye) Kützing	Tabellaria
Tabellaria flocculosa (Roth) Kützing	Tabellaria
Trachelomonas armata (Ehrenb.) F. Stein	Trachelomonas
Trachelomonas oblonga Lemmerm.	Trachelomonas
Trachelomonas volvocina Ehrenberg	Trachelomonas
Trachelomonas volvocinopsis Svirenko	Trachelomonas
Ulnaria ulna (Nitzsch) P.Compère	Ulnaria
Volvox sp1	Volvox
Xanthidium sp1	Xanthidium

Environmental variables were transformed to obtain a central distribution of the data. Thus, alkalinity, turbidity, Si, total Fe, Mg^{2+}, Mn^{2+}, TKN, and TOC were log10 transformed, TP was adjusted to a central distribution using cubic root transformation, and SD and pH were not transformed. PCA was performed by standardizing the data and using a correlation matrix. Carlson's (1977) trophic state index was calculated using the correction of Salas & Martino (1990) for tropical ecosystems.

The relationships between phytoplankton and the environment were analyzed with redundancy analysis (RDA) (Jongman et al., 1995) using Hellinger transformation for species and genera data (Legendre & Gallagher, 2001). In the models, we included variables known to have a causal relationship with algal biomass: SD, alkalinity, conductivity, temperature, TOC, TKN, Si, Fe, and TP. To avoid collinearity, we used all variables with inflation factors lower than 5% (Lepš & Šmilauer, 2003). The analyses were carried out by separating the data from three different hydrological systems: San Rafael, Chuza, and Chisacá-La Regadera.

Analyses were performed using species and grouping them into genera. For each dataset, species with a frequency lower than six samples (<2%) were excluded. A Monte Carlo test (999 permutations, $\alpha = 0.05$) was used to determine the significance of the axes of species and the relationship between species and the environment. The forward selection method (Lepš & Šmilauer, 2003) was used to calculate the variance explained for each variable.

According to the RDA results, plankton indices of trophic state (I) were developed for TP (I_{TP}), TKN (I_{TKN}), conductivity (I_{Cond}), Secchi disk (I_{SD}), and TOC (I_{TOC}) using a weighted average of the optima from the genera with the proportion of total abundance as weights (Equation 1):

$$I = \frac{\sum n_i \cdot x_i}{\sum n_i} \quad (1)$$

where n_i is the proportion of *i*th genus in the sample, and x_i is the optimum of the *i*th genus in the sample (Pasztaleniec, 2016; Phillips et al., 2013).

The optimum for each species was calculated as the weighted average of its abundance with respect to the variable of interest; thus, it was the value for the variable in which a species showed the maximum abundance. Therefore, it provides a quantitative representation of the ecological niche of a species. Although the trophic state was mainly evaluated from the values of the Secchi disk, phosphorus, and nitrogen, we also included TOC and conductivity as indicator variables of the trophic state. In tropical environments, when the trophic state is not high, the increase in pollution due to anthropogenic activity and the consequent elevated phosphorus input reduce its limiting role. Instead, the limiting factors are nitrogen, light, and organic matter (Dunalska, 2011). Therefore, TOC may be related to the trophic status of ecosystems in tropical lakes.

To test the relationships between the indices and environmental variables, we correlated each *I* index with the variables using the Pearson product-moment correlation coefficient. *I* is essentially an inference of the value of the variable from the abundances and optima of the species present; therefore, the correlation represents the degree of predictability of the index. Second, we examined the relationship between partial *I* indices and chlorophyll-a using linear regression models. Due to different factors, including sampling frequency, food web structure, and temporal turnover of species, the ability of the indices to represent trophic status can be better evaluated by their ability to predict chlorophyll-a values.

A global trophic index (IM_{total}) was calculated per sample by adding partial *I* indices ranging from 0 to 1. This approach allows for the generation of an index that can be easily used by decision makers. The relationships between IM_{total} and the principal components of the PCA analysis were analyzed using linear regression models. Akaike´s information criterion (AIC) was used to estimate the prediction error and the relative quality of the regression models. All analyses and models were performed using the packages 'stats' 3.6.2, 'vegan' 2.5-6, and 'rioja' 0.9-21 in the R software (R Development Core Team, 2018).

3. Results

3.1. Physical and chemical ordination

The studied reservoirs had low ionic concentrations, circumneutral pH, and low water transparency (Table 3). The temperature of the reservoirs ranged from 11.8 °C to 19 °C (average = 15.9 °C). Water transparency, chlorophyll-a, and TP indicated that the reservoirs were mainly mesotrophic (Table 3), but the annual variation was very high. The TOC ranged from 0.5 to 93 (average = 4.6 mg/L). The four reservoirs have very different characteristics, with Chuza tending to be permanently ologotrophic and the Chisacá and La Regadera reservoirs tending to be more eutrophic (Table 3). The San Rafael Reservoir had the greatest temporal variability.

