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Comparative Analysis of Diatom Algae Diversity in the Pamir Protected Lakes, Tajikistan

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Abstract: *Diatom algae from six Pamir lakes located at an altitude from 3,729 to 4,213 m above the sea level were studied in 466 samples collected in summer period of 2000-2018. Altogether 300 species of diatom algae (330 with infraspecies) of 76 genera were revealed in periphytonic 466. The richest communities were found in two freshwater lakes Turumtaykul with 171 species (184 taxa) and Rangkul with 162 species (176 taxa). Floristic analysis with help of statistical methods show that the water salinity can be regulating factor of diatom diversity development in high mountain lakes. The Pinnularia genus was the richest in five from six lakes floras. The two floristic core were revealed in the analysis of the species overlapping. The natural status of the protected high mountain lakes as a result of our analysis is indicates a high level of conservation of diversity in the territory of the Tajik National Park and the adjacent high-mountainous areas. Advanced statistical methods help us to characterize the stability of studied algal floras in protected high mountain lakes as higher on the genera level then on the species level, and therefore species of studied floras can be source of evolutionary speciation.*

Keywords: *diatom algae, diversity, Pamir Natural Reserve, Tajikistan*

1. Introduction

Pamir is one of high altitude area in Eurasia with close relations to Hindu Cush, Altay, and Himalayas. Numbers of lakes are placed in its territory, which are occupied by diverse algal communities. Algal species richness and occurrence up to now are studied not enough in mountain lakes because their usually placed in hard-to-reach areas. Most of natural lakes in Tajikistan are under protection [1] and can represent some natural environment as reference characteristics in the context of an increase in the anthropogenic load of the surrounding areas and climate changes. More of them, most number of the lakes take place in the Eastern Pamir Mountains and has been included to the Tajik Natural Reserve [2, 3]. Despite the fact that in recent years we have been making efforts to enrich and summarize data on the Pamir algae, the study of algal diversity in Pamir lakes is in initial stage [4-9]. Although it's algal species richness and ecology can help to characterize the reference natural habitats in this important and interesting area of the world. In the protected lakes, waters a special community of algae with a specific species composition was formed which can characterize native diversity of algae in the high mountains of Central Asia.

The aim of this work were characteristic of taxonomical diversity and comparative floristic of the diatom algal flora of six lakes located in the Tajik National Park and surrounding high mountain areas..

2. Material and Methods

2.1. Description of Study Site

The Tajik National Park (TNP) is the biggest high mountain park and nature reserve in eastern Tajikistan with a total area of 2.6 million hectares, which is 18% of the total size of Tajikistan [2] (Fig. 1). It was established in 1992 and designated by Decision No. 267 of the Tajikistan Government. In 2013, the park was accepted as UNESCO World Heritage.

The national park features a mix of steppe, desert, grassland and alpine regions. The climatic features of this territory (which also called "the World Roof") are a long cold winters and cool summers, with an average annual rainfall of 12.7 cm only [3]. The lakes in Pamir Mountains has a wide range of dissolved solids in water and are affiliated to three geological formations: Hydrocarbonate, Sulfate, and Sodium (Table 1) [10].

Fig 1. *Map of the Tajik National Park and location of studied lakes in Tajikistan in blue circles: 1– Karakul; 2 – Bulunkul; 3 – Sassykkul; 4 – Yashilkul; 5 – Turumtaykul; 6 – Rangkul*

Table 1. *Hydrochemical properties of protected lakes in Pamir Mountains according A.M. Muzafarov [10]*

Formation	Facies	Average Water TDS, mg l^{-1}	Lakes
Hydrocarbonate	$HCO_3^- – Ca^{2+} – SO_4^{2-}$	80–200	Yashilkul, Sarezskoye,
Hydrocarbonate	$HCO_3^- – Ca^{2+} – Na^+ + K^+$	30–80	Zorkul
Hydrocarbonate	$HCO_3^- – Na^+ + K^+ – SO_4^{2-}$	150–150	Bulunkul, Kichikkul
Hydrocarbonate	$HCO_3^- – SO_4^{2-} – Ca^{2+}$	200–500	Rangkul, Yashilkul, Sarezskoye
Sulfate	$SO_4^{2-} – HCO_3^- – Ca^{2+}$	>500	Rangkul
Sulfate	$SO_4^{2-} – HCO_3^- – Mg^{2+}$	900–1,500	Rangkul, Shorkul
Sulfate	$SO_4^{2-} – Cl^- – HCO_3^-$	2,800	Karakul
Sulfate	$SO_4^{2-} – Cl^- – Mg^{2+}$	>1000	Shorkul
Sulfate	$SO_4^{2-} – Cl^- – Mg^{2+}$	4500 – 7600	Karakul
Sulfate	$SO_4^{2-} – Cl^- – Na^+ + K^+$	> 9,500	Karakul
Sodium	$Na^+ + K^+ – SO_4^{2-} – Cl^-$	70,000–100,000	Sassykkul

2.2. Sampling and laboratory studies

Earlier was presented total list of diatom algae of high mountains of Tajikistan that has been published in the base of references and our investigation during 2000-2015 [4]. Now the list from which we take in account the lakes floras was enriched by our field trips in 2015-2018 results which were focused on algal communities of six Pamir lakes, especially.

So, the material for this analysis is represented by our own data from 466 samples collected during nine field trips in the summer period of 2000-2018 from six lakes located at an altitude from 3,729 to 4,213 m above the sea level (Fig. 2, Tab. 2). Algal periphytonic samples were collected by scratching, planktonic samples - by scooping and lather filtering with pore 0.8-1.2 mkm. Samples were fixed in 3% neutral formaldehyde solution, transported to the lab in the icebox. Diatom samples were processed in the laboratory of flora and systematics of thalloid plants of the Institute of Botany, Plant Physiology and Genetics of the Academy of Sciences of the Republic of Tatarstan, the Institute of Evolution of the University of Haifa, and in the Laboratory of Plant Systematics and Geography named I.D. Papanin, RAS in Borok. A light microscope Nikon Eclipse E 600 and a scanning electron microscope JSM-25S were used. For the determination of diatom species, the relevant handbooks, systematic reports, monographs, and individual articles were used [11-14].

The list of revealed diatoms in six lakes was updated with an algaebase.org [15]. Calculation of similarity was doing in the GRAPHS program [16] and network analyses in JASP on the bootnet package in R [17]. The network graphs and Pearson correlation coefficients that JASP produces are based on the R Statistica package [17].

Fig 2. *Studied lakes in Pamir Mountains: Lake Karakul (left), Lake Rangkul (right)*

3. RESULTS AND DISCUSSION

3.1. Environmental variables

Data about studied communities from six lakes in Pamir are represented in Table 2. Can be seen that altitude of studied lakes is very high but varied in small amplitude. Nevertheless the water in all six lakes have different salt content and related to three different groups as Hydro carbonate, Sulfate, and Sodium (Table 1), the most varied properties is water TDS. So, whereas TDS in Bulunkul, Yashilkul, Turumtaykul, and Rangkul is about 300 mg l^{-1}, two other lakes have very high level of TDS as 10,867 mg l^{-1} in Karakul and 141,000 mg l^{-1} in Sassykkul.

Table 2. *Environmental variables of the studied lakes in the Pamir Mountains*

Name of lake	Karakul	Bulunkul	Sassykkul	Yashilkul	Turumtaykul	Rangkul
No. on the map	1	2	3	4	5	6
Latitude, N	39° 00′ 33.52″	37° 43′ 28.14″	37° 41′ 48.85″	37° 44′ 53.42″	37° 28′ 47.94″	38° 28′ 32.72″
Longitude, E	73° 33′ 04.93″	72° 57′ 26.67″	73° 10′ 48.48″	72° 54′ 19.80″	72° 32′ 42.00″	74° 15′ 20.39″
Altitude, m	3921	3792	3851	3729	4213	3827
Average Water TDS, mg l^{-1}	10,867-11,568	114.3	141,000	341.2	100-300	463

3.2. Diversity and ecology of algae and cyanobacteria

Taxonomical diversity of diatom communities of the studied lakes is presented in Table 3. Altogether 300 species of diatom algae (330 with infraspecific variables) from 76 genera were revealed in six studied Pamir lakes (Table 4).

