Topics of limnological research in Mexico

Coordinator
Alfredo Pérez Morales

UNIVERSIDAD DE COLIMA

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This book is dedicated to
Dr. Singaraju Sri Subrahmanya Sarma,
in gratitude for all his teachings in the world of limnology.

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Zooplankton Community and Trophic State in Lake Chapala

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Abstract

Lake Chapala is the largest lake in Mexico, it supplies water for the city of Guadalajara and suffers a serious eutrophication problem. In the last 40 years, many indices related to trophic state, based on zooplankton abundance, have been developed for monitoring programs. In this study, we compared different trophic state indices (TSI) based on rotifers, cladocerans, and copepods at the end of the cold season during March 2023 at Lake Chapala, Mexico. We selected four sampling sites where limnological variables such as temperature, dissolved oxygen, pH, conductivity, depth, Secchi transparency, and zooplankton samples were obtained. The temperature was 25.6±1.6°C, dissolved oxygen 7.3±0.4 mg/l, oxygen saturation around 90 %, pH 9.1±0.06, conductivity 1012±5.3 µS/cm with a depth of 4.23±0.13 m and Secchi transparency of 0.46 m. The zooplankton community was composed of 19 species; 10 rotifers, 7 cladocerans, and 2 copepods. The dominant species were both copepods as well as *Ceriodaphnia* spp., *Diaphanosoma* cf. *birgei*, *Chydorus brevilabris*, *Filinia opoliensis*, *F. longiseta*, and *Horaella thomassoni*. Around 75 % of the total zooplankton abundance was represented by copepods, 13 % by rotifers, and 12 % by cladocerans. Carlson TSI based on Secchi transparency and TSI_{ROT} (BAC) indicate hypertrophic conditions, while TSI_{ROT} based on rotifer abundance results in mesotrophic conditions; for most TSI based on crustacean density, the eutrophic state was determined. The implications of calculations of TSI for zooplankton developed in temperate conditions may not completely match with observed conditions for Lake Chapala where heterotrophic bacteria and cyanobacteria dominance play a key factor in the zooplankton community structuration. Formulation of indices in tropical conditions is important for monitoring water assessment.

Keywords

Bioindicators, Cladocera, Copepoda, Rotifera, TSI_{CR}, $TSI_{ROT.}$

Introduction

Eutrophication is one of the main environmental challenges to solve in order to maintain water supply for human activities (Downing, 2014). The eutrophication process generates an increase in phytoplankton biomass with toxic potential and oxygen diurnal fluctuations, causing water quality and diversity reduction and the loss of ecosystem services (Janssen et al., 2020); moreover, climate change and cultural eutrophication enhance this problem (Moss et al., 2011). Hence, trophic state monitoring is critical to the adequate management and conservation of aquatic ecosystems (Dodds & Whiles, 2010).

For surveilling trophic levels on lakes, several trophic state indices have been developed. The Carlson trophic state index (TSI) based on total phosphorus, chlorophyll *a,* and Secchi transparency stands out as one of the earliest and most extensively employed classification schemes devised for assessing lake trophic conditions (Carlson, 1977). Additionally, the biological composition of a given lake is strongly influenced by its trophic state; for instance, a decrease in the average body size of zooplankton is correlated with an increase in trophic level; moreover, an increase in the overall abundance of rotifers and crustaceans exhibits a strong and positive correlation with the trophic state of lakes and some species have particular preferences for determined trophic state and water conditions (Ejsmont-Karabin, 2012; Ejsmont-Karabin & Karabin, 2013). Consequently, trophic state indices based on zooplankton have been proposed to estimate and classify trophic state conditions in freshwater ecosystems (*i.e.,* Slácedêcek, 1983; Ejsmont-Karabin, 2012; Ejsmont-Karabin & Karabin, 2013; Ochocka, 2021).

Freshwater zooplankton is a key component in the food webs of lentic ecosystems because it consumes phytoplankton, protozoans, and bacteria, and determines the abundance of secondary consumers such as macroinvertebrates and fish (Dodds & Whiles, 2010). Many species of zooplankton are abundant, some with wide geographical distribution, high reproductive rate, short generation time, and high sensitivity to environmental changes; therefore, they easily respond to environmental conditions (Beisner & Thackeray, 2023). Thus, these attributes make zooplankton an excellent tool for trophic state monitoring (Ejsmont-Karabin, 2012). Moreover, zooplankton is essential in enabling the provision of ecosystem services, including supporting fisheries, controlling phytoplankton growth, and regulating carbon levels all of which enhance the quality of drinking water and irrigation. Additionally, they contribute to scientific advancements by providing model systems and ecological bioindicators (Declerck & de Senerpont Domis, 2023).

Slácedêcek (1983) proposed the *Brachionus*/*Trichocerca* quotient (B/T_Q) and the saprobic index (SI) for rotifers to determine trophic conditions; nevertheless, genera *Brachionus* and *Trichocerca* are not always present and indicative weight of the species and individual saprobic index are not available for all rotifers. Additionally, indices for rotifers (Ejsmont-Karabin, 2012) and crustaceans (Ejsmont-Karabin & Karabin, 2013) were proposed in temperate lakes. Stamou et al. (2019) evaluated these indices in zooplankton communities of 16 lakes in Greece compared with the trophic state index based on Secchi transparency proposed by Carlson (TSI_{SD}) (Carlson, 1977); they found that these indices exhibited a rise along the eutrophication gradient, but they inaccurately assess the trophic state. Ochocka (2021) developed a multimetric index ($ZIPLA_S$) for Polish lakes considering the taxonomic composition and abundance, diversity, and stressor-sensitive species with the highest correlation with Secchi disk transparency.