PCA including the data of the four reservoirs showed that the majority of chemical variation was summarized in the first two principal components (Figure 2). The first principal component (PC) was correlated with variables associated with the ionic composition and trophic conditions of the reservoirs, such as chlorophyll-a and SD. However, TP and TKN were mainly correlated with the fourth

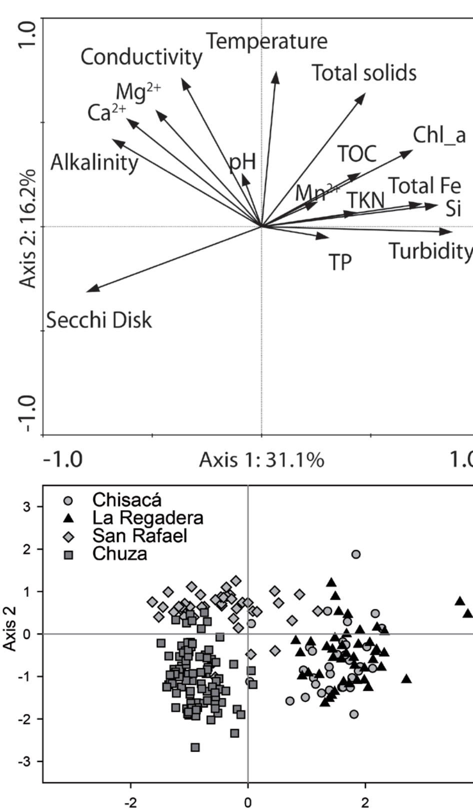

Figure 2. Biplot of the principal component analysis of physical and chemical variables of the studied reservoirs.

Table 3. Summary of the chemical characteristics of each reservoir. Carlson's (1977) trophic state index for TP (TI_{PT}), water transparency (TI_{SD}), and Chlorophyll-a ($TI_{Chl.a}$) are shown

	San Rafael (n=183)					Chisacá-La Regadera (n=76)					Chuza (n=93)				
	min	max	med.	mean	std.dev	min	max	median	mean	std.dev	min	max	median	mean	std.dev
Alkalinity (mg $CaCO_3^-$/L)	7.00	47.25	16.00	16.93	4.17	3.00	24.00	8.00	8.42	2.50	11.00	27.00	14.00	14.56	2.58
Ca^{2+} (mg/L)	0.98	13.78	5.32	5.57	1.48	1.29	11.83	2.29	2.57	1.30	2.82	12.78	4.97	5.13	1.45
Chlorophyll-a (mg/m^3)	0.01	128.43	8.18	12.67	12.98	0.47	246.20	33.02	40.63	34.82	0.04	21.15	3.23	4.00	3.43
Conductivity (µS/cm)	10.00	74.00	51.45	51.12	9.41	9.68	61.50	24.70	24.63	7.02	5.00	47.70	33.40	32.73	7.25
TOC (mg/L)	0.90	93.21	3.85	4.74	7.36	2.30	10.63	5.00	5.18	1.34	0.51	10.30	2.60	2.80	1.27
Total phosphorus (mg/L)	0.01	3.57	0.02	0.10	0.44	0.01	2.14	0.04	0.08	0.19	0.01	0.88	0.01	0.05	0.14
Total Fe (mg/L)	0.01	1.76	0.21	0.28	0.22	0.15	2.37	0.47	0.55	0.30	0.01	1.05	0.16	0.19	0.12
Mg^{2+} (mg/L)	0.03	1.16	0.70	0.70	0.15	0.22	1.70	0.42	0.44	0.14	0.26	1.22	0.65	0.67	0.15
Mn^{2+} (mg/L)	0.00	0.27	0.01	0.02	0.02	0.00	0.14	0.02	0.03	0.02	0.00	0.40	0.01	0.02	0.05
TKN (mg/L)	0.05	2.80	0.50	0.62	0.54	0.05	2.84	1.00	0.90	0.62	0.05	2.16	0.40	0.50	0.47
pH (mg/L)	6.32	9.17	7.36	7.43	0.52	6.14	10.00	7.15	7.60	1.02	6.10	8.00	7.40	7.35	0.33
Si (mg/L)	0.08	3.98	1.55	1.53	0.48	0.67	10.40	2.99	2.99	1.04	0.16	2.81	0.99	1.02	0.39
Total solids (mg/L)	13.00	84.20	44.40	45.15	8.34	20.00	122.00	41.60	44.24	13.43	12.00	54.00	30.00	30.63	6.56
Temperature (°C)	13.50	18.70	16.70	16.63	0.92	11.70	18.80	15.70	15.45	1.48	9.90	17.80	14.40	14.21	1.24
Secchi disk (m)	0.60	4.60	2.05	2.30	0.72	0.10	3.70	0.90	0.97	0.48	1.20	6.40	3.50	3.50	1.04
Turbidity (NTU)	0.34	10.00	1.97	2.46	1.75	0.83	110.00	6.77	10.17	12.57	0.40	12.00	1.60	1.94	1.51
TI_{PT}	19.94	114.74	39.94	40.26	17.96	19.94	107.38	51.48	49.23	17.32	19.94	94.54	29.94	35.87	17.51
TI_{SD}	28.75	58.14	40.41	39.55	4.99	31.89	83.99	52.29	53.19	8.42	23.99	48.14	32.69	33.36	4.56
$TI_{Chl.a}$	5.00	100.62	60.90	62.00	12.65	19.67	110.01	81.02	79.04	13.29	5.00	74.59	47.48	44.27	15.58

min: minimum; max: maximum; med.: median; std.dev: Standard deviation.

PC (r = 0.79 and 0.54, respectively). The second PC was correlated with conductivity and temperature; this axis summarizes the temporal and spatial variations of inorganic compounds and temperature. Chisacá and La Regadera showed higher organic and solid concentrations and a higher trophic state than other reservoirs. Chuza was the reservoir with the highest water transparency, whereas San Rafael had the most variable water transparency.

