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Algal Flora and Ecology of the High Mountain Lakes in the Artabel Lakes Nature Park (Gümüşhane, Turkey), I- Bacillariophyta

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Abstract: *The species composition of benthic diatoms of 18 selected high mountain lakes in the Artabel Lakes Nature Park of Turkey were investigated (on 15 August 2013 and on 13 August 2016). In all, 95 species of diatoms belonging to 46 genera were recorded. The most species rich genera are Pinnularia (15), Eunotia (6) and Gomphonema (6), while other genera are presented with one or more species. Only Eunotia praerupta and Pinnularia interrupt are considered as very frequent (VF) (2.10%) species. The diatom flora of the Artabel Lakes Nature Park was formed by cosmopolitan species with a large influence from species in alpine and subalpine area. A comparison of the benthic assemblages of the investigated lakes showed differences in both in relative abundance and species present in the individual lakes. The physico-chemical conditions of the studied waters also provided a suitable environment for the development of the diatom flora. The Willis curve of the diatom flora in the Artabel Lakes Nature Park was determined to be close to a hyperbolic shape. This study provides the groundwork for future researches.*

Keywords: *benthic diatoms, high mountain lakes, Artabel Lakes Nature Park, Turkey*

1. Introduction

Benthic algae are one of the living groups that constitute the primary producers in aquatic ecosystems and they are also the main energy source in the food chain for aquatic organisms [1]. Diatoms are one of the important groups in water ecosystems and form a large part of the benthic communities (often 90-95%) [2].They are also very important indicators of environmental changes and are used in the biological monitoring of water ecosystems [3]. Therefore, it is of great significance to describe their prevalence and ecology [4].

In many parts of the world, there are mountain lakes in high altitudes in nature conservation areas that are still and are relatively far from anthropogenic impacts. They can reveal important information on biodiversity conservation, recreation, and storage of good-quality water [5]. In Turkey, Artabel Lakes Nature Park is an important protected area and has 23 high mountain lakes. Unfortunately, there is only one published data about the algal flora of these lakes [6].Therefore, the investigation of algal flora of the park is very important both for Turkey and the world.

The basic aim of this study was to identify the floristic and ecological of the diatom assemblages inhabiting the lakes in the Artabel Lakes Nature Park.

2. Materials And Method

2.1. Description of Study Site

The Artabel Lakes Nature Park is an important protected area of Turkey. It was declared as a nature park in 1998. It is within the borders of Torul County of the Gümüşhane province of the Eastern Black sea region. It is located between 40º21'36" - 40º26'42" north and 39º0'24" - 39º8'23" east. The area of Artabel Lakes Nature Park is 5859 hectares (Fig.1) The Artabel Lakes Nature Park includes terrestrial and aquatic ecosystems with rich biodiversity and has endemic species listed in the International Nature Conservation Union (IUCN) and the Berne Convention Annex I, II and III [7].

Figure 1. *The Studied Area [7]*

In the Artabel Lakes Nature Park, there are three stream basins, which are the Gümüştuğ Stream basin (Kara and Beş Lakes), the Artabel Stream basin (Artabel Lakes), and the Kongel Stream basin (Yıldız and Acembol Lakes). The total basin area is approximately 58.2 km^2 and is composed of 5 different lake sites including the Artabel Lakes (ARL), Acembol Lakes (ACL), Beş Lakes (BL), Kara Lakes (KL) and Yıldız Lakes (YL). In total, there are 23 lakes: the Artabel Lakes (6), Acembol Lakes (3), Beş Lakes (5), Kara Lakes (6) and Yıldız Lakes (3). Some of the different size of the lakes have been linked to othersor are independence of each other [7]. There is also a previously unnamed lake (Isimsiz Lake: IL) and a small pond (Yıldız Lakes Pond (YLP)).These lakes are glacial in origin, covered with iced layers for at least 8 months of the year and situated in the alpine zone (2687-3030 m a.s.l.).It is not possible to fully describe the diatom flora year-round because of difficulties surrounding the access to these areas.

The aim of this study was to investigate 17 lakes and one pond situated at different sea levels (2687-2980 m a.s.l.) and characterizes its flora and environment on the base of physical and chemical parameters of the waters as well as epipelic, epilithic, and epiphytic diatom algae.

