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DETERMINATION OF EUTROPHICATION AND INDICATOR SPECIES BASED ON SEDIMENT DEPTH IN RELATION TO DIATOM INFERRED WATER QUALITY DATA IN LAKE TÖDÜRGE

ABSTRACT

Lake Tödürge located in Sivas Province is one of the most characteristic lakes with its high alkalinity in Eastern Anatolia. The lake is well known for its characteristic high water quality. The present study aimed to investigate the paleolimnological past of Lake Tödürge in relation to changes in concentrations of total nitrogen (TN), total phosforus (TP), chlorophyll-*a* (Chl-*a*), and secchi depth (Secc) that occurred in past years. Diatom-inferred paleolimnological evidence is also studied and evaluated. Core samples were taken from the lake using the Kajak Gravity Corer. The 113-year history of Lake Tödürge was re-dated using the Constant Supply Rate model (CRS) in the dating of ^{210}Pb. The TN, TP, chl-a, secchi depth, pH, and $CaCO_3$ variables were reconstructed using weighted average (WA) transfer functions and modern analog techniques (MAT). Identifications and relative abundance of fossil/subfossil diatom species were made for each dated depth. A total of 104 diatom taxa belonging to 59 genera were identified. The relative abundance of diatom taxa was poor despite the high species diversity. Species diversity and relative abundance of species showed some variations in core samples dated between 2022 and 1909. Pantocsekiella comensis, Tetramophora Croatia, and Cymbopleura pyrenaica were found to be dominant diatom species in core samples. The relative abundance of the diatoms did not display considerable changes in the past 113 years. According to ecological assessments based on DI-TN, DI-TP, DI-Chl-*a*, and DI-Secc it has been determined that the lake has been eutrophic for 113 years.

Keyswords: Paleolimnology, Fossil diatom, Transfer functions, Eutrophication, Lakes

1. INTRODUCTION

Excessive proliferation as a result of anthropogenic activities (cultural eutrophication) such as untreated sewage, fertilizier runoff from agriculture, and municipal and industrial effluent are known to cause eutrophication in aquatic ecosystems. Nutrients especially phosphorus and nitrogen play an important role in the eutrophication process. Due to the increase in the amount of algal bloom (such as toxic Cyanobacteria), aquatic macrophytes, and decayed organic matter in the sediment in the lake, oxygen decrease, and taste and odour deterioration are intensely observed in the deep parts of the water [1 and 2]. Although many regional lakes are currently being investigated within the scope of water quality monitoring programs, the absence long-term data is a significant problem in determining the timing, rate and magnitude of ecological changes in the lake [3]. The realism,

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availability and reliability of lake management and restoration targets determined by lake managers are not based on stronge foundations [4]. According to Anon [5], in order to develop realistic targets for lake management and restoration, determining the reference conditions at which lakes are exposed to the least anthropogenic impact or before deterioration of lakes, determining the ecological status of lakes with an updated/at present water quality monitoring program, and determining the magnitude and causes of chemical and biological changes in aquatic ecosystems, are necessary information [3].

Developing modeling studies of calibration sets that reflect the relationship between the relative abundance values of current diatom assemblages of lakes and their environmental variables (such as weighted average regression and calibration, weighted averaging partial least squares and diatom inferred transfer functions), quantitative determination of data on historical environmental variables of a lake (for example, under threat of eutrophication) based on these regional calibration sets (training-sets) [6]. Paleolimnological modeling approaches are of great importance in the process until the lake is evaluated according to the appropriate trophic status classification [2] categories. The main scopes of paleolimnological studies are as follows: (1) Dating the lake shows the starting point of the threat and the process in which it became effective, (2) The production of quantitative data produces concrete/strong data that can be observed in the change of both the current and historical rates and magnitude of the threat from the determined date to the present, (3) Determination of each environmental variable that threatens the lake [1].

Trophic status classification values vary regionally and even from country to country [1]. The most common variable used to determine the past eutrophication status of lakes based on ecological data was TP ve TN [7 and 8]. There are many regional calibration datasets in the world used to develop diatom-inferred TP data [9 and 10]. To evaluate water quality data in the correct calibration set that reflects the environmental variables, diatom diversity and abundance of the lake are important for the reliability of diatom inferred data [1]. One of the most important indicators used in paleolimnological studies is diatoms. Because their cell walls contain silica, they can be preserved in lake sediment for a long time without deterioration [11]. They can be easily identified by their species-specific wall decorations [12]. In addition, they have specific optimum and tolerance values for each environmental variable in water, and thus, they have been the subject of many studies as indicator species that provide the first and fastest response to water quality changes [3].

