TRANSYLVANIAN REVIEW OF SYSTEMATICAL AND ECOLOGICAL RESEARCH

24.1

The Wetlands Diversity

Editors

Angela Curtean-Bănăduc, Sophia Barinova & Doru Bănăduc

Sibiu – Romania
2022

TRANSYLVANIAN REVIEW OF SYSTEMATICAL AND ECOLOGICAL RESEARCH

24.1

The Wetlands Diversity

Editors

Angela Curtean-Bănăduc, Sophia Barinova & Doru Bănăduc

Applied Ecology Research Center,
"*Lucian Blaga*" University of Sibiu

International Association for Danube Research	"*Lucian Blaga*" University of Sibiu	Ecotur Sibiu N.G.O.	Applied Ecology Research Center of *LB*US	Broward College, Fort Lauderdale	Institute of Evolution, University of Haifa

Sibiu – Romania
2022

Editorial Assistants

IN MEMORIAM

Gregor Johann Mendel

(1822 – 1884)

Gregor Johann Mendel was born in Heinzendorf, Silesia, Austrian Empire, now Czech Republic, botanist, teacher, an Augustinian priest, and the first one to lay the mathematical base of the genetics, in what came to be called later Mendelism.

He was raised in a rural area. His academic essential qualities were identified by the local priest, who convinced his parents to send him at distance to school when he was eleven years old. His Gymnasium studies ended in 1840, Mendel enrolled a program in philosophy at the Philosophical Institute of the University of Olmütz (Olomouc), where he shined in physics and mathematics, finishing this studies in 1843. His beginning years away from his birthplace were difficult, due to the fact that his family was not able to back him enough. He tutored students to support himself, and twice he experienced severe depression and had to return home to improve in health. As a single son, Mendel was anticipated to take over the family farm, but he chosen another way, to join the Augustinian order Altbrünn monastery as a novitiate, where he was given the Christian name Gregor.

The relocation to the monastery took him to Brünn (Brno), the capital of Moraviaprovince, where his general life became for the first better. He was accepted in a diversified intellectual society. As a priest, Mendel found his parish responsabilities to visit sick and dying so paintful that he repeatedly became ill. In this circumstance, abbot Cyril Napp found him a substitute-teaching position at Znaim (Znojmo), where he was realy successful. In 1850 Mendel was sent to the University of Vienna for two years to join a program of scientific education. He was dedicated especially to physics, mathematics, anatomy-physiology-microscopy, working under the famous Christian Doppler, Andreas von Ettinghausen, and Franz Unger.

In 1853 Mendel returned in Brünn (Brno) to the monastery, and in the next year he was again a teacher, this time at the Brünn (Brno) secondary school, where he remained until elected abbot 14 years later. All these 14 years were his more successfull in terms of teaching and as scientific experimental results. Once abbot, his administrative obligations came to occupy the most of his time.

Mendel followed an important experimental program in hybridization at the monastery. The goal of this research program was to evidence the transmission of hereditary characters in succeeding generations of hybrid ofspring. He handle his research with edible pea due to the fact that this plant is characterised by highly diverse varieties, the ease of cultivation and pollination control, and the high percentage of successful seed germinations. Between 1854 to 1856 he worked on 34 varieties for constancy of their traits. Mendel’s way to experimentation was based on his education in physics and mathematics, particularly combinatorial mathematics. As the planner and designer of genetic experimental and statistical analysis, Mendel remains in the science history as the father of genetics. Mendelian heritage, also called Mendelism, the laws of heredity formulated by Mendel, constitute what is well known today as the system of particulate inheritance by units/genes. The coming after revelation of chromosomes as the carriers of genetic units backed Mendel’s two main laws, known as the law of segregation and the law of independent assortment. Mendel also developed the law of dominance, in which one allele exerts higher influence than the other on the same inherited character.

By 1871 Mendel had time to carry over his meteorological and apicultural work. He traveled not much, and his only visit to England was to see the Industrial Exhibition in 1862. Bright disease made his final years painful, and he died at the age of 61, letting behind an excellent scientific legacy for the humanity. He was survived by two sisters and three nephews.

The Editors

Transylvanian Review of Systematical and Ecological Research

24.1 The Wetlands Diversity ***2022***

CONTENTS

Preface

In a global environment in which the climate changes are observed from few decades no more only through scientific studies but also through day by day life experiences of average people which feel and understand allready the presence of the medium and long-term significant change in the "average weather" all over the world, the most comon key words which reflect the general concern are: heating, desertification, rationalisation and surviwing.

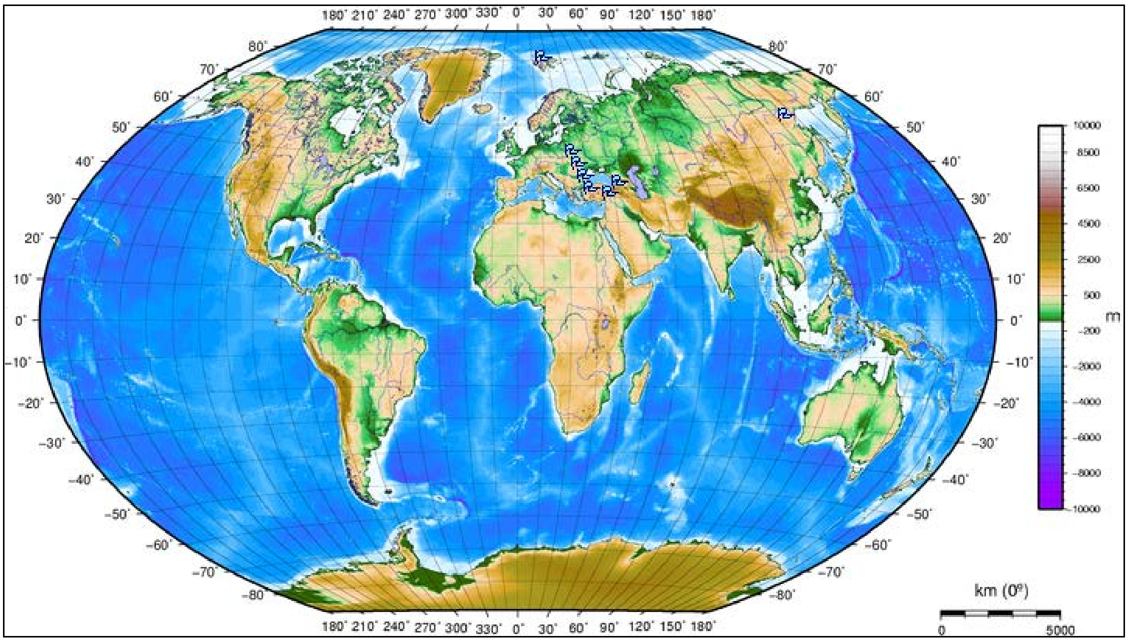
The causes, effects, trends and possibilities of human society to positively intervene to slow down this process or to adapt to it involve a huge variety of aproacess and efforts.

With the fact in mind that these aproaces and efforts shuld be based on genuine scientific understanding, the editors of the *Transylvanian Review of Systematical and Ecological Research* series launch three annual volumes dedicated to the wetlands, volumes resulted mainly as a results of the *Aquatic Biodiversity International Conference*, Sibiu/Romania, 2007-2022.

The therm wetland is used here in the acceptance of the Convention on Wetlands, signed in Ramsar, in 1971, for the conservation and wise use of wetlands and their resources. **Marine/Coastal Wetlands** – Permanent shallow marine waters in most cases less than six metres deep at low tide, includes sea bays and straits; Marine subtidal aquatic beds, includes kelp beds, sea-grass beds, tropical marine meadows; Coral reefs; Rocky marine shores, includes rocky offshore islands, sea cliffs; Sand, shingle or pebble shores, includes sand bars, spits and sandy islets, includes dune systems and humid dune slacks; Estuarine waters, permanent water of estuaries and estuarine systems of deltas; Intertidal mud, sand or salt flats; Intertidal marshes, includes salt marshes, salt meadows, saltings, raised salt marshes, includes tidal brackish and freshwater marshes; Intertidal forested wetlands, includes mangrove swamps, nipah swamps and tidal freshwater swamp forests; Coastal brackish/saline lagoons, brackish to saline lagoons with at least one relatively narrow connection to the sea; Coastal freshwater lagoons, includes freshwater delta lagoons; Karst and other subterranean hydrological systems, marine/coastal. **Inland Wetlands** – Permanent inland deltas; Permanent rivers/streams/creeks, includes waterfalls; Seasonal/intermittent/irregular rivers/streams/creeks; Permanent freshwater lakes (over eight ha), includes large oxbow lakes; Seasonal/intermittent freshwater lakes (over eight ha), includes floodplain lakes; Permanent saline/brackish/alkaline lakes; Seasonal/intermittent saline/brackish/alkaline lakes and flats; Permanent saline/brackish/alkaline marshes/pools; Seasonal/intermittent saline/brackish/alkaline marshes/pools; Permanent freshwater marshes/pools, ponds (below eight ha), marshes and swamps on inorganic soils, with emergent vegetation water-logged for at least most of the growing season; Seasonal/intermittent freshwater marshes/pools on inorganic soils, includes sloughs, potholes, seasonally flooded meadows, sedge marshes; Non-forested peatlands, includes shrub or open bogs, swamps, fens; Alpine wetlands, includes alpine meadows, temporary waters from snowmelt; Tundra wetlands, includes tundra pools, temporary waters from snowmelt; Shrub-dominated wetlands, shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils; Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils; Forested peatlands; peatswamp forests; Freshwater springs, oases; Geothermal wetlands; Karst and other subterranean hydrological systems, inland. **Human-made wetlands –** Aquaculture (e. g., fish/shrimp) ponds; Ponds; includes farm ponds, stock ponds, small tanks; (generally below eight ha); Irrigated land, includes irrigation channels and rice fields; Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture); Salt exploitation sites, salt pans, salines, etc.; Water storage areas, reservoirs/barrages/dams/impoundments (generally over eight ha); Excavations; gravel/brick/clay pits; borrow pits, mining pools; Wastewater treatment areas, sewage farms, settling ponds, oxidation basins, etc.; Canals and drainage channels, ditches; Karst and other subterranean hydrological systems, human-made.

The editors of the *Transylvanian Review of Systematical and Ecological Research* started and continue the annual sub-series (*Wetlands Diversity*) as an international scientific debate platform for the wetlands conservation, and not to take in the last moment, some last heavenly "images" of a perishing world …

This volume included variated original researches from diverse wetlands around the world.



The subject areas ( ) for the published studies in this volume.

No doubt that this new data will develop knowledge and understanding of the ecological status of the wetlands and will continue to evolve.

Acknowledgements

The editors would like to express their sincere gratitude to the authors and the scientific reviewers whose work made the appearance of this volume possible.

The Editors

Editorial Office:

"Lucian Blaga" University of Sibiu, Applied Ecology Research Center, Dr. Ion Raţiu Street 5-7, Sibiu, Sibiu County, Romania, RO-550012, Angela Curtean-Bănăduc & Doru Bănăduc (angela.banaduc@gmail.com, ad.banaduc@yahoo.com)

(ISSN-L 1841 – 7051; online ISSN 2344 – 3219)

PALYNOLOGICAL ANALYSIS OF SURFACE SEDIMENTS IN A HIGH ARCTIC POND, REVEALING DESMIDS AS INDICATORS OF WETLANDS AND CLIMATE CHANGE

Vartika SINGH * and *Sophia BARINOVA* **

* Birbal Sahni Institute of Palaeosciences, Lucknow, India, IN-226007, vartika_singh@bsip.res.in, ORCID: 0000-0002-0448-0860.

** Institute of Evolution, University of Haifa, Mount Carmel, Abba Khoushi Avenue, 199, Haifa, Israel, IL-3498838, sophia@evo.haifa.ac.il, ORCID: 0000-0001-9915-2503.

DOI: 10.2478/trser-2022-0001

KEYWORDS: *Cosmarium*, Ny-Alesund, Palynomorphs, Cladocera, Thecamoebians.

ABSTRACT

This is a first attempt to study the palynological remains from the surface sediments of a pond near the Kongsfjorden coast in Ny-Alesund, Svalbard, Norway. The palynomorphs display a high relative abundance of desmids, Cladocera, thecamoebians, chironomids, and fungal remains inherent to the inland aquatic ecosystem. The *Cosmarium* indicators characterize water as neutral pH, fresh, mesotrophic, without organic pollution, Class 2 of Water Quality as in wetlands with coastal vegetation. The single procedure of palynological analysis excluding the acetolysis step, and bioindicators allows us to perceive the basic framework of the ecosystem, consisting of in-situ and transported remains. This approach could be effectively used for paleoenvironmental reconstructions in High Arctic Regions.

ZUSAMMENFASSUNG: Palynologische Analyse von Oberflächensedimenten eines Teiches in der Hohen Arktis und das Vorkommen von Desmiden als Beweis für Feuchtgebiete und Klimawandel.

Dies ist ein erster Versuch, die palynologischen Überreste aus den Oberflächensedimenten eines Teiches nahe der Küste des Kongsfjords in Ny-Alesund, Svalbard, Norwegen zu untersuchen. Die Palynomorphs weisen eine hohe relative Häufigkeit von Desmiden, Cladocera, Thecamöben, Chironomiden und Pilzresten auf, die dem Inland aquatischen Ökosystem inhärent sind. Die *Cosmarium*-Indikatoren charakterisieren Wasser als neutralen pH-Wert, frisch, mesotroph, ohne organische Verschmutzung, Klasse 2 der Wasserqualität wie in Feuchtgebieten mit Küstenvegetation. Das einzige Verfahren der palynologischen Analyse ohne den Schritt der Acetolyse und Bioindikatoren ermöglicht es uns, das Grundgerüst des Ökosystems bestehend aus in-situ und transportierten Überresten wahrzunehmen. Dieser Ansatz könnte effektiv für paläoökologische Rekonstruktionen in hocharktischen Regionen verwendet werden.

REZUMAT: Analiza palinologică a sedimentelor de suprafață ale unui iaz din Marea Arctică și prezența desmidelor ca dovadă a zonelor umede și a schimbărilor climatice.

Aceasta este o primă încercare de a studia rămășițele palinologice din sedimentele de suprafață ale unui iaz din apropierea coastei Kongsfjorden din Ny-Alesund, Svalbard, Norvegia. Palinomorfele prezintă o abundență relativă mare de desmidii, Cladocera, thecamoebiae, chironomide și rămășițe fungice inerente ecosistemului acvatic continental. Indicatorii *Cosmarium* caracterizează apa ca fiind cu pH neutru, proaspătă, mezotrofă, fără poluare organică, clasa 2 de calitate a apei ca în zonele umede cu vegetație de coastă. Procedura unică de analiză palinologică, excluzând etapa de acetoliză și bioindicatorii, ne permite să percepem cadrul de bază al ecosistemului constând din rămășițe in-situ și transportate. Această abordare ar putea fi utilizată eficient pentru reconstrucțiile paleomediului în regiunile arctice înalte.

INTRODUCTION

High Arctic ecosystems are experiencing some profound changes in the environmental and climatic conditions due to warming (Jiang et al., 2011). The small water bodies of the Arctic are sensitive to changes in environmental conditions like hydrology, temperature, and light, etc. The biota inhabiting these water bodies is subjected to environmental changes and responds to survive. The microscopic green algae are primary producers and form an important part of the terrestrial Arctic tundra ecosystem. The primary producers are directly affected by changes in the physical environmental factors such as light, temperature, etc. (Richter, 2018). The study of the biota of these ponds is, therefore, crucial to understand recent abrupt warming of the Arctic region and the impact of these changes on the ecosystem. In recent decades, viable prokaryotes and eukaryotes have been found isolated from deep horizons of ancient permafrost up to three million years old from depths of up to 400 meters in the Arctic regions of Siberia and Canada (Gilichinsky et al., 1995; Vishnivetskaya et al., 2001; Vorobyova et al., 1997), as well as from the lowest-temperature layers of Antarctica (Gilichinskiy et al., 1996).

The palynological remains could serve as an important tool to understand and study the ecological and environmental conditions of the past. The microscopic remains are linked to the surviving biota and are very useful for climate interpretations on a local and regional scale. Palynological studies from temperate and tropical regions have provided important palaeoclimate data based on established palynological proxies for various paleoclimate and paleoenvironmental parameters (Gelorini et al., 2011; Prager et al., 2012). On the other hand, there is only limited palynological proxy data of algal remains from the northern high latitude region. The palynological data based on pollen, diatoms, chironomids are also fragmentary (Holmgren et al., 2010). Due to the presence of tundra vegetation cover on high Arctic Svalbard, the pollen assemblage reflects only less diverse plant cover of the tundra vegetation where the high diversity is displayed by cyanobacteria, microalgae, lichens, etc. This makes it difficult to perceive recent climate fluctuations using pollen records of modern sediments. The study of microalgal palynological remains could be useful in recording rapid climate fluctuations of the Arctic region because they form the base of the ecological setup and are major contributors to the terrestrial vegetation cover (Birks et al., 2016). The Svalbard archipelago is experiencing some very drastic warming in recent years and is thus an important place to conduct paleoclimate research based on the study of palynological remains. They could also be potentially important to understand past climate conditions and to infer future ecological setup. The preserved remains of biota inhabiting the water bodies of the high Arctic region could be useful in deciphering the paleoecological and paleoenvironmental conditions.

The desmids are unicellular algae belonging to the conjugating green algae Class Zygnematophyceae. The desmids belonging to the Order Desmidiales are considered as true desmids (Denboh et al., 2001). The characteristic morphological feature of desmids is the presence of two symmetrical halves (semi-cells) separated by an isthmus. The nucleus of the desmid cell is located at the isthmus while the two semi-cells contain the chloroplast. The genus *Cosmarium* belongs to Desmidiales, the coccoid, unicellular freshwater algae and member of the Division Charophyta. The genus *Cosmarium* is the oldest and has the highest number of species that have a cosmopolitan to limited range. Desmids occur as a major group of phytobenthos in standing freshwater, terrestrial shallow water pools, ponds, and lakes. A high diversity population of desmids is found in mesotrophic, slightly acidic to the slightly alkaline environment (Coesel and Meesters, 2007; Coesel, 1982). The desmids of small shallow water bodies are susceptible to environmental stresses such as desiccation in warming conditions of the Arctic and are helpful in the ecological monitoring of freshwater habitats.

The remains of unicellular photosynthetic desmidian algae serve as a reflection of the ecological situation, since they form the basis of the food chain. They are all the more important for the high-altitude Arctic regions, where the ecological diversity is significantly lower compared to other climatic zones. This limits the number of species that can be used to reconstruct the paleoclimate remains of lacustrine sediments.

The preservation potential of green algae is low as it does not have many hard and resistant remains. Only a few forms including desmids have parts likely to be preserved. The Svalbard biota study as a representative High Arctic ecosystem is crucial as it provides fundamental information of the biotic communities thriving in the region. The changes in the population have been noticed in the form of addition or removal of forms or both. An attempt has been made to study the algal remains preserved in the surface sediments of a large pond. The algal remains have been identified as the empty semi cells of the desmids. The green algae member desmids have specific environmental requirements and are thus extremely sensitive to even subtle environmental fluctuations. They are both planktic and benthic.

Ny-Alesund, Svalbard acts as a representative High Arctic region (Fig. 1) for the study of present and past climatic variation.

Figure 1: Location map of studied lake in the Ny-Alesund, Svalbard, Norway.

The High Arctic region area experiences stresses such as freezing, desiccation, and high ultraviolet radiation from 24-hour daylight during summer and darkness during winter. The terrestrial biota of the Polar Regions experiences these environmental extremes. Polar biota show early signs of environmental shifts, especially climatic warming, as compared to the tropical regions where such changes are subtle and hard to record. Numerous shallow ponds are a frequent feature of an Arctic landscape and are rich in biodiversity. The rapidly changing environmental conditions and the resulting biotic response are critical in understanding ecosystem shifts and rearrangements. The terrestrial biota of arctic ponds holds important information on changing environmental conditions. Algae can frequently be used over pollen as a traditional terrestrial palaeoclimatic proxy in Polar Regions, where pollen data has limited importance because some past studies have suggested that the terrestrial ecosystem represented by higher plants/vascular plants has not shown any significant change in the past 70 years (Treut et al., 2007; Prach et al., 2010; Nikulina et al., 2016). On the contrary, the limnological diatom proxy data from lakes have provided evidence of marked shifts in lake ecosystems in the 20th century due to warming (Jiang et al., 2011).

The studies on lake sediments of Svalbard are mainly based on the traditional biotic palaeolimnological proxies like diatoms, chrysophytes, chironomids, and pollen. Algal palynomorph have not been considered in a more comprehensive way that cover most of the terrestrial habitats involving the study of surface sediments as well as lake core sediments. The palynomorph data can provide information about the varied biota inhabiting various sub environments, their ecological preferences, and the trophic status of a water body (McCarthy et al., 2018). This can serve as important baseline data that can be traced back in time to understand and reconstruct palaeoenvironmental and palaeoclimatic conditions. A more systematic and detailed observation of the modern ecosystem components, especially the less studied micro biotic components, is highly crucial and critical to consolidate our understanding of environmental and climatic conditions of the more recent past and during the interglacial periods. The Svalbard archipelago is a unique place to carry out climate-related studies because the Arctic is experiencing drastic changes due to warming and shrinking ice cover, due to its location at the gateway (mendley) of the Arctic Ocean, where the warm West Spitsbergen current and cold East Greenland current enter the Arctic Ocean through the Fram Strait. The biota inhabiting Svalbard is subjected to various stresses and their response in the form of adjustments and rearrangements of the ecosystem is important to understand.

MATERIAL AND METHODS

Description of study site

The pond is located at an elevation of 54 m above sea-level on the west coast region of Ny-Alesund, Svalbard (Figs. 1-2). This pond was investigated under the Norwegian-Russian joint project study on the effect of climate change and related stressors on fresh and brackish water ecosystems in Svalbard using invertebrate fauna (Dimante-Deimantovica et al., 2015). It has been classified as a large pond based on the area covered by the pond and depth. The pond is about 1.2 km away from the Kongsfjorden coast and covers an area of approx. 0.2 ha with an average depth of about one m. The pH of the water has been measured as 8.44, conductance (EC) 195 µS/cm, and temperature of 6.5°C during the summer month of August (Dimante-Deimantovica et al., 2015).

Figure 2: Landscape imagery of studied lake (encircled) in the Ny-Alesund, Svalbard, Norway.

The Lake surface sediment was manually collected as the top five cm of sediment, including the water-sediment interface sediment from the lake margin. The sediment sample was air-dried at 30°C in a hot air oven of the Kings Bay marine laboratory. The completely dried sediment was then carefully packed and sent to the laboratory of Birbal Sahni Institute of Palaeosciences for further processing. The sediment was processed to recover the microfossils including desmids. The dry sediment sample (five g) was processed following the standard procedure for the extraction of dispersed organic matter. The procedure involves the use of 35% cold hydrochloric acid (HCl) for the removal of carbonate content, followed by treatment with 30% hydrofluoric acid (HF). Acid was removed by washing with deionized water after the treatment with acids HCL and HF. The recovered organic matter was sieved using 20-micron mesh. Slides were mounted using glycerine jelly and were studied under the Leitz Laborlux D microscope at 400x and 1000x. The identification followed (Prescott et al., 1981, 1982; Forster, 1982; Croasdale and Flint, 1988; Dillard, 1991). The palynomorphs were counted to 200 counts. The slides of the studied material are deposited in the museum of the Birbal Sahni Institute of Palaeosciences, Lucknow vide statement no. 1554.

Desmid species, indicators of environmental conditions, were used to collect ecological, species-specific information (Barinova et al., 2006, 2019; Barinova, 2017a) and water quality classification ranks (Barinova, 2017b). Index saprobity S was calculated on the base of species-specific index saprobity (Barinova et al., 2006, 2019) and abundance of each species in samples.

RESULTS

The palynological/organic-walled micro remains have been recovered from the surface sediments of a small pond and consist of desmid genus *Cosmarium* (Fig. 3), cladocerans, black opaque debris, chironomids, thecamoebians, phytoclasts, and fungal remains (Fig. 4).