In Mexico, there have been some attempts to calculate trophic state using zooplankton indicators in reservoirs and lakes (Muñoz-Colmenares et al., 2017; González-Gutiérrez et al., 2017, 2023; Moreno-Gutiérrez et al., 2018; Torres-Sánchez, 2020); nonetheless, all these studies only use rotifers whereas crustaceans have not been considered. Therefore, comparing these indices in a polymictic lake located at lower latitudes will provide us with information about how these indices respond in tropical conditions. Lake Chapala exhibits significant water quality decline related to an increase of nutrients (mainly nitrogen and phosphorus compounds) from domestic, livestock, industrial, and agriculture wastewater that enhanced primary production (Membrillo-Abad et al., 2016) with elevated presence of potentially toxic cyanobacteria (De Anda & Shear, 2001). Also, high concentrations of heavy metals such as cadmium, chromium, lead, mercury, copper, zinc, and, nickel have been recorded (Hansen et al., 1995). Earlier reports, discarded eutrophication as the main concern because light limitation, due to high inorganic clay turbidity, regulates phytoplankton productivity with a low annual average of 5.4 mg/m^3 and lack of filamentous cyanobacteria without algal blooms (Limón & Lind, 1990).

Recently, degradation of water hyacinth (*Eichhornia crassipes*), inputs from the Lerma River, and excessive use of fertilizers in the agriculture catchment area were related to eutrophic conditions with cyanobacteria blooms of *Anabaena flos-aquae* (De Anda & Shear, 2001). Membrillo-Abad et al. (2016) summarized that Lake Chapala has been in eutrophic condition at least in the last 25 years with mean chlorophyll *a* concentration of 11.7 mg/m^3 and mean Secchi transparency of 0.38 m. Therefore, monitoring and maintaining of water quality in Lake Chapala is a determinant task due to the increasing water demand, because this lake supplies over 60 % of the freshwater requirements of the city of Guadalajara (Membrillo-Abad et al., 2016). Despite the physical and chemical characteristics of this lake being well known, biological data is not complete (Lind & Dávalos-Lind, 2001).

In Chapala 57 species of rotifers (mostly limnetic) were registered by Rico-Martínez et al. (2003); however, there is no data about abundance. For cladocerans and copepods, what we have in Lake Chapala is not clear with no records from recent zooplankton reviews in Mexico (Alcocer et al., 2023; Cervantes-Martínez et al., 2023). In the case of copepods, recent studies (Velázquez-Ornelas et al., 2021) have allowed us to know the diversity of species in the area. Some studies come from gut fish content analysis or gray literature, where taxonomical determination may not be accurate; in these studies, 14 cladocerans and 5 copepods have been registered (Rodríguez-Ruíz & Granado-Lorencio, 1988; Trotter, 1988). Thus, the objective of this study was to compare different trophic state indices (TSI) based on rotifers, cladocerans, and copepods at the end of the cold season during March 2023 at Lake Chapala, Mexico.

Materials and Methods

Study Area

Lake Chapala (Fig. 1) is a RAMSAR site located at the western edge of the Trans-Mexican Volcanic Belt in the eastern part of the state of Jalisco. It is a tectonic warm polymictic lake (20º06'08" - 20º18'08"N, and 102º42'00" - 103º25'20"W) with a maximum depth (Z_{MAX}) of 10.5 m, and a mean depth (Z_{MEAN}) of 7.2 m. Its maximum length (L_{MAX}) is 77 km, and its maximum width (W_{MAX}) 22.5 km, with a volume (V) of 7.9 Km^3. It is located at 1524 m a. s. l. in the Lerma-Santiago basin and has a catchment area of approximately 1,000 km^2. By area and water volume, Chapala is the largest lake in Mexico, turbidic, with highly suspended clay and nutrient content (SRP=0.4-0.5 mg/l, TN=0.5-0.8 mg/l) where the dominance of the cyanobacteria *Microcystis aeruginosa*, *Aphanizomenon flos-aquae,* and *Anabaena* have been recorded (Dávalos-Lind & Lind, 2001; Alcocer & Bernal-Brooks, 2010).

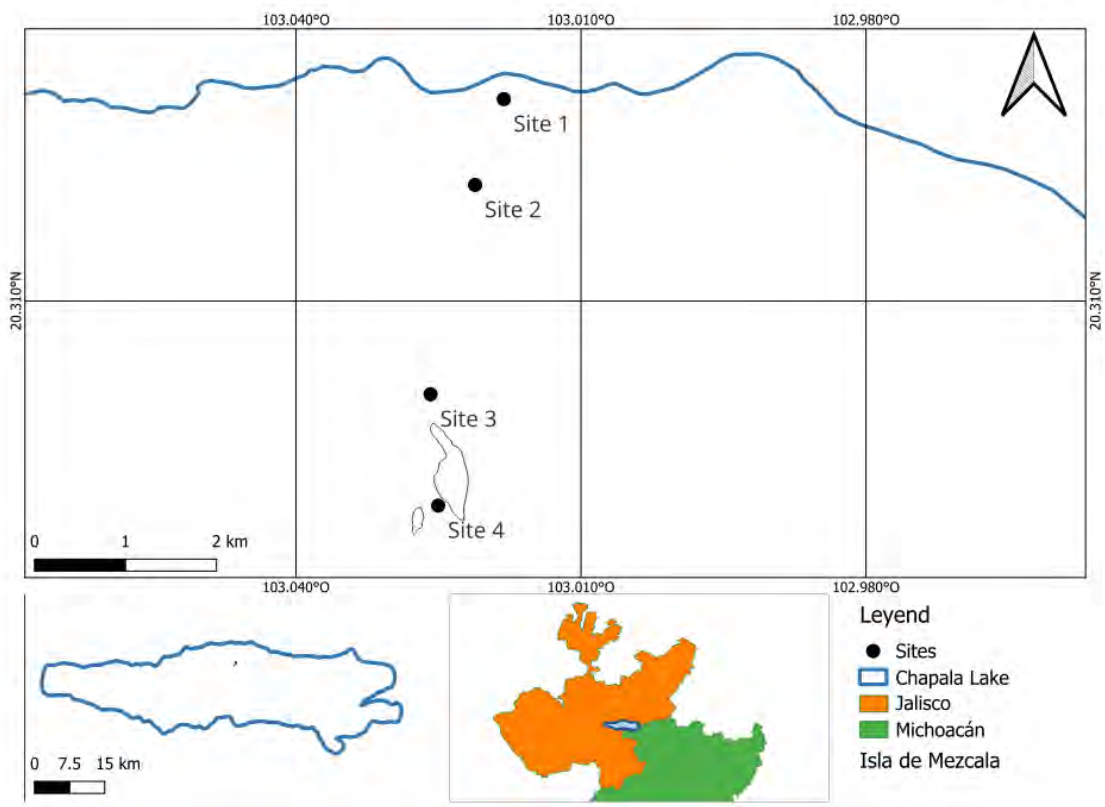

Figure 1. Lake Chapala Showing Sampling Sites.