The paleolimnological studies are new in Türkiye, and the historical past of chemical and biological traces of many lakes are needed to be investigated. Lake Tödürge which is characteristic with its high pH and salinity values, is one of them. The specific objectives of the present study are (1) To show 113 years of quantitative data of Lake Tödürge on diatom inferred environmental variables based on the regional data sets we developed, (2) to determine the 113-year physico-chemical quality of water based on the quantitative results of diatom inferred environmental variables, (3) To determine the 113-year trophic status change of the lake, based on the quantitative results of diatom inferred environmental variables and evaluated according to OECD trophic status index [2], (4) To determine indicator types of physico-chemical changes in the lake.

2. RESEARCH SIGNIFICANCE

This study aimed to investigate the relationship between the paleolimnological history of Lake Tödürge and changes in total nitrogen (TN), total phosphorus (TP), chlorophyll-a (Chl-a), and Secchi depth (Secchi) over the years. Additionally, the study examined eutrophication and identified indicator species based on water quality data obtained from diatom extractions in Lake Tödürge. This research is significant as it serves as a valuable example for similar studies in the future.

Highlights

- Fossil/subfossil diatom species diversity and relative abundance of dated and sliced sediment samples were determined. Depth-dependent diatom zones and indicator species belonging to these zones were found.
- Physico-chemical changes of Lake Tödürge between 2022 and 1909 were calculated quantitatively with the transfer functions of diatom-referenced environmental variables, and water quality classes of the lake were determined for 113 years.
- When the quantitative results of diatom inferred physico-chemical transfer functions were evaluated in the OECD trophic status index, it was determined that Tödürge Lake had maintained its current status for 113 years and had a eutrophic status.

3. MATERIAL AND METHOD

3.1. Overview of Sampling Points

Lake Tödürge is an eutrophic lake situated at coordinates 39°52′57″N, 37°35′59″E at 1295m altitude in Kızılırmak Basin. It has a surface area of 3.5km^2, and its mean depth is 5.5m. Lake Tödürge is fed largely by surface waters, springs, and precipitation. Therefore, Tödürge lake level varies depending on the rainfall in the region. The lake is slightly salty and has calcareous water.

3.2. Sample Collection and Preparation

On 01 August 2022, two 52cm core samples were taken from the point 39°53'08.0"N, 37°36'06.2"E at a water depth of 8m using the Kajak Gravity Corer. Core samples were sliced at 2cm intervals and packaged in bags with sampling date, location, water, and sediment depth written on them. Sliced sediment samples in the first core sample were preserved for fossil/subfossil diatom identification frustule counting, whilst the other one was for ^{210}Pb dating of the lake. 1gr of wet sediment sample that was transferred into a 250ml glass beaker. After treatment with 10% HCl to remove carbonates, samples were treated with 30% hydrogen peroxide (H_2O_2) to remove organic materials. Permanent preparations of diatoms were made using Diatom Naphrax®. Diatom counts were performed in a 100mm^2 area of each permanent slide. Diatom frustules were photographed by means of an Olympus BX51 microscope with differential interference constrast (DIC). Frustule morphology measurements were photographed with the Nikon Eclipse 80i Microscope and Spot brand camera with an image analysis software integrated into the microscope. Diatom taxonomy was based on [13, 14, 15, 16 and 17]. Guiry and Guiry is used for nomenclature revisions of current diatoms [18].

Sliced sediment samples were set at 110°C, ground and placed in labeled bags. It was sent to Ankara University Faculty of Nuclear Sciences for ^{210}Pb activity measurements. ^{210}Pb activity measurements in the samples were made using the gamma-ray spectrometric analysis method in the gamma measurement system with a semiconductor high-purity germanium detector. Ortec Brand GMX70P4-S Model Ge (germanium) detector was used in the lead shielded gamma measurement system. The HPGe detector operates at 78.5% relative efficiency (Resolution Power: 2.01 keV/1.33 MeV (60Co–FWHM). Two standards were used in ^{210}Pb activity measurements. The first is Lake Sediment Reference Material/Lake Sediment (IAEA-SL-2), and the other is Moss Soil (IAEA 447). ^{210}Pb dating was calculated according to the Constant Rate of Supply Model [19].