2.2. Sampling and Laboratory Studies

The Artabel Lakes Nature Park was visited on two different dates (on 15 August 2013 and on 13 August 2016). The diatom samples were collected from three different habitats: sediments (epipelic), stones (epilithic), mosses, and macro algae (epiphytic). The Kara Lakes could not be visited because the terrain was too difficult to traverse. Also, there was no water in the BL5 Lake; therefore, diatom and water samples could not be taken. Epipelic samples were collected with a glass tube from the surface of the sediment at all water bodies, except Lake BL2. Epilithic samples were taken once from the littoral zone of ARL1, ARL2, BL2, ACL1, ACL2, ACL3 and IL lakes. The epilithic diatoms were scraped from randomly chosen stones with the toothbrush. The samples were then washed and placed into plastic bottles. Epiphytic diatoms were collected by squeezing out mosses *(*Hygrohypnum luridum (Hedw.) Jenn.), and filamentous algae (*Microspora* sp.) From the ARL1, ARL3, YL1, YL2, YL3, ACL2, ACL3, IL lakes, and YLP Pond. All algological materials were preserved in 4% formaldehyde. Dissolved oxygen, water temperature, pH and conductivity were measured with portable devices Orion-4Star and YSI-55 at each sampling site.

A total of 43 samples were analyzed. Hydrogen peroxide technique to clean diatoms frustules off [8] and mounted in Naphrax®. Diatoms were identified using a Leica DM 2500 microscope and were photographed with a Leica DFC 290 camera attached to the microscope. Diatoms were identified with help of international handbooks [9-20]. The validity of the species name was checked from Algae Base [21].

Frequencies of algal taxa were determined according to the following scale based on the number of lakes studied in the Artabel Lakes Nature Park. Very rare (VR): taxa recorded in 1-20% of investigated lakes; rare (R): taxa recorded in 21-40% of investigated lakes; common (C): taxa recorded in 41-60% of investigated lakes; frequent (F): taxa recorded in 61-80% of investigated lakes; very frequent (VF): taxa recorded in 81-100% of investigated lakes [22].

3. Results and Discussion

3.1. Physical and Chemical Analysis

The results of physico-chemical analysis of the studied waters are given in other paper [23]. From these results, it can be concluded that the waters are characterized by fewer temperature fluctuations (10.1-19.1 ^{0}C). According to values of pH of the examined waters, it can be said that the waters of the Artabel Lakes Nature Park are acidic and circumneutral (pH 6.19-7.52). The concentrations of dissolved oxygen (DO) and total dissolved matter (TDS) varied from 2.10 to 9.45 mg/L and 6 to 30.55 mg/L, respectively. The values of water conductivity (C) of the studied waters can be characterized as low (12.0-49.9 µS/cm).Measured environmental variables as well as diatom species richness are represented in Fig. 2 where all parameters are organized according to altitude of habitats. Therefore, it was observed that the water pH was rather stabile, but temperatures slightly decreased with altitude. It was intersting to find that water variables dissolved oxygen and conductivity had a tendency to increase in the middle altitude interval, whereas total dissolved solids and species richness decreased.

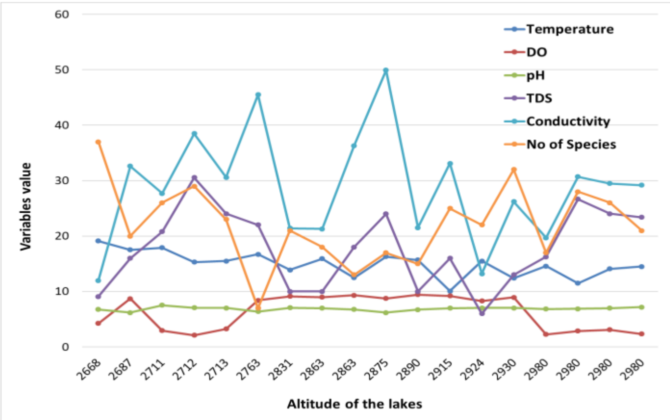

Figure 2. *Distribution of water variables and number of species in the examined lakes of the Artabel Lakes Nature Park according to altitude.*

In Table 1 a linear, negative, high level relationship between altitude and water temperature (T) (r = -0.701; p<0.01) can be seen. This means that as the altitude of the lakes increases, the temperature decreases. There is also a linear, negative, moderate relationship between total dissolved solids (TDS) and dissolved oxygen (DO) (r = -0.574; P<0.01). This finding suggests that as the amount of total dissolved solids increases, the amount of dissolved oxygen decreases. In addition, it is seen that there is a linear, positive, high-level relationship between total solids (TDS) and conductivity (C) (r = 0.738; P<0.01). This means that as the amount of total dissolved solids increases, the conductivity increases.