Table 3. *Taxonomical diversity of diatom algae in the Pamir Mountains lakes. Note: Number of lakes like in Table 2: 1 - Karakul; 2 - Bulunkul; 3 - Sassykkul; 4 - Yashilkul; 5 - Turumtaykul; 6 - Rangkul.*

Taxa	**1**	**2**	**3**	**4**	**5**	**6**
Achnanthes brevipes C.Agardh var. *brevipes*	1	0	1	0	0	1
Achnanthes brevipes var. *intermedia* (Kützing) Cleve	0	0	1	0	0	0
Achnanthes coarctata (Brébisson ex W.Smith) Grunow	1	0	0	1	0	1
Achnanthes dispar var. *angustissima* (Jasnitsky) Sheshukova	0	0	0	0	1	0
Achnanthes pamirensis Hustedt	0	1	0	0	0	0
Achnanthidium exiguum (Grunow) Czarnecki	0	0	0	0	1	1
Achnanthidium exile (Kützing) Heiberg	0	0	0	1	0	0
Achnanthidium lanceolatum var. *ventricosum* (Hustedt) Poretsky	1	0	0	0	0	0
Achnanthidium minutissimum (Kützing) Czarnecki	1	1	1	1	1	0
Amphora commutata Grunow	1	1	1	1	1	0
Amphora mongolica Østrup var. *mongolica*	0	0	0	0	1	1

Amphora mongolica var. *cornuta* Skvortzov	1	1	1	1	1	1
Amphora ovalis (Kützing) Kützing var. *ovalis*	1	1	1	1	1	1
Amphora ovalis var. *gracilis* (Ehrenberg) Van Heurck	1	1	1	1	1	0
Amphora pediculus (Kützing) Grunow in A.W.F.Schmidt	1	0	1	0	0	0
Amphora proteus W.Gregory	0	0	1	0	1	1
Amphora robusta W.Gregory	1	0	1	0	0	1
Aneumastus apiculatus (Østrup) Lange-Bertalot in Lange-Bertalot & Genkal	1	0	0	0	0	0
Aneumastus minor Lange-Bertalot	1	0	1	0	0	0
Aneumastus rostratus (Hustedt) Lange-Bertalot	1	1	1	1	1	0
Aneumastus tuscula (Ehrenberg) D.G.Mann & A.J.Stickle in Round, R.M.Crawford & D.G.Mann	1	0	1	1	0	1
Anomoeoneis costata (Kützing) Hustedt	1	1	1	1	0	0
Anomoeoneis sphaerophora Pfitzer var. *sphaerophora*	1	1	1	1	1	1
Anomoeoneis sphaerophora var. *guentheri* Otto Müller	0	0	0	0	0	1
Anomoeoneis sphaerophora var. *sculpta* (Ehrenberg) Otto Müller	0	0	0	0	0	1
Aulacoseira granulata (Ehrenberg) Simonsen	1	1	1	1	1	1
Brachysira exilis (Kützing) Round & D.G.Mann	1	1	0	1	0	1
Brachysira microcephala (Grunow) Compère	1	1	1	1	1	0
Caloneis bacillum (Grunow) Cleve	1	1	0	1	1	1
Caloneis limosa (Kützing) R.M.Patrick	1	1	0	1	1	1
Caloneis molaris (Grunow) Krammer in Krammer & Lange-Bertalot	0	1	1	1	0	0
Caloneis nubicola (Grunow) Cleve	1	1	1	1	1	0
Caloneis schumanniana (Grunow) Cleve	1	1	1	1	1	0
Caloneis silicula (Ehrenberg) Cleve var. *silicula*	1	1	1	1	1	0
Caloneis silicula var. *jenissejensis* Grunow	1	0	0	0	0	0
Caloneis silicula var. *kjellmaniana* (Cleve) Cleve	1	1	1	1	1	0
Caloneis tenuis (Gregory) Krammer	0	0	0	0	1	1
Caloneis undulata (Gregory) Krammer	0	0	0	0	1	1
Caloneis ventricosa (Ehrenberg) F. Meister var. *ventricosa*	1	0	0	0	1	1
Caloneis ventricosa var. *truncatula* (Grunow) Meister	1	1	1	1	1	1
Cavinula cocconeiformis (W.Gregory ex Greville) D.G.Mann & A.J.Stickle in Round, R.M.Crawford & D.G.Mann	0	0	1	0	0	1
Cavinula scutelloides (W.Smith) Lange-Bertalot in Lange-Bertalot & Metzeltin	1	1	1	1	1	0
Cocconeis disculus (Schumann) Cleve in Cleve & Jentzsch	0	0	1	0	0	0
Cocconeis fluviatilis JHWallace	0	0	0	0	0	1
Cocconeis lineata Ehrenberg	0	0	0	0	0	1
Cocconeis pediculus Ehrenberg	0	0	0	0	0	1
Cocconeis placentula Ehrenberg var. *placentula*	1	1	0	1	0	1
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	0	0	0	0	0	1
Cocconeis placentula var. *intermedia* (Héribaud-Joseph & M.Peragallo) Cleve	1	1	0	1	1	0
Cocconeis scutellum Ehrenberg	1	1	1	1	1	0
Craticula ambigua (Ehrenberg) D.G.Mann in Round, Crawford & D.G.Mann	0	0	0	0	1	1
Craticula cuspidata (Kützing) Mann	0	0	0	0	1	1
Craticula halophila (Grunow) D.G.Mann in Round, R.M.Crawford & D.G.Mann var. *halophila*	1	1	1	1	0	0
Craticula halophila var. *subcapitata* (Østrup) Czarnecki	1	1	1	1	0	0
Ctenophora pulchella (Ralfs ex Kützing) D.M. Williams et Round	1	1	1	0	0	1
Cyclostephanos mansfeldensis Houk, Kleen & H.Tanaka	1	1	1	1	0	1
Cyclotella caspia Grunow	1	1	1	1	1	1
Cyclotella meneghiniana Kützing	0	0	0	0	1	1
Cymatopleura elliptica (Brébisson) W.Smith	0	0	0	0	1	1
Cymatopleura librile (Ehrenberg) Pantocsek	1	1	0	1	1	1
Cymbella affinis Kützing	0	1	0	1	0	1

Cymbella angustata var. *diversistriata* Muzafarov	0	1	0	1	0	0
Cymbella aspera (Ehrenberg) Cleve var. *aspera*	1	0	1	0	0	1
Cymbella aspera var. *intermedia* Skvortzov	1	1	1	0	0	1
Cymbella cistula (Ehrenberg) O.Kirchner	1	1	1	1	1	0
Cymbella helvetica Kützing	1	1	1	0	1	1
Cymbella hustedtii f. *lineolata* Muzafarov	1	0	0	0	0	1
Cymbella hustedtii Krasske f. *hustedtii*	1	1	1	1	1	1
Cymbella laevis Nägeli in Rabenhorst	1	1	0	1	0	1
Cymbella lanceolata var. *cornuta* f. *minuta* Muzafarov	0	0	0	0	0	1
Cymbella obtusiuscula Kützing	1	1	1	1	1	0
Cymbella parva (W.Smith) Kirchner	0	1	1	1	0	0
Cymbella proschkinae Muzafarov	0	0	0	0	0	1
Cymbella stuxbergii (Cleve) Cleve	0	0	0	0	0	1
Cymbella subsymmetrica J.B.Petersen	0	1	0	1	0	0
Cymbella tartuensis Molder	0	0	1	0	1	0
Cymbopleura amphicephala (Nägeli) Krammer	0	1	1	1	0	1
Cymbopleura anglica (Lagerstedt) Krammer	0	0	0	0	1	0
Cymbopleura angustata (W. Smith) Krammer	1	0	1	0	1	1
Cymbopleura florentina (Grunow) Krammer	0	0	0	0	0	1
Cymbopleura gutwinskii (Wislouch) Krammer	0	1	1	1	0	0
Cymbopleura inaequalis (Ehrenberg) Krammer	0	1	1	1	1	0
Cymbopleura incerta (Grunow) Krammer	0	1	1	1	0	0
Cymbopleura reinhardtii (Grunow) Krammer	1	0	0	0	1	0
Cymbopleura subaequalis (Grunov) Krammer	0	0	0	0	0	1
Delicata delicatula (Kützing) Krammer	0	0	0	0	1	1
Denticula elegans Kützing	0	0	0	0	0	1
Denticula kuetzingii Grunow	0	0	0	0	0	1
Denticula tenuis Kützing	0	1	0	1	1	0
Diadesmis contenta var. *biceps* (Grunow) P.B.Hamilton	0	0	0	0	0	1
Diatoma elongata (Lyngbye) C.Agardh	1	1	1	1	1	1
Diatoma tenuis Agardh	0	0	0	0	0	1
Diatoma vulgaris Bory var. *vulgaris*	1	1	1	1	1	0
Diatoma vulgaris var. *producta* Grunow	1	0	0	0	0	0
Didymosphenia geminata (Lyngbye) Mart.Schmidt	1	1	1	1	1	1
Diploneis elliptica (Kützing) Cleve	0	0	0	0	0	1
Diploneis oculata (Brébisson) Cleve	0	0	0	0	0	1
Diploneis ovalis (Hilse) Cleve	0	0	0	0	0	1
Diploneis parma Cleve	0	0	0	0	0	1
Diploneis subovalis Cleve	1	1	1	1	1	0
Encyonema elginense (Krammer) D.G.Mann in Round, Crawford & Mann	0	1	1	0	1	1
Encyonema gracile Rabenhorst	1	0	1	0	1	1
Encyonema lacustre (C.Agardh) Pantocsek	1	1	1	1	1	0
Encyonema leibleinii (C.Agardh) W.J.Silva, R.Jahn, T.A.Veiga Ludwig & M.Menezes	0	0	0	0	1	1
Encyonema minutum (Hilse in Rabenhorst) D.G. Mann	0	0	0	0	1	0
Encyonema silesiacum (Bleisch in Rabenhorst) D.G. Mann	0	0	0	0	1	0
Encyonema ventricosum (C.Agardh) Grunow	1	1	1	0	0	0
Encyonopsis falaisensis (Grunow) Krammer	1	1	1	0	0	1
Encyonopsis microcephala (Grunow) Krammer	0	0	0	0	1	1
Entomoneis alata (Ehrenberg) Ehrenberg	1	1	1	1	1	0
Entomoneis ornata (Bailey) Reimer in R.M.Patrick & C.W.Reimer	1	1	1	1	1	0
Entomoneis paludosa (W. Smith) Reimer var. paludosa	1	1	0	0	1	1
Entomoneis paludosa var. *duplex* (Donkin) Makarova & Achmetova	1	0	0	0	1	1
Epithemia adnata (Kützing) Brébisson var.	1	1	1	0	0	1