3.3. Establishment of Diatom Inferred Environmental Variables Transfer Functions

Diatom inferred environmental variables of the lake were reconstructed using two different modeling techniques from the same calibration set. These are classical and inverse weighted averaging (C-WA and I-WA) regression and calibration techniques and modern analog technique (MAT). The performance of the transfer functions for TN and TP were evaluated by the correlation squares (R^2) between the observed and inferred value, by the root mean-squared error (RMSE, observed-inferred), by the root mean square error of the predictions (RMSEP) and the square of the correlation of the observed-predicted values by the leave-one-out cross-validation (jackknifing) (r_{jack}^2) methods. Accordingly, the performance of the transfer functions for the other environmental variables (pH, conductivity, Secchi depth, silica, chlorophyll-*a,* and calcium carbonate) was evaluated with a weighted standard deviation of 10 closest analogs using MAT by the leave-one-out cross-validation (jackknifing) (r_{jack}^2) methods (Table 1). All transfer functions were developed using the software program C2 [20].

Table 1. Model performance evaluation results of transfer functions of TN and TP variables with inferred to diatom

Model	Variable	R^2	RMSE	Max Bias	r_{jack}^2	RMSEP
C-WA	TN	0.779	0.01	0.343	0.536	0.140
I-WA	TP	0.743	0.017	0.059	0.719	0.044

3.4. Diatom Zones

Biogeostratigraphically constrained cluster analyses of diatom inferred environmental variables transfer functions and diatom relative abundances of the lake were defined using the CONISS algorithm, and diatom zones were determined. Data regarding the age of the lake depending on sediment depth, diatom relative abundances, diatom zones, and diatom inferred environmental variables transfer functions were shown using the Tilia version 3.0.1 program [21].

3.5. Indicator Species Tests

Indicator species for each diatom zones in the 28cm core sample for which the cluster analysis was performed were determined separately for all identified species and dominant species using Indicator Species Test analyses. The reliability of the analyses was shown by Monte Carlo tests of significance of observed maximum indicator value for species 4999 permutations. According to the Monte Carlo test results, diatom species <0.05 were determined as indicator species belonging to the relevant zones [22]. All analyzes were completed using the PC-ORD statistical program [23].

4. RESULTS

4.1. Diatom Inferred Environmental Variables Transfer Functions

Reconstructed diatom inferred water quality results of the lake's 0-28cm sediment depth showed that there were similar changes in the lake from 1909 to 2022. Data between the minimum (8.67) and maximum (8.90) values of diatom inferred (DI-pH) indicate that the lake has been slightly alkaline since 1909. $CaCO_3$ was determined to be at a minimum 197.51mg/L at a depth of 24cm (1952), which reached a maximum value of 274.56mg/L in the surface sediment (2022). According to the United Nations World Water Development Report [24], observed diatom inferred calsium carbonate (DI-$CaCO_3$) showed that lake water has been in the hard water category for 113 years. According to Anonim [25], diatom inferred total nitrogen (DI-TN, mg/L) was determined Class I (<3.5mg/L, high-quality water-HQW). Diatom inferred (DI-TP, µg/L) was found to be Class I (<80 µg/L, high-quality water-HQW) up to a depth of 22cm (65 years old, 1957), and Class II (<0.2mg/L, slightly polluted water-SPW) at a depth of 22-28cm. According to diatom inferred conductivity (DI-Cond, µS/cm) values, the lake had Class II (1000 µS/cm, slightly polluted water-SPW) water quality for 113 years (Table 2).

Table 2. Results of depth-dependent diatom inferred environmental variables in Tödürge Lake according to Surface Water Quality Regulation (C); D: Depth; S-A: Slightly Alkaline; F: French Hardness Degree; H: Hard

D	Age	Year	DI-TN	C	DI-TP	C	DI-Cond	C	DI-pH	pH	DI-$CaCO_3$	F
0	0	2022	2.01	HQW	68	HQW	955.54	SPW	8.67	S-A	274.56	H
2	5	2017	1.73	HQW	58	HQW	696.15	SPW	8.81	S-A	223.30	H
4	10	2012	2.29	HQW	77	HQW	839.71	SPW	8.73	S-A	273.43	H
6	16	2006	1.92	HQW	66	HQW	734.13	SPW	8.79	S-A	228.37	H
8	21	2001	1.82	HQW	70	HQW	671.35	SPW	8.83	S-A	203.76	H
10	26	1996	1.90	HQW	71	HQW	756.61	SPW	8.77	S-A	270.56	H
12	32	1990	1.87	HQW	70	HQW	732.32	SPW	8.80	S-A	245.28	H
14	36	1986	1.76	HQW	67	HQW	642.13	SPW	8.82	S-A	241.15	H
16	37	1985	1.89	HQW	72	HQW	674.92	SPW	8.79	S-A	236.61	H
18	41	1982	2.01	HQW	78	HQW	655.13	SPW	8.90	S-A	231.52	H
20	63	1959	2.13	HQW	75	HQW	758.53	SPW	8.75	S-A	204.74	H
22	65	1957	2.32	HQW	85	SPW	756.66	SPW	8.76	S-A	204.61	H
24	70	1952	2.18	HQW	83	SPW	720.16	SPW	8.74	S-A	197.51	H
26	100	1922	2.09	HQW	80	SPW	765.90	SPW	8.77	S-A	202.78	H
28	113	1909	2.27	HQW	86	SPW	812.74	SPW	8.73	S-A	228.77	H