Table 1. *Correlations among several morphological, physical, chemical and biological variables of the studied lakes*

		Altitude (m a.s.l)	T (°C)	DO (mg/L)	pH	TDS (mg/L)	EC (µS/cm)	Number of species
Altitude (m a.s.l)	N	-	18	18	18	18	18	18
	r		-0.701	0.018	0.065	-0.037	-0.103	-0.172
	p		0.002*	0.943	0.797	0.884	0.684	0.495
T (°C)	N	18	-	18	18	18	18	18
	r	-0.701		-0.163	-0.254	-0.113	-0.122	0.040
	p	0.002*		0.518	0.310	0.656	0.630	0.876
DO (mg/L)	N	18	18	-	18	18	18	18
	r	0.018	-0.163		-0.223	-0.574	0.088	-0.371
	p	0.943	0.518		0.374	0.009*	0.728	0.130
pH	N	18	18	18	-	18	18	18
	r	0.065	-0.254	-0.223		0.124	-0.110	0.435

	p	0.797	0.310	0.374		0.624	0.664	0.071
TDS (mg/L)	N	18	18	18	18		18	18
	r	-0.037	-0.113	-0.574	0.124	-	0.738	-0.038
	p	0.884	0.656	0.009*	0.624		0.000*	0.882
C (µS/cm)	N	18	18	18	18	18		18
	r	-0.103	-0.122	0.088	-0.110	0.738	-	-0.366
	p	0.684	0.630	0.728	0.664	0.000*		0.135
Number of species	N	18	18	18	18	18	18	
	r	-0.172	0.040	-0.371	0.435	-0.038	-0.366	-
	p	0.495	0.876	0.130	0.071	0.882	0.135	

Note:T:Temperature, DO:Dissolved oxygen, TDS: Total dissolved solids, C: Conductivity, N: Number of studied lake, r: Pearson correlation coefficient, P: Significance.* $P<0.01$

3.2. Diatom Communities

A total of 95 diatom species have been recorded from epipelic, epilithic and epiphytic samples of the studied waters in the Artabel Lakes Nature Park (Table 2). The diatoms found are subdivided into three classes: Bacillariophyceae, Coscinodiscophyceae and Mediophyceae. The richest class is Bacillariophyceae, which included 89.58% of the species. Observed species were classified in 46 genera. The most abundant genera were Pinnularia (15), *Eunotia* (6) and *Gomphonema* (6); less abundant genera were *Aulacoseira* (4), *Navicula* (4), *Cymbella* (3), *Diploneis* (3), *Neidium* (3), and *Surirella* (3). Two or single species presented by other genera (Table3).

Table 2. *List of the benthic diatoms in the studied lakes in the Artabel Lakes Nature Park*

TAXA	H	F	LAKES
BACILLARIOPHYTA			
Class: Coscinodiscophyceae			
Order: Aulacoseirales			
Family: Aulacoseiraceae			
Genus: Aulacoseira			
**Aulacoseira lacustris* f. *tenuior* Houk, Klee & Passauer	1	VR	ARL3
A. muzzanensis (F.Meister) Krammer	1,3	VR	ARL3,BL3
A. subarctica (Otto Müller) E.Y.Haworth	1,3	VR	ARL1
A. valida (Grunow) Krammer	1,2,3	VR	BL4,IL
Subclass: Melosirophycidae			
Order: Melosirales			
Family: Melosiraceae			
Genus: Melosira			
Melosira varians C.Agardh	3	VR	ARL3
Family: Orthoseiraceae			
Genus: Orthoseira			
Orthoseira dendroteres (Ehrenberg) Genkal & Kulikovskiy	1,2,3	R	ARL5,ACL3,YL2,YL3,IL
**O. roeseana* (Rabenhorst) Pfitzer	1	VR	YL3
Class: Mediophyceae			
Subclass: Thalassiosirophycidae			
Order: Stephanodiscales			
Family: Stephanodiscaceae			
Genus: Cyclotella			
**Cyclotella ambigua* Grunow	1	VR	ARL4
Genus: Discotella			
Discostella pseudostelligera (Hustedt) Houk & Klee	1	VR	ACL2
D. stelligera (Cleve & Grunow) Houk & Klee	1	VR	ACL3
Class: Bacillariophyceae			
Subclass: Bacillariophycidae			
Order: Bacillariales			
Family: Bacillariaceae			