Sampling

We sampled four sites during March 2023 in a transect from the shore of the town of Mezcala to the island: site 1 inshore in the town of Mezcala (20º19'52.6"N, 103º01'05.3"W); site 2 between site 1 and the island of Mezcala (20º19'20.1"N, 103º01'16.2"W); site 3 close to the island of Mezcala (20º18'0.79"N, 103º01'33.1"W) and site 4 in vegetated area with *Schoenoplectus* sp. (20º17'18.6"N, 103º01'30.2"W). In each sampling point, temperature, dissolved oxygen, and conductivity were measured with a YSI85 probe, pH was registered with a potentiometer conductronic PC-20, depth with an ecosound Hondex digital, and transparency with Secchi disk. Zooplankton was sampled with vertical hauls from 1.5 m in the littoral zone up to 3 m depth in the pelagic zone using a Wisconsin planktonic net of 64 µm mesh size. Later, samples were labeled with sampling data and fixed to a final formaldehyde concentration of 4 %.

Samples Analysis

Each sample was analyzed under a Zeiss Axiostar plus microscope using a Sedgwick-Rafter counting chamber considering a minimum of five subsamples or 400 individuals of the most abundant species (Wetzel & Likens, 2001). Taxonomical determination was done with the taxonomical keys of Koste (1978), Elías-Gutiérrez et al. (2008a), Sarma and Nandini (2017), and Sousa and Elmoor-Loureiro (2021). Zooplankton species photos were taken with an AxioScope A1 with camera Axiocam ICc 5. Names and status of the rotifers were verified in the Rotifer World Catalog database (http://rotifera.hausdernatur.at/); for cladocerans, we used Kotov et al. (2013) and for copepods Elías-Gutiérrez et al. (2008a).

Data Analysis

Trophic State Indices

We calculate the TSI_{SD} of three of four sampling sites according to the following formula (Carlson, 1977):

$$\underline{TSI_{SD}=60-14.41\ \ln(SD)}$$

TSI allows to determine trophic state based on a scale from 0 to 100, and the scale values correspond to different trophic conditions: $0<TSI\leq 40$ oligotrophic, $40<TSI\leq 50$ mesotrophic, $50<TSI\leq 70$ eutrophic, and $70<TSI\leq 100$ hypereutrophic.

We also consider trophic state indices based on rotifers (Ejsmont-Karabin, 2012) and crustaceans (Ejsmont-Karabin & Karabin, 2013) for polymictic lakes (POL) and indistinct mixis patterns according to the following formulas:

TSI_{ROT} POL (rotifer numbers)=4.64 ln(N)+25.36

TSI_{ROT} (rotifer numbers)=5.38 ln(N)+19.28

TSI_{ROT} POL (BAC, %)=8.20 ln(BAC)+28.63

TSI_{CR1} POL (crustaceans numbers)=6.89 ln(N)+20.7

TSI_{CR1} (crustaceans numbers)=25.5 $N^{0.142}$

TSI_{CR6} POL (ratio Cladocera/Calanoida)=0.41 ln(CL/CA)+59.2

TSI_{CR7} POL (ratio Cyclopoida/Calanoida)=1.18 ln(CY/CA)+56.6

These indices calculate trophic state from abundance, bacterivorous percentage (BAC, %), and the ratio between crustacean groups and assumed that those lakes with a TSI_{ROT} and TSI_{CR} lower than 45 are mesotrophic, from 45 to 55 are meso-eutrophic, 55 to 65 eutrophic, and those over 65 are hypertrophic.

Results

The mean values ± standard deviation from the four sampling stations for temperature was 25.6±1.6°C, dissolved oxygen 7.3±0.4 mg/l, oxygen saturation around 90 %, pH 9.1±0.06, conductivity 1012±5.3 µS/cm with a depth of 4.23±0.13 m and Secchi transparency of 0.46±0.005 m (Table 1).

Table 1. Physical and Chemical Variables in Four Sampling Sites of Lake Chapala at the End of the Cold Season in 2023.

Variables	S1	S2	S3	S4
Temperature (°C)	27	24.3	24.1	27
Dissolved Oxygen (mg/l)	7.98	7.27	7.34	6.9
Oxygen Saturation (%)	100.7	88.4	87.6	86.6
pH	9.06	9.19	9.21	9.14
Conductivity (µS/cm)	1016	1009	1006	1017
Depth (m)	3.76	5.1	5.23	2.86
Secchi Depth (m)	0.46	0.47	0.47	-

Table 2 presents 19 zooplankton species found in Lake Chapala; 10 rotifers, 7 cladocerans, and 2 copepods. We found 7 families of rotifers, the majority of species belonging to Trochosphaeridae and Brachionidae where *Filinia longiseta*, *F. opoliensis*, *Horaella thomassoni,* and *Keratella tropica* were the most abundant (Fig. 2A-F). We found five families of cladocerans where *Ceriodaphnia* spp., *Diaphanosoma* cf. *birgei,* and *Chydorus brevilabris* were more abundant (Fig. 3A-H). For copepods, we registered one calanoid and one cyclopoid (*Acanthocyclops* sp.) with a dominance of *Mastigodiaptomus* cf. *albuquerquensis* (Fig. 4A and 4F). We also found abundant *Trichodina* sp. (Fig. 2G) and a microturbellarian (Fig. 2H).

Table 2. Species Richness and Frequency of Metazoa Zooplankton Species Found in Four Sites of Lake Chapala at the End of the Cold Season of 2023.