4.2. ^{210}Pb Dating

The use of the CRS (Constant Rate of Supply) method was preferred because the age error rate was determined to be lower in the ^{210}Pb dating of the sediment compared to the others [CIC (Constant Initial Concentration) and CF-CS (Constant Flux-Constant Sediment Accumulation)]. Dating of ^{210}Pb has been showed to a depth of 28cm. After this depth, the dating was finished because the age error rate was greater than the determined age. The depth, age and error rate, sediment accumulation and error rate of the sample in the surface sediment were assumed to be zero. The year of surface sediment was determined as the date of sampling (2022). The age of Lake Tödürge was determined with low age error rates in each sliced sediment sample. The 28cm sediment depth of the lake represents 113 age and in 1909. The sediment accumulation rate of the lake increased rapidly after a depth of 14cm and reached a value of 85.18cm/y at a depth of 16cm. This situation was also supported by the data showing that the sediment, which was 36±3.411 years old at a depth of 14cm, was 37±8.655 years old at a depth of 16cm. The same situation was also detected at a depth of 22cm. It has been determined that there is not much age difference between the depths where the sediment accumulation rate (SAR) is high and the depths representing the following years (Table 3).

Table 3. ^{210}Pb dating results calculated according to the CRS method of Lake Tödürge

Depth (cm)	Age	Error of age	Year (yy)	SAR (cm/y)	Speed Error (cm/y)
0	0	0	2022	0	0
2	5	0.312	2017	0.352	0.020
4	10	0.551	2012	0.416	0.016
6	16	1.056	2006	0.272	0.014
8	21	1.499	2001	0.381	0.018
10	26	2.725	1996	0.428	0.025
12	32	2.648	1990	0.261	0.012
14	**36**	3.411	**1986**	0.576	0.023
16	**37**	**8.655**	**1985**	**85.180**	**5.011**
18	41	3.949	1982	0.358	0.019
20	63	4.142	1959	0.065	0.003
22	**65**	**11.696**	**1957**	**0.939**	**0.053**
24	70	9.928	1952	0.329	0.022
26	100	9.847	1922	0.040	0.003
28	113	15.813	1909	0.125	0.005

4.3. Diatom Zones

According to the OECD trophic status index [2], observed DI-TN (0.753-1.875mg/L), DI-TP (26.7-84.4µg/L), DI-Secc (4.2-2.45m), and diatom inferred chlorophyll-*a* (DI-Chl-*a*) (4.7-14.3mg/m^3) data show that the lake has a eutrophic character. The ecologically based pH of the lake was determined to be alkaliphilic [26] (Table 4) (Figure 1). It was determined that the lake has been eutrophic and has alkaliphilous water character throughout the 113 history (2022-1909) of the lake.

Table 4. Results of depth-dependent diatom inferred environmental variables in Tödürge Lake according to the OECD trophic status index. D: Depth (cm); A: Age; Y: Year (yy); DZ: Diatom Zones; Eut: Eutrophic; A: Alkaliphilous; H: According to [26] acidification classication

D	A	Y	DZ	DI-TN	TSI-TN	DI-TP	TSI-TP	DI-Secc	TSI-Secc	DI-Chl-*a*	TSI-Chl-*a*	H
0	0	2022	1	2.01	Eut	68	Eut	1.55	Eut	7.98	Eut	A
2	5	2017	1	1.73	Eut	58	Eut	1.79	Eut	6.57	Eut	A
4	10	2012	1	2.29	Eut	77	Eut	1.56	Eut	8.16	Eut	A
6	16	2006	2	1.92	Eut	66	Eut	1.70	Eut	7.12	Eut	A
8	21	2001	2	1.82	Eut	70	Eut	1.47	Eut	8.65	Eut	A
10	26	1996	2	1.90	Eut	71	Eut	1.52	Eut	8.48	Eut	A
12	32	1990	3	1.87	Eut	70	Eut	1.72	Eut	6.77	Eut	A
14	36	1986	3	1.76	Eut	67	Eut	1.84	Eut	6.60	Eut	A
16	37	1985	3	1.89	Eut	72	Eut	1.77	Eut	6.67	Eut	A
18	41	1982	3	2.00	Eut	78	Eut	1.62	Eut	7.81	Eut	A
20	63	1959	4	2.13	Eut	75	Eut	1.51	Eut	8.26	Eut	A
22	65	1957	4	2.32	Eut	85	Eut	1.49	Eut	8.28	Eut	A
24	70	1952	4	2.18	Eut	83	Eut	1.52	Eut	8.20	Eut	A
26	100	1922	4	2.09	Eut	80	Eut	1.49	Eut	8.42	Eut	A
28	113	1909	4	2.27	Eut	86	Eut	1.52	Eut	8.16	Eut	A