Genus: Hantzschia			
Hantzschia amphioxys (Ehrenberg) Grunow	1	R	ARL5,BL1,BL3,YL2,YL3,IL
Genus: Nitzschia			
Nitzschia perminuta (Grunow) M.Peragallo	1	VR	IL,YLP
Order: Cocconeidales			
Family: Achnanthidiaceae			
Genus: Achnanthidium			
Achnanthidium minutissimum (Kützing) Czarnecki	1	VR	BL3,IL
Genus: Planothidium			
**Planothidium distinctum* (Messikommer) Lange-Bertalot	1	VR	BL4
P. lanceolatum (Brébisson ex Kützing) Lange-Bertalot	1	VR	YL2
Genus: Psammothidium			
**Psammothidium helveticum* (Hustedt) Bukhtiyarova & Round	1	VR	ARL5
Family: Cocconeidaceae			
Genus: Cocconeis			
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	1,2,3	R	BL3,ACL2,ACL3,YL1,YLP
Order: Cymbellales			
Family: Cymbellaceae			
Genus: Cymbella			
Cymbella affinis Kützing	1,2,3	R	ARL1,ARL2,ARL3,ARL6,BL2
C. aspera (Ehrenberg) Cleve	1,2,3	C	BL2,BL3,ACL1,ACL2,ACL3,YL1,YL2,YL3
C. cistula (Ehrenberg) O.Kirchner	1,2,3	C	ARL5,BL2,BL3,BL4,ACL1,ACL2,ACL3,YL2
Genus: Cymbopleura			
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer	1,2,3	R	ACL1,ACL2,ACL3,YL2,IL
C. subcuspidata (Krammer) Krammer	1	VR	ARL6
Genus: Didymosphenia			
Didymosphenia geminata (Lyngbye) Mart.Schmidt	1,2,3	C	ARL5,BL1,BL2,BL3,ACL1,ACL2,ACL3,YL1,YL3,YLP
Family: Gomphonemataceae			
Genus: Encyonema			
Encyonema gracile Rabenhorst	3	VR	ARL1,YL2
E. minutum (Hilse) D.G.Mann	1,2,3	F	ARL5,ARL6,BL1,BL2,BL3,BL4,ACL1,ACL2,ACL3,YL1,YL2,YL3,IL, YLP
Genus: Gomphonema			
Gomphonema acuminatum Ehrenberg	1,3	VR	ACL2,ACL3
G. angustatum (Kützing) Rabenhorst	1,3	VR	YL2,YL3,IL
G. augur Ehrenberg	1,2,3	VR	ACL2,ACL3
G. calcareum Cleve	1	VR	IL,YLP
G. olivaceum (Hornemann) Brébisson	1,2,3	C	BL2,BL3,ACL2,YL1,YL2,YL3,IL,YLP
G. parvulum (Kützing) Kützing	1,2,3	R	ARL1,ARL5,ARL6,BL3,BL4,YL3,IL
Genus: Placoneis			
Placoneis hambergii (Hustedt) K.Bruder	1	VR	ACL1
Order: Mastogloiales			
Family: Achnanthaceae			
Genus: Achnanthes			
Achnanthes semiaperta Hustedt	1	VR	ARL5,BL4
Genus: Platessa			
Platessa salinarum (Grunow) Lange-Bertalot	1	VR	ARL5
Order: Naviculales			
Suborder: Diploneidineae			
Family: Diploneidaceae			

Genus: Diploneis			
Diploneis oblongella (Nägeli ex Kützing) Cleve-Euler	1,3	VR	ARL5,ACL2
D. parma Cleve	3	VR	YLP
**D. petersenii* Hustedt	3	VR	YLP
Suborder: Naviculineae			
Family: Naviculaceae			
Genus: Caloneis			
Caloneis alpestris (Grunow) Cleve	1	VR	ARL4,ACL1
C. silicula (Ehrenberg) Cleve	1,2	C	ARL5,ARL6,BL1,BL2,BL3,ACL1,ACL2,ACL3,YL1
Genus: Chamaepinnularia			
Chamaepinnularia hassiaca (Krasske) Cantonati & Lange-Bertalot	1	VR	IL
Genus: Mayamaea			
Mayamaea atomus (Kützing) Lange-Bertalot	1	VR	IL
Genus: Navicula			
Navicula cryptocephala Kützing	1,3	R	BL3,ACL1,ACL2,ACL3,YL1,YL2,IL
N. radiosa Kützing	1,3	R	ARL3,ARL5,ARL6,BL1,BL3,BL4,YL3
N. rhynchocephala Kützing	1	R	BL3,ACL2,YL3,IL
N. veneta Kützing	1	VR	ACL1,YLP
Family: Stauroneidaceae			
Genus: Craticula			
Craticula cuspidata (Kützing) D.G.Mann	1	R	ARL4,ARL5,BL4,ACL2,YL1
C. halophilioides (Hustedt) Lange-Bertalot	1,3	VR	ARL1,IL
Genus: Stauroneis			
Stauroneis acuta W.Smith	2	VR	ACL1
S. anceps Ehrenberg	1,3	F	ARL1,ARL3,ARL4,ARL5,ARL6,BL3,BL4,ACL2,ACL3,YL2,YL3,IL
Suborder: Neidiineae			
Family: Amphipleuraceae			
Genus: Frustulia			
**Frustulia crassinervia* (Brébisson ex W.Smith) Lange-Bertalot & Krammer	1,3	R	ARL1,ARL4,BL1,BL4,YL2,YLP
F. vulgaris (Thwaites) De Toni	2	VR	BL2
Genus: Halamphora			
Halamphora coffeiformis (C.Agardh) Levkov	1,2	VR	BL4,ACL1
Family: Neidiaceae			
Genus: Neidium			
Neidium affine (Ehrenberg) Pfitzer	1	VR	ARL4
N. ampliatum (Ehrenberg) Krammer	1,2,3	R	ACL2,ACL3,YL2,IL
N. iridis (Ehrenberg) Cleve	1,3	R	ARL3,ARL5,BL1,BL3,ACL3,IL
Genus: Neidiomorpha			
Neidiomorpha binodis (Ehrenberg) M.Cantonati, Lange-Bertalot & N.Angeli	1	VR	ARL6
Suborder: Sellaphorineae			
Family: Pinnulariaceae			
Genus: Pinnularia			
Pinnularia abaujensis (Pantocsek) R.Ross	1	VR	BL3
P. aestuarii Cleve	1,3	R	BL1,YL2,YL3,YLP
P. borealis Ehrenberg	1,2,3	F	ARL1,ARL2,ARL3,ARL5,ARL6,BL1,BL4,ACL1,ACL3,YL1,YL2,YL3,IL,YLP
P. divergens W.Smith	1	VR	ACL3
P. episcopalis Cleve	1,3	VR	IL
P. hemiptera (Kützing) Rabenhorst	1	VR	ARL4,BL1
P. interrupta W.Smith	1,2,3	VF	ARL1,ARL2,ARL3,ARL4,ARL5,ARL6,BL1,BL3,BL4,ACL1,ACL2,