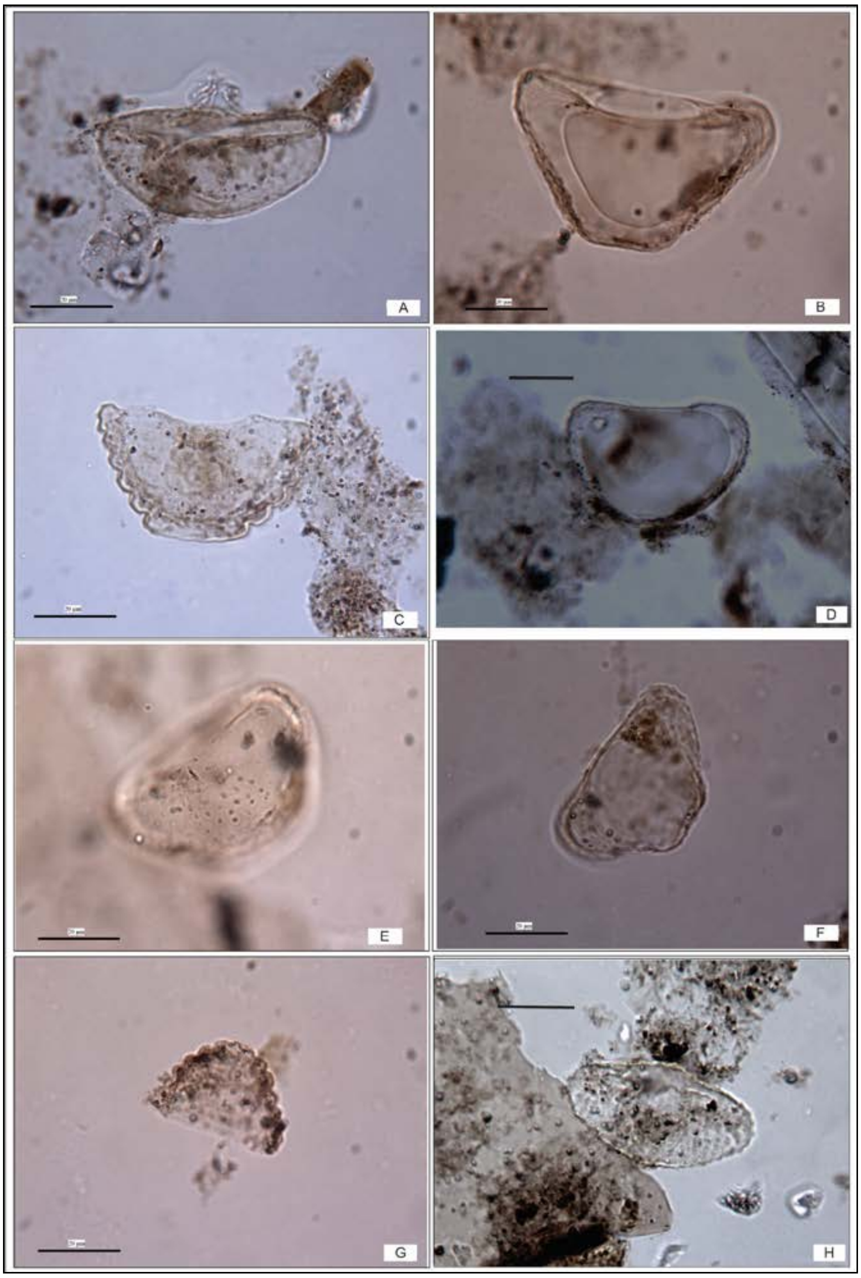


Figure 3: *Cosmarium* forms in sediments; A. *Cosmarium punctulatum* (EFP F23/3; BSIP S. No. 16262); B. *C. turpinii* (EFP Q54/3; BSIP S. No. 16258); C. *C. crenatum* (EFP H24/1; BSIP S. No. 16262); D. *C. botrytis* (EFP L52/3 16262); E. *C. Granatum* (EFP P40/2 S. No. 16258); F. *C. protractum* (EFP V33/2; S. No. 16262); G. *C. excavatum* (EFP F40/3; BSIP S. No. 16262); H. *C. formosulum* (EFP R22/4 BSIP S. No. 16260). EFP – England finder position, BSIP S. No. BSIP Slide Number, Scale Bar-20 µm.

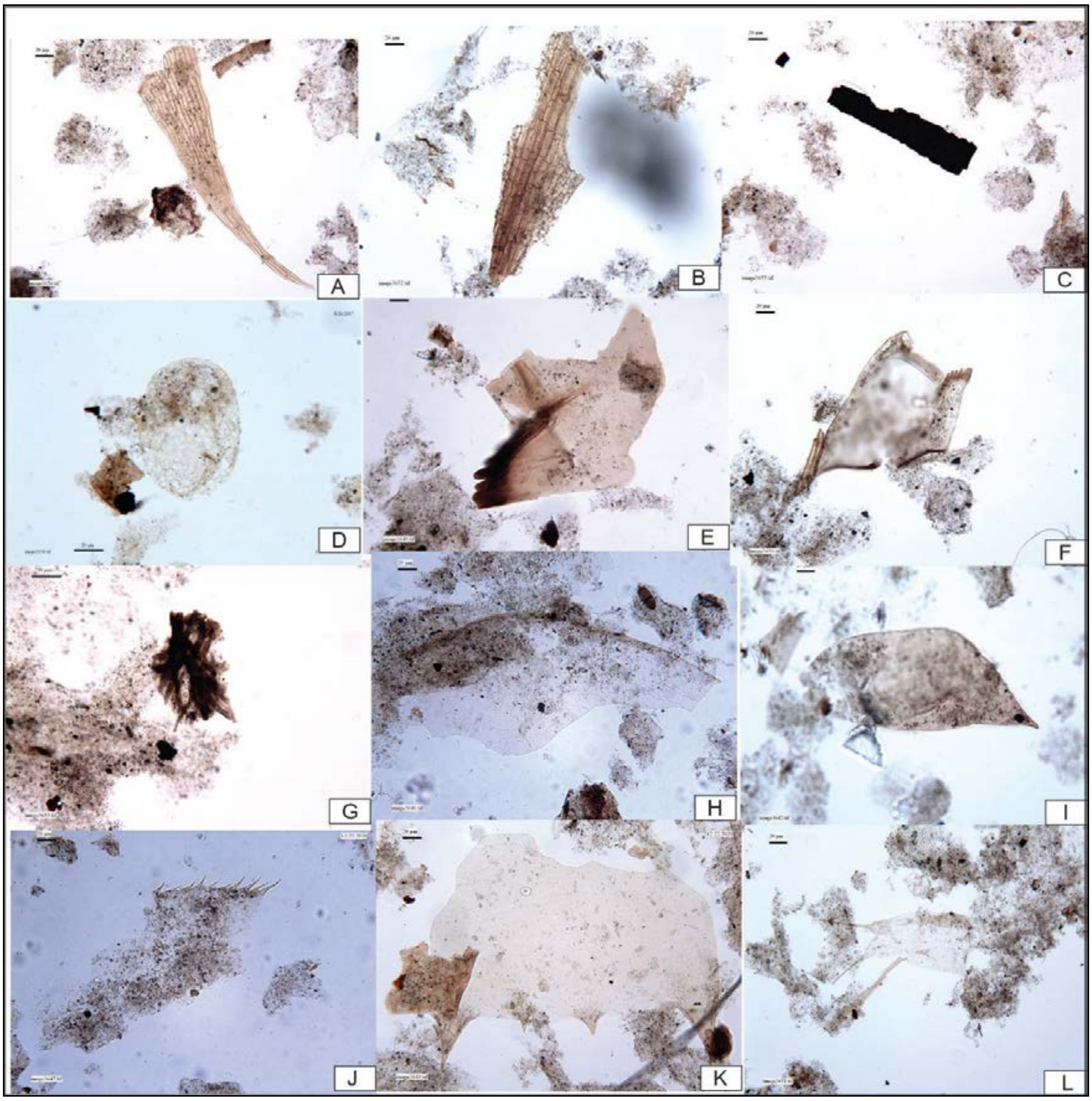


Figure 4: Other palynomorphs; A, B- Phytoclasts (A. EFP D39/3, B. EFP U36/4, BSIP S. No. 16261); C. Black Opaque (EFP K38/3, BSIP S. No. 16261); D. Thecamoebian (EFP Q38/4, BSIP S. No. 16260); E, F. Chironomid remains (E. EFP R43/1, BSIP S. No. 16258; F. EFP Q42/2, BSIP S. No. 16261); G. Fungal remains (EFP K51/3, BSIP S. No. 16261); H.-L. Cladoceran remains (H. EFP S26/1, BSIP S. No. 16258; I. P42/4 BSIP S. No. 16258; J.-K. 23/2 BSIP S. No. 16258, K. R34/4 BSIP S. No. 16261, L. S27/1, BSIP S. No. 16261). EFP – England finder position, BSIP S. No. BSIP Slide Number, Scale Bar-20 µm.

Other components viz. cladocerans, black opaque debris, chironomids, thecamoebians, phytoclasts, and fungal remains have the relative abundance of 17%, 15%, 7%, 6%, 4%, and 4% respectively (Fig. 5). The relative abundance of the palynomorphs consists of highest desmid concentration with 46% of total recovered remains (Fig. 5). Desmid semi-cells are the most abundant component of the palynomorph assemblage and largely belong to the genus

Cosmarium. The identified species of *Cosmarium* are *Cosmarium punctulatum*, *C. protractum*, *C. turpinii*, *C. formosulum*, and *C. granatum*. Among the recovered desmid genus *Cosmarium*, the recorded species of highest relative abundance is *C. punctulatum* (43%) followed by *C. protractum* (19%), *C. turpinii* (11%), *C. formosulum* (8%), whereas the species *C. granatum*, *C. excvatum*, *C. crenatum*, and *C. botrytis* have the relative abundance of about 4% (Fig. 6).

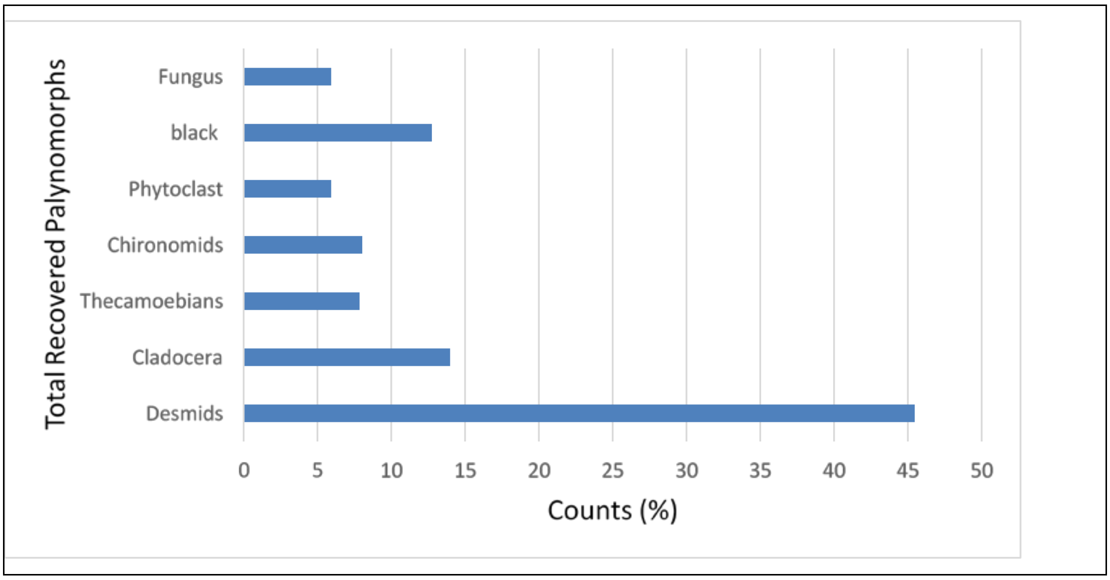


Figure 5: Relative abundance of the palynomorphs.

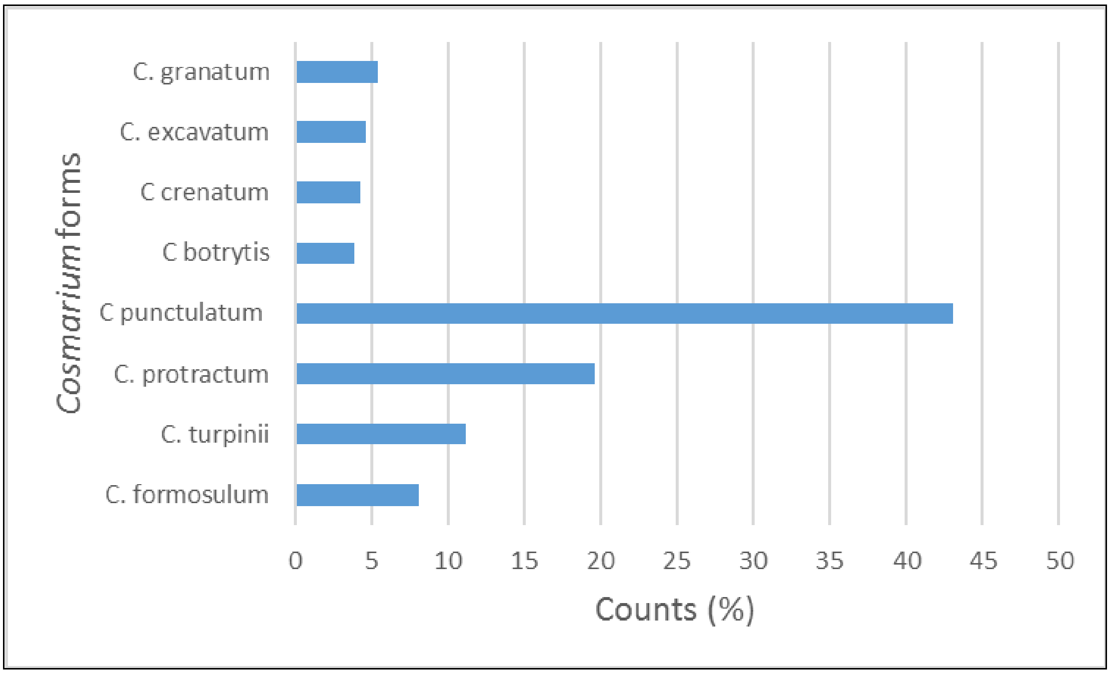


Figure 6: Relative abundance of the *Cosmarium* forms.

All revealed species of *Cosmarium* were inhabitants of planktonic-benthic communities that usually exist in shallow standing waters (Tab. 1). They will be indicators of well or middle oxygenated waters with neutral pH and low salinity. Species-specific index saprobity S varied in range 0.7-1.9 that correlated with saprobity self-purification zones affiliated to Class 2 and 3 of Water Quality. Index saprobity S that calculated for whole community was 1.29 that correspond to Class 2 of Water Quality. Species of *Cosmarium* in studied lake survived in mesotrophic to meso-eutrophic condition.

Table 1: Ecological preferences of revealed species of *Cosmarium* remains with percent in samples; Habitat (Hab): P-B – plankto-benthic, B – benthic, aer-aerophiles. Oxygenation and water moving (Oxy): st-str – low streaming water, aer-aerophiles. pH (pH): acf – acidophil, ind – pH indifferent. Halobity degree (Sal): i – oligohalobes-indifferent, hb – halophobes. Saprobity (Sap): o-x – oligo-xenosaprob, o-a – oligo-alpha-mesosaprob, o – oligosaprob. Trophic state (Tro): o – oligotraphentic; m – mesotraphentic; me – meso-eutraphentic. "–" property is unknown.

Species	Hab	Oxy	pH	Sal	Sap	Index S	Tro	Percent in samples
Cosmarium botrytis Meneghini ex Ralfs	P-B	st-str	ind	i	o-a	1.9	m	4
Cosmarium crenatum Ralfs ex Ralfs	B, aer	aer	ind	–	–	–	m	4
Cosmarium excavatum Nordstedt	–	–	acf	–	–	–	o	4
Cosmarium formosulum Hoff	P-B	–	ind	–	o-a	1.8	me	8
Cosmarium granatum Brébisson ex Ralfs	B	st-str	ind	i	o	1.2	m	4
Cosmarium protractum (Nägeli) De Bary	P-B	–	ind	–	–	–	me	19
Cosmarium punctulatum Brébisson	P-B	–	ind	hb	o	1.3	m	43
Cosmarium turpinii Brébisson	P-B	–	ind	i	o-x	0.7	me	11

Modern desmid record of Svalbard

The desmids are present as both benthic and planktic algae in water bodies ranging from small pools of water to lakes and streams. The previous studies provide a record of living algal samples from different aquatic habitats of Svalbard. Lenzenweger and Lütz (2006) reported 58 taxa of desmids from the snow and terrestrial samples collected from the Kongsfjord coast near Ny-Alesund. Kim et al. (2008, 2011) have studied and reported the sporadic occurrence of *Cosmarium undulatum* in the soil and freshwater samples collected from mud puddles, moss bogs, glacial meltwater stream, and other water bodies in and around Ny-Alesund, Svalbard during the years 2006 and 2009. They have demonstrated the presence of *Cosmarium undulatum*, and its annual fluctuation with higher numbers reported in 2006 as compared to 2009. Richter et al. (2015) recorded desmids *Cosmarium costatum* var. *costatum, C. granatum, C. holmiense, C. hornavense, C. speciosum, C. undulatum* collected from various aquatic habitats around Hornsund fjord. Five species of *Cosmarium* were recorded from the snow samples collected in Petuniabukta (Kvíderová, 2012). In an interesting study, Richter (2018) studied hydro-terrestrial habitats of the Hornsund fjord region of Svalbard. The study included cyanobacterial and microalgal communities, which are important components of terrestrial vegetation in Svalbard and reported 64 species of desmids from 20 hydro-terrestrial habitats. *C. crenatum* were recovered from two lakes and five ponds with an alkaline pH range of 7-9. *C. formosulum* and *C. punctulatum* were recorded from two lakes with a pH range of 7.3-7.9. Our findings from the studied lake represent only eight species of *Cosmarium* from 457 with known ecological properties. Bioindication that was firstly implemented for Svalbard aquatic communities shows similar results of environment assessment, as were found previously in respect of water pH (Richter, 2018) and for close related well studied regions such as Kola Peninsula (Denisov and Barinova, 2015), where there were found 16 species of *Cosmarium* as bioindicators of similar environmental conditions. Four of them were found in Svalbard also. Bioindication by revealed species of *Cosmarium* can characterize the studied lake as shallow with a well-developed coastal community of algae, low saline, neutral or low alkaline waters and mesotrophic condition during the studied sediment deposition. The present of such a large number of desmid species can also characterize the studied lake as a wetland (Adamus and Brandt, 1990) where desmids can find the best environments for flourishing.

The study of living algae provides crucial baseline data of desmids that inhabit the High Arctic region, especially during the rapid warming scenario. On the other hand, palynological data in the form of preserved remains (palynomorphs) recovered from the surface sediments represents a modern analogue with important implications for Quaternary paleoenvironmental, palaeoecological, and palaeoclimate studies.

The fossil record of desmids

The empty semi-cells as well as complete desmids are preserved in sediments and leave a sedimentary record. However, there are fewer studies on the occurrence of fossil desmids from the past sedimentary record. The fossils record of desmids comparable to the modern desmid morphotypes dates back as early as from Late Proterozoic sequence of the chert beds of uppermost Tindir Group limestones, Tindir Creek, Yukon Territory, Canada, which has shown similarity to the modern genus *Staurastrum* (Allison and Awramik, 1989). Besides having a long geological record dating back to Cambrian, desmids have been rarely reported and studied from other deep time sequences. The Quaternary record of desmids is also meager which could be easily compared to the modern morphotypes and serves as valuable paleoenvironmental proxy data. This makes desmids much understudied and unconventional yet potentially promising tool for future studies. Desmids have also been used to study the anthropogenic impact in the Great Lake region of Canada. In this study they have been used as proxy of water quality assessment, anthropogenic impact (McCarthy et al., 2018).

Other palynomorphs

The palynological remains of desmids form a major fraction of all the preserved acid-resistant organic constituents and the other recovered biotic remains belong to Cladocerans, chironomids, thecamoebians, and fungi. In addition to this, undifferentiated plant remains have also been recovered and are classified as phytoclasts and the dark coloured opaque fragments are classified as opaque black (Fig. 4) (Tyson, 1995). The studied palynomorphs derived from the surface sediments take in to account all the acid-resistant organic remains of organisms inhabiting the water body as well as transported and/or in situ fragments. The remains are preserved in the surface sediments after the death and disintegration of the biota. The organic-walled microfossils have a better chance of preservation than the calcareous forms because they are not affected by dissolution.

The study involving all the preserved palynological organic remains provides more information on the ecological setup of any aquatic environment and its surroundings (Gilichinsky et al., 1995; Vishnivetskaya et al., 2001). The complete assemblage contains organic remains of primary producers (algae), consumers (protists and other zooplankton), and decomposers (fungi, etc.). The recovered palynomorph assemblage includes different ecosystem components in the form of green algae *Cosmarium* as primary producers, Cladocerans, Thecamoebians, and Chironomids as consumers, fungi representing decomposers (Fig. 7). Phytoclasts and black opaque particles display transported components that are deposited in the pond from the surrounding areas. Organic walled algal remains are derived from the green algae desmid. The Cladocerans are small crustaceans that are commonly found in freshwater aquatic habitats. Chironomids larvae are produced by the insects, non-biting midges. Cladocerans and chironomids feed on algae, chironomid larvae are opportunistic and other than algae, they feed on all kinds of detritus available to them including dispersed particles of wood. The organic-walled body parts of Cladocerans (Figs. 4H, L) and mouthparts of chironomid larvae (Figs. 4E, F) are preserved in the sediments (Fig. 4). They have been used in paleolimnological studies from Svalbard (Brooks and Birks, 2004; Birks et al., 2016).

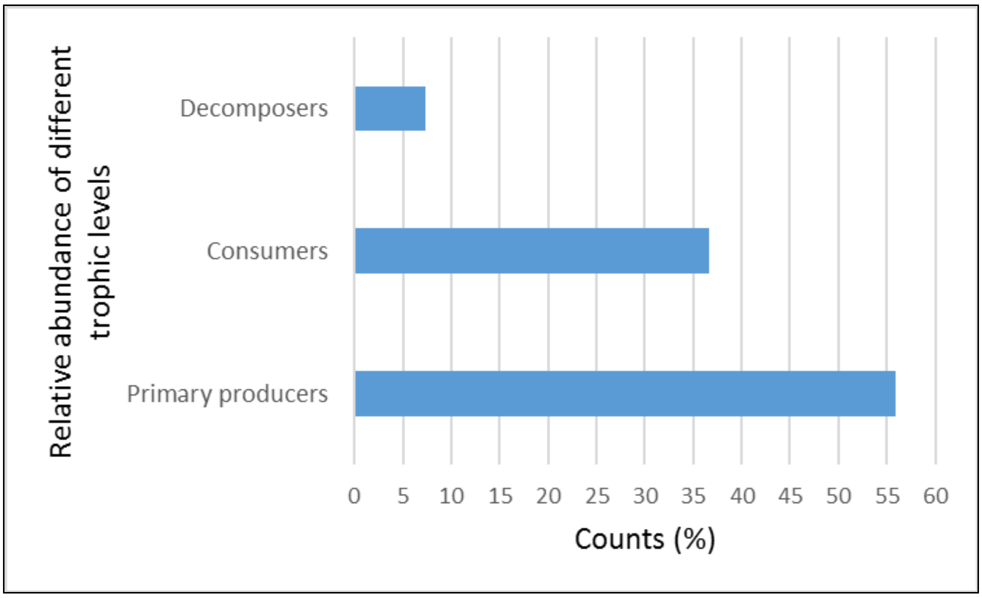


Figure 7: Relative abundance of producers, consumers, and decomposers.

Cladocerans and chironomids are an important part of the aquatic food web because being primary consumers, they form a link between producers and secondary consumers. Their role becomes even more significant in the small aquatic habitats of the High Arctic, where ecosystems generally have low species richness. Thecamoebians are eukaryotic heterotrophic protists that are found in fresh as well as brackish water conditions (Fig. 4D). They feed on algae, bacteria, fungi, and other small organisms. The autogenous (test secreted by the individual) and xenogenous (test made up of particles picked from the surrounding) tests of the camoebians get preserved in the sediment (Singh et al., 2015). Despite their presence in the sediments and environmental significance, they have not been systematically studied and utilized in recent environmental monitoring, assessment, and palaeoenvironmental reconstructions from Svalbard.

Apart from the above-discussed microfossils, the recovered plant remains which retain some cellular structure but could not be assigned to any specific plant genera, are classified as phytoclasts (Figs. 4A, B) (Tyson, 1995). They could be the remains of algae, bryophytes, and vascular plants. The presence of algal fragments could be related to their growth and presence in the pond or transport from an area close to the pond. On the contrary, the black opaque particles are allochthonous and transported by melt water streams or by the wind to get deposited in the pond. Some internal cellular structures are visible in phytoclasts but are indiscernible in the black opaque component (Fig. 4C). The microscopic fungal remains are scarcely reported from Svalbard. Fungal elements provide a signature of the decomposers and are an important component of an ecosystem. The microscopic remains of fungi are recovered in the form of fungal hyphae and spores (Figs. 4G, H).

This is a first attempt to study all the preserved organic remains from the High Arctic Region of Svalbard and is an initial study that can be extended both spatially and temporally to generate a more extensive and meaningful data set.

The relative abundance of recovered palynomorphs

The relative abundance of the palynomorphs recovered from the surface sediments shows a dominant presence of half-cells of desmids forming about half of the total palynomorph assemblage. The abundance of desmids is displayed by one identified genus *Cosmarium*, which is represented by eight identified species (Fig. 3). Among the recovered semi-cells, the semi-cells of *C. punctulatum* (Fig. 3) have the highest abundance followed in decreasing order of abundance by *C. protractum* (Fig. 3), *C. turpinii* (Fig. 3), *C. formosulum* (Fig. 3), *C. granatum* (Fig. 3), *C. excvatum* (Fig. 3), *C. crenatum* (Fig. 3), and *C. botrytis* (Fig. 3). *C. punctulatum* strains are cosmopolitan but also include some tropical and polar strains. The recovered desmid assemblage shows the dominant presence of some forms over others, but overall diversity is low. Sub-polar, temperate, and Polar forms are abundant as compared to the cosmopolitan desmids which prefer benthic life habitats and meso-oligotrophic to meso-eutrophic nutrient conditions. In Ny-Alesund water bodies, the pH varies from about six to nine with large variations recorded in puddles and small ponds. Large ponds and lakes do not show a large variation in pH. The pH of the studied large pond has been measured in the summer of 2015 to 8.44 (Dimante-Deimantovica et al., 2015). The high relative abundance of *C. punctulatum* could be due to its wide range of pH tolerance because it has been reported from slightly acidic to alkaline habitats. However, *C punctulatum* has been recovered from a lake in Hornsund with pH 7.3 (Richter et al., 2018). The desmid assemblage record from snow samples and moss patches along the rim of ponds situated on the coast in Ny-Alesund includes the forms *C. botrytis*, *C. crenatum*, and *C. granatum* that are present in the surface sediments (Lenzenweger and Lütz, 2006). Desmids being primary producers form about 45% proportion of the total recovered palynomorphs/microfossils. The remaining 55% are displayed as consumers (30%) (Cladocera, chironomids, and thecamoebians), the relative abundance of primary consumer Cladocera (about 17%) is highest among the consumers along with chironomids and thecamoebians having relative abundances of 10% and 8% respectively.

CONCLUSIONS

The recovered desmid assemblage represented by only one genus and eight species from one pond could represent an assemblage devoid of any preservation bias because the prior studies show the occurrence of only one species, one genus, or even complete absence of desmids in ponds and lakes. This observation warrants more data and studies for further validation. Despite this, even now, the identified species of *Cosmarium* in the lake sediments allow us to characterize the environment as neutral pH, freshwater, mesotrophic, without organic pollution, Class 2 of Water Quality, and representing a wetland with well-developed coastal vegetation.