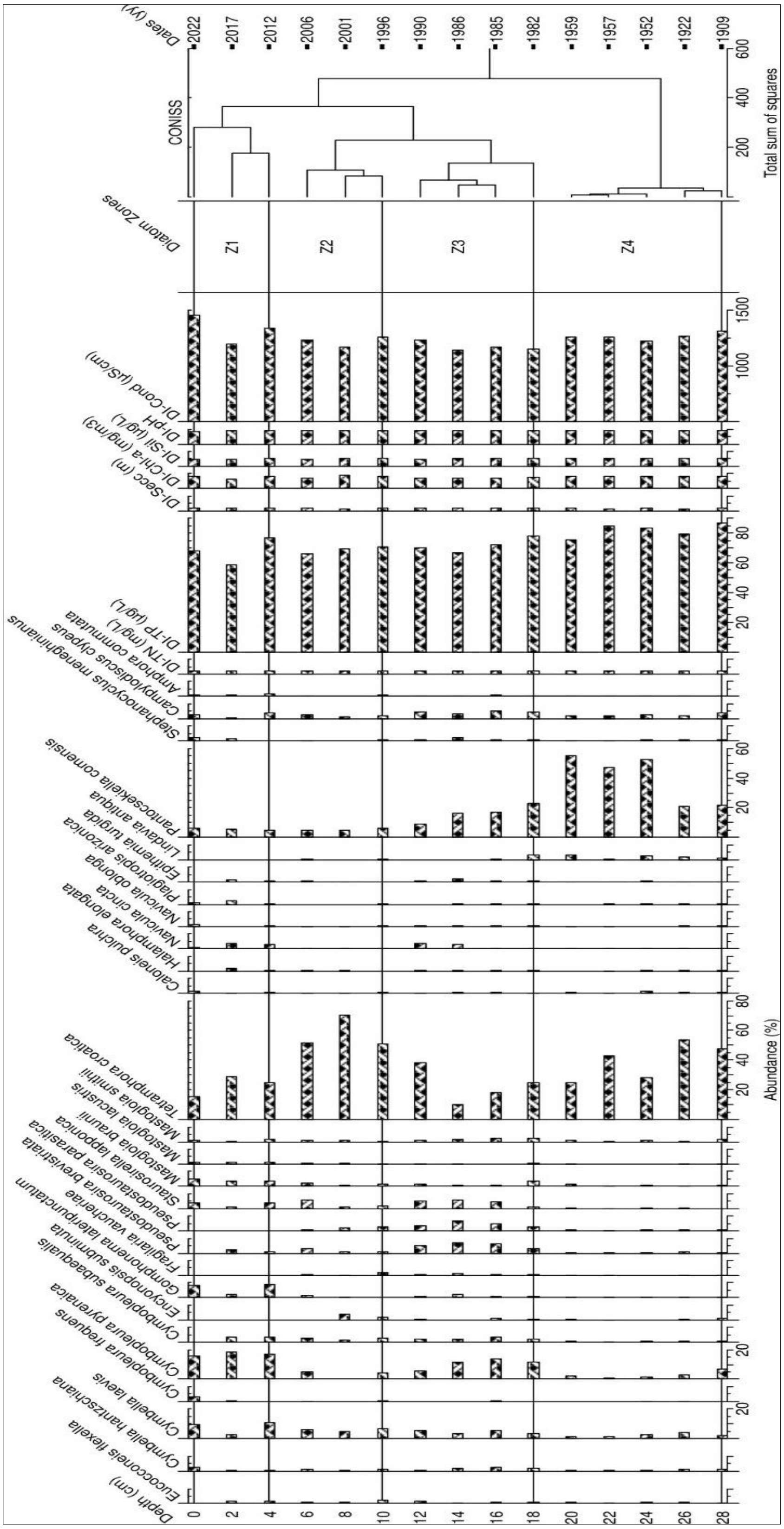

Figure 1. Graph of the relative abundance of important dominant species, diatom zones and age depending on depth in Lake Tödürge