The PCA carried out for each of the reservoirs independently showed differences in the chemical variability of each reservoir (Figure 3). In San Rafael, the first PC axis is mainly associated with temperature, Fe, conductivity, and SD, whereas the second axis is associated with TP, TKN, and conductivity. In the Chisacá–La Regadera, the first axis is mainly associated with SD, and the second axis is associated with TP, Fe, and TOC. In the case of Chuza, the first axis of variation is explained mainly by TKN, SD, Fe, conductivity, and TP, whereas the second axis is related to temperature, alkalinity, and TOC (Figure 3). According to this, there is variation in the variables associated with the trophic state, but their importance and interaction vary according to the system

3.2. Temporal and spatial patterns of the phytoplankton

The mean density of phytoplankton was 2410 cells/ml. The reservoirs with high mean density were La Regadera (3786 cell/ml) and San Rafael (2288 cells/ml), and the low density occurred in Chuza (1562 cell/ml) and Chisacá (1419 cell/ml). The phytoplankton was composed of 63 genera (excluding genera with low frequency), 59% of which were present in the four reservoirs, and 12.6% of which were present in only one or two reservoirs. A summary of the density and frequency of each genus is presented in Table 4. *Cryptomonas*, *Peridinium*, *Oocystis*, *Sphaerocystis*, *Discostella*, *Staurodesmus*, *Elakatothrix*, *Ceratium*, and *Staurastrum* were the most frequent genera (>70% of the samples). The genera with the highest mean cellular density were *Anabaena*, *Sphaerocystis*, *Volvox*, *Oocystis*, *Staurodesmus*, *Elakatothrix*, *Ochromonas*, and *Nephrodiella*.

Each RDA performed for species and genera showed three significant axes (p<0.01). The first three axes of the models for species explained 69.4 to 77% of species-environment relation and 13.8–19.5% of species variation (Table 5). The model for genera explained a higher percentage of variance of the genera-environment relation and genera data

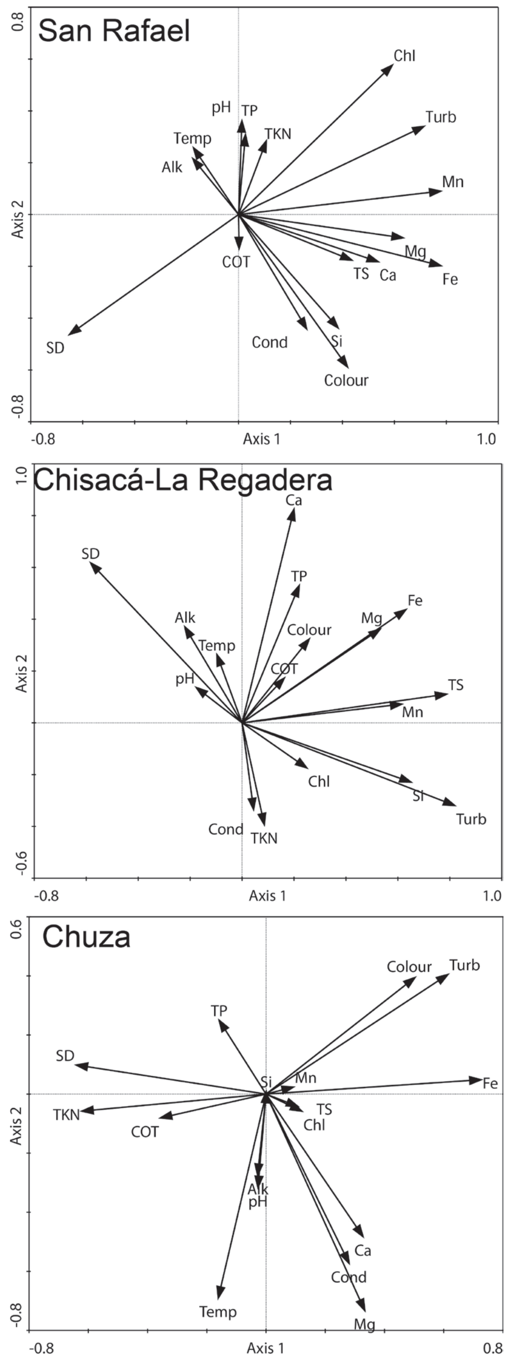

Figure 3. Biplot of the principal component analysis of physical and chemical variables of each studied reservoir.

(70.1–81.1% and 13.5–20.8%, respectively). Both models had similar explanatory variables (Table 5). Accordingly, given that the two models present a similar response, the following analyses are focused on the model based on the genera data.

The RDA of the genera data for the San Rafael reservoir indicated that the first axis was explained by SD, TP, and TKN (Figure 4). The second axis is related to conductivity. The RDA for the

Table 4. Summary of the abundance of the groups of Genera (*sensu lato*) found in the study.