The presence of palynomorphs of the aquatic biota and transported elements in the surface sediments provide information on many components of the ecological set up of a High Arctic pond.

The study involving different ecological components provides important information on the biological interactions within the aquatic ecosystem, the impact of allochthonous components on the aquatic ecosystem, and the influence of physical parameters impacting a terrestrial ecosystem.

The implications of the study are especially important because the Arctic Regions are undergoing drastic changes due to warming. The same approach can be effectively used to study and understand the past ecological conditions and ecosystem makeup during fluctuating environmental and climatic conditions.

ACKNOWLEDGEMENTS

We gratefully acknowledge the Director of Birbal Sahni Institute of Palaeosciences, Lucknow, India and the Directors of the Institute of Evolution, University of Haifa, Israel for providing permission, continuous support and encouragement to carry out collaborative research work. We are also thankful to the Director ESSO-NCPOR, Goa, India and the Kings bay AS, Ny-Alesund, Svalbard for providing the logistics and laboratory facilities in Ny-Ålesund, Svalbard. This is a BSIP contribution no. BSIP/RDCC/Publication no. 76/2020-2021.

REFERENCES

1. Adamus P. R. and Brandt K., 1990 – Impacts on quality of inland wetlands of the United States survey of indicators techniques and applications of community level biomonitoring data, Corvallis, Oregon, USA, 392.
2. Allison C. W. and Awramik S. M., 1989 – Organic-walled microfossils from Earliest Cambrian or Latest Proterozoic Tindir Group Rocks, Northwest Canada, *Precambrian Research*, 43, 253-294.
3. Barinova S., 2017a – Essential and practical bioindication methods and systems for the water quality assessment, *International Journal of Environmental Sciences and Natural Resources*, 2, 3, 555588, https://doi.org/10.19080/ijesnr.2017.02.555588.
4. Barinova S., 2017b – On the classification of water quality from an ecological point of view, *International Journal of Environmental Sciences and Natural Resources*, 2, 2, 1-8, https://doi.org/DOI: 10.19080/IJESNR.2017.02.555581.
5. Barinova S., Bilous O. and Tsarenko P. M., 2019 – Algal indication of water bodies in Ukraine: methods and perspectives, Haifa University Publishing House, Haifa, Kiev, 367. (in Russian)
6. Barinova S., Medvedeva L. A. and Anissimova O. V., 2006 – Diversity of algal indicators in environmental assessment, Tel Aviv, Pilies Studio, 458. (in Russian)

7. Birks H. J. B., Birks H. H. and Ammann B., 2016 – The fourth dimension of vegetation: 100 years ago, Lennart von Post first used pollen analysis to reconstruct past ecosystems, *Science*, 354, 412-413, https://doi.org/10.1126/science.aai8737.
8. Brooks S. J. and Birks H. J. B., 2004 – The dynamics of Chironomidae (Insecta: Diptera) assemblages in response to environmental change during the past 700 years on Svalbard, *Journal of Paleolimnology*, 31, 483-498, https://doi.org/10.1023/B:JOPL.0000022547.98465.d3.
9. Coesel P. F. M. and Meesters J., 2007 – Desmids of the Lowlands, Mesotaeniaceae and Desmidiaceae of the European Lowlands, KNNV Uitgeverij, 352.
10. Coesel P. F. M., 1982 – Structural characteristics and adaptations of desmid communities, *Journal of Ecology*, 70, 163-177.
11. Croasdale H. and Flint E. A., 1988 – Flora of New Zealand. Freshwater Algae, Chlorophyta, Desmids, II, DSIR, Botany Division, Christchurch, DOI:10.2307/3668173, 147.
12. Denboh T., Hendrayanti D. and Ichimura T., 2001 – Monophyly of the genus Closterium and the order Desmidiales (Charophyceae, Chlorophyta) inferred from nuclear small subunit rDNA data, *Journal of Phycology*, 37, 1063-1072.
13. Denisov D. B. and Barinova S., 2015 – Algal diversity and ecological variables in the Arctic lakes of the Kola Peninsula, Russian North, *Issues of Modern Algology*, 2, 9, 1-47, http://algology.ru/742.
14. Dillard G. E., 1991 – Freshwater algae of the southeastern United States, 4, Chlorophyceae: Zygnematales: Desmidiaceae, 2, 4, Chlorophyceae: Zygnematales: Desmidiaceae, 2, Cramer J., Stuttgart, *Bibliotheca Phycologica*, 89, 1-205.
15. Dimante-Deimantovica I., Chertoprud M., Chertoprud E., Christoffersen K. S., Novichkova A. and Walseng B., Nina Publications, 2015 – 1218 FREMONEC: Effect of climate change and related stressors on fresh and brackish water ecosystems in Svalbard, 40.
16. Forster K., 1982 – Conjugatophyceae: Zygnematales und Desmidiales (excl. Zygnemataceae), in Huber-Pestalozzi G. (ed.), Das Phytoplankton des Süsswassers: systematik und biologie, Stuttgart, Schweizerbart’sche Verlagsbuchhandlung, 543.
17. Gelorini V., Verbeken A., van Geel B., Cocquyt C. and Verschuren D., 2011 – Modern non-pollen palynomorphs from East African lake sediments, *Review of Palaeobotany and Palynology*, 164, 143-173, https://doi.org/10.1016/j.revpalbo.2010.12.00.
18. Gilichinsky D. A., Wagener S. and Vishnivetskaya T. A., 1995 – Permafrost microbiology, *Permafrost and Periglacial Processes*, 6, 4, 281-291.
19. Gilichinskiy D. A., Friedmann I., Vorobieva E. A., Wilson G., Rivkina E. M., Soina B. C., Ostroumov V. E., McKay S., Shcherbakova V. A. Vishnivetskaya T. A., Chanton J., Erokhina L. G., 1996 – Study of the permafrost of Antarctica as a paleobank of ancient life forms for the reconstruction of Cenozoic history, Abstract of Basic research of the Earth's cryosphere in the Arctic and Subarctic, Pushchino, 41-43.
20. Kim G. H., Klochkova T. A., Han J. W., Kang S. H., Choi H. G., Chung K. W and Kim S. J., 2011 – Freshwater and Terrestrial Algae from Ny-Ålesund and Blomstrandhalvøya Island (Svalbard), *Arctic*, 64, 1, 25-31.
21. Holmgren S. U., Bigler C., Ingólfsson Ó. and Wolfe A. P., 2010 – The Holocene-Anthropocene transition in lakes of western spitsbergen, Svalbard (Norwegian high arctic): Climate change and nitrogen deposition, *Journal of Paleolimnology*, 43, 393-412, https://doi.org/10.1007/s10933-009-9338-3.
22. Kvíderová J., 2012 – Research on cryosestic communities in Svalbard: the snow algae of temporary snowfields in Petuniabukta, Central Svalbard, *Czech Polar Reports*, 2, 8-19.
23. Jiang S., Liu X., Sun J., Yuan L., Sun L. and Wang Y., 2011 – A multi-proxy sediment record of late Holocene and recent climate change from a lake near Ny-Ålesund, Svalbard, *Boreas*, 40, 468-480, https://doi.org/10.1111/j.1502-3885.2010.00198.x.

24. Kim G. H., Klochkova T. A. and Kang S. H., 2008 – Notes on freshwater and terrestrial algae from Ny-Alesund, Svalbard (high Arctic sea area), *Journal of Environmental Biology*, 29, 4, 485-491.
25. Lenzenweger R. and Lütz C., 2006 – A contribution to knowledge of the desmid flora (Desmidiaceae, Zygnemaphyceae) of Spitzbergen, *Algological Studies/Archiv für Hydrobiologie*, 119, 79-89, https://doi.org/10.1127/1864-1318/2006/0119-0079.
26. Nikulina T. V., Kalitina E. G., Vakh E. A. and Kharitonova N. A., 2016 – List of diatoms from three hot springs from Kamchatka-Malkinskiye, Nachikinskiye and Verhne-Paratunskiye (Russia), in Freshwater Life; Bogatov V. V., ed.; Dalnauka, Vladivostok, Russia, 2, 108-115. (in Russian)
27. Prach K., Košnar J., Klimešová J. and Hais M., 2010 – High Arctic vegetation after 70 years: A repeated analysis from Svalbard, *Polar Biol*ogy, 33, 635-639, https://doi.org/10.1007/s00300-009-0739-6.
28. Prager A., Theuerkauf M., Couwenberg J., Barthelmes A., Aptroot A. and Joosten H., 2012 – Pollen and non-pollen palynomorphs as tools for identifying alder carr deposits: A surface sample study from NE-Germany, *Review of Palaeobotany and Palynology*, 186, 38-57, https://doi.org/10.1016/j.revpalbo.2012.07.006.
29. Prescott G. W., Croasdale H. T., Vinyard W. C. and Bicudo C. E. M., 1981 – A synopsis of North American Desmids, II, Desmidiaceae: Placodermae, 3, University of Nebraska, Lincoln, 720.
30. Prescott G. W., Croasdale H. T. and Vinyard W. C., 1982 – A synopsis of North American Desmids, II, Desmidiaceae: Placodermae, 4, University of Nebraska, Lincoln, 704.
31. Richter D., 2018 – Diversity of cyanobacteria and microalgae in hydro-terrestrial habitats in Svalbard and its ecological evaluation, *Polish Polar Research*, 39, 255-311. https://doi.org/10.24425/11874.
32. Richter D., Matuła J., Pietryka M., Wojtuń B., Zwolicki A., Zmudczyńska-Skarbek K. and Stempniewicz L., 2018 – Cyanobacterial and green algal assemblages in various tundra habitats in the high Arctic (West Spitsbergen, Norway), *Acta Societatis Botanicorum Poloniae*, 87, 4, 1-21, https://doi.org/10.5586/asbp.360.
33. Richter D., Pietryka M. and Matuła J., 2015 – Relationship of cyanobacterial and algal assemblages with vegetation in the high Arctic tundra (West Spitsbergen, Svalbard Archipelago), *Polish Polar Research*, 36, 239-260, https://doi.org/10.1515/popore-2015-0013.
34. Singh V., Pandita S. K., Tewari R., Van Hengstum P. J., Pillai S. S. K., Agnihotri D., Kumar K. and Bha, G. D., 2015 – Thecamoebians (Testate Amoebae) straddling the permian-triassic boundary in the Guryul Ravine Section, India: Evolutionary and palaeoecological implications, *PLoS One*, 10, 8, e0135593, https://doi.org/10.1371/journal.pone.0135593.
35. Treut L., Somerville R., Cubasch U., Ding Y., Mauritzen C., Mokssit A., Peterson T., Prather M., Qin D., Manning M., Chen Z., Marquis M., Averyt K. B. and Tignor M., 2007 – Historical overview of climate change science, *Earth*, 43, 93-127, https://doi.org/10.1016/j.soilbio.2010.04.001.
36. Tyson R. V., 1995 – Sedimentary organic matter; organic facies and palynofacies, Chapman and Hall, London, 633.
37. Vishnivetskaya T., Erokhina L., Spirina E., Shatilovich A., Vorobyova E. A. and Gilichinsky D., 2001 – Ancient viable green algae and cyanobacteria from permafrost, in Algae and extreme environments, (eds Elster J., Seckbach J., Vincent W. and Lhotsky O.), *Nova Hedwigia Beiheft*, 123, 427-441.

38. Vorobyova E. A., Gilichinsky D. A., Soina V. S., Gorlenko M. A., Minkovskaya N. E., Rivkina E. M. and Vishnivetskaya T. A., 1997 – Deep cold biosphere: facts and hypothesis, *FEMS Microbiological Reviews*, 20, 3-4, 277-290.

DIVERSITY AND ECOLOGY OF NON-DIATOM ALGAE IN A SWAMPY MOUNTAIN LAKE OF THE SUNTAR-KHAYAT RIDGE (REPUBLIC SAKHA, YAKUTIA, RUSSIA)

Liubov KOPYRINA *, *Elena PSHENNIKOVA* ** and *Sophia BARINOVA* ***

* Institute for Biological Problems of Cryolithozone Siberian Branch of RAS, Lenina Avenue 41, Yakutsk, Russia, RU-677000, l.i.kopyrina@mail.ru, ORCID: 0000-0002-0374-3323.
** North-Eastern Federal University named after M. K. Amosov, Belinskogo Street 58, Yakutsk, Russia, RU-677000, el_viss@mail.ru, ORCID: 0000-0003-1527-3426.
*** Institute of Evolution, University of Haifa, Mount Carmel, Abba Khoushi Avenue 199, Haifa, Israel, IL-3498838, sophia@evo.haifa.ac.il, ORCID: 0000-0001-9915-2503.

DOI: 10.2478/trser-2022-0002

KEYWORDS: freshwater algae, ecological preferences, bioindication, mountain lakes, Yakutia.

ABSTRACT

The first studied flora of a mountain lake on the Suntar-Khayat ridge was represented by 170 species of non-diatoms in addition to 112 previously studied diatoms. The calculated similarity indices, correlation analysis and bioindication showed the uniqueness of the non-diatom flora, dominated by charophytes in general and species of the genera *Cosmarium* and *Closterium*. The results of the study of flora suggest that the altitude and the lake location in the zone of the Arctic deserts were major factors that affected the process of formation of the unique species composition.

ZUSAMMENFASSUNG: Diversität und Ökologie von Nicht-Kieselalgen in einem versumpften Bergsee des Suntar-Khayat-Kamms (Republik Sacha, Jakutien, Russland).

Erstmalig wurden nach einer vorangegangenen Studie der Algenflora eines Bergsees auf dem Suntar-Khayat-Kamm, bei der 112 Arten von Kieselalgen festgestellt wurden, nun zusätzlich 170 Arten von Nicht-Kieselalgen festgestellt. Die berechneten Ähnlichkeitsindizes, die Korrelationsanalyse und die Bioindikation zeigten die Einzigartigkeit der Nicht-Diatomeen-Flora, die im Allgemeinen von Charophyten im Allgemeinen und sowie Arten der Gattungen *Cosmarium* und *Closterium* dominiert wird. Die Ergebnisse der Untersuchung der Flora deuten darauf hin, dass die Höhe und die Lage des Sees in der Zone der arktischen Wüsten wichtige Faktoren waren, die den Entstehungsprozess der einzigartigen Artenzusammensetzung beeinflussten.

REZUMAT: Diversitatea și ecologia algelor fără diatomee într-un lac de munte mlăștinos de pe creasta Suntar-Khayat (Republica Sakha, Yakutia, Rusia).

Prima floră studiată a unui lac de munte de pe creasta Suntar-Khayat a fost reprezentată de 170 de specii de non-diatomee, față de 112 specii de diatomee studiate anterior. Indicii de similitudine calculați, analiza corelației și bioindicația au evidențiat unicitatea florei de non-diatomee, dominată de carofite în general și specii din genurile *Cosmarium* și *Closterium*. Rezultatele studiului florei sugerează că altitudinea și locația lacului în zona deșerturilor arctice au fost factori majori care au afectat procesul de formare a compoziției unice a speciilor.

INTRODUCTION

The study of the species composition of water bodies located in extreme natural and climatic conditions, in particular, in the territory of the north of the Russian Far East, has been carried out for a number of years (Kopyrina et al., 2020). At present, we are focusing on the division of works on lotic and lentic objects, since conclusions about the influence of water parameters and macroclimatic parameters are based on different bases and reflect the influence of various climatic factors (Denisov and Barinova, 2015, 2016; Barinova, 2017; Gabysheva et al., 2022). However, while river floras are subject to influences associated with currents and changes in latitude, the floras of lentic water bodies of lakes can more accurately characterize the influence of macroclimatic parameters on the formation of algae flora. On the other hand, the study of algae in lentic water bodies in the Arctic can help to reveal the catchment basins input and represent the effect of natural and anthropogenic conditions throughout the entire catchment area over many years, so its ecosystems stay relatively stable.

Of course, floristic studies in such hard-to-reach areas as the Arctic North, first of all, contribute to supplementing the list of species of regional floras. The first information about algae of the lakes in Central Yakutia comes in 1935 (Kiselev, 1935; Komarenko and Vasilyeva, 1975, 1978; Vasilyeva, 1989; Pestryakova, 2008; Troeva, et al., 2010; Kopyrina, 2014).

The objective of the present study was to reveal the non-diatom species in a mountain lake on Suntar-Khayat ridge in Yakutia and compare it to floras of previously studied lakes in the region with the help of ecological preferences by bioindication and statistical methods for defining major factors influenced the floristic formation process.

MATERIAL AND METHODS

Description of study site

The alpine lake (63°03’57”N, 138°48’47”E) is located in the upper reaches of the Vodopadny Stream (left tributary of the Eastern Khandyga River), six km to the south, at an altitude of 1,330 m a.s.l., on Suntar-Khayat ridge (North-East of Yakutia, Russia) (Fig. 1). The lake is flowing, with a length of 120 m, an 80 m width, a surface area about 3.01 ha, and a muddy bottom. Mosses grow in the coastal part of the lake, the water temperature was 13.3°C, and the transparency was up to 1.2 m. Rhododendron-dryad tundra with *Cassiopeia* are described on the slope of the ravine, a narrow strip of sedge-reed grass *Hypnum* swamp runs along the lake shore.

The high-mountainous regions of Suntar-Khayat are characterized by the harsh climate of the Arctic desert. Winter lasts eight months. The height of the snow cover in the mountains is 50-90 cm. The climate varies from sharply continental to cold maritime. The northeastern regions have a sharply continental climate. Here is the Pole of Cold of the Northern Hemisphere – the village of Oymyakon with an absolute minimum of –71.2°C. Winter is long, up to seven months, with little snow. The height of the snow cover in some years does not exceed 25-30 cm. The summer in the mountains is cool and does not last long. It starts from the second half of June and lasts two months. The average daily air temperature is 10°C. (Izyumenko, 1966) The water nutrition of the lakes in this region is mixed, glacial and snow-rain, as well as due to feeding by melting glaciers.

We studied the algal flora of this lake for the first time and identified 112 taxa of rare and new species of diatoms (Potapova et al., 2014).

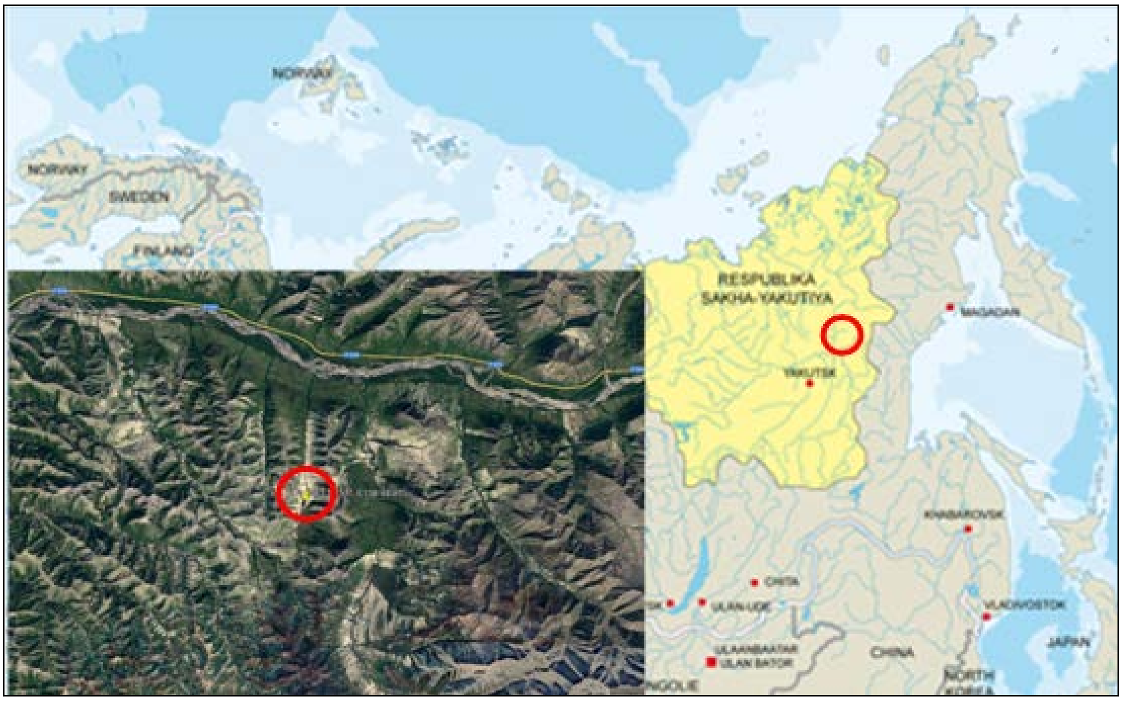


Figure 1: The studied lake in the Suntar-Khayat ridge (red circle)
(Republic Sakha, Yakutia, Russian Far East).

Sampling and laboratory study

The material for the study was eight samples of phytoperiphyton collected from higher aquatic plants and mosses in August 2003. During sampling, the water temperature was measured, and transparency was determined.

The collection of materials was carried out according to the research methods generally accepted in algology (*, 1989; **, 1992; Komulainen, 2003). For further study of the collected material, samples in 15 ml plastic tubes were fixed in a 4% solution of neutral formaldehyde. Identification of non-diatom phytoperiphyton algae was carried out in the Department of Botanical Research of the Institute of Biotechnology of the Siberian Branch of the Russian Academy of Sciences using a Mikmed-6 microscope.

Taxa names are given according to the database (Guiry and Guiry, 2021; http://www.algaebase.org) with the latest additions and clarifications.

Species and varieties within each phylum are arranged alphabetically.

The ecological preferences of the identified species were determined using bioindication methods (Barinova, 2017a; Barinova et al., 2006, 2019).

A similarity tree was calculated and constructed with the help of BioDiversity Pro 9.0 program.

Correlation of species content was calculated with JASP networks (Love et al., 2019).

RESULTS

Physical and chemical variables

Hydrochemical variables are given for the first time. The surface waters of this reservoir have no taste and smell. The water temperature was 16.2°C, the transparency is up to one m, water pH is neutral (7.20), water of the bicarbonate class, calcium group of type three. Bicarbonates (25% equivalent) and calcium ions (37% equivalent) dominate the ionic composition. In terms of TDS, the waters are fresh, have low salinity and are soft.

Taxonomical species content

A taxonomic diversity of 170 species and varieties was identified in the composition of algae and cyanobacteria communities at the end of the short summer period, in August (Tab. 1). They belonged to seven taxonomic phyla. Charophyta (63) dominated, and then Cyanobacteria (38) was significantly less, while Chlorophyta and Ochrophyta accounted for 30 and 29 species, respectively. The remaining three phyla included a total of one to five species (Fig. 2). The richest division of charophytes was dominated by the genera *Cosmarium* Corda ex Ralfs with 18 species and *Closterium* Nitzsch ex Ralfs with nine species. These are usually inhabitants of wetland habitats of shallow clear waters or coastal communities. As can be seen from table 1, the revealed flora of non-diatoms is represented in the majority by typical varieties. We calculated the Ssp/Sp index, which reflects the intraspecific variability of the flora (Barinova, 2011), and it turned out to be only 1.006 for the studied lake, which characterizes the studied flora as practically monotypic with low intraspecific polymorphism. Next, the specific content of the taxonomic list per lake area (species – area index as number of species per one square kilometer) was calculated (Barinova et al., 2011; Barinova and Stenina, 2013). The species per area index turned out to be high, 56.5 species per km^2.

Table 1: Diversity and ecological preferences of non-diatom algae in the lake in the Suntar-Khayat ridge (Republic Sakha, Yakutia). Abbreviations of the Ecological groups: Substrate – S, soil; Ep, epiphytes; B, benthic as a whole; P-B, planktonic-benthic; and P, planktonic. Temperature – eterm, eurythermal. Water disturbance and Oxygenation – aer, aerophiles; str, streaming well-oxygenated waters; st-str, low streaming, mid-oxygenated waters; st, standing, low-oxygenated waters; and H_2S, sulfide indicators. Water pH – acf, acidophiles; ind, pH-indifferents; alf, alkaliphiles; and alb, alkalibiontes. Salinity – hb, halophobes; i, chloride-tolerated (indifferent); hl, halophiles. Class of Water Quality – Classes 1-4 according EU FWD. Trophy – ot, oligotraphentes; om, oligo-mesotraphhentes; m, mesotraphentes; me, meso-eutraphentes; e, eutraphentes.

Taxa	Hab	Temp	OXY	Index S	SAP	HAL	pH	TRO
Charophyta								
Actinotaenium curtum (Brébisson ex Ralfs) Teiling ex Růžička and Pouzar	P-B	–	aer	0.90	x-b	–	ind	om
Actinotaenium cruciferum (De Bary) Teiling	P-B	–	aer	–	–	–	acf	om
Closterium attenuatum Ralfs	–	–	–	–	–	–	–	–
Closterium baillyanum (Brébisson ex Ralfs) Brébisson	B	–	–	–	–	–	ind	om
Closterium leibleinii Kützing ex Ralfs	P-B	–	st-str	2.60	a-o	–	ind	e
Closterium parvulum Nägeli	P-B	–	–	2.00	b	i	ind	m
Closterium peracerosum Gay	–	–	–	–	–	–	–	–

Table 1 (continued): Diversity and ecological preferences of non-diatom algae in the lake in the Suntar-Khayat ridge (Republic Sakha, Yakutia).