Epithemia adnata var. *saxonica* (Kützing) R.M.Patrick in Patrick & Reimer	1	1	0	1	0	1
Epithemia argus var. *longicornis* (Ehrenberg) Grunow	0	0	0	0	0	1
Epithemia argus (Ehrenberg) Kützing var. *argus*	1	1	1	1	1	1
Epithemia argus var. *alpestris* (W.Smith) Grunow	1	1	1	1	1	1
Epithemia operculata (C.Agardh) Ruck & Nakov in Ruck et al.	1	1	0	1	1	0
Epithemia parallela (Grunow) Ruck & Nakov in Ruck et al.	0	1	0	1	1	0
Epithemia porcellus Kützing	1	0	1	0	0	0
Epithemia sorex Kützing	1	1	1	1	1	1
Epithemia turgida (Ehrenberg) Kützing	0	0	0	0	1	1
Eucocconeis flexella (Kützing) Meister	0	1	0	1	1	0
Eucocconeis quadratarea (Østrup) Lange-Bertalot & Genkal	0	0	0	0	0	1
Eunotia arcus Ehrenberg	0	0	0	0	1	1
Eunotia bidens Ehrenberg	0	1	1	1	0	0
Eunotia exigua (Brébisson in Kützing) Rabenhorst	0	1	1	1	1	0
Eunotia lunaris (Ehrenberg) Grunow	0	0	0	1	0	0
Eunotia minor (Kützing) Grunow	0	0	0	1	0	0
Eunotia polydentula (Brun) Husted	0	0	0	1	0	1
Eunotia praerupta Ehrenberg	0	0	0	1	0	0
Fallacia pygmaea (Kützing) De Mann	0	0	0	0	1	1
Fragilaria acus (Kützing) Lange-Bertalot in Krammer & Lange-Bertalot	0	0	0	0	1	1
Fragilaria alpestris Krasske ex Hustedt	0	0	0	0	1	1
Fragilaria amphicephaloides Lange-Bertalot in Hofmann, Werum & Lange-Bertalot	0	0	1	1	1	0
Fragilaria bidens Heiberg	0	0	0	0	1	0
Fragilaria capucina Desmazières var. *capucina*	0	0	0	1	1	0
Fragilaria capucina var. *lanceolata* Grunow in van Heurck	0	0	1	0	0	0
Fragilaria crotonensis Kitton	0	1	1	1	1	0
Fragilaria inflata var. *istvanffyi* (Pantoscek) Hustedt	0	0	1	0	0	0
Fragilaria radians (Kützing) D.M.Williams & Round	0	0	0	0	0	1
Fragilaria recapitellata Lange-Bertalot & Metzeltin in Metzeltin, Lange-Bertalot & Nergui	0	0	0	1	0	0
Fragilaria vaucheriae (Kützing) J.B.Petersen	1	0	1	1	1	1
Fragilariforma bicapitata (A.Mayer) D.M.Williams & Round	0	0	0	0	1	1
Fragilariopsis cylindrus (Grunow) Helmcke & Krieger	0	0	0	0	0	1
Frustulia rhomboides (Ehrenberg) De Toni	0	0	0	0	1	0
Genkalia digituloides (Lange-Bertalot) Lange-Bertalot & Kulikovskiy in Kulikovskiy et al.	1	1	1	1	1	1
Gomphoneis herculeana (Ehrenberg) Cleve	0	0	0	0	0	1
Gomphonema acuminatum Ehrenberg	0	1	0	0	0	1
Gomphonema angustatum (Kützing) Rabenhorst	1	1	1	1	1	1
Gomphonema constrictum var. *capitatum* (Ehrenberg) Grunow	1	1	0	0	0	0
Gomphonema gracile Ehrenberg	1	1	1	1	0	1
Gomphonema grunowii R.M.Patrick & Reimer	1	1	1	1	1	1
Gomphonema kobayasii Kociolek & J.C.Kingston	0	0	0	0	0	1
Gomphonema lagenula Kützing	0	1	1	1	1	0
Gomphonema longiceps Ehrenberg	1	1	1	1	1	0
Gomphonema micropus Kützing	0	0	0	0	1	1
Gomphonema olivaceum (Hornemann) Brébisson	1	0	0	0	0	0
Gomphonema parvulum (Kützing) Kützing	1	1	1	1	1	0
Gomphonema subclavatum (Grunow) Grunow	1	1	1	1	1	0
Gomphonema truncatum Ehrenberg	1	1	1	1	1	0
Gomphosinica hedinii (Hustedt) Kociolek, Q.-M.You, Q.-X.Wang & Q.Liu	1	1	1	1	1	1
Gyrosigma acuminatum (Kützing) Rabenhorst	0	1	1	1	0	0
Gyrosigma attenuatum (Kützing) Rabenhorst	0	0	0	1	1	1
Gyrosigma peisonis (Grunow) Hustedt в Pascher	0	0	0	1	1	1