Group	label used in RDA	Abundance (cel/ml)			Number of reservoir	Frequency
		min	mean	max		
Cymbella	Cymbella	0.02	1	12	4	17.6
Cyclotella	Cyclotel	0.02	224	9144	4	84.9
Eunotia	Eunotia	0.02	1	6	3	2.0
Fragilaria	Fragilar	0.02	10	104	4	15.1
Gomphonema	Gomphone	0.02	3	16	4	5.1
Hannaea	Hannaea	0.02	2	10	3	1.7
Navicula	Navicula	0.02	2	7	4	5.4
Nitzschia	Nitzschi	0.02	27	471	4	32.7
Pinnularia	Pinnular	0.02	1	9	4	5.7
Stauroneis	Staurone	0.02	2	5	4	1.7
Tabellaria	Tabellar	0.02	24	778	4	26.4
Ulnaria	Ulnaria	0.02	1	6	2	2.0
Closterium	Closteri	0.02	2	15	4	18.8
Cosmarium	Cosmariu	0.02	241	3147	4	62.2
Elakatothrix	Elakatot	0.02	287	4416	4	79.0
Euastrum	Euastrum	0.02	5	38	3	2.8
Mougeotia	Mougeoti	0.02	2	15	3	3.7
Spondylosium	Spondylo	0.02	14	118	4	13.9
Staurastrum	Staurast	0.02	87	3032	4	71.3
Staurodesmus	Staurode	0.02	298	9160	4	83.2
Xanthidium	Xanthidi	0.02	11	513	4	33.0
Ankistrodesmus	Ankistro	0.04	8	28	2	4.3
Ankyra	Ankyra	0.70	113	1244	4	17.6
Asterococcus	Asteroco	2.39	42	155	2	2.8
Botryoccocus	Botryocc	0.02	70	1149	4	62.8
Chlamydomonas	Chlamydo	0.20	32	337	3	27.0
Chlorococcales	Chloroph	0.02	12	130	4	21.3
Closteriopsis	Closterio	0.02	8	99	4	43.8
Coelastrum	Coelastr	0.06	35	270	4	11.6
Crucigenia	Crucigen	0.08	119	1308	2	44.6
Crucigeniella	Crucigen	26.23	108	211	1	4.8
Dictyosphaerium	Dictyosp	0.52	103	347	3	3.4
Eudorina	Eudorina	0.08	57	1947	3	22.2
Eutetramorus	Eutetram	0.16	81	235	3	8.2
Monoraphidium	Monoraph	0.58	8	35	3	10.8
Nephrocytium	Nephrocy	0.04	45	939	4	33.2
Oocystis	Oocystis	0.02	389	3191	4	91.8
Pandorina	Pandorin	0.08	20	118	2	3.1
Pediastrum	Pediastr	0.08	17	54	3	4.8
Pseudosphaerocystis	Pseudosp	0.36	41	75	3	4.0
Quadrigula	Quadrigu	0.08	31	207	3	23.9
Scenedesmus	Scenedes	0.08	66	479	4	50.3
Sphaerocystis	Sphaeroc	0.16	701	6892	4	88.9
Volvox	Volvox	3.00	687	7397	3	3.4
Cryptomonas	Cryptomo	0.04	150	1766	4	98.9
Plagioselmis	Plagiose	0.51	97	1733	4	69.9
Anabaena	Anabaena	0.22	1200	18076	4	4.5
Aphanothece	Aphanoth	1.50	114	508	2	2.0
Chroococcus	Chroococ	0.04	5	12	3	1.7
Gomphosphaeria	Gomphosp	0.02	42	606	2	24.1
Oscillatoria	Oscillat	0.18	6	22	3	3.1
Pseudanabaena	Pseudana	0.02	40	249	3	4.8
Ceratium	Ceratium	0.02	232	2914	4	76.7
Gymnodinium	Gymnodin	0.02	24	279	4	45.2
Peridinium	Peridini	0.02	225	5076	4	92.9
Euglena	Euglena	0.02	6	38	4	19.9
Phacus	Phacus	0.02	1	12	3	11.6
Trachelomonas	Trachelo	0.02	113	8381	4	62.5
Dinobryon	Dinobryo	0.02	54	1375	3	33.8
Mallomonas	Mallomon	0.02	14	348	4	25.6
Nephrodiella	Nephrodi	0.02	259	3583	4	36.6
Ochromonas	Ochromon	1.99	278	2330	4	7.4
Synura	Synura	0.02	6	71.57409	4	9.1

Table 5. Summary of the first three axes of the Redundancy Analysis carried out for species and genera groups data in each reservoir.

	Axis 1	Axis 2	Axis 3	Total variance
	San Rafael	(n=183)		
RDA species data				
Eigenvalue	0.082	0.052	0.032	1
Species-environment correlations	0.553	0.809	0.65	
variance of species data	8.2	13.5	16.7	
variance species-environment relationship	38.1	62.4	77	
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.216
RDA genera data				
Eigenvalue	0.094	0.045	0.033	1
Genera-environment correlations	0.543	0.75	0.655	
variance of genera data:	9.4	14	17.2	
variance genera-environment relationship	44.4	65.8	81.1	
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.213
	Chisacá-	**Regadera**	**(n=76)**	
RDA species data				
Eigenvalue	0.109	0.052	0.034	1
Species-environment correlations	0.714	0.744	0.577	
variance of species data	10.9	16.1	19.5	
variance species-environment relationship	42.1	62	75.1	
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.26
RDA genera data				
Eigenvalue	0.113	0.056	0.039	1
Genera-environment correlations	0.719	0.718	0.573	
variance of genera data	11.3	16.9	20.8	
variance genera-environment relation	41.7	62.5	76.9	
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.27
	Chuza	**(n=93)**		
RDA species data				
Eigenvalue	0.051	0.047	0.039	1
Species-environment correlations	0.535	0.731	0.667	
variance of species data	5.1	9.9	13.8	
variance species-environment relation	25.9	49.7	69.4	
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.198
RDA genera data				
Eigenvalue	0.055	0.042	0.038	1
Genera-environment correlations	0.549	0.628	0.658	
variance of Genera data	5.5	9.7	13.5	
variance genera-environment relation	28.3	50.3	70.1	
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.193

Chisacá-La Regadera showed that SD and TKN mainly explained the first axis; Fe, TOC, TP, and conductivity explained the second axis. The RDA for Chuza indicated that the first axis was explained by SD and TOC, whereas the second axis was explained by temperature, Si, alkalinity, and TKN. In all models, the trophic variable with the highest explanation of genera variance was SD (Table 6). Although TP and TKN showed low explanatory power, they were also significantly related to the first two axes of the model (Table 6).