Taxa	Hab	Temp	OXY	Index S	SAP	HAL	pH	TRO
Charophyta								
Closterium pritchardianum W. Archer	P-B	–	–	–	–	–	ind	m
Closterium setaceum Ehrenberg ex Ralfs	P-B	–	–	–	–	hb	acf	om
Closterium siliqua West and West	P	–	st-str	–	–	–	–	–
Closterium striolatum Ehrenberg ex Ralfs	P-B	–	–	1.20	o	–	acf	om
Cosmarium asphaerosporum Wittrock	B	–	–	–	–	i	acf	ot
Cosmarium botrytis Meneghini ex Ralfs	P-B	-	st-str	1.90	o-a	i	ind	m
Cosmarium conspersum Ralfs	–	–	–	–	–	–	–	–
Cosmarium dentiferum Corda ex Nordstedt	–	–	–	–	–	–	acf	m
Cosmarium exiguum W. Archer	–	–	–	–	–	–	–	–
Cosmarium hornavanense Gutwinski	B, aer	–	aer	1.00	o	-	acf	m
Cosmarium humile Nordstedt ex De Toni	P-B	–	–	1.10	o	i	ind	m
Cosmarium margaritatum (P. Lundell) J. Roy and Bisset	B	–	–	–	–	–	acf	m
Cosmarium monomazum P. M. Lundell	–	–	–	–	–	–	–	–
Cosmarium ochthodes Nordstedt	B	–	–	1.20	o	–	ind	m
Cosmarium pokornyanum (Grunow) West and G. S .West	B, aer	–	aer	–	–	hl	acf	m
Cosmarium pseudoholmii O. Borge	P	–	–	–	–	i	ind	m
Cosmarium sp.	–	–	–	–	–	–	–	–
Cosmarium subcrenatum Hantzsch	B, aer	–	aer	1.10	o	–	acf	m
Cosmarium sublatereundatum West and G. S. West	–	–	–	–	–	–	–	–
Cosmarium subprotumidum Nordst.	P-B	–	st-str	1.90	o-a	–	ind	me
Cosmarium subquadrans West and G. S. West	–	–	–	–	–	–	acf	m
Cosmarium subundulatum Wille	–	–	–	–	–	–	acf	m
Cosmarium turpinii Brébisson	P-B	–	–	0.70	o-x	i	ind	me
Cosmarium undulatum var. wollei West	–	–	–	–	–	–	–	–
Cylindrocystis brebissonii (Ralfs) De Bary	B, S	–	st, aer	0.80	x-b	–	acf	om
Desmidium graciliceps (Nordstedt) Lagerheim	–	–	–	–	–	–	–	–
Desmidium swartzii C. Agardh ex Ralfs	B	–	–	0.60	o-x	i	ind	m
Euastrum ansatum Ehrenberg ex Ralfs	P-B	–	–	0.50	x-o	–	acf	ot
Euastrum bidentatum Nägeli	P-B	–	–	0.60	o-x	hb	ind	m

Table 1 (continued): Diversity and ecological preferences of non-diatom algae in the lake in the Suntar-Khayat ridge (Republic Sakha, Yakutia).

Taxa	Hab	Temp	OXY	Index S	SAP	HAL	pH	TRO
Charophyta								
Euastrum binale Ehrenberg ex Ralfs	B	–	–	0.60	o-x	–	acf	ot
Euastrum crassicolle P. Lundell	B	–	aer	0.50	x-o	–	acf	om
Euastrum cuneatum Jenner	P-B	–	–	0.50	x-o	–	acf	m
Euastrum tumoriferum (Kossinskaja) Van Westen and Coesel	–	–	–	–	–	–	–	–
Gonatozygon monotaenium De Bary	B	–	st-str	0.80	x-b	hb	acf	me
Gonatozygon pilosum Wolle	–	–	–	–	–	–	–	–
Mougeotia laetevirens (A. Braun) Wittrock	B	–	–	1.00	o	–	–	–
Mougeotia notabilis Hassall	–	–	–	–	–	–	–	–
Mougeotia scalaris Hassall	B	–	–	1.50	o-b	i	–	–
Netrium digitus (Brébisson ex Ralfs) Itzigsohn and Rothe	P-B	–	–	0.50	x-o	i	acf	om
Penium spirostriolatum J. Barker	B	–	–	0.50	x-o	–	acf	om
Penium cylindrus Brébisson ex Ralfs	B	–	–	0.40	x-o	–	acf	om
Pleurotaenium truncatum (Brébisson ex Ralfs) Nägeli	B	–	–	0.80	x-b	–	acf	m
Spirogyra varians (Hassall) Kützing	P-B	–	–	2.10	b	oh	–	–
Spirogyra protecta H. C. Wood	B	–	–	1.10	o	–	–	–
Staurastrum bieneanum Rabenhorst	B	–	–	–	–	–	acf	m
Staurastrum cyrtocerum var. inflexum (Brébisson) Coesel and Meesters	–	–	–	–	–	–	–	–
Staurastrum pachyrhynchum Nordstedt	–	–	–	–	–	–	acf	m
Staurastrum paradoxum Meyen ex Ralfs	P	–	st	–	–	i	ind	ot
Staurastrum platycerum Joshua	–	–	–	–	–	–	–	–
Staurastrum polytrichum (Perty) Rabenhorst	B	–	–	1.60	b-o	–	acf	m
Staurastrum saxonicum Bulnheim ex Rabenhorst	–	–	–	–	–	–	–	–
Temnogyra punctiformis (Transeau) Yamagishi	–	–	–	–	–	–	–	–
Xanthidium aculeatum Ehrenberg ex Ralfs	P-B	–	–	0.60	o-x	–	acf	om
Xanthidium smithii W. Archer	–	–	–	–	–	–	acf	ot
Zygnema pectinatum (Vaucher) C. Agardh	B	–	st-str	1.00	o	oh	–	–
Zygnema cruciatum (Vaucher) C. Agardh	B	–	–	0.80	x-b	–	–	–

Table 1 (continued): Diversity and ecological preferences of non-diatom algae in the lake in the Suntar-Khayat ridge (Republic Sakha, Yakutia).

Taxa	Hab	Temp	OXY	Index S	SAP	HAL	pH	TRO
Chlorophyta								
Actinastrum aciculare Playfair	P	–	–	–	–	–	–	–
Ankistrodesmus spiralis (W. B. Turner) Lemmermann	P	–	–	2.10	b	–	–	e
Ankistrodesmus fusiformis Corda	P-B	–	st-str	2.00	b	i	–	e
Blidingia marginata (J. Agardh) P. J. L. Dangeard ex Bliding 1963	B	–	–	–	–	–	–	–
Bulbochaete setigera C. Agardh ex Hirn	B	–	–	1.30	o	–	–	–
Bulbochaete nana Wittrock ex Hirn	B	–	–	1.30	o	–	–	–
Chaetophoropsis elegans (Roth) B. Wen Liu, Qian Xiong, X. Dong Liu, Z. Yu Hu and G. Xiang Liu	B	–	–	1.20	o	–	–	–
Characiochloris apiculata Korshikov	–	–	–	–	–	–	–	–
Cladophora fracta (O. F. Müller ex Vahl) Kützing	P-B	–	st-str	2.30	b	–	–	e
Cladophora glomerata (Linnaeus) Kützing	P-B	–	st-str	1.90	o-a	i	alf	e
Geminella interrupta Turpin	B	–	–	1.30	o	–	–	–
Gloeotila scopulina (Hazen) Heering	B	–	–	–	–	–	–	–
Koliella longiseta (Vischer) Hindák	P	–	st	2.00	b	i	–	–
Monoraphidium griffithii (Berkeley) Komárková-Legnerová	P-B	–	st-str	2.20	b	i	–	e
Oedogonium oblongum Wittrock ex Hirn	B	–	–	–	–	oh	–	–
Oedogonium pringsheimii C. E. Cramer ex Hirn	B	–	–	1.40	o-b	–	–	–
Oedogonium undulatum A. Braun ex Hirn	B	–	–	–	–	i	–	–
Palmodictyon varium (Nägeli) Lemmermann	–	–	–	–	–	–	–	–
Planctococcus sphaerocystiformis Korshikov	P	–	st	–	–	–	–	–
Prasiola sp.	–	–	–	–	–	–	–	–
Prasiola subareolata Skuja	–	–	–	–	–	–	–	–
Prasiola velutina (Lyngbye) Trevisan	–	–	–	–	–	–	–	–
Pseudocharacium obtusum (A. Braun) Petry-Hesse	B, Ep	–	st	–	–	i	–	–
Pseudopediastrum kawraiskyi (Schmidle) E. Hegewald	P	–	–	1.40	o-b	–	–	–
Siderocelis ornate (Fott) Fott	P-B	–	st-str	2.20	b	i	–	–
Stigeoclonium amoenum Kützing	–	–	–	–	–	–	–	–

Table 1 (continued): Diversity and ecological preferences of non-diatom algae in the lake in the Suntar-Khayat ridge (Republic Sakha, Yakutia).

Taxa	Hab	Temp	OXY	Index S	SAP	HAL	pH	TRO
Chlorophyta								
Ulothrix implexa (Kützing) Kützing	–	–	–	–	–	–	–	–
Ulothrix oscillarina Kützing	B, aer, S	–	st-str	–	–	–	–	–
Ulothrix zonata (F. Weber and Mohr) Kützing	P-B	–	st-str	1.80	o-a	i	ind	–
Ulothrix albicans Kützing	B	–	–	1.30	o	–	–	–
Cyanobacteria								
Anabaena sp.	P-B	–	–	–	–	–	–	e
Anabaena catenula Kützing ex Bornet and Flahault	P-B	–	–	–	–	–	–	m
Chlorogloea microcystoides Geitler	Ep, B, S	–	aer	–	–	–	–	–
Gloeocapsa violacea Kützing	S	–	–	–	–	–	–	–
Gloeocapsopsis magma (Brébisson) Komárek and Anagnostidis ex Komárek	S	–	–	–	–	i	ind	–
Gloeothece palea (Kützing) Nägeli	Ep, B, S	–	aer	–	–	–	–	–
Gloeotrichia echinulata P. G. Richter	P-B	–	–	1.50	o-b	–	–	m
Gomphosphaeria aponina Kütz.	P-B	–	st-str	1.20	o	hl	alf	ot
Limnothrix guttulata (Goor) I. Umezaki and M. Watanabe	P-B	–	st,H2 S	3.00	a	–	–	–
Lyngbya kuehniana Migula	–	–	–	–	–	–	–	–
Lyngbya sp.	B	–	–	–	–	–	–	–
Merismopedia smithii De Toni	P-B	–	–	1.50	o-b	i	–	ot
Nodularia spumigena Mertens ex Bornet and Flahault	P-B, S	–	–	1.80	o-a	–	–	e
Nostoc kihlmanii Lemmermann	P	–	–	1.40	o-b	i	–	ot
Nostoc linckia Bornet ex Bornet and Flahault	P-B, Ep	–	–	1.60	b-o	–	–	–
Nostoc paludosum Kützing ex Bornet et Flahault f. *paludosum*	P-B, S	–	st	1.60	b-o	–	–	m
Nostoc punctiforme Hariot	P-B, S	–	aer	1.60	b-o	–	–	–
Oscillatoria limosa C. Agardh ex Gomont	P-B	–	st-str	2.60	a-o	hl	alf	e
Oscillatoria rupicola (Hansgirg) Hansgirg ex Forti	P-B, S	–	aer	–	–	–	–	–
Oscillatoria simplicissima Gomont	P-B	–	st-str	–	–	i	–	ot
Oscillatoria sp.	B	–	–	–	–	–	alf	–
Phormidium ambiguum Gomont	B, S	eterm	st-str	2.30	b	i	ind	me
Phormidium deflexoides (Elenkin and Kossinskaja) Anagnostidis and Komárek	–	–	–	–	–	–	–	–

Table 1 (continued): Diversity and ecological preferences of non-diatom algae in the lake in the Suntar-Khayat ridge (Republic Sakha, Yakutia).

Taxa	Hab	Temp	OXY	Index S	SAP	HAL	pH	TRO
Cyanobacteria								
Phormidium granulatum (N. L. Gardner) Anagnostidis	P-B	–	st-str	–	–	–	alf	–
Phormidium irriguum (Kützing ex Gomont) Anagnostidis et Komárek	B, Ep	–	aer	–	–	–	–	me
Phormidium schroeteri (Hansgirg) Anagnostidis	P-B, S	–	st	3.10	a	–	–	–
Planktothrix prolific (Gomont) Anagnostidis and Komárek	P	–	–	–	–	–	alf	–
Plectonema tomasinianum Bornet ex Gomont	B, S	–	st-str	0.80	x-b	–	–	ot
Pseudophormidium radiosum (Gomont) Anagnostidis and Komárek	–	–	–	–	–	–	–	–
Snowella lacustris (Chodat) Komárek and Hindák	P	–	–	1.60	b-o	i	alb	me
Snowella rosea (J. W. Snow) Elenkin	P	–	–	1.70	b-o	–	–	–
Stigonema mamillosum C. Agardh ex Bornet and Flahault	S, B	–	aer	–	–	–	–	–
Stigonema ocellatum Thuret ex Bornet and Flahault	B	–	–	0.60	o-x	–	–	–
Stigonema informe Kützing ex Bornet and Flahault	S, B	–	aer	–	–	–	–	–
Tolypothrix tenuis Kützing ex Bornet and Flahault	B, S	–	st	1.00	x-b	i	–	ot
Tolypothrix distorta Kützing ex Bornet and Flahault	B, S	–	–	0.95	x-b	–	–	ot
Trichodesmium lacustre Klebahn	P	–	st	–	–	–	–	–
Woronichinia compacta (Lemmermann) Komárek and Hindák	P-B	–	–	–	–	–	–	om
Euglenozoa								
Phacus striatus France	–	–	–	–	–	–	–	–
Trachelomonas curta A. M. Cunha	P	–	–	2.10	b	–	–	–
Trachelomonas hispida (Perty) F. Stein	P-B	eterm	st-str	2.20	b	i	acf	–
Trachelomonas volvocina (Ehrenberg) Ehrenberg	P-B	eterm	st-str	2.00	b	i	ind	–
Miozoa								
Glenodiniopsis steinii Wołoszyńska	P	–	st-str	1.20	o	–	–	–
Gymnodinium latum Skuja	P	–	–	1.50	o-b	–	–	–
Parvodinium inconspicuum (Lemmermann) Carty	P	–	–	–	–	–	–	–
Parvodinium lubieniense (Woloszynska) Carty	P	–	–	1.00	o	–	–	–
Peridinium sp.	P	–	–	1.40	o-b	–	ind	–

Table 1 (continued): Diversity and ecological preferences of non-diatom algae in the lake in the Suntar-Khayat ridge (Republic Sakha, Yakutia).

Taxa	Hab	Temp	OXY	Index S	SAP	HAL	pH	TRO
Ochrophyta								
Bumilleria borziana N. Wille	–	–	–	–	–	–	–	–
Characiopsis borziana Lemmermann	Ep	–	–	–	–	–	–	–
Characiopsis falx Pascher	–	–	–	–	–	–	–	–
Characiopsis grandis Pascher	–	–	–	–	–	–	–	–
Characiopsis pyriformis (A. Braun) Borzì	Ep	–	–	–	–	–	–	–
Characiopsis saccata N. Carter	–	–	–	–	–	–	–	–
Characiopsis sublinearis Pascher	–	–	–	–	–	–	–	–
Characiopsis korschikovii Matvienko	–	–	–	–	–	–	–	–
Chloropedia plana Pascher	–	–	–	–	–	–	–	–
Codonodendron ocellatum Pascher	–	–	–	2.00	b	–	–	–
Derepyxis dispar (A. Stokes) Senn	Ep	–	–	1.50	o-b	–	–	–
Dinobryon borgei Lemmermann	P	–	–	1.20	o	–	–	–
Dinobryon cylindricum O. E. Imhof	P-B	–	–	1.20	o	i	–	–
Dinobryon eurystoma (A. Stokes) Lemmermann	P-B	–	–	1.20	o	–	–	–
Dinobryon sertularia Ehrenberg	P-B	–	–	1.30	o	i	–	–
Dinobryon sociale (Ehrenberg) Ehrenberg	P	–	–	1.20	o	i	–	–
Dinobryon asymmetricum D. G. Hilliard and B. C. Asmund	P	–	–	1.20	o	–	–	–
Ducellieria chodatii (Ducellier) Teiling	–	–	–	–	–	–	–	–
Epipyxis utriculus (Ehrenberg) Ehrenberg	Ep	–	–	1.20	o	–	–	–
Mallomonas spinulosa Conrad	–	–	–	–	–	–	–	–
Mallomonas teilingii Conrad	P	–	–	1.60	b-o	–	–	–
Ophiocytium parvulum (Perty) A. Braun	B	–	–	1.30	o	oh	–	–
Salpingoeca gracilis H. J. Clark	–	–	–	–	–	–	–	–
Stokesiella epipyxis Pascher	–	–	–	–	–	–	–	–
Trachychloron ellipsoideum (Pascher) Pascher	–	–	–	–	–	–	–	–
Tribonema crassum Pascher	–	–	–	–	–	–	–	–
Tribonema spirotaenia Ettl	–	–	–	–	–	–	–	–
Tribonema ulotrichoides Pascher	B	–	–	1.30	o	–	–	–
Tribonema vulgare Pascher	P-B	–	–	1.40	o-b	i	–	–
Rhodophyta								
Audouinella chalybea (Roth) Bory	B	–	str	1.00	x-o	–	alf	–

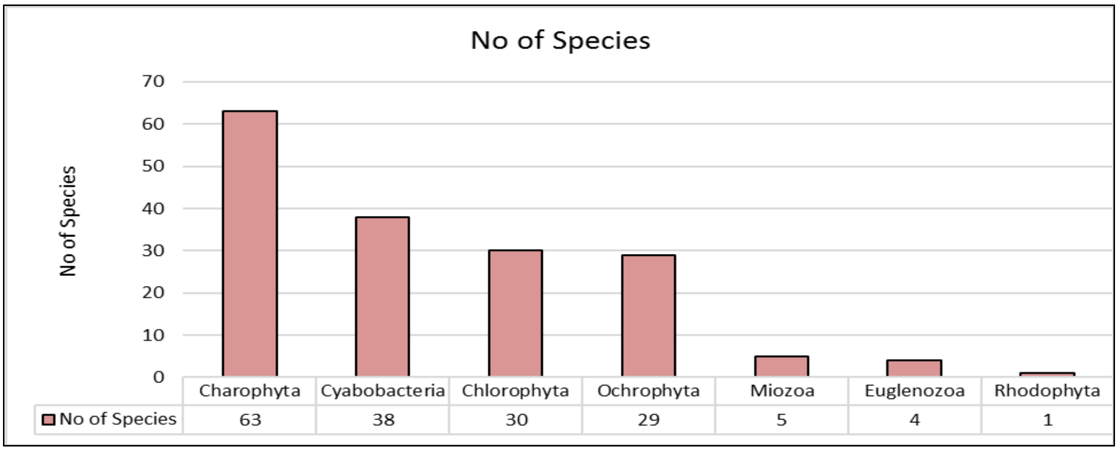


Figure 2: Species distribution over taxonomic phyla of non-diatom algae in the studied area.

Bioindicators

Algae form the basis of the trophic pyramid. Each species is able to survive only under certain environmental parameters. The maximum development of the species is achieved in the amplitude of the optimum parameter of the environment. Bioindication methods are based on this (Dokulil, 2003; Barinova, 2017a). If a species is found in a community of organisms inhabiting a particular water body, then the ecological amplitudes of the identified species can be used to characterize their habitat. Thus, the indication of environmental parameters for the organisms inhabiting it is based on the ecological amplitude of the environmental parameters within which a particular species survives, as well as the community in which it enters. Indication systems have been developed for several environmental parameters. For a species that is an indicator of a specific environmental parameter, the parameters of its optimal development are determined. Since the ecological preferences of species are species-specific, groups of species whose optimums correspond to certain intervals of the environmental index constitute groups of indicators. Thus, the identified species belongs to the group of indicators that develop in certain values of the environmental parameter. If we have identified representatives of this group of species, then, consequently, the amplitude of the parameter of the environment in which the species was found is determined. Each species of algae can indicate several environmental parameters. Thus, a species community can indicate the amplitudes of several environmental parameters and thus characterize the amplitudes of environmental parameters in which the community lived.

The ecological preferences of species can help characterize the habitat conditions for such remote and little explored mountain lakes as the lake on the Suntar-Khayat ridge. From table 1 it can be seen that more than 95% of the identified list of species were indicators. As can be seen from the distribution of indicators by ecological groups, benthic and planktonic-benthic species prevailed; however, planktonic species were also represented in the lake community (Fig. 3a). A very unusual distribution was observed among indicators of water saturation with oxygen (Fig. 3b). Slowly moving water species, moderately enriched with oxygen, dominated, but aerophilic species were in second place. They are adapted to living in waters with high oxygen saturation, that is, they characterize the waters of the lake as well aerated. Among water pH indicators, acidophiles predominated (Fig. 3c), but indifferent were also fairly well represented. The waters of the lake can be characterized as strictly fresh by the predominance of salinity indicators from the group of indifferent (Fig. 3d).

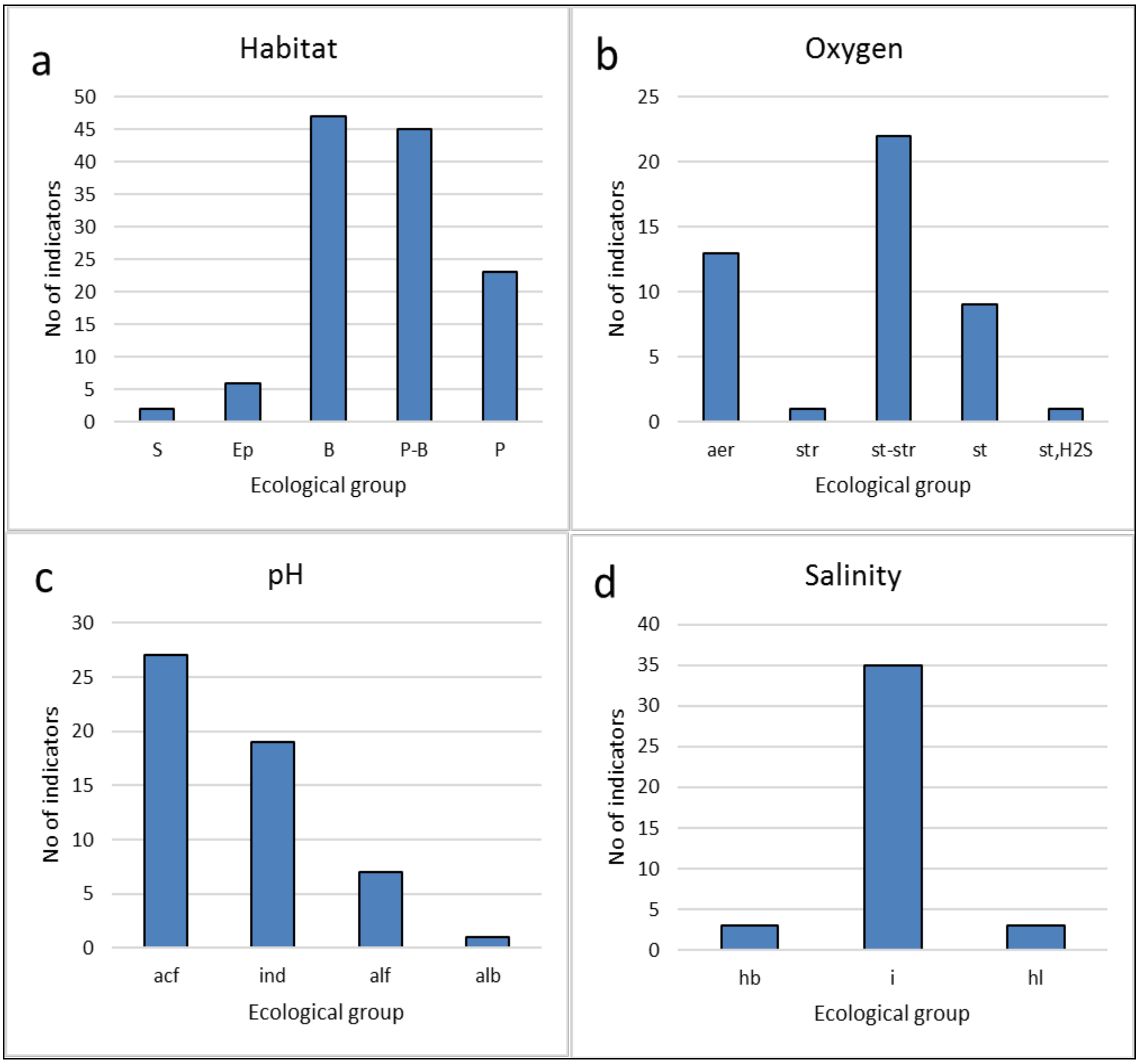


Figure 3: Indicator species distribution over ecological groups of habitats (a), oxygenation (b), water pH (c), and salinity (d) in the of non-diatom algae of the lake in the Suntar-Khayat ridge, (Republic Sakha, Yakutia).

Considerable interest arises in the analysis of the saturation of lake waters with organic matter and its trophic state.

As can be seen from figure 4a, the distribution by water quality classes calculated from the species-specific saprobity indices from table 1 characterizes the waters of the lake as weakly saturated with organic matter, 2 purity classes.

Groups of trophic indicators show the mesotrophic state of the lake (Fig. 4b).

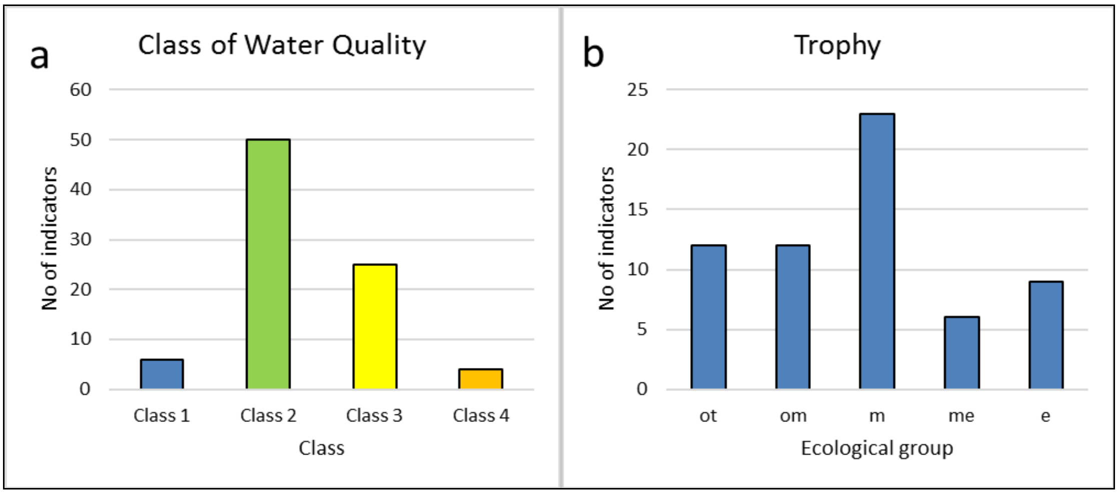


Figure 4: Indicator species distribution over ecological groups of water quality class (a) and trophic state (b) of non-diatom algae of the lake in the Suntar-Khayat ridge.