Halamphora acutiuscula (Kützing) Levkov	0	0	0	0	1	1
Halamphora coffeiformis (C.Agardh) Levkov	1	1	1	0	0	1
Halamphora latecostata J.G.Stepanek & Kociolek	0	0	0	0	0	1
Halamphora normanii (Rabenhorst) Levkov	1	1	1	1	1	0
Halamphora perpusilla (Grunow) Q.-M.You & Kociolek в Q.-M.You, JPKociolek & W.Wang	1	1	1	1	1	0
Halamphora subcapitata (Kisselew) Levkov	1	0	1	0	1	0
Halamphora veneta (Kützing) Levkov	1	1	1	1	1	0
Hannaea arcus (Ehrenberg) RMPatrick в RMPatrick & CWReimer	1	1	1	1	1	1
Hannaea arcus var. *amphioxys* (Rabenhorst) R.M.Patrick	1	1	1	1	0	0
Hantzschia abundans Lange-Bertalot	0	0	0	0	1	0
Hantzschia amphioxys (Ehrenberg) Grunow in Cleve & Grunow var. amphioxys	1	1	1	1	1	0
Hantzschia amphioxys var. *vivax* (Hantzsch) Grunow in Cleve & Grunow	0	1	0	1	0	0
Hantzschia compacta (Hustedt) Lange-Bertalot in Lange-Bertalot & Genkal	0	0	0	0	0	1
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	0	0	0	0	0	1
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	1	1	1	0	1	0
Humidophila contenta (Grunow) Lowe, Kociolek, J.R.Johansen, Van de Vijver, Lange-Bertalot & Kopalová	0	0	0	0	0	1
Iconella curvula (W.Smith) Ruck & Nakov in Ruck et al.	1	0	0	1	1	0
Iconella linearis (W.Smith) Ruck & Nakov in Ruck et al.	1	1	1	1	1	1
Iconella tenera (W.Gregory) Ruck & Nakov in Ruck et al.	1	1	0	0	1	0
Kobayasiella subtilissima (Cleve) Lange-Bertalot	1	0	1	0	0	0
Kurtkrammeria aequalis (W.Smith) L.Bahls	1	0	1	1	0	0
Lindavia antiqua (W.Smith) Nakov, Guillory, Julius, Theriot & Alverson	1	1	1	1	0	1
Lindavia bodanica (Eulenstein ex Grunow) T.Nakov, Guillory, Julius, Theriot & Alverson	1	1	1	1	0	0
Lindavia comta (Kützing) Nakov, Gullory, Julius, Theriot & Alverson	0	1	1	1	1	1
Lindavia kuetzingiana var. *radiosa* (Fricke) T.Nakov et al.	0	0	0	0	1	0
Lindavia lacunarum (Hustedt) Nakov, Guillory, Julius, Theriot & Alverson	1	1	0	0	0	1
Luticola mutica (Kützing) D.G.Mann in Round, R.M.Crawford & D.G.Mann	0	0	0	0	1	0
Luticola nivalis (Ehrenberg) D.G.Mann in Round, R.M.Crawford & D.G.Mann 1990	0	0	0	0	1	1
Mastogloia albertii A.Pavlov, E.Jovanovska, C.E.Wetzel, L.Ector & Z.Levkov	0	0	0	0	1	1
Mastogloia baltica Grunow in Van Heurck	1	1	1	1	1	0
Mastogloia braunii Grunow	1	1	1	1	1	0
Mastogloia elliptica (C.Agardh) Cleve in A.W.F.Schmidt	1	0	0	0	0	0
Mastogloia pseudosmithii S.S.Lee, E.E.Gaiser, B.Van de Vijver, M.B.Edlund & Spaulding	0	0	0	0	0	1
Mastogloia smithii Thwaites ex W.Smith	0	0	0	0	1	1
Meridion circulare (Greville) C.Agardh	1	1	1	1	1	1
Meridion constrictum Ralfs	0	0	0	0	0	1
Navicula capitatoradiata H.Germain	0	0	0	0	0	1
Navicula cari Ehrenberg	0	0	0	0	0	1
Navicula cincta (Ehrenberg) Ralfs	0	1	1	1	1	0
Navicula cryptocephala Kützing var. *cryptocephala*	0	1	0	0	1	1
Navicula cryptocephala var. *lata* Poretz. et Anissimova	0	0	0	0	1	1
Navicula dicephala Ehrenberg	1	1	1	0	0	1
Navicula lacustris var. *parallela* Wisl. & Kolbe	1	0	0	0	0	0
Navicula lanceolata Ehrenberg	1	1	1	1	1	0
Navicula libonensis Schoeman	1	0	0	0	0	0
Navicula minima Grunow in Van Heurck	0	0	0	0	0	1
Navicula oblonga (Kützing) Kützing	1	1	1	1	1	1
Navicula peregrina (Ehrenberg) Kützing	1	1	1	1	1	0
Navicula radiosa Kützing	0	0	0	0	0	1

Navicula rhynchocephala Kützing	0	1	0	1	1	0
Navicula rostellata Kützing	1	1	1	1	1	0
Navicula rotaeana (Rabenhorst) Grunow in van Heurck	0	0	0	0	1	1
Navicula salinarum f. *minima* Kolbe	0	0	0	0	1	1
Navicula semen Ehrenberg	1	0	0	0	0	1
Navicula tenella Brébisson ex Kützing	0	1	0	1	1	0
Navicula tuscula f. *intermedia* Kisselev	1	1	1	1	0	0
Navicula viridula (Kützing) Ehrenberg	1	0	0	0	1	1
Navicula vulpina Kützing	1	1	1	1	1	0
Navicula semen Ehrenberg	0	0	0	0	1	0
Navicymbula pusilla (Grunow in A. Schmidt) Krammer	0	0	0	0	1	0
Neidiomorpha binodis (Ehrenberg) M.Cantonati, Lange-Bertalot & N.Angeli	0	1	0	0	0	0
Neidium iridis (Ehrenberg) Cleve	0	1	1	1	1	1
Neidium kozlowii Mereschkovsky	1	0	1	1	0	0
Nitzschia amphibia Grunow var. amphibia	0	0	0	0	0	1
Nitzschia amphibia var. *thermalis* Grunow	0	1	0	1	1	0
Nitzschia communis Rabenhorst	1	1	1	1	1	0
Nitzschia denticula Grunow in Cleve & Grunow	0	0	0	0	0	1
Nitzschia dissipata (Kützing) Rabenhorst	0	0	1	0	1	0
Nitzschia distans W.Gregory	1	0	1	0	0	0
Nitzschia fonticola (Grunow) Grunow in Van Heurck	0	0	0	0	0	1
Nitzschia frustulum (Kützing) Grunow in Cleve & Grunow var. frustulum	0	0	0	0	0	1
Nitzschia frustulum var. *subsalina* Hustedt	1	1	1	0	1	0
Nitzschia frustulum var. *perpusilla* (Rabenhorst) Van Heurck	0	0	0	0	0	1
Nitzschia gracilis Hantzsch	0	0	0	0	0	1
Nitzschia heidenii (Meister) Hustedt	0	0	0	0	0	1
Nitzschia holsatica Hustedt in A.W.F.Schimidt	1	1	1	0	0	0
Nitzschia hungarica var. *pantocsekii* Wislouch & Poretsky	1	0	0	1	0	0
Nitzschia kuetzingiana Hilse	0	0	0	0	0	1
Nitzschia linearis W.Smith	0	0	0	0	0	1
Nitzschia obtusa W.Smith	0	0	0	0	0	1
Nitzschia ostenfeldii Hustedt	0	0	0	0	0	1
Nitzschia palea (Kützing) W.Smith	0	0	0	0	0	1
Nitzschia paleacea (Grunow) Grunow in Van Heurck	0	0	0	0	1	1
Nitzschia pusilla Grunow	0	1	0	0	0	0
Nitzschia regula Hustedt	0	0	0	0	1	0
Nitzschia sigma (Kützing) W.Smith	0	0	0	0	1	0
Nitzschia sigmoidea (Nitzsch) W.Smith	1	1	1	1	0	0
Odontidium hyemale (Roth) Kützing	1	0	1	0	1	1
Pantocsekiella kuetzingiana (Thwaites) KTKiss & E.Ács in Ács et al.	1	1	1	1	1	1
Paraplaconeis compositestriata (Jasnitsky) Kulikovskiy, Metzeltin & Lange-Bertalot in Kulikovskiy et al.	1	0	1	1	1	1
Paraplaconeis subplacentula (Hustedt) Kulikovskiy & Lange-Bertalot in Kulikovskiy et al.	0	0	1	0	0	1
Pinnularia appendiculata (C.Agardh) Schaarschmidt	0	0	0	0	0	1
Pinnularia biundulata (Otto Müller) Kulikovskiy & Genkal in Kulikovskiy, Genkal & Mikheeva	1	0	1	0	0	1
Pinnularia borealis Ehrenberg	0	0	0	0	1	1
Pinnularia boyeri RMPatrick	0	1	1	1	0	0
Pinnularia brauniana (Grunow) Studnicka	1	1	1	1	1	0
Pinnularia brebissonii (Kützing) Rabenhorst	0	0	0	0	1	1
Pinnularia brevicostata Cleve	1	1	1	1	1	0
Pinnularia canadodivergens Kulikovskiy, Lange-Bertalot & Metzeltin	0	0	0	0	1	0
Pinnularia divergentissima (Grunow) Cleve	0	1	0	1	0	0
Pinnularia fonticola Hustedt	1	1	1	1	1	0