Species	S1	S2	S3	S4
Crustacea				
Branchiopoda				
Anomopoda				
Bosminidae				
Bosmina cf. *longirostris* (O. F. Müller, 1785)	-	X	-	X
Chydoridae				
Chydorus brevilabris Frey, 1980	X	X	X	-
Ovalona setulosa (Megard, 1967)	X	X	X	X
Daphniidae				
Ceriodaphnia cornuta Sars, 1885	X	X	X	X
Ceriodaphnia cf. *dubia* Richard, 1894	X	X	X	X
Moinidae				
Moina cf. *micrura* Kurz, 1875	X	X	-	-
Ctenopoda				
Sididae				
Diaphanosoma cf. *birgei* Kořínek, 1981	X	X	X	X
Maxillopoda				
Copepoda				
Calanoida				
Diaptomidae				
Mastigodiaptomus cf. *albuquerquensis* (Herrick, 1895)	X	X	X	X
Cyclopoida				
Cyclopidae				
Acanthocyclops sp.	X	X	X	X
Rotifera				
Eurotatoria				
Monogononta				
Flosculariaceae				
Hexarthridae				
Hexarthra mira (Hudson, 1871)	-	X	X	X
Trochosphaeridae				
Filinia longiseta (Ehrenberg, 1834)	X	X	X	X
Filinia opoliensis (Zacharias, 1898)	X	X	X	X
Filinia pejleri Hutchinson, 1964	X	X	-	-
Horaella thomassoni Koste, 1973	X	X	X	X
Ploima				
Brachionidae				
Keratella americana Carlin, 1943	-	-	X	-
Keratella tropica (Apstein, 1907)	X	X	X	X
Euchlanidae				
Euchlanis dilatata Ehrenberg, 1832	-	-	-	X
Lecanidae				
Lecane luna (Müller, 1776)	-	-	-	X
Notommatidae				
Cephalodella sp.	-	X	-	-

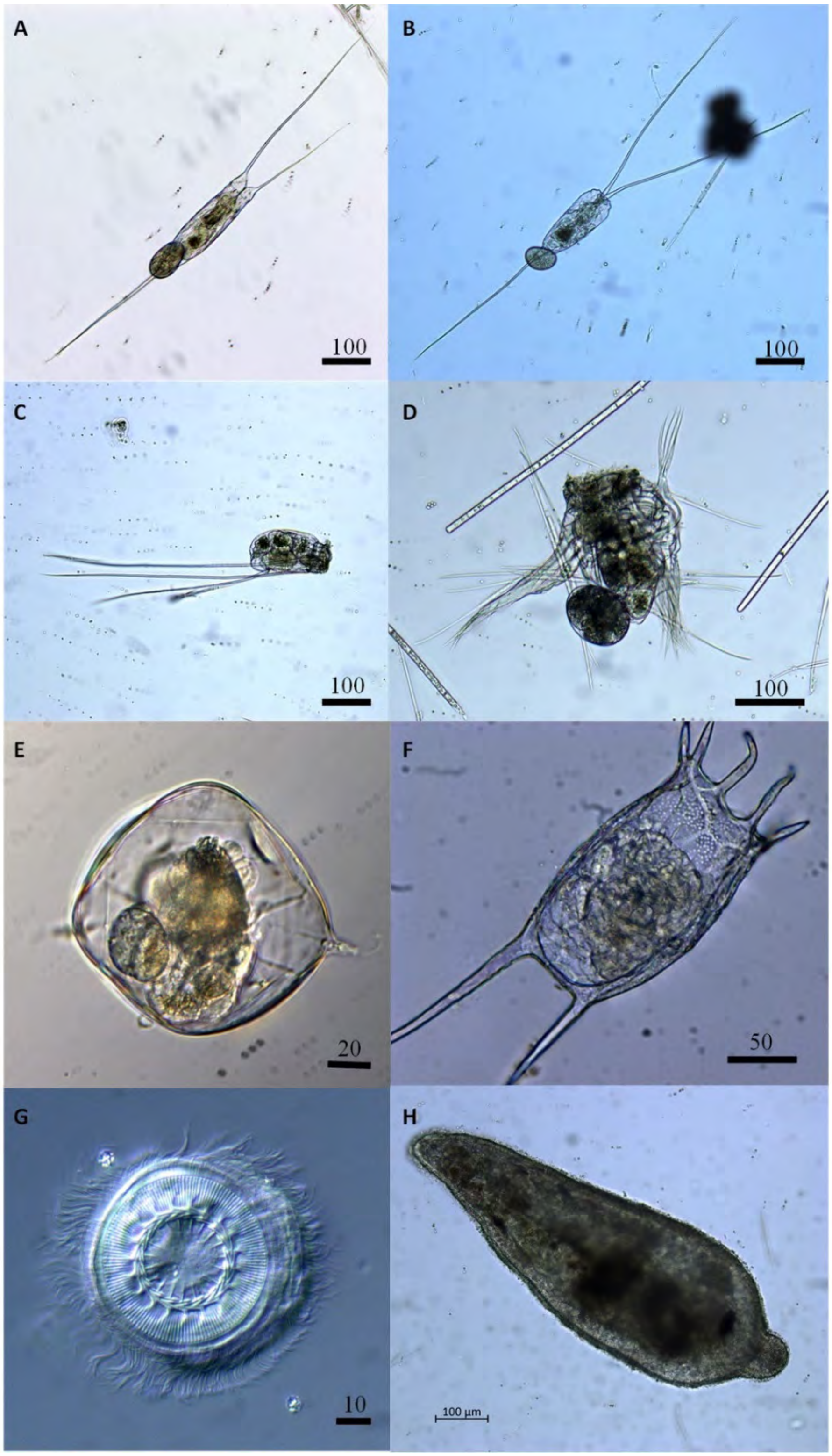

Figure 2. Rotifers, a Protist and Platyhelminth Found in Lake Chapala during the End of the Cold Season of 2023. A) *Filinia opoliensis*, B) *Filinia pejleri*, C) *Filinia longiseta*, D) *Hexarthra mira*, E) *Horaella thomassoni*, F) *Keratella tropica,* G) Protist *Trichodina* sp. and H) Platyhelminth microturbellarian. Scale Measurements are in Micrometers.