Comparative statistics

In order to understand what place the revealed flora of non-diatoms belongs among other previously studied lacustrine floras of Yakutia, a comparative floristic analysis was carried out. The comparison included only non-diatoms from nine lakes studied in detail (Kopyrina et al., 2020) and lakes on the Suntar-Khayat ridge. A general list was compiled with the reduction of the species composition to modern taxonomy. Thus, 489 species of non-diatoms from 10 lakes were included in this calculation (Tab. 2).

Table 2: Distribution of the number of non-diatom species in the floras of the studied lakes of Yakutia.

Lake	Code	Terraces	No. of non-diatom species
Suntar-Khayat	S-Kh	Suntar-Khayat	170
Aalah	B-Aal	Bestyakhskaya	174
Kurelah	B-Kur	Bestyakhskaya	98
Sullah	B-Sul	Bestyakhskaya	33
Dyiere	B-Dyi	Bestyakhskaya	52
Ynah	T-Yna	Tyungulyunskaya	109
Nal Tungulu	T-NalT	Tyungulyunskaya	65
Tungulu	T-Tun	Tyungulyunskaya	68
Abalah	A-Aba	Abalahskaya	53
Nidzhili	L-Nid	Lena-Viluyskaya	57

The flora of Lake Aalah on the Bestyakhskaya terrace near the Lena River was the most similar in terms of species richness of non-diatoms to the flora of Lake Suntar-Khayat (Tab. 2). Lake Aalakh is located approximately at the same latitude (63°3’N) as the lake under study (63°0’N), and also has a close surface area (0.052 km^2), moreover, the number of non-diatoms in it (174) is close to the studied lake (170), as well as the number of species per lake area (64.7). Despite the similarity of the general floristic parameters, both lakes differ significantly in the species composition of non-diatoms, since in the Aalakh, charophytes make up less than a third, along with green and cyanobacteria. The index of intraspecific polymorphism in Lake Aalakh is also higher (1.034) than in the studied lake (1.006). That is, the flora of Suntar-Khayat Lake differs markedly from the floras of the lakes studied earlier.

Comparison of the species composition according to Bray-Curtis (Fig. 5) of the floras of non-diatom algae from 10 lakes of Yakutia demonstrated five clusters. The flora of the lakes located on the terraces of the Lena River (clusters 1-3) was the most similar, but the flora of the Nidzhili Lake was differed from them and located to the north (cluster 4). The studied flora occupies a special place in the tree, forming cluster 5 with a similarity level of less than 10%.

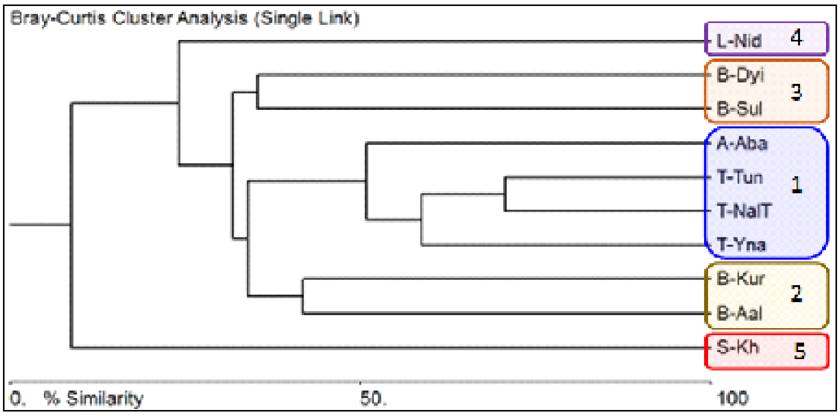


Figure 5: Similarity three of the of non-diatom algae in nine lakes of Yakutia and the lake in the Suntar-Khayat ridge.

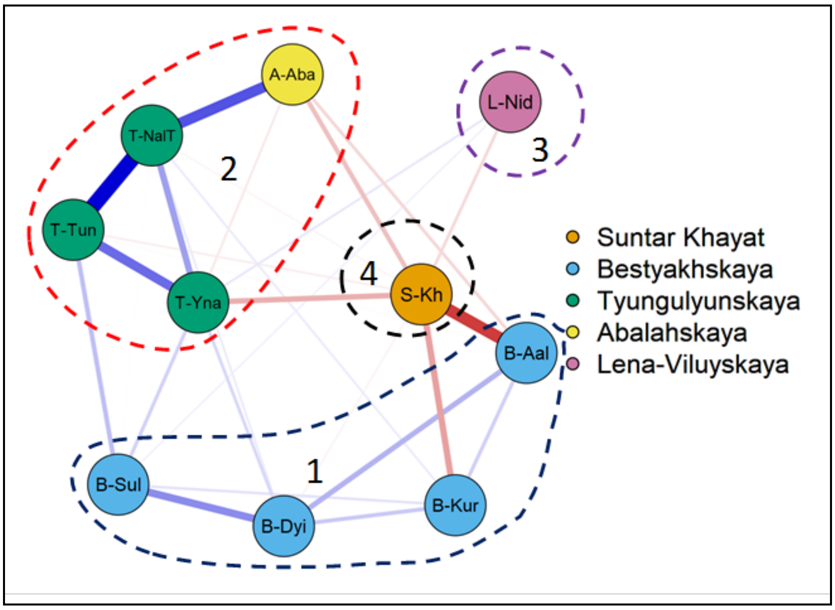


Figure 6: JASP network plot for correlation of the non-diatom algae species in nine lakes of Yakutia and the lake in the Suntar-Khayat ridge; dashed lines outlined the clusters, blue lines are positive correlation, and red lines are the negative correlation; the lines thickness reflects of the correlation power.

The calculation of the correlations of the species composition of 10 lakes showed (Fig. 6) that cluster 1 is formed by the species compositions of the lakes of the Bestyakhskaya terrace, which are in similar natural conditions, including Lake Aalakh. Cluster 2 is composed of correlating species compositions of non-diatom floras from the lakes of the Tyungulun terrace and Lake Abalakh. Cluster 3 corresponds to the unique flora of Lake Nidzhili. The flora of non-diatoms of the studied lake on the Suntar-Khayat ridge show not only a difference from all the floras of 9 lakes (cluster 4), but its species composition also significantly negatively correlates with the species composition of Lake Aalakh, which is similar in general floristic parameters. Thus, the non-diatom flora of the lake on the Suntar-Khayat ridge can be characterized as peculiar, unique in species composition, and with low species polymorphism.

DISCUSSION

Preliminary studies carried out on a lake located in the Suntar-Khayat ridge allowed to identify 170 species of non-diatoms in addition to 112 diatoms (Potapova et al., 2014). Thus, the total floristic composition of the studied lake reached 282 species. Since the survey of this hard-to-reach lake was carried out once, we can assume that its flora can be significantly replenished in the course of further research. However, even at this initial stage, it can be seen that the species composition is quite large and comparable with the floras of previously studied non-diatom lakes in a similar climatic zone or high-mountain habitats (Denisov and Barinova, 2015; Krupa et al., 2016; Barinova and Niyatbekov, 2018; Tsarenko et al., 2021). It is possible that the species richness of the studied samples represents practically the maximum species composition, since the lake was surveyed in detail and during the most favorable period for the development of algae in this region, in August.

The most significant differences in the studied flora were the predominance of charophyte algae with the dominance of the species composition of the genera *Cosmarium* and *Closterium* (Tab. 1). This is comparable to the distribution of the generic composition of the flora in the Artabel Lakes, located at 2,600-3,000 m a.s.l. in northeastern Turkey (Şahin et al., 2020). Here, among 73 species of charophytes, 37 *Cosmarium* and seven *Closterium* species are represented. For other floras studied in the altitude gradient, it turned out that the increase in habitat or desertification leads to similar trends in the structure of the algae flora, namely, an increase in the role of non-diatoms in general and charophytes and greens in particular. This allows us to confirm that non-diatoms are more competitive under conditions of climatic stress (Barinova et al., 2011; Barinova and Alster, 2021). The revealed structure of the taxonomic composition of the lake flora on the Suntar-Khayat ridge can be considered evidence of a climatic impact on the process of formation of lake floras in the Arctic climatic conditions stress previously shown for river floras (Barinova et al., 2015; Barinova, 2017).

Even only, the high saturation of the algal flora with the genera *Cosmarium* and *Closterium* can characterize the flora of the lake as unique. However, besides this, calculations of general floristic parameters were carried out in order to confirm this. It turned out that the intraspecific polymorphism of non-diatoms in the studied lake is at an extremely low level, amounting to only 1.006. That is, the flora is practically monospecific. This drew attention to other methods for comparing its species composition with the floras of previously studied lakes in the region (Kopyrina et al., 2020). Whereas the total species richness of non-diatoms was close in the studied lake and Lake Aalakh, the first terrace of the Lena River, located at the same latitude, the actual species composition differed significantly. The calculations of the similarity (Fig. 5) and correlation (Fig. 6) of the species composition of 10 non-diatom lakes revealed the uniqueness of the flora of the studied lake.

Moreover, the correlation analysis showed a strong negative correlation even between lakes similar in other floristic parameters, such as Suntar-Khayat and Lake Aalakh. That is, the flora of the studied lake remains so unique in this region that it does not reveal the influence on its species composition of general climatic influences characteristic of the terraced lakes of the Lena River. Previously, it was shown that floras are similar in lakes located on terraces that are, having a common origin (Kopyrina et al., 2020). However, the lake under study is located at an altitude of 1,300 m a.s.l. and thus differs in its origin precisely in this parameter. Identification of uniqueness has been made possible with the use of new or rarely used variables, such as indices of the number of species per unit area, intraspecific polymorphism index and statistical methods, actively developed for floristic and hydrobiological studies (Dedić et al., 2020).

In order to identify the characteristics of the environment in which the studied flora develops, a bioindicator analysis was carried out in addition to the measured parameters of the environment. Due to lake inaccessibility, the chemical parameters were determined in a very limited composition and characterized the waters of the lake as neutral pH (7.2), fresh, hydrocarbonate class, with a temperature of 16.2°C, and a transparency of about one m. However, bioindication helped us significantly supplement the characteristics of the environment of the studied lake. It turned out that algae most of all mastered the benthic and plankton-benthic lifestyle, however, planktonic species were also found. Groups of acidophiles, low salinity, and eurythermal inhabitants dominated and characterized the waters of the lake as mesotrophic Class 2 of water quality, which is, weakly saturated with organic matter. The uniqueness of the identified flora was manifested in an unusually high proportion of aerophiles that prefer waters significantly enriched with oxygen. Thus, bioindication helped to characterize the waters of the lake as clean, fresh and slightly saturated with organic matter, neutral or slightly acidic pH and moderate in temperature, and the lake itself as mesotrophic with a unique species composition of non-diatom algae.

CONCLUSION

The study of the species composition of the lentic water bodies of Yakutia has been carried out for a number of years. The floras of lakes can more accurately characterize the influence of macro climatic parameters on the process of the flora formation, while river floras are subject to influences associated with the flow and change of latitude. The flora of the lake on the Suntar-Khayat ridge turned out to be rich, including 170 species of non-diatom algae, comparable in richness to the flora of Lake Aalakh, but differing so much in the composition of the identified species that even unlike it, it formed a special cluster among the 10 compared lake floras. The uniqueness was formed by the dominance of the species composition of Charophytes in general and the genera *Cosmarium* and *Closterium*, in particular. Bioindicator characteristics demonstrated a significant number of aerophilic species that prefer oxygen-enriched waters. The calculation of floristic parameters showed a uniquely low intraspecific polymorphism with an index Ssp/Sp = 1.006, comparable with the desert and mountain floras of Israel and the Caucasus. Thus, the monospecificity of the flora and its adherence to waters enriched with oxygen revealed the influence of the mountainous desert climate on the formation of the flora of non-diatoms, and the Charophytes genera *Cosmarium* and *Closterium*, as the most adapted to these conditions.

ACKNOWLEDGEMENTS

The work was carried out within the framework of the project "Plant cover of Cryolithozone of taiga Yakutia: biodiversity, environment-forming functions, protection and rational use", No. 0297-2021-0023, registration number AAAA-A21-121012190038-0, of the Institute of Biological Problems of Cryolithozone of the Siberian Branch of the Russian Academy of Sciences. This work was partly supported by the Israeli Ministry of Aliyah and Integration.

REFERENCES

1. Barinova S. and Niyatbekov T., 2018 – Alpha-biodiversity of nondiatom algae in the Pamir aquatic habitats, Tajikistan. *Biodiversity International Journal*, 2, 3, 210-237.
2. Barinova S., 2017a – Essential and practical bioindication methods and systems for the water quality assessment, *International Journal of Environmental Sciences and Natural Resources*, 2, 3, 1-11, https://doi.org/10.19080/IJESNR.2017.02.555588.
3. Barinova S., 2017b – Influence of macro-environmental climatic factors on distribution and productivity of freshwater algae, *International Journal of Environmental Sciences and Natural Resources*, 4, 1, 555629, doi: 10.19080/IJESNR.2017.04.555629.
4. Barinova S. and Alster A., 2021 – Algae and cyanobacteria diversity and bioindication of long-term changes in the Hula Nature Reserve, Israel, *Diversity*, 13, 11, 583, https://doi.org/10.3390/d13110583.
5. Barinova S., 2011 – The effect of altitude on distribution of freshwater algae in continental Israel, *Current Topics in Plant Biology*, 12, 89-95.
6. Barinova S., Gabyshev V., Boboev M., Kukhaleishvili L. and Bilous O., 2015 – Algal indication of climatic Gradients, *American Journal of Environmental Protection, Special Issue, Applied Ecology: Problems, Innovations*, 4, 3-1, 72-77, doi: 10.11648/j.ajep.s.2015040301.22.
7. Barinova S. and Stenina A. 2013 – Ecological adaptation of diatoms in the Arctic lakes of the Kostyanoi Nos Cape (Nenezky Natural Reserve, Russian North), *Plant Biosystems*, 147, 2, 397-410.
8. Barinova S. S., Kukhaleishvili L., Nevo E. and Janelidze Z., 2011 – Diversity and ecology of algae in the Algeti National Park as a part of the Georgian system of protected areas, *Turkish Journal of Botany*, 35, 729-774, doi: 10.3906/bot-1009-83.
9. Barinova S. S., Medvedeva L. A. and Anissimova O. V., 2006 – Diversity of algal indicators in environmental assessment, Tel Aviv, Pilies Studio, 458. (in Russian)
10. Barinova S., Bilous O. and Tsarenko P. M., 2019 – Algal indication of water bodies in Ukraine: methods and perspectives, Haifa University Publishing House, Haifa, Kiev, 367. (in Russian)
11. Dedić A., Gerhardt A., Kelly M. G., Stanić-Koštroman S., Šiljeg M., Kalamujić Stroil B., Kamberović J., Mateljak Z., Pešić V., Vučković I., Snigirova A., Bogatova Y., Barinova S., Radulović S., Cvijanović D., Lasić A., Škobić D., Sudar A., Mrđen D. and Herceg N., 2020 – Innovative methods and approaches for WFD: ideas to fill knowledge gaps in science and policy, *Water Solutions*, 3, 30-42.
12. Denisov D. B. and Barinova S., 2016 – Phytoperiphyton and environmental variables in the rivers of the Kola Peninsula, Russian Arctic North, *Issues of Modern Algology*, 1, 11, 1-16, http://www.algology.ru/957.
13. Denisov D. B. and Barinova S., 2015 – Algal diversity and ecological variables in the Arctic lakes of the Kola Peninsula, Russian North, *Issues of Modern Algology*, 2, 9, 1-47, http://algology.ru/742.
14. Dokulil M. T., 2003 – Algae as ecological bioindicators, in Market B. A., Breure A. M. and Zechmeistter H. G. (eds), Bioindicators and biomonitors, Elsevier, Oxford, UK, 285-327.

15. Gabysheva O. I., Gabyshev V. A. and Barinova S., 2022 – Influence of the active layer thickness of permafrost in Eastern Siberia on the river discharge of nutrients into the Arctic Ocean, *Water*, 14, 1, 84, https://doi.org/10.3390/w14010084.
16. Guiry M. D. and Guiry G. M., 2021 – AlgaeBase, World-wide electronic publication, Galway, Ireland: National University of Ireland, Galway (online), http://www.algaebase.org (accessed January 2022).
17. Izyumenko S. A. (ed.), 1966 – Meteorological handbook of USSR, 24, Yakutian ASSR, 2, The temperature of air and soil, Gidrometeoizdat, Leningrad, Russia, 398. (in Russian)
18. Kiselev I. A., 1935 – Phytoplankton of the lakes of Central Yakutia based on limnological survey 1932, in: Studies of the lakes of the USSR, Publishing in State Hydrologycal Institute, Leningrad, Moscow, Russia, 51-84. (in Russian)
19. Komarenko L. E. and Vasilyeva I. I., 1975 – Freshwater diatoms and blue-green algae of Yakutia water bodies, Nauka, Moscow, Russia, 423. (in Russian).
20. Komarenko L. E. and Vasilyeva I. I. 1978 – Freshwater green algae of water bodies of Yakutia, Nauka, Moscow, Russia, 284. (in Russian).
21. Komulainen S. F., 2003 – Methodical recommendations for the study of phytoperiphyton in small rivers, KarRC RAS, Petrozavodsk, Russia, 43.
22. Kopyrina L., Pshennikova E. and Barinova S., 2020 – Diversity and ecological characteristic of algae and cyanobacteria of thermokarst lakes in Yakutia (northeastern Russia), *Oceanological and Hydrobiological Studies*, 49, 2, 99-122, doi: https://doi.org/10.1515/ohs-2020-0010.
23. Kopyrina L. I., 2014 – Epiphytic algae of the lakes of the Tuymaada valley in Central Yakutia, Nauka, Novosibirsk, Russia, 100. (in Russian)
24. Krupa E. G., Barinova S. S., Romanova S. M. and Malybekov A. B., 2016 – Hydrobiological assessment of the high mountain Kolsay lakes (Kungey Alatau, Southeastern Kazakhstan) ecosystems in climatic gradient, *British Journal of Environment and Climate Change*, 6, 4, 259-278, doi:10.9734/BJECC/2016/26496.
25. Love J., Selker R., Marsman M., Jamil T., Dropmann D., Verhagen A. J., Ly A., Gronau Q. F., Smira M., Epskamp S., Matzke D., Wild A., Rouder J. N., Morey R. D. and Wagenmakers E. J., 2019 – JASP: graphical statistical software for common statistical designs, *Journal of Statistical Software*, 88, 2, 1-17, doi:10.18637/jss.v088.i02.
26. Pestryakova L. A., 2008 – Diatom complexes of lakes of Yakutia, Publishing house of YSU, Yakutsk, Russia. (in Russian)
27. Potapova M. G., Hamilton P. B., Kopyrina L. I. and Sosina N. K., 2014 – New and rare diatom (Bacillariophyta) species from a mountain lake in Eastern Siberia, *Phytotaxa*, 156, 3, 100-116.
28. Șahin B., Akar B. and Barınova S., 2020 – Cohabitant charophyte algal flora and its ecology in high-mountain lakes of the Artabel Lakes Nature Park (Gümüşhane, Turkey), *Botanica Serbica*, 44, 1, 11-25, doi: https://doi.org/10.2298/BOTSERB2001011S.
29. Troeva E., Isaev A., Cherosov M. and Karpov N. (eds), 2010 – The far north: plant biodiversity and ecology of Yakutia, 3, Springer, Dordrecht, Germany.
30. Tsarenko P. M., Bilous O. P., Kryvosheia-Zakharova O. M., Lilitska H. H. and Barinova S., 2021 – Diversity of algae and cyanobacteria and bioindication characteristics of the Alpine Lake Nesamovyte (Eastern Carpathians, Ukraine) from 100 years ago to the present, *Diversity*, 13, 256, https://doi.org/10.3390/d13060256.
31. Vasilyeva I. I., 1989 – Analysis of the species composition and dynamics of the development of algae in water bodies of Yakutia, YANTS Publisher SB USSR Academy of Sciences, Yakutsk, Russia, 48. (in Russian)
32. *, 1989 – Handbook, Naukova Dumka, Kiev, 608. (in Russian)
33. **, 1992 – Guidelines for hydrobiological monitoring of surface ecosystems, Gidrometeoizdat, SPb, Russia, 318. (in Russian)

ASSESSMENT OF CHAROPHYTA FLORA AND ECOLOGICAL STATUS IN TWO HIGH-MOUNTAIN LAKES (RIZE, TURKEY)

Bülent ŞAHİN * and *Sophia BARINOVA* **

* Trabzon University, Department of Biology Education, Fatih Education Faculty, Söğütlü-Trabzon, Turkey, TR-61335, bulentsahin61@gmail.com, ORCID: 0000-0002-5477-9676.
** Institute of Evolution, University of Haifa, Mount Carmel, Abba Khoushi Avenue, 199, Haifa, Israel, IL-3498838, sophia@evo.haifa.ac.il, ORCID: 0000-0001-9915-2503.

DOI: 10.2478/trser-2022-0003

KEYWORDS: charophyte algae, high-mountain lakes, systematics, bioindicators, trophic state, Turkey.

ABSTRACT

The benthic algal composition of Charophyta in the Avusor Great Lake and Koçdüzü Great Lake at the altitude of about 3,000 m a.s.l. was investigated on 21 August 2019. A total of 112 species, belonging to Zygnematophyceae, were identified. The genera *Cosmarium* (44), *Staurastrum* (16), *Closterium* (15), and *Euastrum* (13) were most abundant. The members of filamentous charophyta were represented by two species. Bioindicator species characterize water in both lakes as clear, Class 2 of water quality and the lakes ecosystem as mesotrophic. The partly unexpected presence of certain desmids taxa, i.e., species characteristic of eutrophic water, was recorded.

ZUSAMMENFASSUNG: Bewertung der Charophyta-Flora und des ökologischen Zustands in zwei Hochgebirgsseen (Rize, Türkei).

Die benthische Algenzusammensetzung von Charophyta im Großen See Avusor und im Großen See Koçdüzü auf einer Höhe von ungefähr 3.000 m ü. wurde am 21 August 2019 untersucht. Insgesamt wurden 112 Arten identifiziert, die zu den Zygnematophyceae gehören. Am häufigsten waren die Gattungen *Cosmarium* (44), *Staurastrum* (16), *Closterium* (15) und *Euastrum* (13). Die Mitglieder der filamentösen Charophyta wurden durch zwei Arten vertreten. Bioindikatorarten charakterisieren das Wasser in beiden Seen als klar, Klasse 2 der Wasserqualität und das Seenökosystem als mesotroph. Das teilweise unerwartete Vorkommen bestimmter Desmidtaxa, d. h. Arten, die für eutrophes Wasser charakteristisch sind, wurde aufgezeichnet.

REZUMAT: Evaluarea florei charophyta și a stării ecologice în două lacuri de munte de altitudine (Rize, Turcia).

Compoziția algelor bentonice din Charophyta din Marele Lac Avusor și Marele Lac Koçdüzü la altitudinea de aproximativ 3.000 m a fost investigat la 21 august 2019. Au fost identificate în total 112 specii, care aparțin grupului Zygnematophyceae. Cele mai abundente au fost genurile *Cosmarium* (44), *Staurastrum* (16), *Closterium* (15) și *Euastrum* (13). Membrii charophytelor filamentoase au fost reprezentați de două specii. Speciile bioindicatoare caracterizează apa atât din lac ca limpede, clasa 2 de calitate a apei, cât și lacul ca ecosistem ca fiind mezotrof. A fost înregistrată prezența parțial neașteptată a anumitor taxoni de desmidii, adică specii caracteristice apei eutrofice.

INTRODUCTION

The Eastern Black Sea region is one of the most important ecological regions of Turkey and of the world. The region has a rich diversity of flora and fauna, including many endemic species. Therefore, it is among the world's 25 biologically richest terrestrial ecoregions (WWF and IUCN, 1994). It is characterized by its very humid and mild climate (Polat and Sunkar, 2017), high mountains, mountain lakes, streams, ponds, swamps, fens, and waterfalls. This extensive hydrographic network provides a variety of habitats for algae. High mountain lakes, which are far from the influences of humans, are perfect hosts especially for desmids.

In general, studies on the freshwater algae of the Eastern Turkish Black sea region are focused on the provinces of Artvin, Gümüşhane, Bayburt, Trabzon, Giresun, and Ordu (Şahin, 1998a; Maraşlıoğlu et al., 2017; Şahin et al., 2010, 2020; Taş and Hamzaçebi, 2020). As a result of these studies, 122 new records of algal species were added to the freshwater algal flora of Turkey (Şahin, 1994, 1998b, 2000a, 2002, 2007, 2009; Şahin and Akar, 2007, 2018, 2019a, b; Akar and Şahin, 2014; Şahin 2021a, b). One hundred and six of them belong to the desmids. This number proves the importance of the desmid studies carried out in the region. However, considering the current freshwater potential, it is also realised that the information on desmid biodiversity in the region is not sufficient.

Although it has 200 lakes and many streams, studies have been carried out on the algae of two lakes and one stream of the Rize province so far (Şahin, 2001; Demirel, 2013; Taş and Yılmaz, 2015). The aim of this study is to give information about the systematic and ecological characteristics of the species belonging to the Charophyta phylum in the algae community of two high mountain lakes in the province of Rize. The lakes are of glacial origin, are covered with ice for at least eight months a year and are located in the high mountain zone (2,382-2,687 m a.s.l.). It is not possible to completely (i.e., seasonally) describe the Charophyta flora due to the difficulty of sampling throughout the year, so we chose several lakes for sampling during one season, in which the expedition is carried out in difficult relief and climatic conditions.