Pinnularia globiceps W.Gregory	0	0	1	0	1	1
Pinnularia gracillima W.Gregory	0	0	0	0	1	1
Pinnularia grunowii Krammer	0	0	0	0	1	0
Pinnularia lata (Brébisson) W.Smith var. *lata*	1	1	1	1	1	0
Pinnularia lata var. *minor* (Grunow) Cleve	1	1	1	1	1	0
Pinnularia microstauron (Ehrenberg) Cleve	1	0	1	0	1	1
Pinnularia rangoonensis Grunow ex Cleve	0	0	0	0	1	1
Pinnularia rhombica Hustedt in Schmidt et al.	0	0	0	0	1	1
Pinnularia schoenfelderi Krammer	0	0	0	0	1	1
Pinnularia septentrionalis K.Krammer	0	0	0	0	1	0
Pinnularia socialis var. *debesii* (Hustedt) Krammer	1	1	1	1	1	0
Pinnularia subborealis Hustedt	1	0	0	1	0	0
Pinnularia subcapitata W.Gregory	0	0	0	0	1	1
Pinnularia subtibetana Muzafarov	0	0	0	0	0	1
Pinnularia tabellaria Ehrenberg	1	1	1	1	1	0
Pinnularia viridiformis Krammer	0	0	0	0	1	0
Pinnularia viridis (Nitzsch) Ehrenberg var. *viridis*	1	1	1	1	1	1
Pinnularia viridis var. *diminuta* Ant.Mayer	1	0	0	0	0	1
Placoneis exigua (W.Gregory) Mereschkovsky	1	1	1	0	0	0
Placoneis gastrum (Ehrenberg) Mereschkowsky	1	0	0	0	1	1
Planothidium dispar (Cleve) Witkowski, Lange-Bertalot & Metzeltin	1	1	1	1	1	0
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	1	1	1	1	1	0
Platessa salinarum (Grunow) Lange-Bertalot	0	0	0	0	1	1
Prestauroneis integra (W.Smith) Bruder in Bruder & Medlin	1	0	1	0	0	0
Pseudostaurosira brevistriata var. *inflata* (Pantocsek) M.B.Edlund	1	1	1	1	0	0
Pseudostaurosira elliptica (Schumann) Edlund, Morales & Spaulding	1	0	0	0	0	0
Punctastriata lancettula (Schumann) P.B.Hamilton & P.A.Siver	1	1	1	1	1	0
Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot	0	0	0	0	1	1
Rhopalodia gibba (Ehrenberg) Otto Müller	1	1	1	1	1	0
Rhopalodia gibberula (Ehrenberg) Otto Müller	1	1	0	1	0	1
Sellaphora bacillum (Ehrenberg) D.G. Mann	0	0	0	0	1	1
Sellaphora pupula (Kützing) Mereschkovsky	1	0	0	0	1	1
Sellaphora rectangularis (W.Gregory) Lange-Bertalot & Metzeltin	0	0	0	0	1	0
Sellaphora tridentula (Krasske) CEWetzel in Wetzel et al.	1	1	1	1	0	0
Stauroneis acuta W.Smith	0	0	0	0	1	1
Stauroneis anceps Ehrenberg	1	0	1	1	1	1
Stauroneis borrichii (J.B.Petersen) J.W.G.Lund	0	0	0	0	1	1
Stauroneis gracilis Ehrenberg	0	0	0	0	1	0
Stauroneis lauenburgiana Hustedt	0	0	0	0	1	1
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	0	1	1	1	0	0
Stauroneis smithii Grunow	0	0	0	0	0	1
Staurosira construens Ehrenberg var. *construens*	1	1	1	1	0	0
Staurosira construens var. *exigua* (W.Smith) H.Kobayasi in S.Mayama et al.	1	1	1	1	1	0
Staurosira leptostauron (Ehrenberg) Kulikovskiy & Genkal	1	1	1	1	1	0
Staurosirella pinnata (Ehrenberg) Williams and Round	1	1	1	1	1	1
Stephanodiscus astraea (Ehrenberg) Grunow in Cleve & Grunow	1	1	1	1	1	1
Stephanodiscus minutulus (Kützing) Cleve & Möller	1	0	0	0	1	0
Surirella angusta Kützing	1	1	1	1	1	1
Surirella brebissonii Krammer & Lange-Bertalot	0	0	0	0	0	1
Surirella minuta Brébisson in Kützing	1	1	1	1	0	1
Surirella ovalis Brébisson	1	1	1	1	1	1
Surirella splendida (Ehrenberg) Kützing	0	0	0	0	1	0
Synedra pulchella var. *macrocephala* Grunow	1	1	1	1	0	0
Tabellaria fenestrata (Lyngbye) Kützing	1	1	0	1	1	1

Tabellaria flocculosa (Roth) Kützing	1	1	1	1	1	0
Tryblionella angustata W.Smith	1	0	0	0	0	1
Tryblionella apiculata W.Gregory	1	0	0	0	0	1
Tryblionella hantzschiana Grunow	1	1	1	0	0	0
Tryblionella hungarica (Grunow) Frenguelli	0	0	0	0	0	1
Tryblionella levidensis W.Smith	1	0	0	0	0	0
Ulnaria biceps (Kützing) Compére	1	1	1	1	1	0
Ulnaria ulna (Nitzsch) Compére var. *ulna*	0	1	1	1	0	0
Ulnaria ulna var. *aequalis* (Kützing) Aboal in Aboal et al.	0	0	0	0	1	0

The first step of floristic analysis was to reveal the fullness of species list for each lake. On the base of revealed diatom species list we constructed the Willis curve to assess how representative the diatoms in the studied lakes. Earlier S. Barinova [18] has been find that Willis curve can be criteria for fullness of species list because follow hyperbolic shape only in well-studied algal floras in Eurasia. The Willis curve of the diatom flora in the studied Pamir lakes 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. Therefore, we can do floristic, taxonomic and ecological analysis for the diatom flora in the Pamir lakes as well as to compare it in future to other high mountain lakes floras.

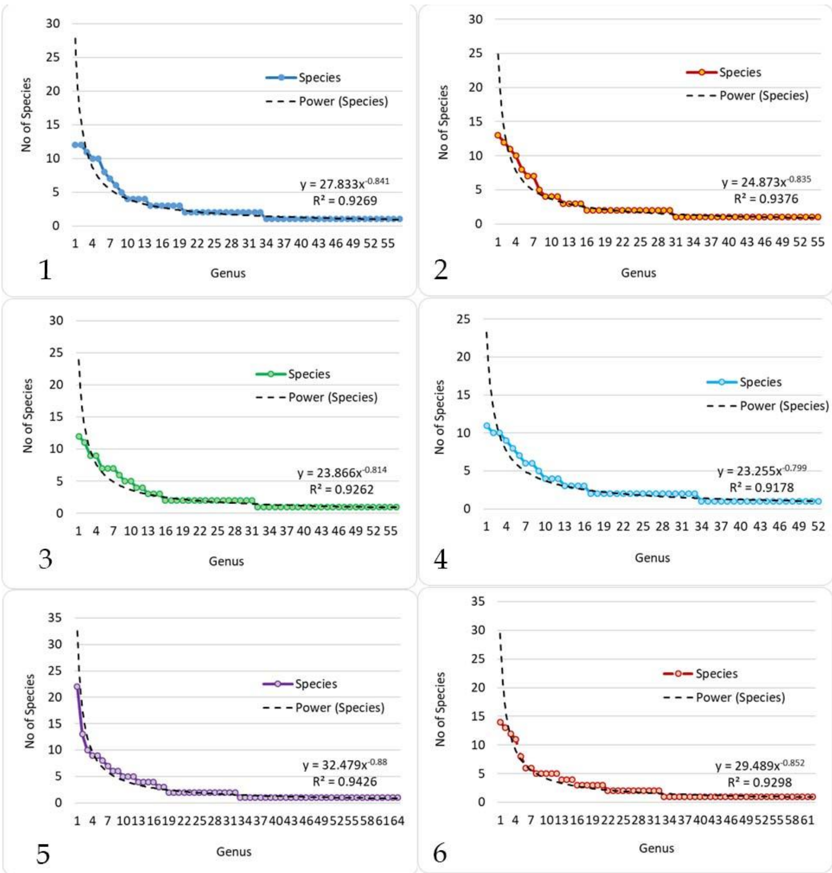

Fig 3. *The Willis curve for the diatom flora of the six studied high mountain Pamir lakes shows the number of species per genera (such as 1 genus with 15 species, 2 genera with 6 species, etc.). Number of lakes is the same as figure number and like in Table 2: 1 - Karakul; 2 - Bulunkul; 3 - Sassykkul; 4 - Yashilkul; 5 - Turumtaykul; 6 - Rangkul.*