3.3. Ecology of genera and trophic indices

Based on the significant relationship between some chemical variables and genera (Table 6), the optimum values of SD, TP, TKN, TOC, and

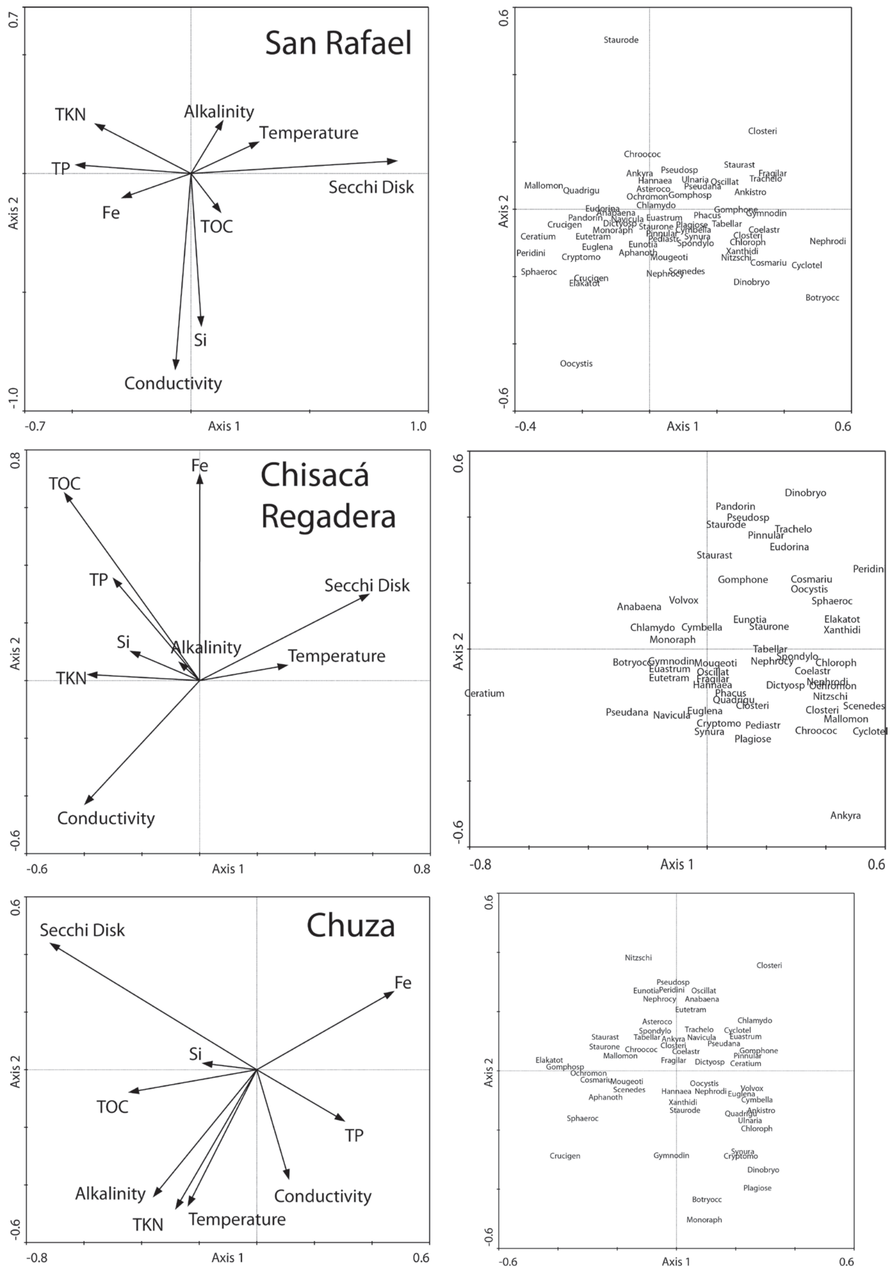

Figure 4. Redundancy Analysis ordination biplot showing the relationships between the environmental variables and genera. Labels of genera are described in the Table 4.

conductivity were calculated for each genus. SD, TP, and TKN were selected as indicators of trophic state, and TOC and conductivity showed close relationship with trophic state.

The indices for SD, TP, TKN, and TOC were correlated with each of their associated variables (Figure 5). I_{Cond} does not show a good relationship between the three datasets. The I_{SD}, I_{TP}, and I_{TKN}, showed a higher correlation with chlorophyll-a in San Rafael (Table 7). In the Chisacá–La Regadera, all indices were correlated with chlorophyll-a, whereas there was no significant correlation in Chuza. The conductivity index I_{Cond} showed a low correlation with the other indices. Linear regression models for San Rafael showed a significant prediction of chlorophyll-a using independent I_{TP}, I_{TKN}, and I_{SD}. The model using I_{TP}, I_{TKN}, and I_{TOC} showed a high chlorophyll-a concentration and the lowest AIC. Models for the Chisacá–La Regadera showed a significant explanation of chlorophyll-a by I_{SD}, I_{TP}, I_{TKN}, and I_{TOC}. The Chuza index did not show a significant relationship with the chlorophyll-a concentration.

Table 6. Summary of variance explained by the significant variables in each model (species and genera models).