A total of 13 orders, 59 genera and 104 diatom taxa have been identified in Tödürge Lake. Since species with the relative abundance (77 species) less than<5 and the relative abundance (27 species) greater than>5 were determined as the dominant species in the lake [27]. The depth-dependent total relative abundance of Mastogloiales was 580.05%, the order had 2 genera and 4 species. The species with the highest total relative abundance in the lake (529.84%) was *Tetramphora croatica* Gligora Udovic, Caput Mihalic, Stankovic & Levkov. *Pantocsekiella comensis* (Grunow) K.T. Kiss and E. Ács (with total relative abundance of 294.16%), found in the Stephanodiscales order (with total relative abundance of 325.57%), was identified as the second dominant species in the lake. Four genera and six species belonging to the order were observed. Although 10 genera and 23 species belonging to the order Cymbellales (with total relative abundance of 301.61%) were detected, *Cymbopleura pyrenaica* Le Cohu & Lange-Bertalot and *Cymbella laevis* Nägeli were determined as prominent diatoms due to their high relative abundance (118.69% and 70.23%).

Firsth Diatom Zone (Z1; 0-4cm; 2022-2012; 10 Age): The dominant species in the zone were determined as *Tetramphora croatica* [**Total Relative Abundance (TRA)** 68.82%], *Cymbopleura pyrenaica* (TRA 50.62%), *Cymbella laevis* (TRA 22.89%), *Gomphonema lateripunctatum* E. Reichardt & Lange-Bertalot (TRA 19.81%), *Pantocsekiella comensis* (TRA 16.04%), *Mastogloia braunii* (TRA 12.13%), *Staurosirella lapponica* (Grunow) D. M. Williams & Round (TRA 8.49%), *Navicula cincta* (Ehrenberg) Ralfs (TRA 7.68%), *Campylodiscus clypeus* (Ehrenberg) Ehrenberg ex Kützing (TRA 7.27%) ve *Cymbopleura subaequalis* (Grunow) Krammer (TRA 6.8%). According to the indicator species test results of the dominant species, the indicator species of the zone was determined as *Mastogloia lacustris* (Grunow) Grunow with a significance of P=0.0042 and an indicator value of 25.9 (Table 5). It was determined that the species is not a dominant species with TRA 3.911%. Despite this, the present study showed that it is the indicator species that best reflects the environmental variables in this zone (Figure 1).

Table 5. Indicator species tests results of identified diatom species in Tödürge Lake. IV: Indicator Value; DZ: Diatom Zones

Species	IV	DZ	p
Pseudostaurosira parasitica	31.3	2	0.0480
Amphora libyca	27.4	3	0.0324
Anomoeoneis sphaerophora	65.2	3	0.0102
Scoliopleura peisonis	32.3	3	0.0004
Staurosira dubia	31.0	3	0.0180
Lindavia antiqua	**31.9**	**4**	**0.0302**
Dominant Species			
Mastogloia lacustris	25.9	1	0.0042
Lindavia antiqua	**30.5**	**4**	**0.0006**

Second Diatom Zone (Z2; 6-10cm; 2006-1996; 26 Age): Changes of the identificated dominant species from diatom zone 1 to this zone (1) total relative abundance of *Tetramphora croatica* increased from 68.82% to 172.94% (2) TRA of *Cymbopleura pyrenaica* decreased significantly from 50.62% to 9.94%, (3) TRA of *Cymbella laevis* decrease from 22.89% to 17.92%, (4) TRA of *Campylodiscus clypeus* decreased from 7.27% to 6.05%, (5) TRA of *Cymbopleura subaequalis* decreased from 6.8% to 6.72%, (6) It was observed that the TRA of *Pantocsekiella comensis* did not change much from 16.04% to 16.14%. According to the indicator species test results of 104 species, *Pseudostaurosira parasitica* (W. Smith) E. Morales was determined as the indicator species with a significance of P=0.048 and an indicator value of 31.3 (Table 5). It was determined that this species was dominant with a TRA value of 6.04% and was identified for the first time in the second diatom zone. *Encyonopsis subminuta* Krammer & E.Reichardt (TRA 68.82%), *Pseudostaurosira brevistriata* (Grunow) D.M. Williams & Round (TRA 5.27%) and *Staurosirella lapponica* (Grunow) D.M. Williams & Round (TRA 8.57%) were other diatom species identified in this zone (Figure 1).