Table 4. *Taxonomic distribution of specific, infraspecific taxa and genera of diatom algae in the protected lakes of Pamir with the Subspecies/Species index of intraspecific variation*

Name of lake	Total	Karakul	Bulunkul	Sassykkul	Yashilkul	Turumtaykul	Rangkul
No. of lake		1	2	3	4	5	6
Taxa	330	164	151	152	148	184	176
Species	300	145	137	139	136	171	162
No of Genera	76	56	55	56	53	60	60

Ssp/Sp Index	1.10	1.13	1.10	1.09	1.09	1.08	1.09
STDEV for genera	5.51	2.75	2.74	2.50	2.44	3.45	2.96
Number of genera over STDEV	17	18	15	15	16	15	21
No of taxa above STDEV	207	107	94	93	92	114	122
Percent of taxa in abundant genera	62.7	66.5	63.5	66.9	63.9	66.7	71.7
No of taxa in 10 genera	159	81	78	74	72	97	88
Percent of taxa in 10 genera	48.2	50.3	52.7	53.2	50.0	56.7	51.8
Taxa per genera	4.3	2.9	2.7	2.5	2.7	2.9	2.8
Taxa per abundant genera	12.2	5.9	6.3	6.2	5.8	7.6	5.8
Taxa per 10 genera	15.9	8.1	7.8	7.4	7.2	9.7	8.8

Table 4. Show that richest communities were found in two freshwater lakes Turumtaykul with 171 species (184 taxa) and Rangkul with 162 species (176 taxa). All other floras are represented of about 150 species in average. The Turumtaykul and Rangkul communities have the same proportion in genera level with 60 against 55 genera average in other lakes. Pearson correlation coefficients were rather weak and insignificant for environmental and biological variables of aquatic ecosystem of six studied lakes represented in Tables 2 and 4 and it is not enough for assessment of species-environment interaction. We compare distribution of species richness over altitude of studied lakes (Fig. 4) and revealed increasing of taxa number with altitude. The same distribution of the lakes water TDS shows oppositional relationship (Fig. 4), so that allow us to conclude that water salinity is more fresh in low altitude lakes and salinity can be named as regulating factor of diatom diversity development in high mountain lakes.

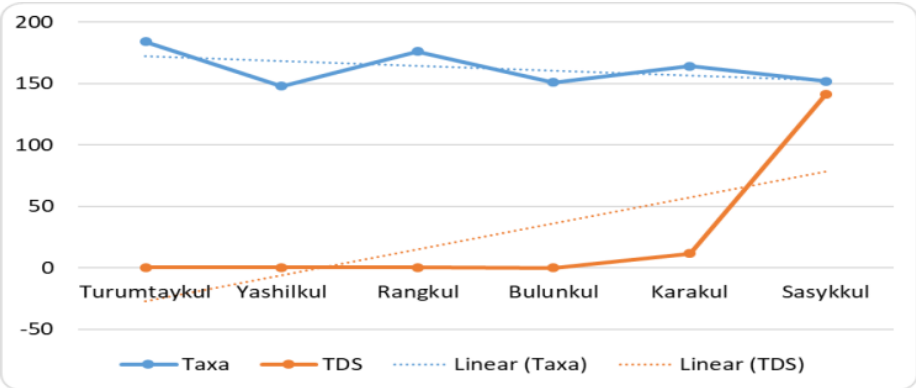

Fig 4. *Distribution of the diatom taxa number and water TDS in studied Pamir lakes*

Table 5 show generic saturation of each flora of six high mountain lakes. In the top of the table can be seen the richest genera. It was very interesting that *Pinnularia* was the richest genera in total list as well as in five from six lakes floras. We decide to characterize the head part of each lake flora with different criteria [19]. In Table 4 are represented calculations of criteria for different ways assessment [20, 21]. Therefore, standard deviation for each distribution of species richness is varied in average about 5.51 that cut off about 17 genera in average. However, number of species in richest genera in this calculation is varied from 122 in the Rangkul to 114 in Turumtaykul in freshwater lakes and about 92-107 in other. In any case, the percent of taxa in abundant genera is varied about 62% average. Another type of abundant taxa calculation is the taxa number in upper ten genera. Therefore, in Table 4 can be seen that total number of taxa in ten abundant genera is 159, but in each lake flora, this number is between 72 and 88 taxa. Percent of species in richest ten genera is above 50%, both ways of analysis can be representative for diatom algae of six high mountain lakes in Pamir. We calculated number of taxa per genus for each floras and see that it is in average for total list 4.3 but rather lower in each flora, such as 2.5 taxa per genus in most saline lake Sasykkul and up to 2.9 in other. Comparison of representativeness of taxa number in abundant genera show 12.5 in average for total list and 5.8-7.6 for the flora lake. Number of taxa per ten richest genera is demonstrated the same proportion as 15.9 for total list average and 7.2-9.7 per ten genera in the floras of the lakes. Therefore, both type of analysis (by standard deviation and by ten richest genera cut off) demonstrated similar results with richest saturation of taxa in genera for flora of most freshwater Turumtaykul Lake. These results look more levelled when compared to the total algal flora of the South Tajik Depression water bodies at an altitude of up to 2500 [20] and, thus, can characterize the peculiar properties of the Pamir algal flora with prevailing of *Pinnularia* species in water bodies of different salinity at an altitude of more than 3700 m a.s.l.

Table 5. *Generic saturation of diatom flora of the Pamir lakes. The most abundant genera over Standard Deviation of each lake diversity is marked by bold*

Genera	Total	Karakul	Bulunkul	Sasykkul	Yashilkul	Turumtaykul	Rangkul
Pinnularia	28	12	10	12	11	21	14
Nitzschia	26	8	7	7	5	8	13
Navicula	24	12	12	9	10	14	12
Cymbella	17	9	11	0	8	0	11
Gomphonema	13	9	10	8	8	8	6
Fragilaria	12	2	2	6	6	8	4
Caloneis	12	9	8	6	8	10	6
Epithemia	10	7	7	5	6	6	7
Cymbopleura	9	2	4	5	4	4	4
Cocconeis	8	3	3	2	3	2	5
Amphora	8	6	4	7	4	6	5
Halamphora	7	5	4	5	3	5	3
Encyonema	7	3	3	4	0	0	0
Eunotia	7	0	2	2	6	2	2
Stauroneis	7	1	1	2	2	5	5
Mastogloia	6	3	2	2	2	4	3
Lindavia	6	4	5	4	4	3	4
Achnanthes	5	2	1	2	1	1	2
Diploneis	5	1	1	1	1	1	4
Surirella	5	3	3	3	3	3	4
Hantzschia	4	1	2	1	2	2	1
Entomoneis	4	4	3	2	2	4	2
Denticula	4	0	1	0	1	1	3
Sellaphora	4	2	1	1	1	3	2
Anomoeoneis	4	2	2	2	2	1	3
Aneumastus	4	4	0	0	0	0	0
Tryblionella	4	3	0	0	0	0	3
Achnanthidium	4	2	1	1	2	2	1
Diatoma	4	3	2	2	2	2	2
Craticula	3	1	1	1	1	2	2
Gyrosigma	3	0	1	1	3	2	2
Ulnaria	3	1	2	2	2	2	0
Placoneis	2	2	1	1	0	1	1
Tabellaria	2	2	2	1	2	2	1
Stephanodiscus	2	2	1	1	1	2	1
Brachysira	2	2	2	1	2	1	1
Staurosira	2	2	2	2	2	1	0
Rhopalodia	2	2	2	1	2	1	1
Cyclotella	2	1	1	1	1	2	2
Cymatopleura	2	0	0	0	0	2	2
Pseudostaurosira	2	2	1	1	1	0	0
Hannaea	2	2	2	2	2	1	1
Planothidium	2	2	2	2	2	2	0
Paraplaconeis	2	1	0	2	1	1	2
Eucocconeis	2	0	1	0	1	1	0
Neidium	2	0	1	2	2	1	1
Iconella	2	2	2	1	1	2	1
Hippodonta	2	0	0	0	0	0	1
Luticola	2	0	0	0	0	2	0