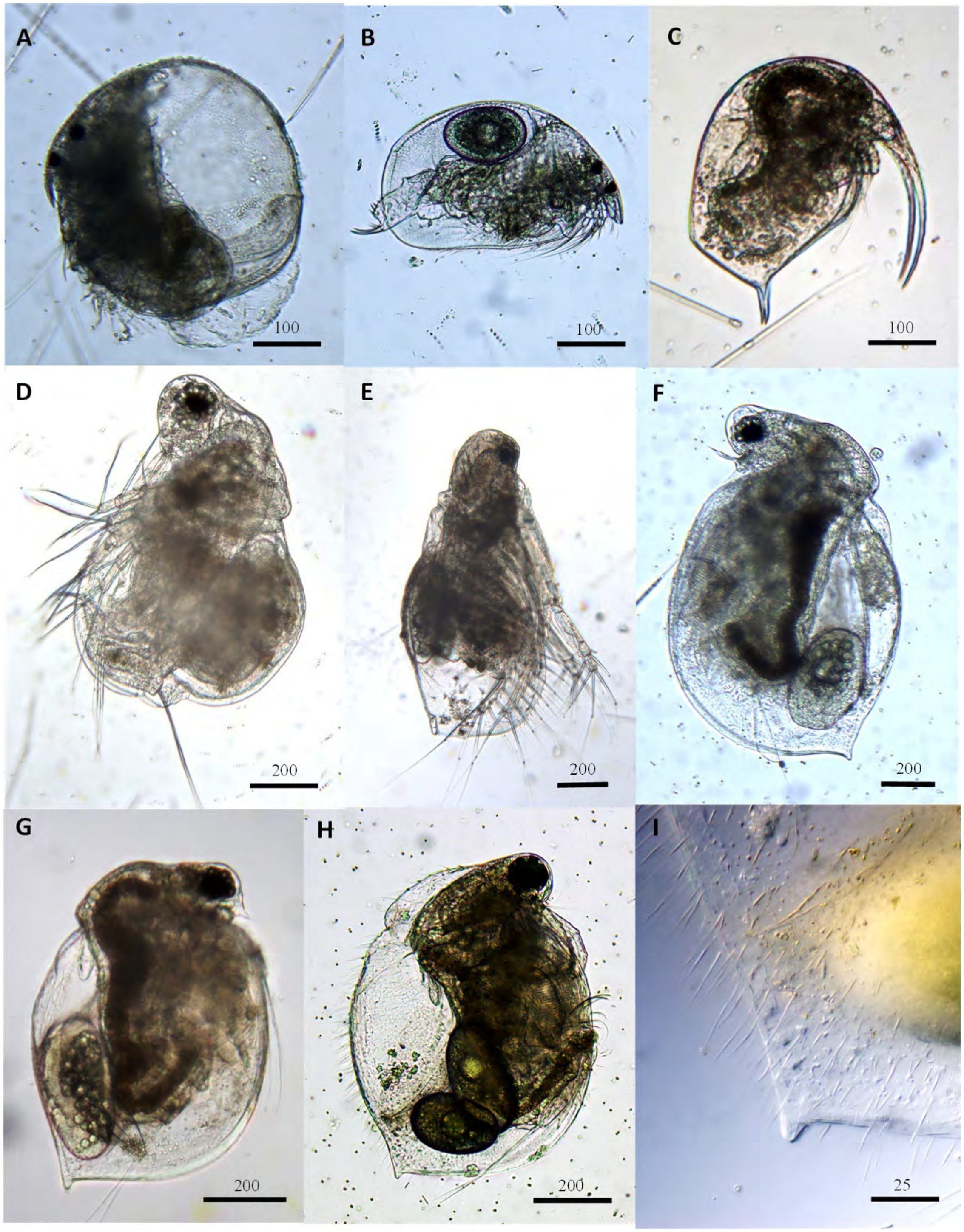

Figure 3. Cladocerans Found in Lake Chapala during the End of the Cold Season of 2023. A) *Chydorus brevilabris*, B) *Ovalona setulosa*, C) *Bosmina* sp., D) *Moina* cf. *micrura*, E) *Diaphanosoma* cf. *birgei*, F) *Ceriodaphnia* cf. *dubia*, G) *Ceriodaphnia cornuta*, H) *Ceriodaphnia* cf. *cornuta* and I) Postero-dorsal Margin of *Ceriodaphnia* cf. *cornuta*. Scale Measurements are in Micrometers.