Third Diatom Zone (Z3; 12-18cm; 1990-1982; 41 Age): Changes of dominant species in this zone: (1) TRA of *Tetramphora croatica* decreased from 172.94% to 91.1%, (2) TRA of *Cymbopleura subaequalis* decreased 6.8% to 6.72%, (3) TRA of *Cymbopleura pyrenaica* increased 9.94% to 42.99%, (4) TRA of *Pantocsekiella comensis* increased 16.14% to 64.84%, (5) TRA of *Pseudostaurosira brevistriata* increased 5.27% to 21.32%, (6) TRA of *Campylodiscus clypeus* increased 6.05% to 17.37%, (7) TRA of *Pseudostaurosira parasitica* increased 6.04% to 17.93%, (8) TRA of Staurosirella lapponica increased 8.57% to 17.37%, (9) TRA of *Cymbopleura subaequalis* increased 6.72% to 9.94% and (10) TRA of *Cymbella laevis* did not change much 17.92% to 17.79%. According to the indicator species test results of 104 species, *Anomoeoneis sphaerophora* Pfitzer, *Scoliopleura peisonis* Grunow, *Staurosira dubia* Grunow and *Amphora libyca* Ehrenberg were determined as indicator species (Table 5). In addition, *Mastogloia smithii* Thwaites ex W. Smith (TRA 7.42%), *Navicula cincta* (TRA 7.22%), *Mastogloia braunii* Grunow (TRA 7.13%) and *Cymbella hantzschiana* Krammer (TRA 6.23%) were other dominant diatoms identificated in this zone. *Gomphonema lateripunctatum* was the dominant species of the first and third diatom zones (Figure 1).

Fourth Diatom Zone (Z4; 20-28cm; 1959-1909; 113 Age): Changes of dominant species in this zone: (1) TRA of Tetramphora croatica increased 91.1% to 196.99%, (2) TRA of *Pantocsekiella comensis* increased 64.84% to 197.13%, (3) TRA of *Cymbopleura pyrenaica* decreased 42.99% to 15.15%, (4) TRA of *Campylodiscus clypeus* decreased 17.37% to 12.68% and (5) TRA of *Cymbella laevis* decreased 17.79% to 11.65%. Indicator species tests of the dominant species in this zone showed that *Lindavia antiqua* (W. Smith) was the indicator species. The dominant indicator species value of this species was determined as 30.5 with a significance of P=0.0006 (Table 5) (Figure 1).

5. DISCUSSION

There are many regional calibration datasets of diatom-inferred TP, TN, conductivity, and pH variables used to determine the eutrophication values of streams and lakes in the world [10 and 26]. We reconstructed the accuracy and reliability of the environmental variables in Tödürge Lake using self-developed calibration sets instead of regional calibrations of different countries. In the reconstructuring of TN and TP, the model performances of our calibration sets are similar to the regional calibration sets of other countries [8 and 10]. When we compare the results of DI-environmental variables with the archived data of the lake [29]:(1) On 30/5/2011, the average TP value of the lake was 62 µg/L, while the average DI-TP value was 67.66µg/L, (2) While average of the total inorganic nitrogen value is 1.48mg/L, an average of the DI-TP value is 2.01mg/L, (3) While the hardness of the water is 177.15mg/L on average, the DI-$CaCO_3$ value is 257.09mg/L on average, (4) While it was stated that pH was 7.7-8.3 and alkaline, DI-pH was determined to vary between 8.6-8.9 and was alkaline. In both cases, when the TN and TP results of 2011 were evaluated according to the OECD trophic status index [2], it was determined that the lake had eutrophic status. According to [31], TP was published as 57.30±10.23µg/L and pH 8.53. In the same years, data for these variables were found to be DI-TP 70µg/L and pH 8.83. These data show that in the relevant year, the lake was eutrophic according to the OECD trophic status index [2] and alkaliphilous according to the ecological indicator pH values of Hustedt [26].

92 diatom species identified were belonging to 29 genera in epipelic samples [31]. However, in the present study, 34 species belonging to 24 genera were identified in benthic samples representing the same year. It was proposed that the decrease in species diversity is caused by wear, breakage, and disintegration of diatoms [1 and 12] in response to the pressure the sediment was exposed.

A total of 59 genera and 104 species were identified in the lake. No data could be found in published articles regarding the presence of *Tetramphora croatica* and *Cymbopleura pyrenaica* species, which were determined as dominant species throughout the core in Lake Tödürge [30, 31, and 32]. The species identified as *Amphora commutata* Grunow in Scanning Electron Microscope (SEM) images in an article published [30] was identified as *Tetramphora croatica* in our study. If the species is *Amphora commutata*, it is an indicator species of brackish, according to Van Dam et al. [33], alkaphilous and eutrophic lakes [34]. It is also known that this species has a high tolerance to TN, SO_4 and secchi depth [35].