		SD	Cond.	Fe	TKN	Temp.	Si	Alk.	TP	TOC
San Rafael	**(n=183)**									
Species data	Explained variance	0.07	0.04	0.02	0.02	0.01	0.02	0.01	0.02	0.01
	p-value	**0.001**	**0.001**	**0.001**	**0.001**	**0.002**	**0.002**	**1**	**0.009**	**0.043**
Genera data	Explained variance	0.07	0.04	0.01	0.01	0.02	0.02	0.01	0.02	0.01
	p-value	**0.001**	**0.001**	**0.017**	**0.016**	**0.001**	**0.002**	**0.011**	**0.003**	**0.048**
Chisacá-	**Regadera (n=76)**									
Species data	Explained variance	0.05	0.03	0.04	0.01	0.01	0.02	0.01	0.04	0.05
	p-value	**0.001**	**0.004**	**0.004**	0.657	0.354	**0.04**	0.532	**0.001**	**0.001**
Genera data	Explained variance	0.06	0.03	0.04	0.01	0.01	0.02	0.01	0.04	0.05
	p-value	**0.001**	**0.002**	**0.004**	0.607	0.306	0.05	0.526	**0.001**	**0.002**
Chuza	**(n=93)**									
Species data	Explained variance	0.04	0.02	0.02	0.03	0.02	0.03	0.01	0.01	0.02
	p-value	**0.005**	0.142	0.094	**0.005**	**0.023**	**0.004**	0.079	0.213	0.092
Genera data	Explained variance	0.04	0.01	0.01	0.03	0.04	0.03	0	0.02	0.02
	p-value	**0.001**	0.663	0.119	**0.001**	**0.001**	**0.001**	0.473	0.187	**0.049**

The variance of each variable corresponds to the conditional effects. SD: Secchi Disk; Cond.: conductivity; Temp.: temperature; Alk.: alkalinity.

The linear regression models performed to relate the IM_{Total} with the axes of the chemical variation of each reservoir showed that at least one principal component of the PCA was significantly related to the grouped index (Table 8). Thus, the I_{SD}, I_{TP} and I_{TKN} can be used as indicators of the trophic state of the studied reservoirs.

The best models were identified using r^2, the standard error of the models, and Akaike's information criterion (AIC). Multiple models were also run to explain chlorophyll-a with different combinations of indices. PC1 and PC2 are the axes of the principal components model of each reservoir shown in Figure 3.

4. Discussion

Phytoplankton species and genera respond to trophic state variables in a similar manner. Trophic indices (*I*) showed a relatively low correlation with the variables from which the indices were generated. Interestingly, for reservoirs with a higher trophic level (San Rafael and Chisacá-La Regadera), the I_{SD}, I_{PT} and I_{TKN} indices showed a strong relationship with chlorophyll-a. Because the measurements of chemical variables are discrete over time, —considering that the phytoplankton community at a given time represents the conditions of weeks (Li et al., 2010)—, lags can be observed between the specific nutrient data and the algal composition (Arteaga et al., 2020) owing to the type and intensity of the selection pressure (Weithoff & Gaedke, 2017). Therefore, environmental filters can distort the response of phytoplankton to nutrient availability, and the direct relationship may be weaker than expected. In contrast, chlorophyll-a is also a variable that changes slowly and is directly related to the composition of phytoplankton. Thus, the relationships between the indices and chlorophyll-a better represent the trophic state (Rakocevic-Nedovic & Hollert, 2005; Mamun et al., 2021). The I_{SD} best relates to chlorophyll in meso-eutrophic reservoirs. The absence of a relationship between these variables in the more oligotrophic system suggests that changes in the transparency of water in the low trophic system must respond mainly to changes in the entry of organic and inorganic materials from the river basin.

Previous studies on European reservoirs have also used genus-level phytoplankton data to assess trophic conditions as positive (Ochocka & Pasztaleniec, 2016; Phillips et al., 2013). The development of ecological indices has shown great performance when the level of identification reaches the species level and their regional ecology is known (Rimet & Bouchez, 2012). Therefore, taxonomy largely affects the capacity of indication, because an adequate taxonomic resolution allows for better identification of the ecological optimum (Jørgensen et al., 2005). In this study, the response along trophic gradients indicates that the relationship can be used to construct indicator models at the genus level. The use of coarser taxonomic resolution or functional groups for plankton is adequate, and taxonomic expertise cannot be obtained (Oliveira Sodré et al., 2020). The local scale and environmental conditions are important drivers of phytoplankton. The classification of plankton into major groups retains a strong taxonomic signal because of its