			ACL3,YL1,YL2,YL3,IL,YLP
P. lata (Brébisson) W.Smith	1	VR	BL4
P. major (Kützing) Rabenhorst	1,3	F	ARL1,ARL3,ARL5,ARL6,BL1,BL4,ACL1,ACL3,YL2,YL3,IL,YLP
P. mesogongyla Ehrenberg	1,3	VR	ARL1,BL1
P. obscura Krasske	1	VR	ARL5
P. rupestris Hantzsch	1	VR	ARL3
P. subcapitata W.Gregory	1	R	ARL1,ARL2,ARL4,ARL5,YLP
P. viridiformis Krammer	1	VR	YL2
P. viridis (Nitzsch) Ehrenberg	1,2,3	R	ARL1,ARL2,ARL3,BL1,YL2,YL3,IL
Family: Sellaphoraceae			
Genus: Sellaphora			
Sellaphora pupula (Kützing) Mereschkovsky	1,2	VR	BL1,ACL1
Order: Rhopalodiaceae			
Family: Rhopalodiaceae			
Genus: Epithemia			
Epithemia gibba (Ehrenberg) Kützing	1,2,3	C	ARL1,ARL3,ARL4,ARL6,ACL2,ACL3,YL2,YL3,IL,YLP
Order: Surirellales			
Family: Surirellaceae			
Genus: Iconella			
Iconella linearis (W.Smith) Ruck & Nakov	1,2,3	VR	ARL5,IL,YLP
Genus: Surirella			
Surirella angusta Kützing	1,2	C	ARL1,ARL5,ARL6,BL1,BL4,ACL2,YL1,YL3,IL
S. robusta Ehrenberg	1	R	ARL4,ARL5,ARL6,ACL1,YL3,IL
S. splendida (Ehrenberg) Kützing	1,2,3	F	ARL1,ARL4,ARL5,ARL6,BL1,BL3,BL4,ACL1,ACL2,ACL3,YL1,YL2,YL3,YLP
Order: Thalassiophysales			
Family: Catenulaceae			
Genus: Amphora			
Amphora ovalis (Kützing) Kützing	1,2,3	F	ARL5,ARL6,BL1,BL3,BL4,ACL1,ACL2,ACL3,YL1,YL2,IL,YLP
A. pediculus (Kützing) Grunow	3	VR	YL3
Subclass: Eunotiophycidae			
Order: Eunotiales			
Family: Eunotiaceae			
Genus: Eunotia			
Eunotia arcus Ehrenberg	1,3	VR	ARL3,YL3
E. bilunaris (Ehrenberg) Schaarschmidt	1,3	R	ARL3,ARL4,ARL5,BL4,IL
E. diodon Ehrenberg	1,3	C	ARL2,ARL4,ARL5,BL1,BL4,YL1,YL2,IL
**E. mucophila* (Lange-Bertalot, Nörpel-Schempp & Alles) Lange- Bertalot	1,2,3	R	ARL1,ARL3,ACL2,YL2,IL
**E. paludosa* Grunow	2	VR	IL
E. praerupta Ehrenberg	1,2,3	VF	ARL1,ARL2,ARL3,ARL4,ARL5,BL2,BL3,BL4,ACL2,ACL3,YL1,YL2,YL3,IL,YLP
Subclass: Fragilariophycidae			
Order: Fragilariales			
Family: Fragilariaceae			
Genus: Odontidium			
Odontidium mesodon (Kützing) Kützing	1,2,3	R	ARL1,ACL1,ACL2,YL2
Family: Staurosiraceae			
Genus: Staurosira			
Staurosira venter (Ehrenberg) Cleve & J.D.Möller	1	VR	BL5,IL
Genus: Staurosirella			
Staurosirella pinnata (Ehrenberg) D.M.Williams & Round	1	VR	IL