Cyclotella, Aulacoseira, Asterionella, Fragilaria, and *Stephanodiscus* are considered as indicator groups that reflect the ecology of lakes with eutrophic status [7]. Diatom species *Pseudostaurosira brevistriata*, *Staurosirella pinnata* and *Pseudostaurosira parasitica* frequently encountered living group at different depths, especially in the benthic zone of marl (karst), alkaline, eutrophic and shallow lakes like Lake Tödürge [3]. According to Van Dam et al. [33], *Mastogloaia lacustris* and *Pseudostaurosira parasitica* are characteristic indicator species of alkalibiontic, brackish-freshwater and mesotrophic-eutrophic waters. The four species were also present at different depths of the lake [30]. *Pseudostaurosira brevistriata* and *Pseudostaurosira parasitica* were determined as dominant species, *Pseudostaurosira parasitica* and *Mastogloaia lacustris* as indicator species at different times and depths [36]. According to Van Dam et al. [3], *Pantocsekiella comensis*, that is dominant at all depths throughout the core. Species adapted to deep, low to medium alkalinity, oligotrophic, acidophilous to circumneutral ecosystems [33]. However, the species was not detected as an indicator species in the present study.

Anomoeoneis sphaerophora was found to have the highest indicator value of diatom inferred environmental variables in the lake with a significance of P=0.01: (1) in our study, the species is a member of benthic, eutrophic, and alkaliphilous lakes, (2) According to Van Dam et al. [33], it is alkalibiontic, brackish-freshwater and eutrophic status, (3) According to Denys [34], it occurs in alkaliphilous, brackish-freshwater and eutrophic waters, (4) According to Solak et al. [37], it is benthic, eutrophic and alkaliphilous species. However, *Staurosira dubia* was detected as an indicator of eutrophic and alkaliphilous lakes in our study. This finding is supported by Sıvacı [31]. According to Solak et al. [37], it is an alkalibiontic species and a characteristic component of freshwater-brackish waters. Nevertheless, Lake Tödürge has already been known as calcareous and salty [38].

According to Van Dam et al. [33], *Lindavia antiqua* is an indicator species of acidophilous, freshwater and oligotrophic ecosystems, oppositely, it was determined as an indicator species of eutrophic and alkaliphilous lakes in our research. An increase in the relative abundance of diatoms due to species diversity was observed in zones where the sediment accumulation rate was high. This situation emerged especially clearly at the depths of 14-16cm of the third zone (Table 3). Although it is not among the dominant species affected by the environmental variables of the lake, *Amphora libyca* has been determined as the indicator species of the DI-TP variable and trophic status [39 and 40]. *Cymbella hantzschiana*, *Cyclotella meneghiniana*, *Epithemia turgida*, *Fragilaria vaucheriae*, *Navicula cincta* and *Staurosirella pinnata* found at different depths are other species used in the evaluation of DI-TP and trophic status [39 and 40] (Figure 1). *Navicula cincta* was among the pollution-tolerant species [41]. According to Solak et al. [37], this is a benthic, eutrophic, and alkaliphilous species. In the present study, *Scoliopleura peisonis* was determined as the indicator species of eutrophication. This species is placed among the species tolerant to high salinity, and *Cymbopleura subaequalis* was defined as a salinity-tolerant species [35].

6. CONCLUSIONS

Given the lack of long-term datasets on water quality and eutrophication processes in Türkiye, It prevents the development of effective and usable lake management strategies for lake managers. In order to manage the threat to the lake correctly, the time, rate and magnitude of ecological changes must be clearly determined. In current studies, it has been determined that Lake Tödürge has a eutrophic character. The most important result of this study is the determination that Lake Tödürge has been eutrophic in its 113-year history. The other is that the observed measurement results of diatom inferred environmental variables in each sliced sediment, which supports this data, showed similar responses with diatom species at the same depth. It has been determined that the main cause of eutrophication in the lake is autogenic rather than anthropogenic.

NOTICE

All data produced in the study were derived from Fatma Küçük's doctoral thesis titled "Reconstructions of lake environmental variables prevaling in past using accumulation and abundance of diatoms in sediments of selected lakes (Turkey): A quantitative approach in paleolimnology".

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ETHICAL STATEMENT

Not applicable.

CONFLICT of INTEREST

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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