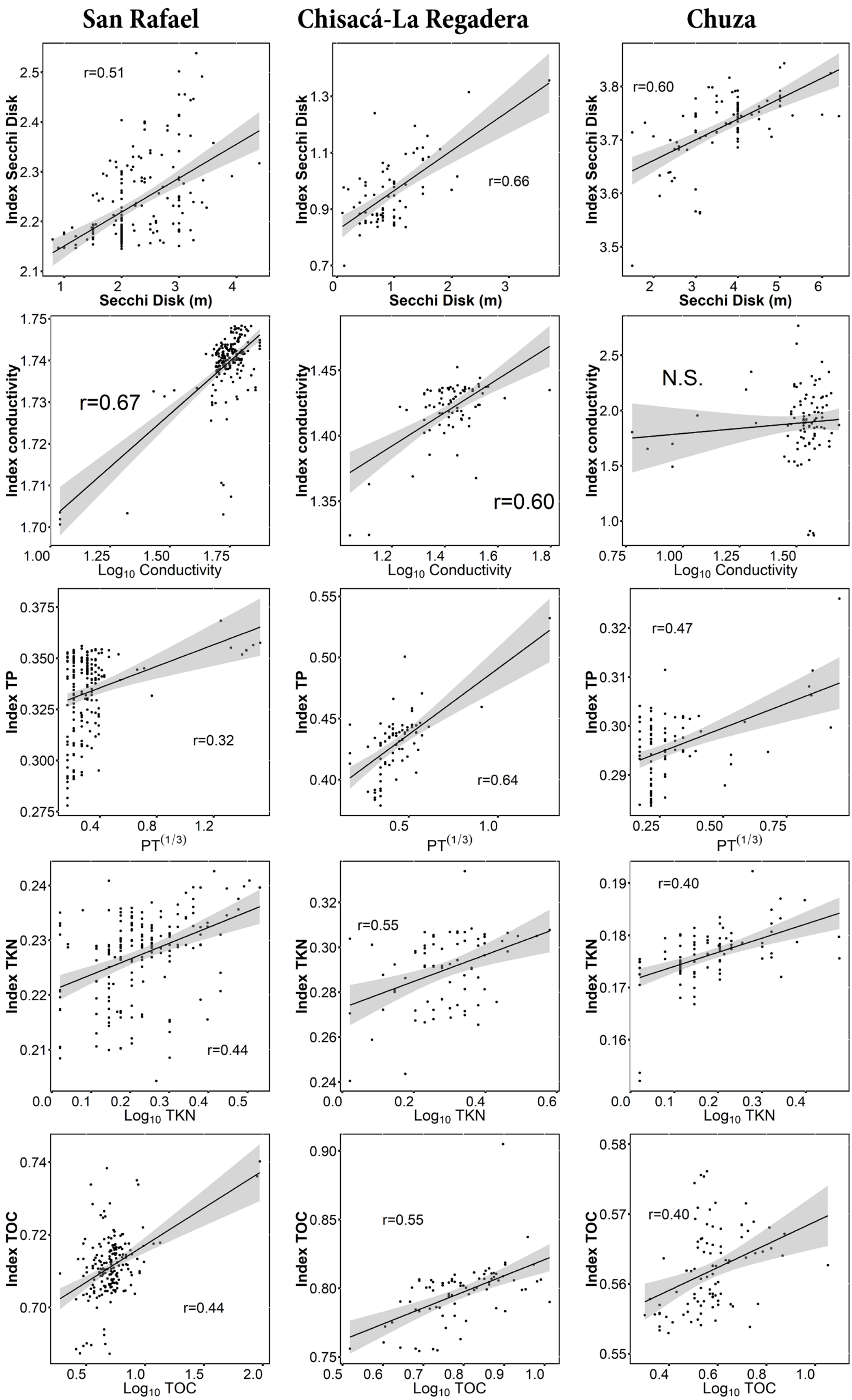

Figure 5. Pearson correlation between the calculated indices and chemical variables for San Rafael (n=183), Chisacá-La Regadera (n=76), and Chuza (n=93) reservoirs.

Table 7. Pearson correlation between the trophic index and Chlorophyll-a for San Rafael (n=183), Chisacá-La Regadera (n=76), and Chuza (n=93) reservoirs.

	I_{SD}	I_{Cond}	I_{TOC}	I_{TKN}	I_{TP}	Chl.a
San Rafael						
I_{SD}	-	-	0.47	-0.86	-0.94	-0.61
I_{Cond}	-	-	0.40	-	-	-
I_{TOC}	0.47	0.40	-	-0.48	-0.52	-
I_{TKN}	-0.86	-	-0.48	-	0.86	0.44
I_{TP}	-0.94	-	-0.52	0.86	-	0.50
Chl.a	-0.61	-	-	0.44	0.50	-
Alkalinity	-	-0.28	-0.11	-	-	-
Conductivity	-	0.67	0.20	-	-	-
Fe	-	-	-	-	-	0.267
Si	-	0.43	0.39	-	-	-
Temperature	-	-	-	-	-	-
Turbidity	-0.423	-	-	0.358	0.270	0.478
Chisaca-La Regadera						
I_{SD}	-	-0.73	-0.44	-0.66	-0.23	-0.51
I_{Cond}	-0.73	-	-	0.45	-0.30	0.33
I_{TOC}	-0.44	-	-	0.59	0.53	0.42
I_{TKN}	-0.66	0.45	0.59	-	0.27	0.49
I_{TP}	-0.23	-0.30	0.53	0.27	-	0.38
Chl.a	-0.51	0.33	0.42	0.49	0.38	-
Alkalinity	-	-	-	-	-	-
Conductivity	-0.40	0.60	-	-	-0.28	-
Fe	-	-	0.24	-0.25	0.24	-
Si	-0.37	-	-	-	0.27	-
Temperature	-	-	-	-	-	-
Turbidity	-0.38	-	-	-	0.30	-
Chuza						
I_{SD}	-	-	-	0.27	-0.50	-
I_{Cond}	-	-	-0.41	-	0.39	-
I_{TOC}	0.53	-0.41	-	0.46	-0.54	-
I_{TKN}	0.27	-	0.46	-	-	-
I_{TP}	-0.50	0.39	-0.54	-	-	-
Chl.a	-	-	-	-	-	-
Alkalinity	-	-	-	-	-	-
Conductivity	-	-	-	-	-	-0.26
Fe	-0.24	-	-	-0.30	-	-
Si	-	0.27	-0.31	-	-	-
Temperature	-	-	-	-	-	-
Turbidity	-0.33	-	-0.33	-0.31	0.30	-

Significant correlations are shown ($p < 0.05$).