Order: Licmophorales			
Family: Ulnariaceae			
Genus: Hannaea			
Hannaea arcus (Ehrenberg) R.M.Patrick	1,2,3	C	ARL5,ARL6,BL2,BL3,ACL1,ACL2,ACL3,YL1
Genus: Ulnaria			
Ulnaria ulna (Nitzsch) Compère	1,2,3	R	ARL5,BL2,BL3,YL3
Order: Tabellariales			
Family: Tabellariaceae			
Genus: Diatoma			
Diatoma vulgaris Bory	1,2	C	ARL5,ARL6,BL1,BL2,BL3,BL4,ACL1,ACL2,IL
Genus: Fragilaria			
Fragilaria crotonensis Kitton	2	VR	ACL2
F. tenera var. *nanana* (Lange-Betalot) Lange-Bertalot & S.Ulrich	1,2,3	VR	ACL1,ACL2,ACL3
Genus: Meridion			
Meridion circulare (Greville) C.Agardh	1,2,3	C	ARL1,ARL5,BL1,BL2,BL3,ACL3,YL1,YL2,YL3,YLP
Genus: Tabellaria			
Tabellaria flocculosa (Roth) Kützing	1,2,3	F	ARL1,ARL3,ARL4,ARL5,ARL6,BL2,BL3,BL4,ACL2,ACL3,IL

Note: *H: Habitat; 1: Epipelic, 2: Epilithic, 3: Epiphytic; F: Frequences; ARL: Artabel Lakes, BL: Beş Lakes, YL: Yıldız Lakes, ACL: Acembol Lakes, IL: İsimsiz Lake, YLP: Yıldız Lakes Pond; *: New record for diatom flora of Turkey.*

Table 3. *List of the diatom genera with the number of species*

Genus	Number of species	Genus	Number of species
Achnanthes	1	*Hantzschia*	1
Achnanthidium	1	*Iconella*	1
Amphora	2	*Melosira*	1
Aulacoseira	4	*Meridion*	1
Caloneis	2	*Mayamaea*	1
Chamaepinnularia	1	*Navicula*	4
Cocconeis	1	*Neidiomorpha*	1
Craticula	2	*Neidium*	3
Cyclotella	1	*Nitzschia*	1
Cymbella	3	*Odontidium*	1
Cymbopleura	2	*Orthoseria*	2
Diatoma	1	*Pinnularia*	15
Didymosphenia	1	*Placoneis*	1
Diploneis	3	*Planothidium*	2
Discotella	2	*Platessa*	1
Encyonema	2	*Psammothidium*	1
Epithemia	1	*Sellaphora*	1
Eunotia	6	*Stauroneis*	2
Fragilaria	2	*Staurosira*	1
Frustulia	2	*Staurosirella*	1
Gomphonema	6	*Surirella*	3
Halamphora	1	*Tabellaria*	1
Hannaea	1	*Ulnaria*	1

On the base of revealed diatom species list, we constructed the Willis curve to assess how representative the diatoms were in the studied lakes. The Willis curve of the diatom flora in the Artabel Lakes Nature Park was determined to be close to the hyperbolic shape (Fig. 3). This situation shows that we have sufficient diatom species in order to make taxonomic and ecological analysis. Earlier, S. Barinova [24] found that the Willis curve can be used as criteria for fullness of species list because the distribution follows the hyperbolic shape in well-studied algal floras in Eurasia. Therefore, we can do floristic, taxonomic and ecological analysis for the diatom flora in the Artabel

Lakes Nature Park and compare it to other high mountain lake floras in this region where the Willis proportion also closely follows the hyperbolic shape [24-28].

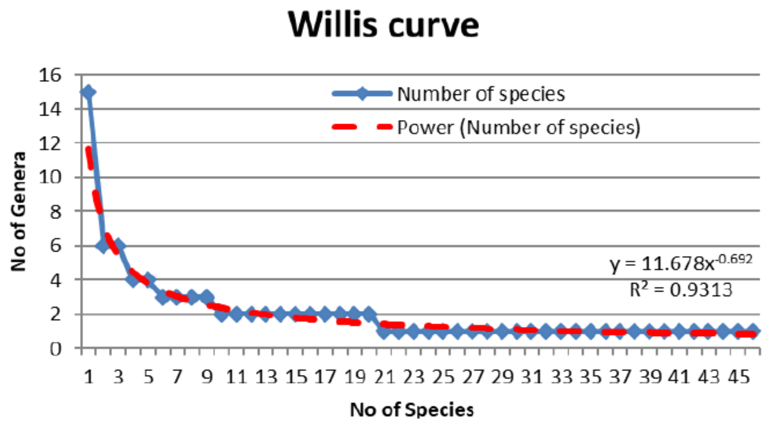

Figure 3. *The Willis curve for the diatom flora of the Artabel Lakes Nature Park shows the number of species per genera (i.e., 1 genus with 15 species, 2 genera with 6 species, etc.).*