Cavinula	2	1	1	2	1	1	1
Meridion	2	1	1	1	1	1	2
Punctastriata	1	1	1	1	1	1	0
Kobayasiella	1	1	0	1	0	0	0
Synedra	1	1	1	1	1	0	0
Humidophila	1	0	0	0	0	0	1
Aulacoseira	1	1	1	1	1	1	1
Staurosirella	1	1	1	1	1	1	1
Ctenophora	1	1	1	1	0	0	1
Cyclostephanos	1	1	1	1	1	0	1
Encyonopsis	1	0	0	0	0	1	1
Rhoicosphenia	1	0	0	0	0	1	1
Fragilariforma	1	0	0	0	0	1	1
Delicata	1	0	0	0	0	1	1
Gomphosinica	1	1	1	1	1	1	1
Prestauroneis	1	1	0	1	0	0	0
Didymosphenia	1	1	1	1	1	1	1
Platessa	1	0	0	0	0	1	1
Neidiomorpha	1	0	1	0	0	0	0
Gomphoneis	1	0	0	0	0	0	1
Kurtkrammeria	1	1	0	1	1	0	0
Genkalia	1	1	1	1	1	1	1
Frustulia	1	0	0	0	0	1	0
Odontidium	1	1	0	1	0	1	1
Fallacia	1	0	0	0	0	1	1
Fragilariopsis	1	0	0	0	0	0	1
Navicymbula	1	0	0	0	0	1	0

Next step in floristic analysis of revealed diversity of diatom algae in six lakes of Pamir was comparative floristic. The dendrograms of species list comparison were constructed with Euclidean distance and Ward method for species and genera level. Fig. 5 demonstrated trees of similarity for species (Fig. 5, 1) and for genera (Fig. 5, 2) numbers in floras of studied lakes and it's are very similar with two different clusters each on the level of 50% similarity. A flora of the lakes Turumtaykul and Rangkul from the red clusters looks like more diverse on the species and genera level. Remarkable that both these lakes are more fresh from six lakes and more species rich.

Dendrites of overlapping of species diversity (Fig. 6, 1) help us to mark the Bulunkul Lake diatoms as floristic core on the species level whereas the Yashilkul flora was core on the genera level (Fig. 6, 2). So, on the Fig. 6 the floras of Bulunkul and Yashilkul have the largest percent of overlapping that allow us to assume that in its environmental properties can be something similar. Table2 show that water of these both lakes corresponds to the same Hydrocarbonate formation of freshwater lakes.

The comparative floristics of the non-diatom algae of the Pamirs [5] separates the group of six studied lakes into a one cluster, and they also form a separate floristic core in the analysis of the species overlap. This indicates not only their peculiarities compared to other water bodies of Pamir, but also their natural status, which indicates a high level of conservation of diversity in the territory of the Tajik National Park and the adjacent high-mountainous areas.

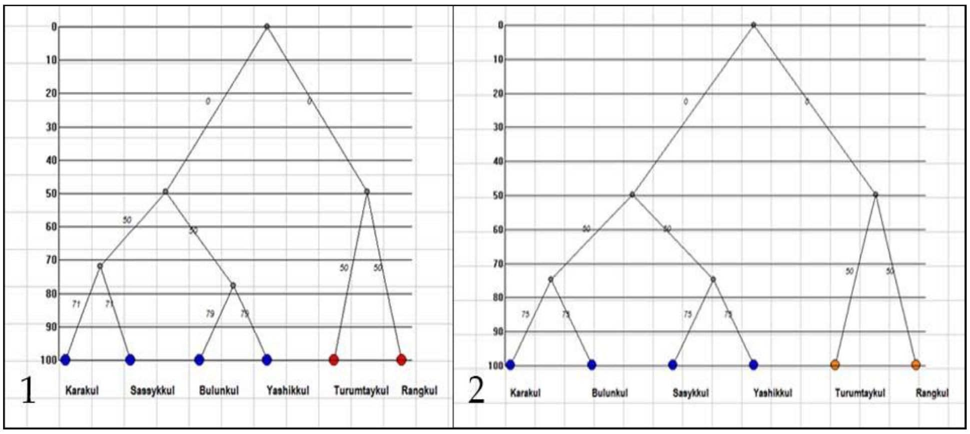

Fig 5. *Comparative floristic tree of the diatom taxa number (1) and genera number (2) of six studied Pamir lakes*

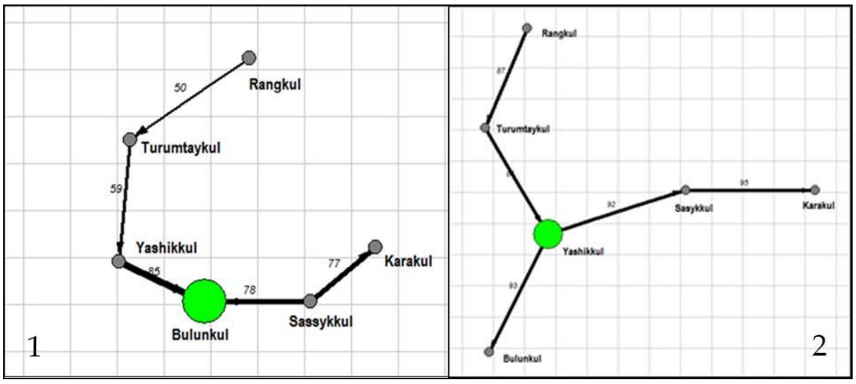

Fig 6. *Dendrite of overlapping of the diatom taxa (1) and genera (2) of six studied Pamir lakes. Percent of overlapping is stay in the lines. The line thickness corresponds to overlap percentage*

The following step in the analysis of the patterns of distribution of diatom diversity was revealing of correlation between the diatom taxa (Fig. 7, 1) and genera (Fig. 7, 2) in the list of six studied Pamir lakes with the JASP network method. Biological neural networks give a mathematical representation of connections found in ecological, evolutionary, and physiological studies [22]. Between-species interaction networks calculation in biology are in the initial stage today but try to implement the new approach to species interactions is highly concerned with understanding what factors lead to network stability [23]. Can be seen that correlation graphs for species on the base of Table 3 and genera on the base of Table 5 are looks like rather different. This method is implemented in first time for the floristic content correlation. So, the floras of the Bulunkul and Yashilkuk are most similar on the species level. The lakes with high salinity, Sasykkul and Karakul have also similar diatom flora but the Rangkul diatoms are different from each other and demonstrated pecularities. The network graph for correlation on the genera level show different relatedness. Floras of the Bulunkul and Karakul lakes have high level of correlation, then follow Yashilkul and Sasykkul floras, then slightly different were Turumtaykul and Rangkul diatoms. Here we can see only one negative correlation between diatom genera of Yashilkul and Rangkul lakes. Therefore, the stability of studied algal floras in protected high mountain lakes looks like higher on the genera level then on the species level.

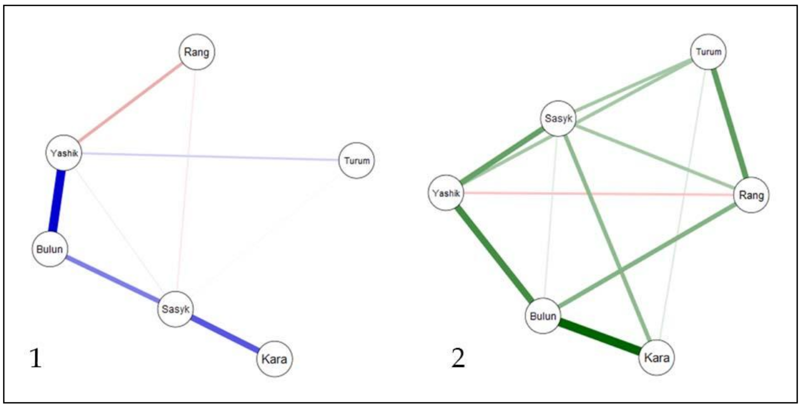

Fig 7. *The JASP network graphs of correlation of the diatom taxa (1) and genera (2) of six studied Pamir lakes. The blue lines are positive correlation; the red lines are negative correlation. Line thickness corresponds to the value of the correlation coefficient*

Comparison of data about taxonomical diversity of diatom algae that represented in Tables 2, 3, and 4 help us to reveal common distributed and abundant genera in all six lakes as *Pinnularia*,*Nitzschia*, *Navicula*, *Gomphonema*, *Epithemia*, and *Amphora* in the order of decreasing its species number. Genera, which are demonstrated specificity of distribution in studied lakes, were *Cymbella*, *Fragilaria*, *Cymbopleura*, *Cocconeis*, *Eunotia*, and *Encyonema*. Ecologically both groups of species are preferred different environment. Therefore, group of common distributed species preferred wide ecological niche whereas species from second group demonstrated ecological narrow range of environmental variables [21].