MATERIAL AND METHODS

Description of study site

Rize is surrounded by the Rize Mountains with an altitude of 3,000 m from the south, Paşakuyusu from the east and Kambursırtı hills from the West (Fig. 1). Due to these geographical conditions, Rize has a very different position in the Black Sea coastal zone in terms of climatic characteristics. In Rize, which has very humid and mild climate characteristics, the soil is always moist, the vegetation is very bushy and green. The annual average temperature in Rize is 14.3°C, and the annual average precipitation is 2,254.4 mm. The lowest temperature was measured as 3.4ºC in February and the highest temperature as 26.7ºC in August (Polat and Sunkar, 2017).

Historically, the mountains of the Eastern Black Sea region are one of the places where glaciers most often develop, formed in the highlands of Anatolia due to the cold climatic conditions that existed during the Quaternary glaciation. There are many glacial lakes in this mountain system with a height of nearly 4,000 m (for example, the Kaçkar Mountains 3,937 m). Rize province, which has approximately 200 lakes, is also included in this mountain system (Demirel, 2013).

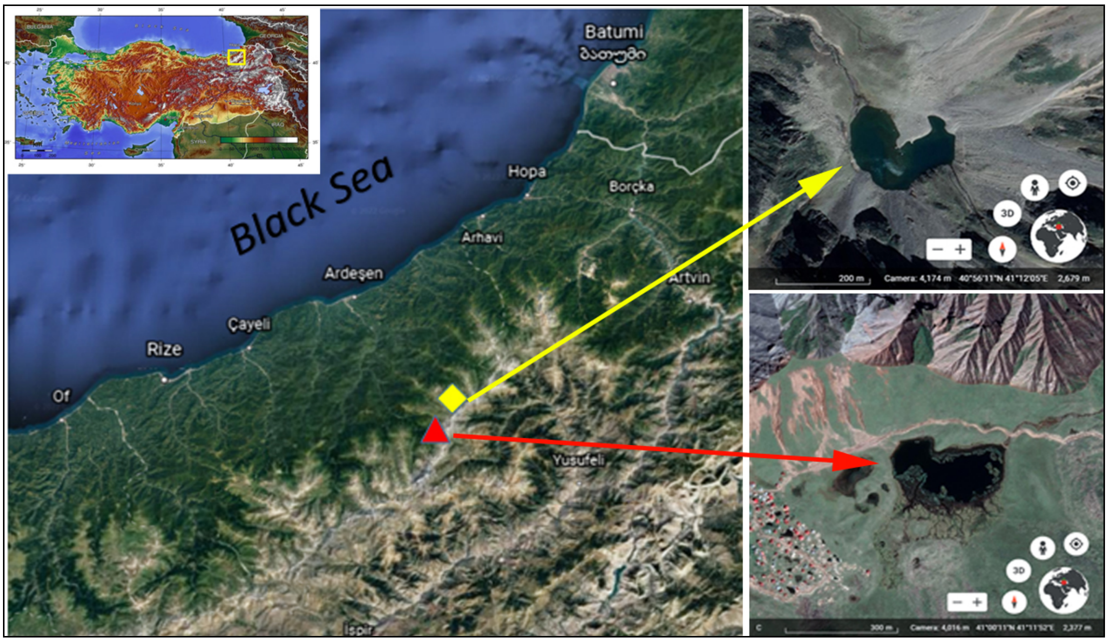


Figure 1: The location of the study area (Turkey elevation map, 2020).
Yellow square – the Avusor Great Lake; Red triangle – Koçdüzü Great Lake.

Sampling and laboratory study

The algae and water samples were taken from Avusor Great Lake (Fig. 2) and Koçdüzü Great Lake (Fig. 3) in Çamlıhemşin District. Avusor Great Lake is located at 40°56’11”N-41°12’01”E coordinates. It has an area of 2.2422 ha and is situated at an altitude of 2,678 m a.s.l. Koçdüzü Büyük Lake has an area of 8.1896 ha. and is located at an altitude of 2,382 m a.s.l. and is located at 41°00’15”N-41°11’53”E.

The bioindication methods were used for revealing the ecological response of the Charophyta species to the environment of each studied lake (Barinova, 2017). Bioidicator properties of species were taken from Barinova et al. (2006, 2019).

Benthic algal samples were taken from Avusor Great Lake and Koçdüzü Great Lake on 21 August 2019. Epipelic algae were taken with a glass tube from the surface of the sediments of the both lakes. Epilithic samples were taken from only Avusor Great Lake and scraped from randomly chosen stones with a toothbrush and washed into plastic bottles. Epiphytic species were collected by squeezing out the macrophytes (*Potamogeton* sp. and *Juncus* sp.) from only Koçdüzü Great Lake (Round, 1953; Sládečková, 1962). All samples were preserved with 4% (v/v) formaldehyde in 100 mL plastic bottles. Water temperature, dissolved oxygen, conductivity and pH were measured in the field using Thermo Orion-4-Star pH and YSI-55 portable meters. Analyses of other hydrochemical parameters were carried out in the DSI General Directorate Laboratories DSI 22nd Regional Directorate Quality Control and Laboratory Branch Office. In the lab, samples were examined on temporary slides under a light microscope (Leica DM 2500) and each species was photographed using a Leica MC170 HD camera attached to the microscope. The abundance estimation was made according to a 6-point scale (Barinova and Medvedeva, 1996), 1 – “single” with 1–5 cells per slide, 2 – “rare” with 10–15 cells, 3 – “common” with 25–30 cells, 4 – “frequent” with one cell over a slide transect, 5 – “very frequent” several cells over a slide transect, 6 – “abundant” with one or more cells in each field of view.

Figure 2: Avusor Great Lake.

Figure 3: Koçdüzü Great Lake.

Relevant books (Schmidle, 1895), West and West (1904, 1905, 1908, 1912, 1923), Ruzicka (1977), Lind and Brook (1980), Förster (1982), Croasdale et al. (1986, 1988, 1994), Ling and Tyler (1986), Dillard (1990, 1991a, b, 1993), Bourrelly and Coute (1991), Lenzenweger (1996, 1997, 1999), Kouwets (1997), Dingley (2001), John et al. (2003), Brook and Williamson (2010), Štastny (2010), Coesel and Meesters (2007, 2013), Kim (2012, 2015) were used for identification of the species. The current status of nomenclature of all taxa identified has been checked in the Algaebase website (Guiry and Guiry, 2021).

RESULTS AND DISCUSSION

Physical and chemical variables

Considering the physico-chemical analysis results of the waters, we can say that Avusor Büyük Lake has neutral water and Koçdüzü Büyük Lake has alkaline water. The conductivity values of the Avusor and Koçdüzü Great Lakes are 45.3 µS/cm and 104.7 µS/cm, respectively. Total dissolved matter value in the Avusor Great Lake is higher than Koçdüzü Great Lake. While nitrate and nitrate nitrogen are found in Avusor Great Lake, they are absent in Koçdüzü Great Lake. Magnesium is not found in either lake. The concentrations of ammonium nitrogen and nitrite nitrogen are almost the same in both lakes. The concentrations of phosphate in both lakes are small (Tab. 1).

Table 1: Averaged physical and chemical data of the Avusor Büyük Lake and Koçdüzü Büyük Lake; (–) could not be detected.

Parameters \ Lakes	Avusor Büyük Lake	Koçdüzü Büyük Lake
Temperature (°C)	15.9	21
Dissolved oxygen (mg/L)	10.2	9.2
pH	7.58	8.45
Conductivity (µS/cm)	45.3	104.7
Total Dissolved Matter (mg/L)	28.01	6.88
Potassium (mg/L)	0.18	0.23
Total Hardness $CaCO_3$ (mg/L)	18.96	12.94
Calcium (mg/L)	5.53	3.12
Magnesium (mg/L)	–	–
Ammonium (mg/L)	0.14	0.16
Chloride (mg/L)	6.31	10.78
Nitrate (mg/L)	1.092	–
Nitrite (mg/L)	0.083	0.081
Ammonium nitrogen (mg/L)	0.11	0.12
Nitrate nitrogen (mg/L)	0.247	–
Nitrite nitrogen (mg/L)	0.025	0.024
Medium phosphate (mg/L)	0.07	0.072
Phosphate (P_2O_5) (mg/L)	0.0525	0.054

Taxonomy and ecology of Charophyta species in studied lakes

At the end of the study, from both lakes 112 Charophyta members were identified, which are belonging to Closteriaceae, Desmidiaceae, Peniaceae, Mesotaeniaceae, and Zygnemataceae families (Tabs. 2 and 3; Figs. 4-6).

Table 2: List of Charophyta in the Avusor Great Lake and Koçdüzü Great Lake with species abundance, habitat preferences and ecological properties. H: Habitat, 1: Epipelic, 2: Epilithic, 3: Epiphytic, AGL: Avusor Great Lake, KGL: Koçdüzü Great Lake, *: New record for Turkey. A: Abundance: Single = 2; Rare = 1. Ecological groups: Hab, substrate preferences, B, benthic, P-B, plankto-benthic, P, planktonic; Oxy, Oxygen indicators, aer, aerophiles, st-str, slowly moving waters, st, standing waters; Hal, salinity indicators, hb, halophobes, i, indifferent, pH, water pH indicators, acf, acidophiles, ind, indifferents, alf, alkaliphiles, Tro, trophic state indicators, ot, ologotrophic, om, oligo-mesotrophic, m, mesotrophia, me, meso-eutropjic, e, eutropjic, Sap, saprobity indicators, x-o, xeno-oligosaprobiont, x, xenosaprobiont, x-b, xeno-betamesosaprobiont, o-x, oligo-xenosaprobiont, o, oligosaprobiont, o-b, oligo-betamesosapronient, o-a, oligo-alphasaprobiont. “–” property is unknown.

Charophyta species	H	AGL	KGL	A	Hab	Oxy	Hal	pH	Tro	Sap	Index S
Actinotaenium cucurbita (Brébisson ex Ralfs) Teiling	1	0	1	2	P-B	aer	–	acf	ot	x-b	0.90
**Actinotaenium cucurbitinum* (Bisset) Teiling	3	0	1	2	P-B	–	–	acf	om	–	–
Actinotaenium curtum (Brébisson ex Ralfs) Teiling ex Růžička and Pouzar	3	0	1	2	P-B	aer	–	ind	om	x-b	0.90
**Actinotaenium rufescens* (Cleve) Teiling	1	0	1	2	B	–	–	acf	m	–	–
Actinotaenium spinospermum (Joshua) Kouwets and Coesel	3	0	1	2	B	–	–	acf	m	–	–
Actinotaenium sp.	3	0	1	2	–	–	–	–	–	–	–
Closterium abruptum West	1, 3	0	1	2	P-B	st-str	-	acf	m	–	–
**Closterium abruptum* f. *nilssonii* (Borge) A. J. Brook and D. B. Williamson	3	0	1	1	–	–	–	–	–	–	–
**Closterium angustatum* Kützing ex Ralfs	1, 3	0	1	1	B	–	–	acf	om	–	–
**Closterium archerianum* var. *pseudocynthia* Ruzicka	3	0	1	2	B	–	–	acf	m	–	–
**Closterium baillyanum* (Brébisson ex Ralfs) Brébisson	1, 3	0	1	2	B	–	–	ind	om	–	–
Closterium calosporum Wittrock	3	0	1	2	B	–	–	acf	m	–	–
**Closterium closterioides* var. *intermedium* (J. Roy and Bisset) Ruzicka	1, 3	0	1	2	B	–	–	acf	om	o-x	0.70
**Closterium dianae* var. *brevius* (S. P. Petkoff) Willi Krieger	3	0	1	2	–	–	–	–	–	–	–
Closterium exiguum West and G. S. West	3	0	1	2	–	–	–	–	–	–	–
Closterium juncidum Ralfs	3	0	1	2	P-B	–	hb	acf	om	–	–
Closterium lunula Ehrenberg and Hemprich ex Ralfs	1	0	1	2	B	–	–	ind	m	x-b	0.80
Closterium macilentum Brébisson	1	0	1	2	P-B	st-str	i	ind	me	–	–
Closterium navicula (Brébisson) Lütkemüller	1, 3	0	1	2	P-B	–	–	acf	om	o-x	0.70
Closterium ralfsii var. *hybridum* Rabenhorst	3	0	1	2	P-B	–	hb	acf	m	x-o	0.50
Closterium rostratum Ehrenberg ex Ralfs	1	0	1	2	B	aer	–	ind	m	o-x	0.70
**Cosmarium amoenum* Brébisson ex Ralfs	1, 3	0	1	1	B	–	–	acf	om	–	–

Table 2 (continued): List of Charophyta in the Avusor Great Lake and Koçdüzü Great Lake with species abundance, habitat preferences and ecological properties.

Charophyta species	H	AGL	KGL	A	Hab	Oxy	Hal	pH	Tro	Sap	Index S
C. bipunctatum Børgesen	1	0	1	0	–	–	–	–	–	–	–
Cosmarium botrytis Meneghini ex Ralfs	1, 3	0	1	2	P-B	st-str	i	ind	m	o-a	1.90
Cosmarium botrytis var. *tumidum* Wolle	1	0	1	2	P-B	–	–	ind	m	o-a	1.90
**Cosmarium caelatum* Ralfs	1	0	1	2	B,aer	aer	–	ind	m	–	–
**Cosmarium canaliculatum* West and G. S. West	3	0	1	2	–	–	–	–	om	–	–
**Cosmarium connatum* Brébisson ex Ralfs	3	0	1	1	B	–	–	acf	m	–	–
Cosmarium contractum O. Kirchner	1	0	1	2	B	–	–	acf	om	–	–
Cosmarium contractum var. *ellipsoideum* (Elfving) West and G. S. West	3	0	1	2	–	–	–	–	–	–	–
**Cosmarium debaryi* W. Archer	3	0	1	2	P-B	–	hb	ind	m	–	–
**Cosmarium difficile* var. *messikommeri* (Croasdale) Kouwets	3	0	1	2	–	–	–	–	–	–	–
Cosmarium holmiense var. *integrum* P. Lundell	1	1	0	2	B,aer	aer	–	acf	m	–	–
Cosmarium laeve Rabenhorst	1, 2	1	1	2	P-B	st-str	hb	ind	me	o-a	1.90
Cosmarium majae Ström	1	1	0	2	P	–	–	ind	me	–	–
Cosmarium margaritiferum Meneghini ex Ralfs	1, 3	0	1	2	B	–	i	acf	m	–	–
Cosmarium neodepressum var. *minutum* (Heimerl) G. J. P. Ramos and C. W. N. Moura	3	0	1	2	–	–	–	–	–	–	–
Cosmarium notabile var. *transiens* Insam and Willi Krieger	1	1	0	2	B, aer	–	–	acf	m	–	–
Cosmarium obtusatum (Schmidle) Schmidle	1, 3	1	1	2	B	–	i	ind	me	o	1.30
**Cosmarium porteanum* var. *nephroideum* Wittrock	1, 3	0	1	1	–	–	–	ind	m	–	–
Cosmarium praemorsum Brébisson	3	0	1	2	P-B	-	hb	acf	m	o	1.20
**Cosmarium pseudoconnatum* Nordstedt	3	0	1	2	–	–	–	acf	om	–	–
Cosmarium pseudoornatum B. Eichler and Gutwinski	1	0	1	2	B	–	–	acf	m	–	–
Cosmarium pseudopyramidatum P. Lundell	3	0	1	2	B	–	–	acf	om	–	–
Cosmarium punctulatum Brébisson	3	0	1	2	P-B	–	hb	ind	m	o	1.30
Cosmarium punctulatum var. *subpunctulatum* (Nordstedt) Børgesen	1, 3	1	1	2	B	–	–	ind	me	o	1.30
Cosmarium pyramidatum Brébisson ex Ralfs	1, 3	0	1	2	B	–	–	acf	om	o	1.30
Cosmarium raeticum Messikommer	1	0	1	2	–	–	–	acf	m	–	–
Cosmarium regnellii var. *pseudoregnellii* (Messikommer) Willi Krieger	1, 3	0	1	2	B	–	–	acf	m	–	–
Cosmarium reniforme (Ralfs) W. Archer	3	0	1	2	P-B	st-str	hb	ind	me	o	1.00

Table 2 (continued): List of Charophyta in the Avusor Great Lake and Koçdüzü Great Lake with species abundance, habitat preferences and ecological properties.

Charophyta species	H	AGL	KGL	A	Hab	Oxy	Hal	pH	Tro	Sap	Index S
**Cosmarium retusiforme* (Wille) Gutwinski var. *retusiforme*	1, 3	0	1	1	–	–	–	acf	m	–	–
**Cosmarium retusiforme* var. *incrassatum* Gutwinski	1, 3	0	1	2	–	–	–	acf	m	–	–
Cosmarium sportella Brébisson ex Kützing	3	0	1	2	B	–	–	ind	e	–	–
**Cosmarium staurastroides* Eichler and Gutwinski	1, 3	0	1	2	–	–	–	acf	ot	–	–
Cosmarium subcostatum Nordstedt	1, 3	1	1	2	P-B	–	i	ind	e	–	–
Cosmarium subcostatum var. *minus* (West and G. S. West) Kurt Förster	1, 3	0	1	2	B	–	–	ind	m	–	–
Cosmarium subcrenatum Hantzsch	1	1	0	2	B,aer	aer	–	acf	m	o	1.10
**Cosmarium subcucumis* Schmidle	1, 3	0	1	2	B	–	–	acf	m	–	–
Cosmarium transitorium (Heimerl) Ducellier	1, 3	0	1	2	–	–	–	acf	m	–	–
Cosmarium vogesiacum Lemaire	1, 3	0	1	2	B	–	–	acf	m	–	–
Cosmarium verrucosum var. *alatum* (Wolle) J. D. Hall and K. Karol	3	0	1	2	–	–	–	–	–	–	–
Cosmarium sp. 1	1	0	1	2	–	–	–	–	–	–	–
Cosmarium sp. 2	2	0	1	2	–	–	–	–	–	–	–
Cosmarium sp. 3	1	0	1	2	–	–	–	–	–	–	–
Cosmarium sp. 4	3	0	1	2	–	–	–	–	–	–	–
Desmidium swartzii C. Agardh ex Ralfs	1, 3	0	1	2	B	–	i	ind	m	o-x	0.60
Euastrum aemoenum F. Gay	1, 3	0	1	2	P-B	–	–	acf	om	x-o	0.40
Euastrum ansatum Ehrenberg ex Ralfs	1	0	1	2	P-B	–	–	acf	om	x-o	0.50
Euastrum bidentatum Nägeli	1, 3	0	1	2	P-B	–	hb	ind	m	o-x	0.60
**Euastrum elegans* Ralfs	3	0	1	2	P-B	–	hb	acf	m	x-o	0.50
**Euastrum humerosum* Ralfs var. *humerosum*	1	1	1	2	B	–	–	acf	om	x-o	0.50
Euastrum humerosum var. *affine* (Ralfs) Raciborski	1	1	1	2	B	–	–	acf	om	x-o	0.50
Euastrum insulare (Wittrock) J. Roy	1	0	1	2	P-B	–	hb	acf	om	o-x	0.60
Euastrum luetkemuelleri var. *carniolicum* (Lütkemüller) Willi Krieger	1	0	1	2	B	–	–	acf	m	x-o	0.50
Euastrum oblongum Ralfs	1, 3	1	1	2	B	–	–	acf	m	o-x	0.60
**Euastrum pulchellum* Brébisson	1, 3	0	1	2	B	–	–	acf	m	o-x	0.60
**Euastrum turneri* West	3	0	1	2	B	–	–	acf	m	o-x	0.60
Euastrum sp. 1	3	0	1	2	–	–	–	–	–	x-o	0.50
Euastrum sp. 2	3	0	1	2	–	–	–	–	–	x-o	0.50
**Micrasterias americana* var. *boldtii* Gutwinski	1	1	0	2	B	–	–	acf	m	x	0.30
**Micrasterias papillifera* Brébisson ex Ralfs	1, 3	0	1	2	B	–	–	acf	m	x-b	0.90

Table 2 (continued): List of Charophyta in the Avusor Great Lake and Koçdüzü Great Lake with species abundance, habitat preferences and ecological properties.

Charophyta species	H	AGL	KGL	A	Hab	Oxy	Hal	pH	Tro	Sap	Index S
Micrasterias rotata Ralfs	1	0	1	2	B	–	–	acf	m	x	0.30
**Micrasterias thomasiana* var. *notata* (Nordstedt) Grönblad	1, 3	0	1	2	B	–	–	acf	om	x	0.30
Micrasterias truncate Brébisson ex Ralfs	1, 3	1	1	2	B	–	–	acf	om	x-b	0.90
Netrium digitus (Brébisson ex Ralfs) Itzigsohn and Rothe	1, 3	0	1	2	P-B	–	i	acf	om	x-o	0.50
Penium cylindrus Brébisson ex Ralfs	1	0	1	2	B	–	–	acf	om	x-o	0.40
Penium margaritaceum Brébisson	1	0	1	2	B	–	–	ind	om	x-o	0.40
Penium polymorphum (Perty) Perty	1	0	1	2	B	st	–	acf	om	x-o	0.40
**Penium spirostriolatum* J. Barker	1	0	1	2	B	–	–	acf	om	x-o	0.50
Pleurotaenium trabecula Nägeli	1, 3	0	1	2	P-B	–	i	ind	me	o	1.20
Spirogyra sp. 1	3	0	1	2	P-B	–	–	alf	e	–	–
Spirogyra sp. 2	1	1	0	2	P-B	–	–	alf	e	–	–
**Staurastrum aculeatum* Meneghini ex Ralfs	3	0	1	2	B	–	–	acf	om	–	–
**Staurastrum acutum* Brébisson	3	0	1	2	–	–	–	acf	om	–	–
Staurastrum anatinum Cooke	3	0	1	2	P	–	i	-	om	–	–
Staurastrum bieneanum Rabenhorst	1	0	1	2	B	–	–	acf	m	–	–
Staurastrum boreale West and West	1	0	1	2	B	–	–	ind	m	–	–
**Staurastrum forficulatum* P. Lundell	3	0	1	2	–	–	–	acf	m	–	–
**Staurastrum heimerlianum* var. *spinulosum* Lütkemüller	3	0	1	2	–	–	–	acf	m	–	–
Staurastrum lapponicum (Schmidle) Grönblad	1	1	0	2	B	–	–	ind	m	–	–
Staurastrum pilosum Brébisson	1	1	0	2	P-B	st-str	–	acf	m	–	–
Staurastrum punctulatum Brébisson	1, 2, 3	1	1	2	P-B	st-str	i	ind	om	o	1.20
**Staurastrum spongiosum* Brébisson ex Ralfs var. *spongiosum*	3	0	1	2	B,aer	aer	–	acf	om	o	1.00
**Staurastrum spongiosum* var. *perbifidum* West	3	0	1	2	B, aer	aer	–	acf	om	o	1.00
**Staurastrum teliferum* Ralfs	1, 3	0	1	2	–	–	–	–	–	–	–
Staurastrum tetracerum Ralfs ex Ralfs	1	1	0	2	P-B	st-str	i	ind	m	o-b	1.50
**Staurastrum tohopekaligense* Wolle	1	0	1	2	–	–	–	acf	om	–	–
Staurastrum sp.	1	0	1	2	–	–	–	–	–	b-o	1.60
Staurodesmus dejectus Teiling	3	0	1	2	P-B	–	hb	ind	om	o-b	1.50
**Staurodesmus octocornis* (Ehrenberg ex Ralfs) Stastny, Skaloud and Neustupa	1, 3	0	1	2	P-B	–	hb	acf	om	x-b	0.90
Teilingia granulate (J. Roy and Bisset) Bourrelly	3	0	1	2	P-B	–	–	ind	m	–	–
Tetmemorus laevis Ralfs ex Ralfs	1	0	1	2	B,aer	aer	–	ind	om	x-o	0.50

Table 3: Taxonomic content of Charophyta species in the Avusor Great Lake (AGL) and Koçdüzü Great Lake (KGL).