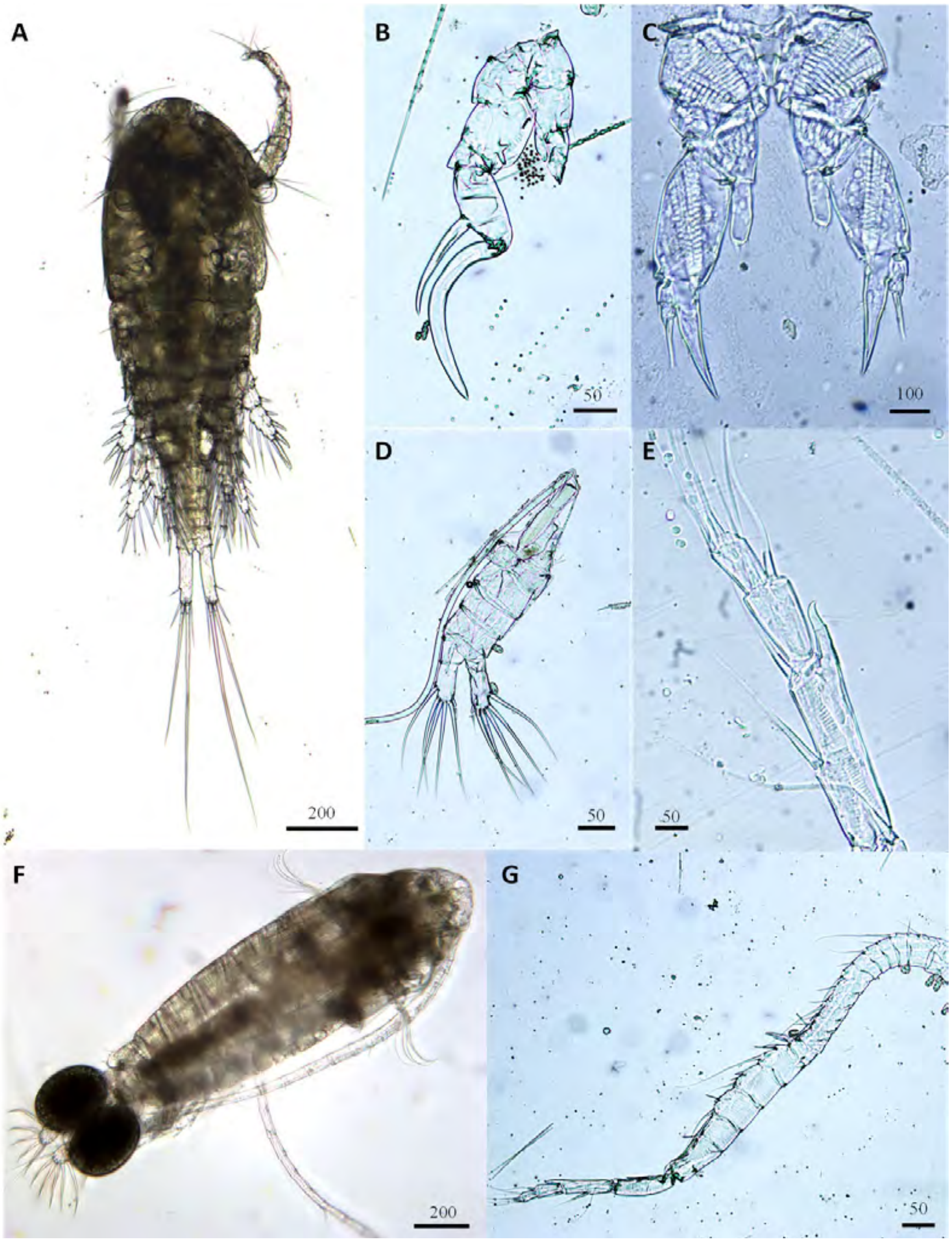

Figure 4. Copepods Found in Lake Chapala during the End of the Cold Season of 2023. A) Male of *Acanthocyclops* sp., B-G) *Mastigodiaptomus* cf. *albuquerquensis* B) Fifth Leg of Male and C) Female D) Urosomite of Male, E) Right Antennule, Segments 20, 21 of Male F) Female Dorsal View, and G) Right Antennule of Male. Scale Measurements are in Micrometers.

Zooplankton density was higher in site 4 with 330 ind/l, while site 1 had lower abundance with 194 ind/l. Abundance was mostly represented by copepods with close to 75 % (200±52 ind/l), while rotifers and cladoceran had similar values with 13% (35±17 ind/l) and 12 % (32±12 ind/l), respectively (Fig. 5).

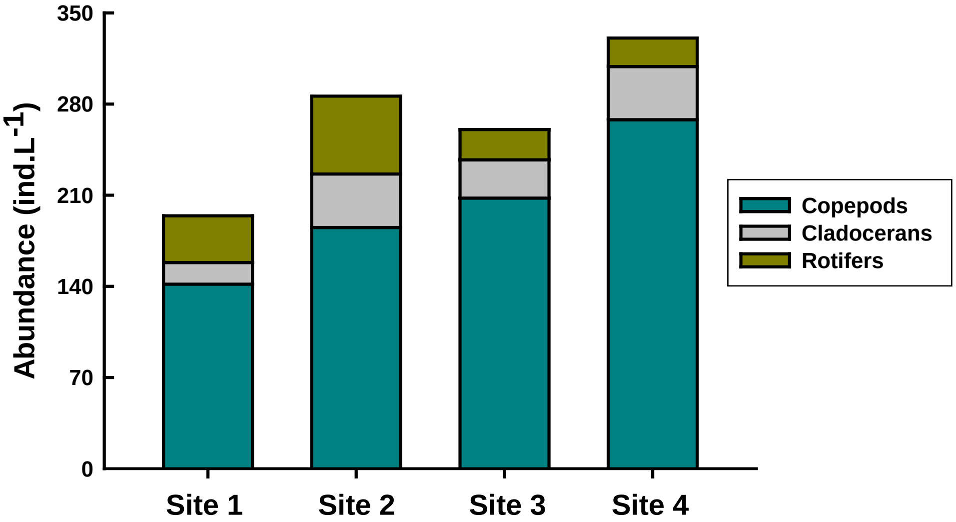

Figure 5. Abundance (ind/l) of Copepods, Cladocerans, and Rotifers in Four Sites of lake Chapala during the Cold Season in 2023.

Carlson TSI based on Secchi transparency determined hypertrophic conditions with values between 70.87 and 71.18. For TSI_{ROT} based on abundances for indistinct mixis pattern and for polymictic lakes, values ranged from 35.89 to 44.33, specifying a meso-trophic state; nevertheless, TSI_{ROT} for bacterivorous species was 66.39 for all sampling sites. TSI_{CR1} based on abundances for indistinct mixis pattern and polymictic lakes, determined in one sampling site meso-eutrophic conditions with a value of 52.33; however, for all the other sites, values ranging from 55.06 to 60.19 indicating the eutrophic state. For $TSI_{CR6,}$ eutrophic conditions were calculated and for $TSI_{CR7,}$ values were close to the eutrophic state (from 53.35 to 54.92) in three sites, while one site was calculated as eutrophic with 55.54 (Table 3).

Table 3. Trophic State Index Based on Rotifers (TSI_{ROT}) and Crustacean (TSI_{CR}) Densities in Four Sites of Lake Chapala during the Cold Season in 2023. H=Hypertrophic, E=Eutrophic, M=Mesotrophic.