Table 8. Linear regressions used to explain chlorophyll-a and the metric index (IM_{total}).

Variable(s)	r^2	standard error	AIC
San Rafael (n=183)			
Chl.a ~−2.65 I_{SD}*	0.36	0.29	70.5
Chl.a ~ 9.36 I_{TP}***	0.25	0.32	101.2
Chl.a ~ 20.7 I_{TKN}***	0.19	0.32	114.7
Chl.a ~−4.9 I_{SD}*** + 7.9 I_{TOC}** − 8.6 I_{PT}**	0.42	0.27	54.9
IM_{total}~ 0.06 PC1*	0.10	0.19	90.0
IM_{total}~ 0.03 PC2*	0.04	0.19	78.7
Chisacá-La Regadera (n=76)			
Chl.a ~−1.92 I_{SD}*	0.25	0.38	74.7
Chl.a ~ 6.70 I_{TP}***	0.13	0.42	86.3
Chl.a ~ 8.65 I_{TOC}***	0.16	0.41	83.1
Chl.a ~ 13.34 I_{TKN}***	0.23	0.39	76.8
Chl.a ~−1.1 I_{SD}* + 4.1 I_{PT}*	0.32	0.36	69.9
IM_{total}~ 0.15 PC2***	0.22	0.28	27.4
Chuza (n=93)			
IM_{total}~ 0.17 PC1***	0.30	0.26	14.2

*p<0.05; **p<0.01; ***p<0.001.

reliance on morphology (Oliveira Sodré et al., 2020). However, the majority of genera found in tropical ecosystems have a cosmopolitan distribution (Silva, 2007) and the results found here can be applied to different tropical ecosystems. Phytoplankton algae in lakes have a very high dispersal ability (Beisner et al., 2006). Therefore, the contribution of environmental factors is more important than that of spatial processes for this group (Mazaris et al., 2010; Padial et al., 2014). Microorganisms may disperse using different vectors, such as streamcourses (Qu et al., 2018) and birds (Atkinson, 1972) and the composition of the genera and species can be interpreted mainly through water chemistry.

Currently, attempts are being made to simplify the response of phytoplankton to environmental factors using the functional group approach (Hakspiel-Segura et al., 2021); however, the use of algal genera can be an intermediate approach in which a part of the evolutionary response of plankton is used, but at the same time, the diversity of responses is conserved. Thus, it allows for a better analysis of the environmental gradient given by the trophic state.

The response of phytoplankton to the N:P ratio is one of the most controversial and studied topics in lakes (Elser et al., 2009), because it is difficult to predict the response of this community to enrichment by global processes (nitrogen deposition) and regional processes (contributions from the basin). Although a high correlation was observed between I_{PT} and I_{TKN}, each could represent different trophic moments of the reservoirs because the genera have different responses to the nitrogen: phosphorus ratio. For example, while many genera of cyanobacteria can respond to eutrophication caused by TP (Huisman et al., 2018), some chlorophyte genera (e.g., *Volvox*, *Eudorina*, and *Pandorina*) require combined enrichment of TP and TKN (Almanza et al., 2016). Thus, the two indices can provide different information regarding the trophic states of the reservoirs. Despite the low contribution of TP and NTK in the RDA, there was significant discrimination of the optimum algal genera along the environmental gradients. Genera such as *Pandorina*, *Eudorina*, *Volvox*, *Anabaena*, and *Monoraphidium*, for instance, are widely reported in phosphorus-enriched environments (Reynolds et al., 2002; Rigosi et al., 2014). In contrast, genera such as *Trachelomonas*, *Pediastrum*, and *Ankistrodesmus* have been reported in environments enriched with organic carbon (Reynolds, 2006; Reynolds et al., 2002).

I_{Cond} showed a relationship with turbidity, alkalinity, and temperature but a low correlation with chlorophyll. The relationship with temperature suggests that these changes are associated with seasonal variation and reservoir management. Conductivity is a variable that integrates basin processes in reservoirs because it reflects inorganic compound inflows by tributaries (Bhateria & Jain, 2016). Thus, conductivity indicates changes in water quality related to mineralization processes, material dragging from the basin, or changes in the ionic composition of the reservoirs. All these factors are important in the treatment of drinking water, and thus, the proposed I_{Cond} is important in the context of water quality. I_{TOC} was related not only to chlorophyll-a, but also to variables associated with trophic state, such as water transparency and total solids. As I_{TOC} may directly represent algal biomass and organic pollution in basins (Chandler et al., 1976), it can also be used to assess the trophic state.

The aggregate I M_{total} index showed a robust relationship with chemical variation in the reservoirs. Therefore, phytoplankton genera responded strongly to different trophic states in these reservoirs. Algae respond simultaneously to the entire set of environmental factors in their ecological environment (Rivera-Rondón & Catalan, 2020). This includes resources such as phosphorus and nitrogen, as well as environmental conditions such as the content of organic matter and the concentration of inorganic compounds. Thus, the models for SD, TP, and NTK can be used as indicators of trophic status. These models can be used for other mountain reservoirs that vary between oligotrophic and mesotrophic conditions.

These results have direct implications for reservoir monitoring and management. Although an approach based on the counting of genera does not contribute much to the knowledge of local biodiversity and ecological questions, its practicality allows for a rapid response to water quality problems. This is very important if one considers that the observations made in this type of ecosystem are necessary to guarantee the water supply of tens of millions of people in the neotropical region. In conclusion, the simplification of routine analysis, grouping very similar genera, will allow an adequate evaluation of the quality of water when its main value is in consumption by the populations.

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