Phylum	Charophyta	AGL	KGL
Class	Zygnematophyceae		
Subclass	Zygnematophycidae		
Order	Desmidiales		
Family	Closteriaceae		
Genus	*Closterium*	0	15
Family	Desmidiaceae		
Genus	*Actinotaenium*	0	6
Genus	*Cosmarium*	8	40
Genus	*Desmidium*	0	1
Genus	*Euastrum*	3	13
Genus	*Micrasterias*	2	4
Genus	*Pleurotaenium*	0	1
Genus	*Staurastrum*	4	14
Genus	*Staurodesmus*	0	2
Genus	*Teilingia*	0	1
Genus	*Tetmemorus*	0	1
Family	Peniaceae		
Genus	*Penium*	0	4
Order	Zygnematales		
Family	Mesotaeniaceae		
Genus	*Netrium*	0	1
Family	Zygnemataceae		
Genus	*Spirogyra*	1	1
Total		18	104

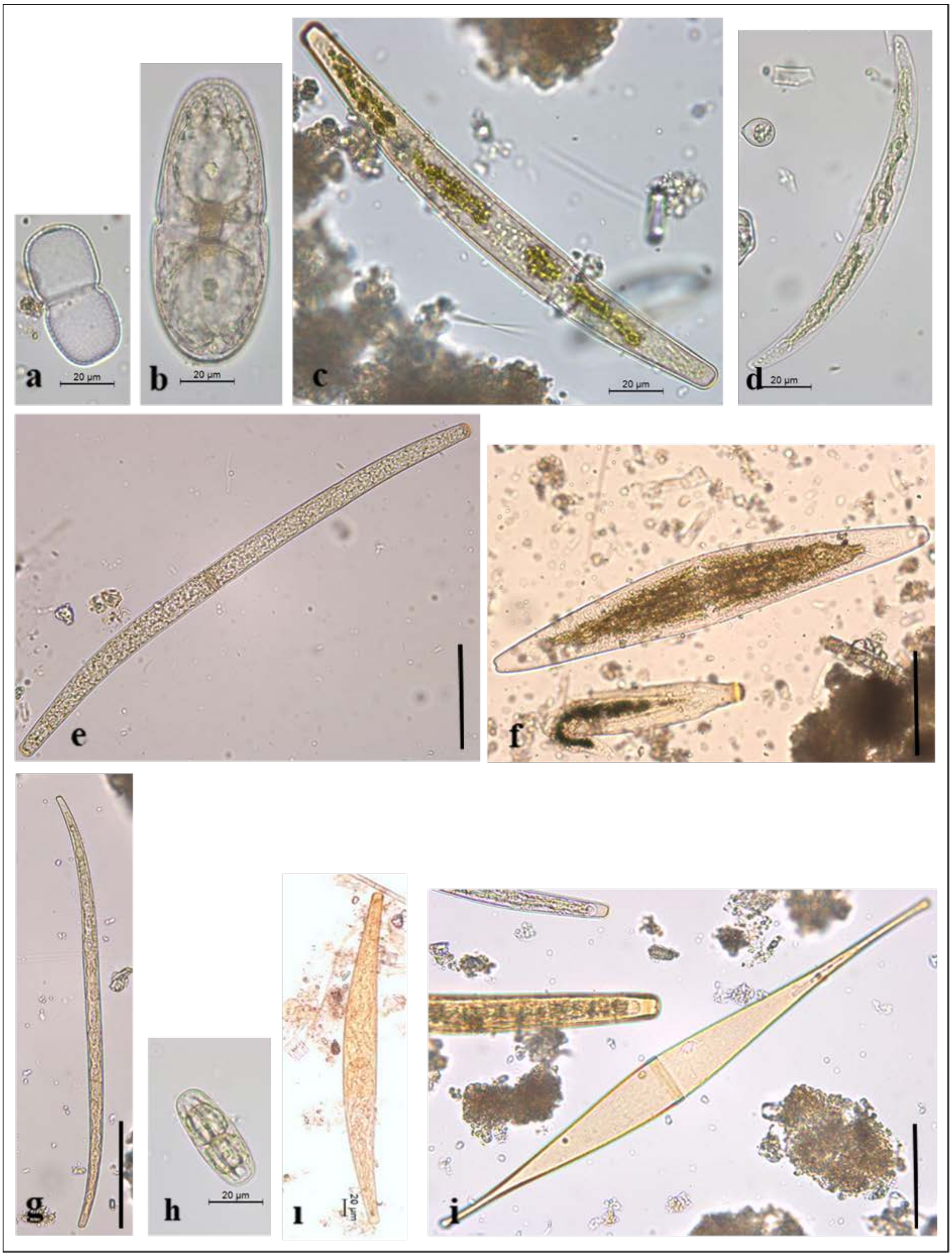


Figure 4: a. *Actinotaenium cucurbita*, b. *A. curtum*, c. *Closterium abruptum*, d. *Cl. calosporum*, e. *Cl. juncidum*, f. *Cl. lunula*, g. *Cl. macilentum*, h. *Cl. navicula*, ı. *Cl. ralfsii* var. *hybridum*, i. *Cl. Rostratum*; scale bar: 20µm.

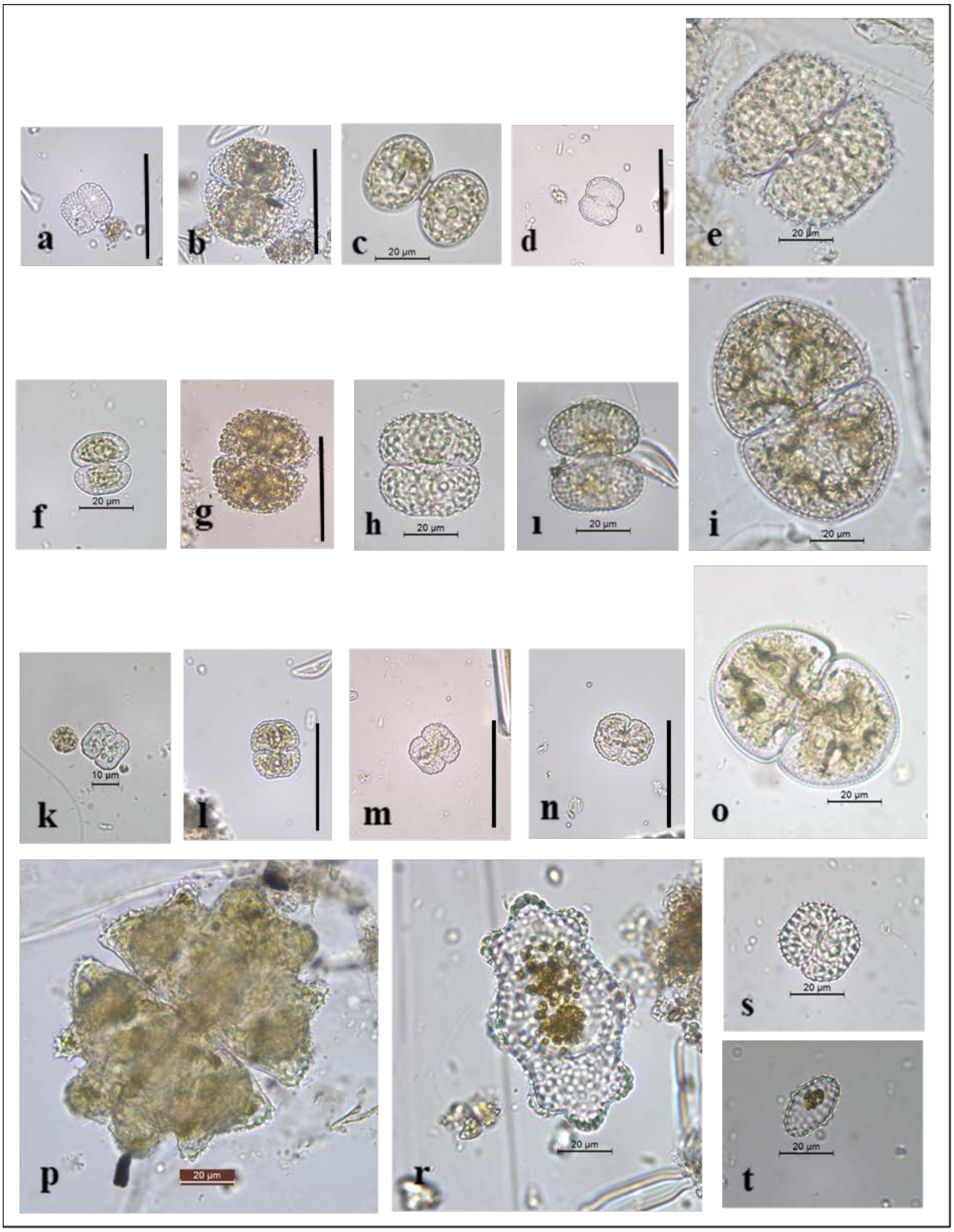


Figure 5: a. *Cosmarium bipunctatum*, b. *C. botrytis* var. *tumidum*, c. *C. contractum*, d. *C. laeve*, e. *C. margaritiferum*, f. *C. neodepressum* var. *minutum*, g. *C. praemorsum*, h. *C. pseudoornatum*, ı. *C. punctulatum* var. *subpunctulatum*, i. *C. pyramidatum*, k. *C. regnellii* var. *pseudoregnellii*, l. *C. subcostatum*, m. *C. subcostatum* var. *minus*, n. *C. subcrenatum*, o. *C. transitorium*, p. *C. verrucosum* var. *alatum* (r. apical view), s. *C. vogesiacum* (t. apical view); scale bar: 20µm.

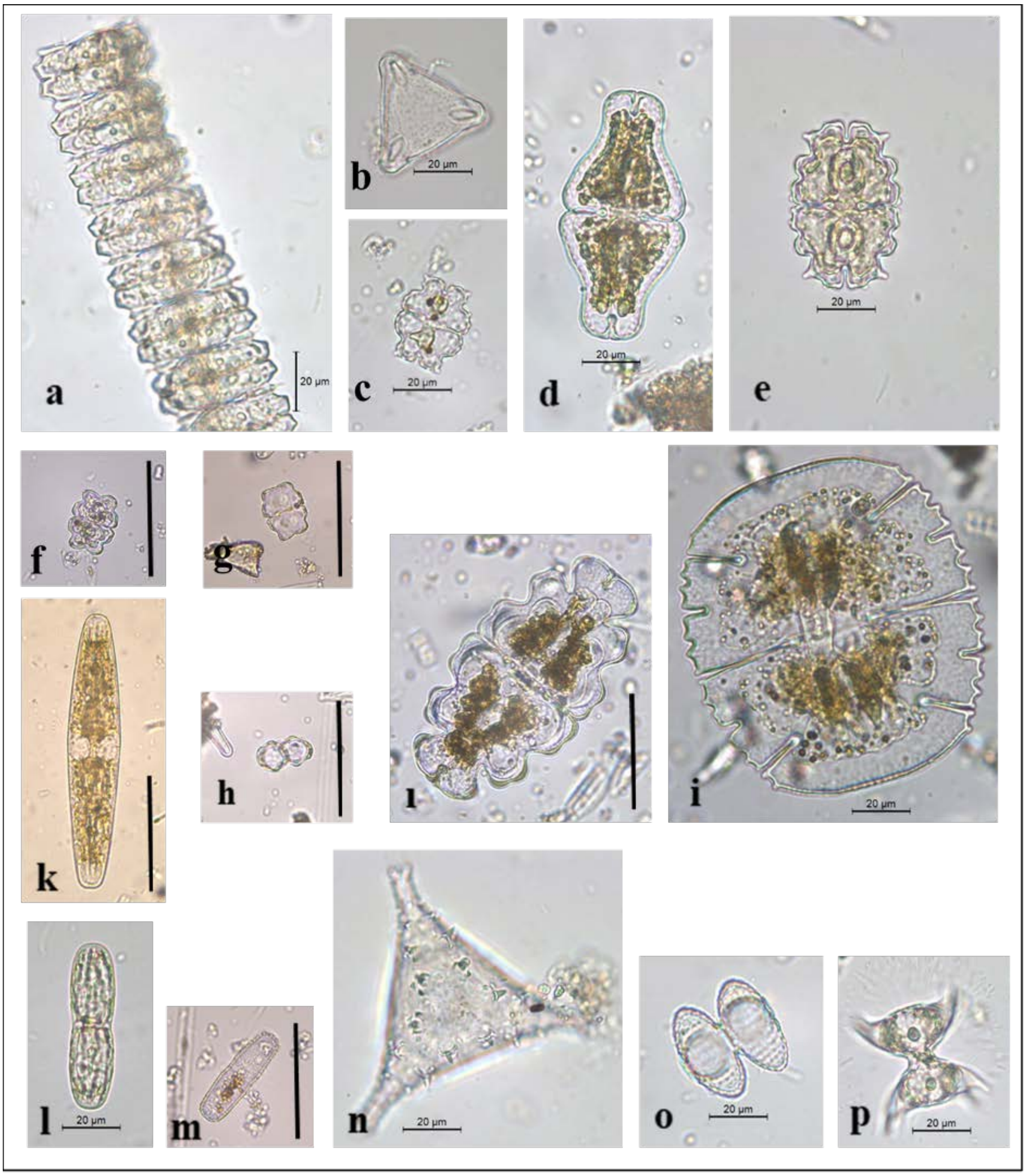


Figure 6: a. *Desmidium swartzii* (b. Apical view), c. *Euastrum aemoenum*, d. *E. ansatum*, e. *E. bidentatum*, f. *E. insulare*, g. *E. luetkemuelleri* var. *carniolicum* (h. Apical view), ı. *E. oblongum*, i. *Micrasterias truncata*, k. *Netrium digitus*, l. *Penium cylindrus*, m. *P. margaritaceum*, n. *Staurastrum anatinum*, o. *S. punctulatum*, p. *Staurodesmus dejectus* var. *dejectus*; scale bar: 20µm.

The families Desmidiaceae and Closteriaceae are dominant groups. This is not surprising, because similar results have been obtained in the other studies conducted in the region (Şahin, 2000b, 2001; Şahin et al., 2020). Also, literature have stated that these families are most diverse in the northern mountainous regions (Sterlyagova, 2008; Stepankovič et al., 2008; Šovran et al., 2013). These families represented 93.75% of the total species, while others were 6.19%.

The highest diversity of species was observed in *Cosmarium* (44 species), *Staurastrum* (16 species), *Closterium* (15 species), and *Euastrum* (13) (Tabs. 2 and 3). These four genera account for 78.57% of all identified species. Such taxonomic composition is typical to the northern European, Russian and Turkish regions (Luknitskaya, 2006; Stamenkovič et al., 2008; Şahin et al., 2020). *Pleurotaenium* and *Teillingia* are also among the typical genera of mountainous regions in the north (Coesel, 1996). But in this study, they were represented by one species each (Tab. 2). Twenty-four species, twelve varieties and one form of the identified desmids were recorded for the first time in Turkey. These species are marked with an asterix (*) in table 2. Detailed knowledge about the species was given in a separate paper (Şahin, 2021b).

The species such as *Actinotaenium cucurbitinum*, *Closterium angustatum*, *Cl. rostratum*, *Cosmarium connatum*, *C. debaryi*, *C. pseudoconnatum*, *Micrasterias papillifera*, *Penium cylindrus*, *P. spirostriolatum*, *Staurastrum aculeatum*, *S. anatinum*, and *S. spongiosum* var. *spongiosum* are included in the Red List of the Netherlands (Coesel, 1998).

The desmid flora of both lakes was represented by a high proportion of cosmopolitan species (91.96% of total desmids taxa number). There were also some holarctic, boreal, boreal-arctic, arctic-alpine, alpine elements such as *Actinotaenium cucurbita*, *A. cucurbitinum*, *A. rufescens*, *Cosmarium amoenum*, *C. debaryi*, *C. sportella*, *Euastrum bidentatum*, *Penium polymorphum*, and *Tetmemorus leavis*, which highlighted the northern character of the desmid flora (Coesel, 1996; Brook and Johnson, 2003; Lenzenweger, 1996, 1997, 1999; Kosteviciene et al., 2003; Sterlyagova, 2008). The existence of these species informs us that lakes are affected by glaciers (Stamenković et al., 2008; Fužınato et al., 2011a, b).

Environmental bioindicators

Ecological response to the environment in both studied lakes was characterised with indicator content in lake communities (Tab. 2) in respect to six variables (Figs. 7 and 8). It can be seen that in charophyte communities of the both lakes, benthic species prevailed (Fig. 7a), preferring well oxygenated water in AGL, but middle oxygen-saturated in KGL (Fig. 7b), very fresh water in KGL but low salinity in AGL (Fig. 7c), and low acidic to neutral pH in both lakes (Fig. 7d). It is known that Charophyte species of Class Zygnematophyceae are indicators of acidic waters (Coesel, 1996; Barinova et al., 2006, 2019), so we can see differences in table 1 data about water pH and bioindication but also very low abundance in acidophilic species (Tab. 2).

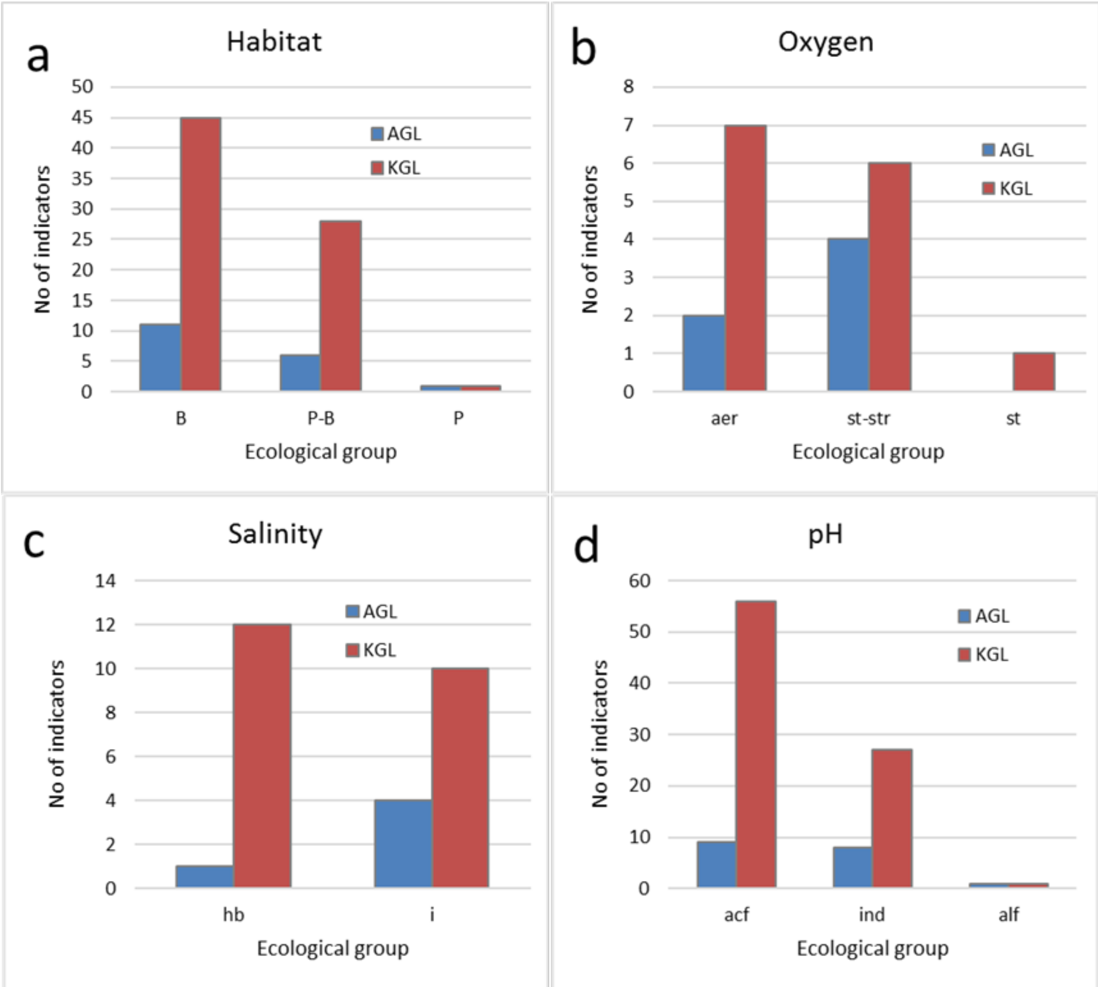


Figure 7: Indicator taxa distribution in the ecological groups of Habitat (substrate) preferences (a), Oxygen (b), Salinity (c), and water pH (d) in the Avusor Great Lake (AGL) and Koçdüzü Great Lake (KGL); abbreviation of ecological groups as in table 2.

Algae-indicators of trophic state

Trophic state of the lake usually correlates to organic matter saturation. In our lakes it can be seen that in both lakes there were an abundance of indicators of clear waters Class 2 of water quality (Fig. 8a). At the same time, trophic state indicators in communities of each lake indicator belong to groups of mesotrophic and oligo-mesotrophic species (Fig. 8b). Mesotrophic desmids, which are 22.32% of all desmid species, are dominant in the desmid community of both lakes. In total, oligotrophic, oligo-mesotrophic and meso-oligotrophic inhabitants comprised 29.46% of all desmid species. On the other hand, meso eutrophic and oligo-eutrophic desmids were also recorded. However, they represented a small share in the desmid community (4.46%). Therefore, bioindicator species distribution over ecological groups allow us to conclude that water in both lakes is clear, Class 2 of water quality and the lakes ecosystem can be characterised as mesotrophic.

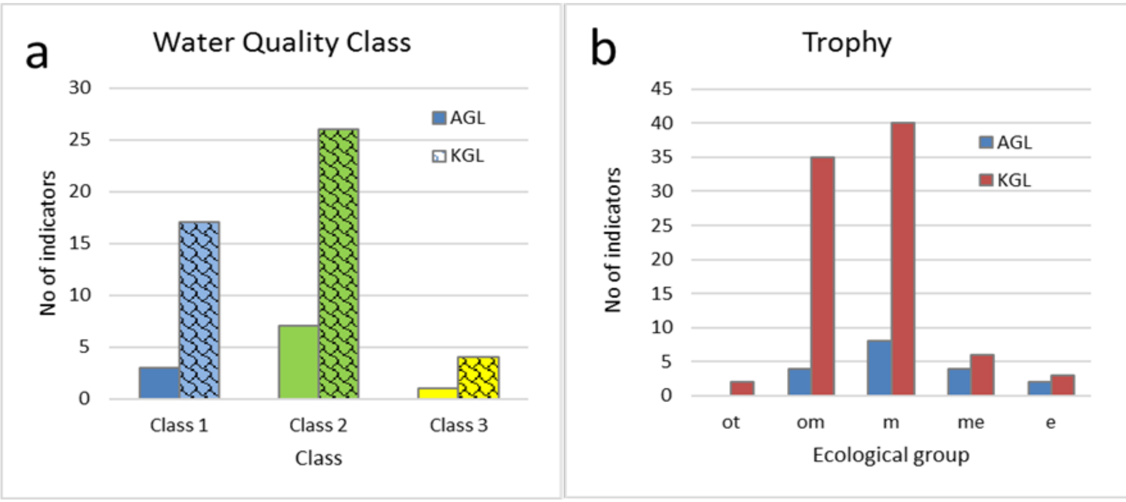


Figure 8: Indicator taxa distribution in the ecological groups of Water Quality Class (a), and Trophic state (b) in the Avusor Great Lake (AGL), and Koçdüzü Great Lake (KGL); abbreviation of ecological groups as in table 2.

According to the results of the physico-chemical analyses, it is concluded that the lakes are circum-neutral and alkaline, soft-water ecosystems with low mineral content (Tab. 1). It is remarkable to identify a high number of desmid species, especially from Koçdüzü Great Lake, which has alkaline water (Tab. 2). The same situation has been identified in Southern Hungary (Feher, 2003) and Northern Serbia (Stamenkovic and Cvijan, 2008). Another interesting result is that some acidic desmid species (e.g. *Closterium archenianum* var. *pseudocynthia*, *Actinotaenium rufescens*, *Cosmarium pseudoconnatum*, *C. raeticum*, *C. retusiforme* var. *incrassatum*, *C. staurostroides*, *Euastrum elegans*, *E. humerosum*, *E. pulchellum*, *E. turneri*, *Staurastrum aculeatum*, *S. forficulatum*, *S. heimerlianum* var. *spinulosum*, *S. spongiosum* var. *spongiosum*, *S. spongiosum* var. *perbifidum*, *S. subradians*, *S. teliferum*, *S. tohopekaligense*, and *Staurodesmus octocornis*) are detected in alkaline water. The fact that both lakes are far from human influence and their physico-chemical analysis parameters have low values may have contributed to the development of this desmid community. In addition, it should not be forgotten that these desmids may reach the lakes by its mountain tributaries and have successfully adapted to this pH value.

CONCLUSIONS

This study reveals that the Eastern Black Sea region houses a well developed desmid flora that has so far been insufficiently investigated. Altogether 112 species of Charophyta were revealed in two high-mountain lakes at an altitude of abut 3,000 m a.s.l. The Koçdüzü Great Lake community was richest with 104 species whereas in Avusor Great Lake 18 species were found only. Thirty-four species turned out to be new records to the flora of Turkey. Bioindicator species characterize water in both lakes as clear, Class 2 of water quality and the lakes ecosystem as mesotrophic. The partly unexpected presence of certain desmid species characteristic of eutrophic water was recorded. The present investigation has also shown that species-specific ecological demands in this part of Turkey may deviate significantly from those in other parts of Turkey.

ACKNOWLEDGEMENTS

This work was partly supported by Trabzon University as well as partly supported by the Israeli Ministry of Aliya and Integration.

REFERENCES

1. Akar B. and Şahin B., 2014 – New desmid records of Karagol Lake in Karagol-Sahara National Park (Şavşat-Artvin/Turkey), *Turkish Journal of Fisheries and Aquatic Sciences,* 14, 269-274.
2. Barinova S. S. and Medvedeva L. A., 1996 – Atlas of algae as saprobic indicators (Russian Far East), Dal'nauka Press, Vladivostok, 364. (in Russian)
3. Barinova S. S., Medvedeva L. A. and Anissimova O. V., 2006 – Diversity of algal indicators in environmental assessment, Tel Aviv, Pilies Studio, 458. (in Russian)
4. Barinova S., Bilous O. and Tsarenko P. M., 2019 – Algal indication of water bodies in Ukraine: methods and perspectives, Haifa University Publishing House, Haifa, Kiev, 367. (in Russian)
5. Barinova S., 2017 – Essential and practical bioindication methods and systems for the water quality assessment, *International Journal of Environmental Sciences and Natural Resources*, 2, 555-588.