One of the important characteristics of the Artabel Lakes Nature Park diatom flora is the composition of the dominant algae genera. Only three genera (*Pinnularia*, *Eunotia* and *Gomphonema*) contain 28.42% of the diatom flora in the studied waters (Table 3). However, two genera of the three are usually in the head part of the diatom flora list, surprisingly, the members of Pinnularia have been influential in the diatom flora of the Artabel Lakes Nature Park. Another important characteristic of the flora is that 9 new records diatom species have been detected for Turkey (Table 2). Information on descriptions, ecology and geographic distribution of these species were published in a separate paper [29].

Only *Eunotia praerupta* and *Pinnularia interrupta* are considered very frequent (VF) (2.10%) species. They are identified in more than 15 of the lakes examined. Frequently (F) recorded diatom species (*Amphora ovalis, Encyonema minutum, Pinnularia borealis, P. major, Stauroneis anceps, Surirella splendia and Tabellaria flocculosa*) comprise 7.36% of all diatom flora. Common (C) species which are *Caloneis silicula, Cymbella aspera, C. cistula, Diatoma vulgaris, Didymosphenia geminata, Epithemia gibba, Eunotia diodon, Gomphonema olivaceum, Hannaea arcus, Meridion circulare, and Surirella angusta*, comprise 11.57% of all diatom species encountered. Remarkably, 78.94% of the diatom species reported as rare (R) or very rare (VR) species (Table 2).

The genus *Pinnularia* was represented by 15 species and accounted for 15.78% of the diatom flora of the studied waters (Table 3). A similar situation was observed in the diatom flora of the Pamir area in Tajikistan [28]. Wehr and Sheath [30] reported that the members of *Pinnularia* is often abundant in low conductivity and slightly acidic freshwater. The results of this study showed that the waters are mostly circumneutral and acidic and have low mineral content [23]. These ecological conditions of the waters formed suitable environments for the development of the genus *Pinnularia*. Pinnularia interrupta is the first important species of the diatom flora; it was found in 17 sites and recorded as very frequent (VF) (94.44%) (Table 2). Patrick and Reimer [11] state that *Pinnularia interrupta* prefers low mineral content freshwater. According to Van Dam et al., [31] it occurs in circumneutral, oligosaprobic, and oligo-mesotrophic waters. *Pinnularia borealis* was found in all benthic habitats and recorded as frequent (F) (77.77%) (Table 2). According to Patrick and Reimer [11], the species prefers cool waters of low mineral content and is often found in rivers, but also in ponds. It also prefers circumneutral, β-mesosaprobic and oligo-mesotrophic waters [31]. *Pinularia major* is widely found in waters of fairly low mineral content [11]. It also occurs in circumneutral, β-mesosaprobic and meso-eutrophic waters [31]. This species was found in the epipelic and epiphytic samples and is considered as frequent (F) 66.66% (Table 2).

Krammer and Lange-Bertalot [13], Wojtal et al. [32] and Hofmann et al. [33] stated that *Eunotia* species were present in tested waters, which have low-to-moderate concentrations of electrolytes, and have pH ranges from acidic to neutral. While the water temperature does not have a significant effect in the widespread species of this genus, the pH and electrolyte content are important factors [34]. The genus *Eunotia* has a wide distribution in the high mountain lakes in Turkey [35-37]. Because they provide the suitable conditions which are saying above for the *Eunotia* genus distribution. In this investigation, physico-chemical analysis of the waters showed that the pH was between 6.16-7.52 and conductivity was 12.0- 49.9 µS/cm, which confirms conditions for the presence of the genus Eunotia [23], which was represented by 6 species in the diatom flora of the Artabel Lakes Nature Park (Table 4). *Eunotia praerupta* is the second important species of the diatom flora; it was found in 15 sites and recorded as very frequent (VF) (83.33%) (Table 2). According to Patrick and Reimer [11], this species occurs usually in northern or mountainous areas in acid to circumneutral waters. It is acidophilus and mainly occurring at pH < 7 [31]. *Eunotia diodon* is a cosmopolitan species. It is often found in northern Europe, as well as in the waters of high mountain regions of Central Europe. These waters are characterized by low-to-moderate conductivity [13]. It is also common in waters with pH<7 [31]. According to Krammer and Lange-Bertalot [13] and Wojtal et al. [32], this species is found on wet rocks, between mosses, and in mud substrate. In this study, it was found in the epipelic and epiphytic samples, recorded as common (C) (44.44%) (Table 2). Patrick and Reimer [11] noted that *Eunotia bilunaris* is widespread in low mineral content waters. It is commonly found in acid waters, but may also occur in slightly alkaline waters. Alles et al. [38] suggest that this taxon has two optima in terms of pH values. The first one is around 4.0-4.3, the second one is pH 7 or slightly above. According to Van Dam et al [31], this species has no apparent optimum in pH. In the studied waters, this species was collected in epipelic and epiphytic habitats with pH of 6.19-7.04, conductivity of 12-49.9µS/cm, and an altitude of 2668-2930 m a.s.l. It was recorded as rare (R) (27.77%) (Table 2). In addition, *Eunotia mucophila* and *E. paludosa* have been identified as new records for the Freshwater Algal Flora of Turkey.