We choose one genus from each group: *Pinnularia* as most abundant in common group, and *Cocconeis* from second group but represented in each lake communities for clarify environmental preferences and compare its distribution to Genera number and Infraspecific variation Ssp/Sp index. Fig. 8 show that generic diversity increase in species rich community of low altitude lakes that similar to Ssp/Sp index distribution. It can be interpreted as friendlier environment in relatively low altitudinal lakes. Most abundant and species diverse genus *Pinnularia* prefer relatively high altitudinal lakes with low water TDS inhabited low diverse communities. Fig. 8 (3,4) demonstrate different influence of altitude on *Pinnularia* species distribution that let us to conclude that it not regulated variable. In the same time *Cocconeis* species abundance and diversity (Fig. 9: 1,2) show lake altitude as regulating factor because in comparison of both graphs these genus members prefer low altitude lakes with low salinity and species rich community.

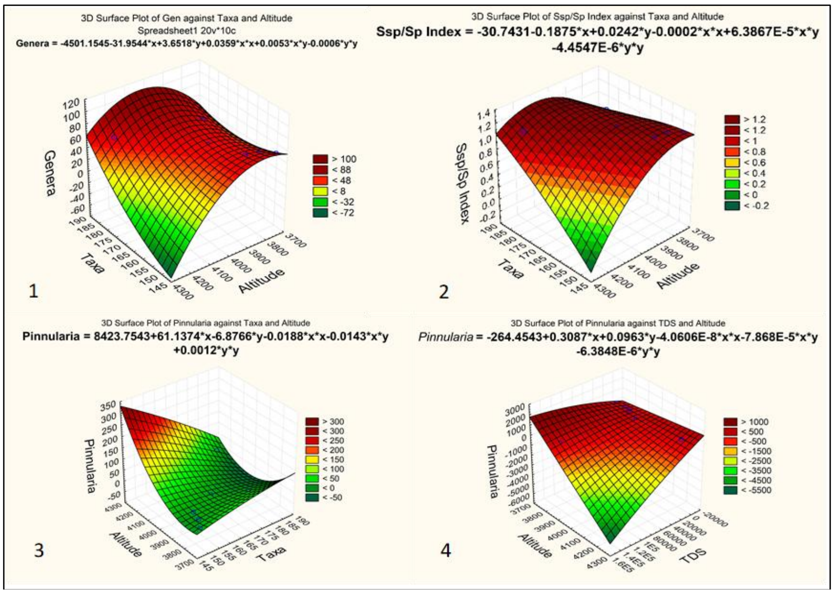

Fig 8. *3D Surface plots of Number of diatom Genera (1), Index of intraspecific variation (2), Pinnularia taxa number (3) over Total taxa number and Altitude of the lake, and Pinnularia taxa number over water TDS and Altitude of the lake (4)*

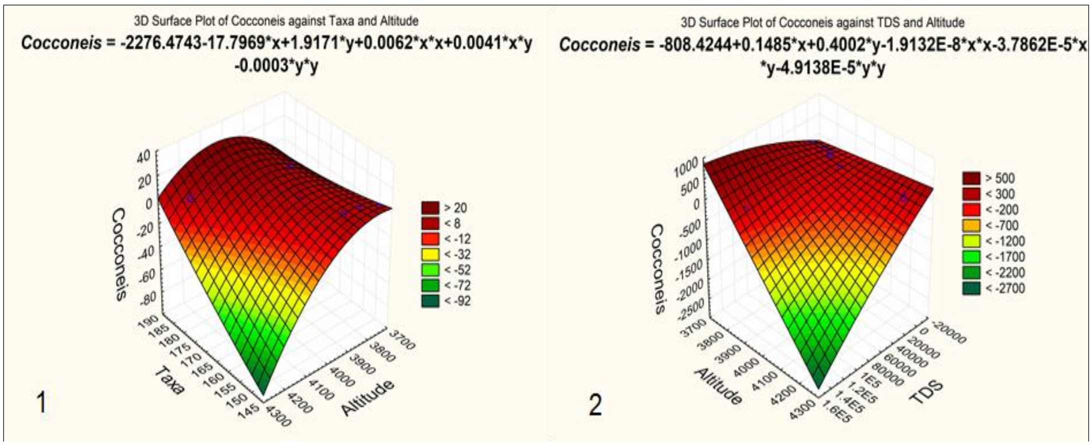

Fig 9. *3D Surface plots of Cocconeis taxa number (1) over Total taxa number and Altitude of the lake, and over water TDS and Altitude of the lake (2)*

Ssp/Sp index can be a measure of intraspecific variability, which increases under the influence of factors destabilizing the genome of a species. Earlier we revealed altitude as one of the influencing factor on the level of habitats up to 2,600 m a.s.l. and also high latitude [24,25]. More of them, the index value that we calculated for the Pamir mineral springs algal communities was 1.24. It is sufficiently grater that current calculation and means that water temperature and salts saturation can be influencing factors also. So, we compare distribution on Ssp/Sp index value over altitude of the lake and its water TDS (Fig. 10). Can be seen that trend lines of both distributions have weak but positive correlations between index and each environmental factor. Therefore, it allows us to conclude that altitude, high water salinity and temperature are influencing factors, which are destabilizing the genomic stability of algal species and thus can be factors of speciation and evolution of diversity.

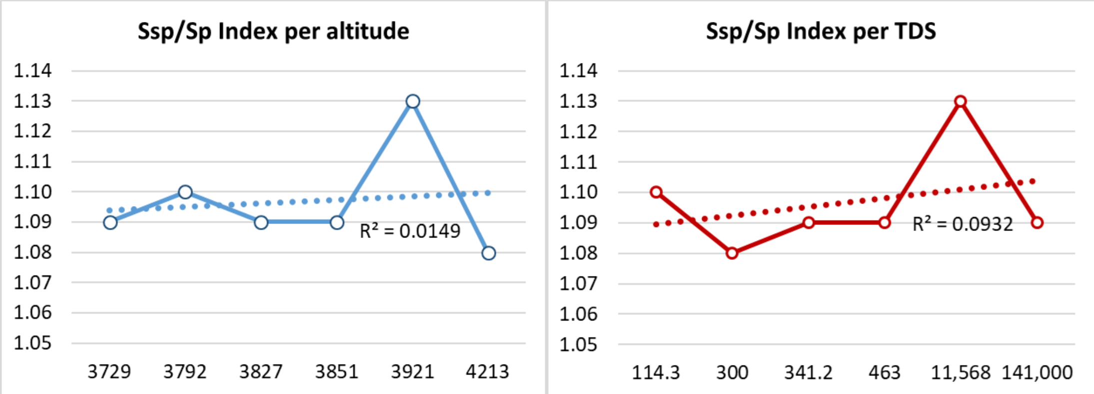

Fig 10. *Distribution of Ssp/Sp index of infraspecific variation over lake altitude and water TDS*

4. Conclusion

Altogether 300 species of diatom algae (330 with infraspecific variables) of 76 genera were revealed in 466 samples collected during nine field trips in the summer period of 2000-2018 from six Pamir lakes located at an altitude from 3,729 to 4,213 m above the sea level. Altitude of studied lakes is extremely high but varied in small amplitude. The water in all six lakes have different salt content from 100 mg l^{-1} in Turumtaykul Lake to 141,000 mg l^{-1} in Sassykkul. Floristic analysis show that richest communities were found in two freshwater lakes Turumtaykul with 171 species (184 taxa) and Rangkul with 162 species (176 taxa). The water salinity is fresher in low altitude lakes and salinity can be named as regulating factor of diatom diversity development in high mountain lakes as a result of statistical methods implementation. The *Pinnularia* genus was the richest in total list as well as in five from six lakes floras. Statistical and comparative floristic methods were characterize the peculiar properties of the Pamir algal flora with prevailing of *Pinnularia* species in water bodies of different salinity at an altitude of more than 3700 m a.s.l. The separate two floristic core were revealed in the analysis of the species overlapping. This indicates not only lakes flora peculiarities compared to other water bodies of Pamir, but also the natural status of the protected high mountain lakes, that indicates a high level of conservation of diversity in the territory of the Tajik National Park and the adjacent high-mountainous areas. Advanced statistical methods help us to characterize the stability of studied algal floras in protected high mountain lakes as higher on the genera level then on the species level, and therefore species of studied floras can be source of evolutionary speciation.

Acknowledgments

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