Trophic State Index	S1	S2	S3	S4
TSIZSD	71.18 (H)	71.18 (H)	70.87 (H)	-
TSIROT Pol	41.97 (M)	44.33 (M)	39.94 (M)	39.68 (M)
TSIROT	38.54 (M)	41.28 (M)	36.18 (M)	35.89 (M)
TSIROT Pol BAC, %	66.39 (H)	66.39 (H)	66.39 (H)	66.39 (H)
TSICR1 Pol	55.59 (E)	58.05 (E)	58.38 (E)	60.19 (E)
TSI CR1	52.33 (M-E)	55.06 (E)	55.43 (E)	57.55 (E)
TSICR6 Pol (CL/CA)	58.34 (E)	58.72 (E)	58.48 (E)	58.49 (E)
TSICR7 Pol (CY/CA)	53.35 (M-E)	55.54 (E)	54.92 (M-E)	54.58 (M-E)

Discussion

Our results from environmental variables coincide with previous reports by Lind and Dávalos-Lind (2001), who mentioned that the annual Secchi depth is 0.5 m, with a mean annual temperature of 22°C. Reported pH values ranging from 8.54 to 8.9 and oxygen concentrations from 6.84 to 7.13 mg/l with oxygen saturation over 90 % due to wind mixing (Limón & Lind, 1990; de Anda & Shear, 2001).

From the 10 rotifers found, *Hexarthra mira*, *Filinia longiseta*, *F. opoliensis*, *Horaella thomassoni*, *Keratella americana*, *K. tropica*, *Euchlanis dilatata,* and *Lecane luna* were previously reported for Lake Chapala by Rico-Martínez and Silva-Briano (1993) and Rico-Martínez et al. (2003). *Euchlanis dilatata*, *Lecane luna,* and *Cephalodella* sp. were only found once in one sample; therefore, TSI_{ROT} was mainly calculated based on the other 7 species. According to Gilbert (2022), these 7 species are microphagous feeding on small particles where bacteria is an important component in their diet. Some studies have found that the trophic relations in Lake Chapala are not completely sustained by phytoplankton productivity, where bacteria play an important role with an annual production that represents 42 % of total edible small particles for zooplankton (Lind & Davalos-Lind, 2001), which explains the dominance of bacterivorous rotifers.

Zooplankton community structure is strongly shaped by the interaction of different factors, such as vagility, physico-chemical variables, and biological attributes of the habitat, where selective predation is the main driving force (Beisner & Thackeray, 2023). In addition, cyanobacterial blooms also differentially affect zooplankton species and it is well known that the proportion of large-bodied cladocerans significantly decline into small-bodied species when microcystin concentration increased in lake sediments (Moss et al., 2011; Kâ et al., 2012; Pérez-Morales et al., 2015; Jiang et al., 2017).

Although there is currently no data on cyanotoxins in Lake Chapala, the samples revealed a high density of potentially toxic cyanobacteria, including *Aphanizomenon* sp., *Microcystis aeruginosa*, *M. wesenbergii*, and *Dolichospermum* sp. Moreover, large filamentous cyanobacteria such as those found in Lake Chapala mechanically interfere with the feeding process of large-bodied cladocerans (Gliwicz, 2003), while small cladocerans, rotifers, and copepods are more selective than large cladocerans (Thackeray & Beisner, 2023). Hence, selective predation and the dominance of cyanobacteria may shape the zooplankton community in Lake Chapala.

Despite food availability for rotifers not being limited in Lake Chapala, their abundances were low (35±17 ind/L) in comparison with microcrustaceans (232±61 ind/l), where cladocerans had similar abundances to rotifers (32±11.6 ind/l), while copepods reached the highest abundances (200±53 ind/l). Rotifer abundances are mainly affected by exploitative competition when food resources are scarce, interference competition with large-size cladocerans, and selective predation (Thackeray & Beisner, 2023). MacIsaac and Gilbert (1989) demonstrated in laboratory experiments that cladocerans smaller than 1.2 mm can easily coexist with rotifers such as we observed for Lake Chapala. Therefore, selective predation may explain low rotifer abundance; Nandini et al. (2011) showed how turbellarians reduce rotifer abundance through the production of toxins and direct predation and despite not registering turbellarian abundance, we observed many specimens in each counting. On the other hand, cyclopoid copepods also exert high predation pressure on rotifers, Sarma et al. (2019) found in field samples that *Acanthocyclops americanus* consume different rotifer species. Under laboratory conditions, it was observed that female *Acanthocyclops* consumed nearly twice as much as males, depending on food availability, ingesting between 40 to 400 rotifers per hour. Hence, the presence of *Acanthocyclops* in our samples may also lead to a decrease in rotifer abundance.

For cladocerans, *Diaphanosoma* cf. *birgei* is the ctenopod with more records in Mexico. Recently, Velázquez-Ornelas et al. (2021) registered this species for Laguna de Cajititlán and there is evidence of this species in the report of the international training course: “zooplankton a tool in lake management” (Rico-Martínez, 1992). Former studies (Rodríguez-Ruíz and Granado-Lorencio, 1988; Trotter, 1988) identified Chapala *Diaphanosoma brachyurum* (originally described for Europe); nevertheless, this species is not confirmed for México (Elías-Gutiérrez et al., 2008a); Dumont et al. (2021) mentioned that *D. brachyurum* is the ctenopod with many citations without figures or morphological evidence, while Alexiou et al. (2021) observed that insufficient knowledge of *Diaphanosoma* morphology resulted in *D. brachyurum* being the most commonly documented species globally. The specimens we found have the posteroventral margin with group denticles increasing in size and one setule between each group. Moreover, Elías-Gutiérrez et al. (2008b) mentioned that this is a complex species with at least 4 species in Mexico with divergence up to 14.5 % from its type locality.