According to Wehr and Sheath [30], the genus Gomphonema is found in nearly every habitat type within circumneutral lakes and streams. Although the genus Gomphonema represented by six species in the diatom flora, only *Gomphonema olivaceum* was recorded as common (C) (44.44%) (Table 2). The others were recorded as rare and very rare (Table 2). This species seems to prefer cool, flowing water, which is fairly hard, although it is found in water with great variation in its calcium content. It does not seem to thrive in water with a very low calcium content [11]. Van Dam et al. [31] state that this species is alkalibiontic, β-mesosaprobic and eutrophic.

The members of the genus *Surirella* are benthic and are found most often on epipelic habitats but may also occupy the epilithic and epiphytic [30]. The only species that received attention in this genus is *Surirella splendida*. It was found in the epipelic, epilithic and epiphytic samples of the 14 sites and recorded as frequent (F) (77.77%) (Table 2). This species has been reported from alkaliphilous (mainly occuring at pH>7), β-mesosaprobous and meso-eutrophic waters [31]. According to Krammer and Lange-Bertalot [15], *Surirella splendida* prefers eutrophic waters with moderate-to- high electrolyte content and is also found in various salt mines, but less common in Alpine lakes.

According to literature, *Amphora ovalis* seems to be characteristic of standing or slowly flowing waters [11], is alkaliphilic, β-mesosaprobic, and eutrophic [31]. In this study, it was found in circumneutral, acidophilous and low- mineral content waters (Fig. 2) and recorded as frequent (F) (66.66%) (Table 2). *Encyonema minutum,* which was recorded as frequent (F) (77.77%) (Table 2), has a wide geographical distribution [11] and prefers circumneural waters [31]. *Stauroneis anceps*, which was found in the twelve sites, is one of the frequent (F) (66.66%) species in the diatom flora (Table 2). This species prefers circumneutral, β-mesosaprobic, and meso-eutrophic waters [31]. According to Patrick and Reimer [11], this species has a wide geographical distribution and prefers pH indifferent waters. *Tabellaria flocculosa* is recorded as frequent (F) (61.11%) (Table 2). This species has a wide tolerance for different types of water. *Tabellaria flocculosa*, which has shorter frustules, more often occur in acid waters of bogs and ponds; however, those with longer frustules were found in oligotrophic and mesotrophic waters [11]. Van Dam et al. [31] state that it prefers acidophilic, β-mesosaprobic, and mesotrophic water. One of the most commonly found benthic algae samples in all freshwater ecosystems is also *Achnanthidium minutissimum* [11, 14]. Van Dam et al [31] state that this species had been found in acidic and alkaline, oligotrophic and hypertrophic waters. Whereas, in this study, this species was found only in the epipelic samples of the two lakes (BL3 and IL) and recorded as very rare (VR) (11.11%) (Table 2).

The investigation of the taxonomic structure of the flora is an important part of the floristic analysis, which makes it possible to identify the most diversified species of the floristic spectrum, showing the direction of the algal flora development of the region as a whole [28]. In conclusion, the diatom flora of the Artabel Lakes Nature Park was formed by cosmopolitan species with a large involvement of species from alpine and subalpine area, as was found in the other studied high mountain lakes in the region [35-37,39,40,41,42,43,44].When the benthic habitats of the studied lakes were compared, differences were observed in species composition and relative abundance of each lake. The diatom flora of Artabel Lakes Nature Park is composed of indifferent (48.31%), alkaliphiles (31.46%), and acidophiles (16.85%) species. It was also identified north-alpine and alpine diatom species. The physico-chemical conditions of the studied waters also provided a suitable environment for the development of the diatom flora. In this study, a total of 95 species belonging to Bacillariophyta were identified only in benthic habitats. Whereas, Atıcı [6] recorded 58 diatom species in the plankton and benthic habitats of the 18 lakes in the Artabel Lakes Nature Park. These findings highlighted the necessity for further fundamental investigations in the Artabel Lakes Nature Park. The data obtained from this study contribute to information about both bioindicator diatom species and high mountain lakes.

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