Ceriodaphnia is a very confusing genera, records from Lake Chapala listed *Ceriodaphnia lacustris*, *C. pulchella* (Trotter, 1988), and *Ceriodaphnia* cf. *reticulata* (Rodríguez-Ruíz & Granado-Lorencio, 1988) and we also found three morphospecies but it does not coincide with previous records (Trotter, 1988). One of the species we found was determined as *Ceriodaphnia* cf. *dubia* (Fig. 3G) which is highly variable and widely distributed in Mexico. We also found two morphotypes of *C. cornuta* species complex (Fig. 3G and 3H), one of them is referred by Elías-Gutiérrez et al. (2008b) such as *Ceriodaphnia cornuta-rigaudi*; nevertheless, *C. rigaudi* is *species inquirenda* according to the Cladocera checklist (Kotov et al., 2013). Elías-Gutiérrez et al. (2008b) discussed that *Ceriodaphnia cornuta* belongs to the species complex *C. cornuta-rigaudi* with high morphological diversity, broad distribution, and three lineages in Mexico. In addition, Berner (1985) worked with three typical forms of this species complex and mentioned that *C. rigaudi* is synonymous with *C. cornuta*. She also reported a *C. cornuta* form that lacks the rostral projection and it has a hairy surface carapace similar to the population found in this study, which was identified as *C*. cf. *cornuta*. *Moina micrura* s str. is a Palaearctic species but is considered a complex where at least three species are registered for Mexico. However, formal descriptions of these species have not been made (Elías-Gutiérrez et al., 2019). Chydorids also represent new records for Lake Chapala (*i.e., Chydorus brevilabris* and *Ovalona setulosa*).

On the other hand, *Acanthocyclops vernalis* and *Mastigodiaptomus albuquerquensis* were previously registered by Rodríguez-Ruíz and Granado-Lorencio (1988) and Trotter (1988), respectively. In addition, Velázquez-Ornelas et al. (2021) indicate the presence of *M. montezumae* in another lake close to Lake Chapala, but it was not recorded in our samples. However, due to the recent description of complexes of cryptic species in both genera, it is necessary to carry out genetic and detailed morphological studies to corroborate the identity of the collected specimens.

The trophic state condition of Lake Chapa is eutrophic. Lind and Dávalos-Lind (2001) mentioned that regarding nutrients, Lake Chapala indicates the eutrophic-hypertrophic condition. According to remote sensing analysis, Membrillo-Abad et al. (2016) showed that Mezcala is an area with high chlorophyll *a* concentration (up to 65 mg/m^3) with low transparency and Carlson TSI from 40 and 70 cm in the inshore of the town of Mezcala. Cyanobacteria abundance is high with dominance of filamentous and colonial species such as *Anabaena limnetica* (Lind & Dávalos-Lind, 2001), *Aphanizomenon flos-aquae*, *Microcystis aeruginosa*, *M. flos-aquae* (Mora-Navarro et al., 2004). Despite the trophic state being clear, our idea was to compare some zooplankton trophic state indices to test how these come across Lake Chapala conditions.

Our data reveal mesotrophic conditions using rotifers abundances, hypertrophic state when calculations are based on the percentage of bacterivorous rotifers, and mostly eutrophic conditions using crustacean ratios and abundances. González-Gutiérrez et al. (2023) derived rotifers as indicators through the saprobic index, the *Brachionus*:*Trichocerca* quotient, and TSI_{ROT} in a high-altitude the El Llano Reservoir ,where they determined oligosaprobic, oligotrophic and meso-eutrophic conditions, respectively. Ejsmont-Karabin (2012) mentioned that discrepancies may be expected and the use of different methods and indices of different scales are not always in close agreement where TSI_{ROT} BAC % does not seem to be a strong predictor of trophic state for polymictic lakes. Even though generally rotifers seem to be better indicators of trophic state than microcrustaceans because of their susceptibility to the negative influence of algal blooms and toxic effects of cyanobacteria (Ejsmont-Karabin & Karabin, 2013), in Lake Chapala, microcrustaceans coincide with the eutrophic condition of Lake Chapala in a better way than rotifers.

It is also relevant to the role of copepods where calanoids were much more abundant (164±45 ind/l) than cyclopoids (36±19 ind/l). Ejsmont-Karabin and Karabin (2013) mentioned that usually, an increase in a lake trophy may cause an increase in the ratio Cladocera to Calanoida numbers and an increase in the ratio of Cyclopoida to Calanoida numbers; however, it does not occur in Lake Chapala during cold season. It is important to consider this study is based on a sampling taken during one moment; however, according to its water chemistry, Lake Chapala exhibits less than 20 % spatial and seasonal variation (Limón & Lind, 1990); hence, our observations may open a window to research on zooplankton dynamics and bioindicator in Lake Chapala.

Conclusion

In summary, we registered, for the first time, for Lake Chapala *Filinia pejleri*, *Diaphanosoma* cf. *birgei*, *Ceriodaphnia* cf. *dubia*, *C*. cf. *cornuta*, *Ovalona setulosa*, and *Chydorus brevilabris*, where the zooplankton community may be mainly shaped by selective predation and dominance of bacteria (heterotrophic and cyanobacteria). TSI based on rotifers was not precise about Lake Chapala conditions, instead, TSI based on crustaceans was useful to determine trophic state.

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Authors' Contributions

CAER: Conceptualization; sampling; identification of rotifers and cladocerans; photography; data analysis; original draft preparation; review, and editing manuscript. LCP: Description of the study area; photography; samples and data analysis; original draft preparation; review, and editing manuscript. OABM: Identification of copepods, writing, original draft preparation, review, and editing manuscript. All authors have read and agreed to the published version of the manuscript.

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This book takes a significant step in showcasing the relevance of limnology to our survival. Freshwater habitats, though they cover less than 1 % of the Earth's surface, are home to a substantial portion of the world's biodiversity—at least 10 % of all known species. Freshwater habitats and the biodiversity they support are under threat. Moreover, our survival depends on access to high-quality freshwater. This book not only highlights the beauty of limnology and the scientific methods used to study it, but it also draws attention to the major causes of biodiversity loss in freshwater ecosystems. It shows all readers what it means to deal with inland waters as a scientist interested in understanding ecosystems and protecting them.

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