6 Bourrelly P. and Couté A., 1991 – Desmidiees de Madagascar (Chlorophyta, Zygophyceae), Cramer J., Stuttgart, 348.

7. Brook A. J. and Johnson L. R., 2003 – Order Zygnematales, The freshwater algal flora of British Isles (Eds. John D. M., Whitton B. A. and Brook A. J.), 479-530. The British Phycological Society, the Natural History Museum, Cambridge University Press, Cambridge.
8. Brook A. J. and Williamson D. B., 2010 – A monograph on some British Desmids, Ray Society, London, 364.
9. Climate data for cities worldwide. Climate Çamlihemşin (Turkey), Accessed 18 January 2022, available https://en.climate-data.org/asia/turkey/rize/caml%c4%b1hemsin-30517/.
10. Coesel P. M., 1996 – Biogeography of desmids, *Hydrobiologia*, 336, 41-53.
11. Coesel P. F. M., 1998 – Sieralgen en Natuurwaarden, KNNV Publishing, Utrecht, 56. (in Dutch)
12. Coesel P. F. M. and Meesters K. J., 2007 – Desmids of the lowlands Mesotaeniaceae and Desmidiaceae of the European Lowlands, KNNV Publishing, Zeist, 351.
13. Coesel P. F. M. and Meesters K. J., 2013 – European flora of the desmid genera Staurastrum and Staurodesmus, KNNV Publishing, Zeist, 357.
14. Croasdale H. and Flint E. A., 1986 – Flora of New Zealand Desmids, I, Ward V. R., Government Printer, Wellington, 133.
15. Croasdale H. and Flint E. A., 1988 – Flora of New Zealand Desmids, II, Wellington, Ward V. R., Goverment Printer, 147.
16. Croasdale H., Flint E. A. and Racine M. M., 1994 – Flora of New Zealand Desmids, III, Canterbury, Manaaki Whenua Press, 218.
17. Demirel E., 2013 – Buzul Gölleri Kenti Rize, Kaçkar Turizm Birliği, 135. (in Turkish)
18. Dillard G. E., 1990 – Freshwater algae of the Southeastern United States: Part 3, Chlorophyceae: Zygnematales: Zygnemataceae, Mesotaeniaceae and Desmidiaceae, 1, Cramer J., Stuttgart, 172.
19. Dillard G. E., 1991a – Freshwater algae of the Southeastern United States: Part 4, Chlorophycea: Zygnematales: Desmidiaceae, 2, Cramer J., Stuttgart, 205.
20. Dillard G. E., 1991b – Freshwater algae of the Southeastern United States: Part 5, Chlorophyceae: Zygnematales: Desmidiaceae, 3, Cramer J., Stuttgart, 155.
21. Dillard G. E., 1993 – Freshwater algae of the Southeastern United States, 6, Chlorophycea: Zygnematales: Desmidiaceae, 4, Cramer J., Stuttgart, 166.
22. Dingley M., 2001 – Desmids of New South Wales: New species and new records, *Telopea*, 9, 601-637.
23. Feher G., 2003 – The desmid flora of some alkaline lakes and wetlands in Southern Hungary, *Biologia*, 58, 671-683.

24. Förster K., 1982 – Conjugatophyceae Zygnematales und Desmidiales (excl. Zygnemataceae), in Das Phytoplankton des Süßwassers Systematik und Biologie (Band) 8, Teil 1, Hälfte, Stuttgart, E. Schweizerbart'sche Verlangbuchhandlung (Nägele u. Obermiller), 543. (in German)
25. Fužinato S., Cvijan M. and Krizmanić J., 2011a – A checklist of desmids (Conjugatophyceae, Chlorophyta) of Serbia, III, Genus *Staurastrum*, *Cryptogamie*, *Algologie*, 32, 363-377.
26. Fužinato S., Cvijan M. and Stamenković M., 2011b – A checklist of desmids (Conjugatophyceae, Chlorophyta) of Serbia, II, Genus *Cosmarium*, *Cryptogamie* and *Algologie*, 32, 77-95.
27. Guiry M. D. and Guiry G. M., 2021 – AlgaeBase, World-wide electronic publication, Galway, Ireland, National University of Ireland, Galway (online), http://www.algaebase.org (accessed October 2021).
28. John D. M., Whitton B. A. and Brook A. J., 2003 – The freshwater algal flora of the British Isles: An identification guide to freshwater and terrestrial algae, Cambridge, Cambridge University Press, 702.
29. Kim H. S., 2012 – Algal flora of Korea, 6, 1, Republic of Korea National Institute of Biological Resources Ministry of Environment, Incheon, 94.
30. Kim H. S., 2015 – Algal flora of Korea, 6, 6, Republic of Korea National Institute of Biological Resources Ministry of Environment, Incheon, 95.
31. Kouwets F. A. C., 1997 – Contributions to the knowledge of the French Desmid Flora, I, New and noteworty taxa from the Central and Eastern Pyrenees, *Archiv Für Protistenk unde*, 148, 33-51.
32. Lenzenweger R., 1996 – Desmidiaceenflora von Östereich, 1, Bibliotheca Phycologica, 101, Stutgart, Cramer, J. 162. (in German)
33. Lenzenweger R., 1997 – Desmidiaceenflora von Östereich, 2, Bibliotheca Phycologica, 102, Stutgart, Cramer J., 216. (in German)
34. Lenzenweger R., 1999 – Desmidiaceenflora von Östereich, 3, Bibliotheca Phycologica, 104, Stutgart, Cramer J., 218. (in German)
35. Lind E. M. and Brook A. J., 1980 – Desmids of the English Lake District, Cumbria, Freshwater Biological Association Scientific Publication, 123.
36. Ling H. U. and Tyler P. A., 1986 – A limnological survey of the Alligator Rivers Region, II, Freshwater algae, exclusive of diatoms, Australian Government Publishing Service, Canberra, 173.
37. Maraşlıoğlu F., Soylu E. N. and Karaca S. A., 2017 – Seasonal and spatial variation of epilithic algal community in Batlama Stream (Giresun, Turkey), *Hittite Journal of Science and Engineering*, 4, 39-44.
38. Polat P. and Sunkar M., 2017 – The climatic characteristics of Rize and the trend analyses of long-term temperature and precipitation data around Rize, *The Journal of International Social Sciences*, 27, 1-23.
39. Round F. E., 1953 – An investigation of two benthic algal communities in Malharm Tarn, Yorkshire, *Journal of Ecology*, 41, 174-197.
40. Ruzicka J., 1977 – Die desmidiaceen Mitteleuropas, 1, Stuttgart, E. Schweizerbart'sche Verlangbuchhandlung (Nägele u. Obermiller), 292. (in German)
41. Schmidle W., 1895 – Beiträge zur alpinen algenflora, *Österreichische Botanische Zeitschrift*, 45, 249-253. (in German)
42. Sládečková A., 1962 – Limnological investigation methods fort he periphyton ("Aufwuchs") community, *Botanical Review*, 28, 286-350.
43. Šovran S., Jovanovič V., Krizmanič J. and Cvijan M., 2013 – Desmid flora from four peat bogs in Serbia, *Archives of Biological Sciences*, 65, 721-732.
44. Stamenkovič M., Cvijan M. and Fužinato S., 2008 – Achecklist of desmids (Conjugatophyceae, Chlorophyta) of Serbia, *Cryptogamie*, 29, 325-347

45. Stamenkovič M. and Cvijan M., 2008 – Some new and interesting ecological observations on desmids from the Province of Vojvodina (Northern Serbia), *Biologia*, 63, 921-927.
46. Štastny J., 2010 – Desmids (Conjugatophyceae, Viridiplantae) from the Czech Republic; new and rare taxa, distribution, ecology, *Fottea*, 10, 1-74.
47. Sterlyagova I. N., 2008 – Desmids in mountain lakes of the subpolar Urals, *Biologija*, 63, 951-920.
48. Şahin B., 1994 – A new record for the algal flora of Turkey, *Turkish Journal of Botany*, 18, 515-516.
49. Şahin B., 1998a – A study on the benthic algae of Uzungöl (Trabzon), *Turkish Journal of Botany*, 22, 171-189.
50. Şahin B., 1998b – Some new records of desmids from Turkey, *Pakistan Journal of Botany*, 30, 7-13.
51. Şahin B., 2000a – Some new records for the freshwater algal flora of Turkey, *Flora Mediterranea*, 10, 223-226.
52. Şahin B., 2000b – Algal flora of Lakes Aygır and Balıklı (Trabzon, Turkey), *Turkish Journal of Botany*, 24, 35-45.
53. Şahin B., 2001 – Epipelic and epilithic algae of Dağbaşı Lake (Rize-Turkey), *Turkish Journal of Botany* 25, 187-194.
54. Şahin B., 2002 – Contribution to the desmid flora of Turkey, *Algological Studies*, 107, 39-48.
55. Şahin B., 2007 – Two new records for the freshwater algae of Turkey, *Turkish Journal of Botany*, 31, 153-156.
56. Şahin B., 2009 – Contribution to the desmid flora of Turkey, *Turkish Journal of Botany*, 33, 457-460.
57. Şahin B. and Akar B., 2007 – The desmid flora of some high mountain lakes of the Turkish Eastern Black Sea Region, *Pakistan Journal of Botany*, 39, 1817-1832.
58. Şahin B., Akar B. and Bahçeçi İ., 2010 – Species composition and diversity of epipelic algae in Balık Lake (Şavşat-Artvin, Turkey), *Turkish Journal of Botany*, 34, 441-448.
59. Şahin B. and Akar B., 2018 – Nine new records from high mountain lakes (Artabel Lakes Nature Park, Gümüşhane/Turkey) for the freshwater diatom flora of Turkey, *Biological Diversity and Conservation*, 11, 56-63.
60. Şahin B. and Akar B., 2019a – New desmid records from high mountain lakes in Artabel Lakes Nature Park, Gümüşhane, Turkey, *Turkish Journal of Botany*, 43, 570-583.
61. Şahin B. and Akar B., 2019b – New records from Artabel Lakes Nature Park (Gümüşhane/Turkey) to the freshwater algal flora of Turkey, *Turkish Journal of Botany*, 43, 135-142.
62. Şahin B., Akar B. and Barinova S., 2020 – Cohabitant charophyte algal flora its ecology in high-mountain lakes of the Artabel Lakes Nature Park (Gümüşhane, Turkey), *Botanica Serbica*, 44, 11-25.
63. Şahin B., 2021a – A new record for the freshwater algal flora of Turkey, *Bağbahçe Bilim Dergisi*, 8, 27-31.
64. Şahin B., 2021b – New desmid records from two high mountain lakes in Çamlıhemşin/Rize (Turkey), *Botanica Serbica*, 45, 273-284.
65. Taş B. and Yılmaz Ö., 2015 – Epilithic algal diversity of Cimil Stream (Rize, Turkey), *Türk Tarım-Gıda Bilim ve Teknoloji Dergisi*, 3, 826-833.
66. Taş B. and Hamzaçebi E. Ş., 2020 – Assessment of algal diversity and hydrobiological preliminary results in a high-mountain lake (Karagöl Lake, Giresun Mountains, Turkey), *Review of Hydrobiology*, 13, 11-38.
67. Turkey elevation map, accessed 18 January 2022, available https://maps-turkey.com/img/0/turkey-elevation-map.jpg
68. West W. and West G. S., 1904 – A monograph of the British Desmidiaceae, I, London, printed for the Ray Society

69. West W. and West G. S., 1905 – A monograph of the British Desmidiaceae, II, London, printed for the Ray Society, 204.
70. West W. and West G. S., 1908 – A Monograph of the British Desmidiaceae, III, London, printed for the Ray Society, 274.
71. West W. and West G. S., 1912 – A monograph of the British Desmidiaceae, IV, London, Printed for the Ray Society, 194.
72. West W. and West G. S., 1923 – A Monograph of the British Desmidiaceae, V, London, printed for the Ray Society, 300.
73. WWF, IUCN, 1994 – Centers of Plant Diversity, A guide and strategy for their conservation, 1, Europe, Africa, South West Asia and the Middle East, Cambridge, UK, IUCN Publications Unit.

A REVIEW OF CURRENT KNOWLEDGE ON PARASITES OF NON-INDIGENOUS FISH SPECIES IN THE INLAND WATERS OF TURKEY

Deniz INNAL * and *Mala-Maria STAVRESCU-BEDIVAN* **

* Mehmet Akif Ersoy University, Department of Biology, Burdur, Turkey, TR-15030, innald@gmail.com, ORCID: 0000-0002-1686-0959.

** University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Agriculture, Department of Plant Protection, Mărăşti Boulevard 59, Bucharest, Romania, RO-011464, mala_stavrescu@yahoo.com, ORCID: 0000-0001-9825-417X.

DOI: 10.2478/trser-2022-0004

KEYWORDS: parasite, endemic fish species, exotic fish species, Turkey.

ABSTRACT

The parasite fauna of alien fish species living in the new habitats has rarely been investigated and there is still poor information about this topic.

This research not only provides a thorough list of parasite taxa found in non-indigenous fish species in Turkey, but it highlights the risk of infection for both native and alien ichthyofauna.

With respect of native range, exotic fishes imported into Turkey have been found to be hosts for parasities from Eurasian, Asian, and North American origins, respectively.

RÉSUMÉ: Une revision des connaissances actuelles sur les parasites des espèces de poissons non indigènes dans les eaux intérieures de la Turquie.

La faune parasitaire des espèces de poissons exotiques vivant dans les nouveaux habitats a été rarement étudiée et il y a encore peu d'informations sur ce sujet.

Cet article fournit non seulement une liste de contrôle complète sur les différents taxons de parasites des espèces de poissons non indigènes de Turquie, mais en même temps, met en évidence le risque d'infection pour l'ichtyofaune indigène et aussi pour l'ichtyofaune invasive.

En ce qui concerne la zone de répartition natale, on a été montré que les poissons exotiques introduits en Turquie sont des hôtes à la fois pour les parasites d'origine eurasienne ou d'origine asiatique et nord-américaine, respectivement.

REZUMAT: O revizuire a cunoştinţelor actuale despre paraziţii speciilor de peşti neindigeni din apele interioare ale Turciei.

Fauna parazită a speciilor de peşti străini introduşi în habitate noi a fost rareori investigată şi există încă informaţii sporadice despre acest subiect.

Această lucrare oferă nu numai o listă de verificare cuprinzătoare a diferiţilor taxoni de paraziţi ai speciilor de peşti neindigeni din Turcia ci, în acelaşi timp, evidenţiază riscul de infecţie pentru ihtiofauna nativă şi, de asemenea, pentru ihtiofauna invazivă.

În legătură cu arealul nativ, s-a arătat că peştii exotici introduşi în Turcia sunt gazde atât pentru paraziţi de origine eurasiatică, cât şi pentru cei cu origine asiatică şi nord-americană.

INTRODUCTION

Freshwater fish are threatened by many factors, such as habitat degradation and fragmentation, species introductions and translocations, impoundment of rivers, water quality deterioration as well as overexploitation (Cowx and Collares-Pereira, 2002).

Non-native fish species have been intentionally introduced in numerous regions of the world for various reasons and by several vectors, such as sport, food, biocontrol, ornamental, contaminated stock, escapes from cage aquaculture, or man-made water connections (Welcomme, 1988; Copp et al., 2005a; Canning-Clode, 2015; Tarkan et al., 2015). Non-indigenous fish introductions in freshwater resources can result in extremely severe issues, including: wide borders of tolerance, competition with indigenous species, parasitism, emergence of new diseases, predation, hybridization, alteration of habitat quality, and ecosystem health (Kumar, 2000; Copp et al., 2005b; Emiroğlu, 2011).

Anthropochore movements of host population are important in the dispersal of their helminth parasites in new habitats (Kennedy et al., 1991; Kennedy, 2006). Intensive modern aquaculture caused increased introduction and translocation of infectious pathogens, considered to be serious threats to aquatic biodiversity and management of fisheries (Gozlan et al., 2006; Reading et al., 2011). The colonization, establishment, and pathogenicity of introduced parasites are influenced by numerous biotic and abiotic factors (Kennedy, 1994).

A variety of alien and translocated fish species have been introduced into inland waters of Turkey in the past (Çetinkaya, 2006; Innal and Erk'akan, 2006). Tarkan et al. (2015) postulated that Turkey introduced 30 fish species, of which 11 species represent translocations. The main reason for introduction of aquatic species in Turkey is for the purpose of aquaculture, followed by ornamental fish production, recreational fisheries, and fisheries improvement. There have been reports concerning the release of many aquarium fishes into spring water and the severe impact on native biota (Emiroğlu et al., 2016).

There is still limited information in the studied area about the parasite fauna of non-native fish species introduced in new habitats. Öktener (2014a, b) provided a list of freshwater and marine fish parasites from Turkey, excluding parasitic helminths and crustaceans. Some alien parasite species such as Asian fish tapeworm, *Schyzocotyle acheilognathi*, and Eel swimbladder nematode, *Anguillicoloides crassus*, are widespread and have been recorded on native fish species (Genç, 2005; Çolak et al., 2012; Innal et al., 2016; Innal et al., 2018; Hansen and Alarcón, 2019). This research provides an overview of the current state of knowledge on various groups of parasites with different origin recorded in alien fish species living in Turkish freshwater bodies.

MATERIAL AND METHODS

This study scanned the scientific data of the inland waters of Turkey. The following systems were considered: closed (laboratory), farm in creek, dam lake, or natural lake. A checklist comprising parasite species, alien fish host species, native range, and species authorship was compiled based on available scientific literature. For those taxa for which sufficient data regarding the origin of the parasite and their status was uncertain, the checklist includes "unknown" or "limited data". The mentioned parasites belong to alien species living in natural waters, and some parasites have been detected under aquaculture conditions. Some parasites of *Oncorynchus mykiss* (Walbaum, 1792) and *Salvelinus fontinalis* (Mitchill, 1814) have been reported from the marine environment. Some references are used in the regulations on taxonomy of fish parasites (Bunkley-Williams and Williams, 1994; Woo et al., 1995; Kirjušina and Vismanis, 2007; Wootten, 2012; Colorni et al., 2014). The scientific and common names for fish species were given according to Fishbase (Froese and Pauly, 2021).

RESULTS AND DISCUSSION

The systematic status and name of fish hosts are listed in table 1, while the check list of parasites of alien fish in Turkey is presented in table 2.

Table 1: Systematic status of non-indigeneous host fish species in Turkey.

No.	Species	Common name	Family
1.	*Lepomis gibbosus* (Linnaeus, 1758)	Pumpkinseed	Centrarchidae
2.	*Oreochromis aureus* (Steindachner, 1864)	Blue tilapia	Cichlidae
3.	*Oreochromis niloticus* (Linnaeus, 1758)	Nile tilapia	Cichlidae
4.	*Sarotherodon galilaeus* (Linnaeus, 1758)	Mango tilapia	Cichlidae
5.	*Coptodon rendalli* (Boulenger, 1897)	Redbreast tilapia	Cichlidae
6.	*Coptodon zillii* (Gervais, 1848)	Redbelly tilapia	Cichlidae
7.	*Carassius auratus* (Linnaeus, 1758)	Goldfish	Cyprinidae
8.	*Carassius gibelio* (Bloch, 1782)	Prussian carp	Cyprinidae
9.	*Pseudorasbora parva* (Temminck and Schlegel, 1846)	Topmouth gudgeon	Gobionidae
10.	*Morone saxatilis* (Walbaum, 1792)	Striped bass	Moronidae
11.	*Morone chrysops* × *Morone saxatilis*	Hybrid bass	Moronidae
12.	*Gambusia holbrooki* (Girard, 1859)	Eastern mosquitofish	Poeciliidae
13.	*Oncorynchus mykiss* (Walbaum, 1792)	Rainbow trout	Salmonidae
14.	*Salvelinus fontinalis* (Mitchill, 1814)	Brook trout	Salmonidae
15.	*Ctenopharyngodon idella* (Valenciennes, 1844)	Grass carp	Xenocyprididae

Parasites occur in alien freshwater fishes both in natural water systems and in aquaculture environments. Parasite species were reported from the following 15 alien fish hosts: *Carassius auratus* (Linnaeus, 1758), *Carassius gibelio* (Bloch, 1782), and *Ctenopharyngodon idella* (Valenciennes, 1844) introduced for the weed control, *Gambusia holbrooki* (Girard, 1859), hybrids of *Morone chrysops* (Rafinesque, 1820) × *Morone saxatilis* (Walbaum, 1792), *Morone saxatilis*, *Lepomis gibbosus* (Linnaeus, 1758), *Oreochromis aureus* (Steindachner, 1864), *Oreochromis niloticus* (Linnaeus, 1758), *Oncorynchus mykiss* (Walbaum, 1792) introduced in many dam lakes, *Pseudorasbora parva* (Temminck and Schlegel, 1846), *Salvelinus fontinalis* (Mitchill, 1814) introduced in fish farming in the Black Sea region, *Sarotherodon galilaeus* (Linnaeus, 1758), *Coptodon rendalli* (Boulenger, 1897) and *Coptodon zillii* (Gervais, 1848).

Some parasite species of these alien fish hosts have been found in aquaculture systems and potentially pose a threat towards species of natural water systems.

According to the present bibliographical research, both protozoans and metazoans major groups of parasitofauna are recorded in non-indigenous fish species of Turkey, as follows: ciliates (eight genera), flagellates (three genera), mixozoans (one species), monogeneans (five genera), cestodes (three genera), digeneans (five genera), acanthocephalans (two genera), nematodes (six genera), annelids (one species), bivalve mollusks (*Glochidium larvae*), and crustaceans (three genera).

In addition to these categories, for the parasitofauna of non-indigenous ichthyofauna representatives in Turkey it can also be mentioned *Sphaerothecum destruens*, a mesomycetozoean fish pathogen (Arkush et al., 2003).

Based on previous published records, the highest numbers of parasites taxa (24) were reported in salmonid *Oncorhynchus mykiss*.

On the other hand, the highest numbers of infected fish hosts (6) related to a specific parasites species were observed in protozoans *Chilodonella piscicola* and *Ichthyophthirius multifiliis*.

While the majority of parasitofauna in freshwater fish of Turkey has an Asian origin (originated mainly in China), seven taxa have an Eurasian origin (*Ichthyobodo necator*, *Chilodonella cyprini*, *Ichthyophthirius multifiliis*, *Apiosoma piscicolum*, *Dactylogyrus minutus*, *Trichodina acuta*, and *Piscicola geometra*, and *Lernaea cyprinacea*), six species are native in Europe (*Trichodina claviformis*, *Trichodina domerquei*, *Ligula intestinalis*, *Crepidostomum farionis*, *Schulmanela petruschewskii*, and *Argulus foliaceus*), and only one parasite species has an North American origin (*Onchocleidus similis* syn. *Urocleidus similis*).

Overall, the most frequently found parasites in freshwater alien fish of Turkey were protozoans. Among them, *Ichyophthirius multifiliis*, *Ichthyobodo necator*, and *Trichodina* spp., are the most important and common in all aquatic systems (Kayış et al., 2013). *I. necator* represents a detrimental species that economically affects the cultured *Oncorhynchus mykiss* (Ogut and Akyol, 2007).

Although the parasites of non-native species are introduced in a new range, it has been hypothesized that native parasites could also infect the non-native fishes (Sheath et al., 2015). Yuryshynets et al. (2019) noted that is difficult to assess whether it is about a co-introduction with the fish host or an acquisition in the new environment, as long as parasites remain unidentified to species level. Sometimes it could be possible that non-indigenous fish invading a local ichthyofauna have transmitted fewer parasite species than they have received from the native hosts (Rauque et al., 2018).

Anguilla anguilla (Linnaeus, 1758) is a threatened species of brackish water systems in Turkey. It is native and has an economic value. Some alien parasite such as *Anguillicoloides crassus* Kuwahara, Niimi and Itagaki 1974 affect the health status of this fish species, producing inflammations and hemorrhages in the swimbladder. The nematode *A. crassus* arrived from Asia to Mediterranean countries at the beginning of 1980s, with Japanese eel, *Anguilla japonica* (Innal et al., 2018). Moreover, in estuarine habitats of Turkey, another Asian parasite, namely the monogenean *Pseudodactylogyrus anguillae* (Yin and Sproston, 1948) Gusev, 1965 was reported on the gills of *A. anguilla* (Çolak et al., 2012).

Another highly invasive parasite species that cause massive fish kills is *Schyzocotyle acheilognathi* (Yamaguti, 1934), a cestode introduced from China with the grass carp *Ctenopharyngodon idella* (Valenciennes, 1844), used for weed control of the aquatic systems (Innal et al., 2016). After its discovery in Turkey in the 1970s, *S. acheilognathi* has negative implications for the populations of native and endemic fish species (Innal et al., 2016).

The monogenean *Onchocleidus similis* Müller, discovered in 1936, is also considered an alien parasitic species of ichthyofauna in Turkey (Çolak, 2013). It has been recorded on the host *Lepomis gibbosus* (Soylu, 2014), a North American freshwater fish. In Turkey, *Lepomis gibbosus* is one of the most successful alien fish species, with an increasing dispersal area (Innal, pers. obs.).

Infecting multiple organs within its host, the fungus-like parasite *Sphaerothecum destruens*, originated in China, belongs to Mesomycetozoea class (Sana et al., 2017). In Turkey, it is found in the cyprinid species *Pseudorasbora parva* (Ercan et al., 2015), a fish native to East Asia.

Also, the parasitic copepod *Neoergasilus japonicus* (Harada, 1930) (Ergasilidae), native to East Asia, was observed in inland water systems of Turkey. It was reported from the native fish species *Scardinius erythrophthalmus* (Soylu and Soylu, 2012).

Table 2a: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Mesomycetozoea				
Sphaerothecum destruens Arkush, Mendoza, Adkison and Hedrick, 2003	*Pseudorasbora parva*	Sarıçay stream, Muğla	Ercan et al. (2015)	China
	Lepomis gibbosus			
Euglenozoa, Kinetoplastida				
Ichthyobodo sp.	*Oncorhynchus mykiss*	Aquaculture	Soylu (1985)	ld/u
			Altunay (2006)	
			Altunay and Yıldız (2008)	
			Balta et al. (2019)	
Ichthyobodo necator (Henneguy, 1883) Pinto, 1928	*Oncorhynchus mykiss*	Aquaculture	Soylu (1996)	Eurasia
			Burgu et al. (1988)	
			Kayiş (2006)	
			Ögüt and Akyol (2007)	
			Balta et al. (2008)	
	Salvelinus fontinalis	Aquaculture	Kayiş (2006)	
			Balta et al. (2008)	
Metamonada, Trepomonadea				
Hexamita salmonis (Moore, 1922)	*Oncorhynchus mykiss*	Aquaculture	Öğüt and Akyol (2005)	ld/u
			Ögüt and Akyol (2007)	
			Balta et al. (2018)	
Spironucleus salmonicida Jørgensen and Sterud (2006)	*Oncorhynchus mykiss*	Aquaculture	Balta et al. (2019)	ld/u

Table 2b: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Ciliophora, Oligohymenophorea				
Ambiphrya sp.	Hybrid bass	Aquaculture	Tokşen (2006)	ld/u
	Morone saxatilis	Aquaculture	Tokşen (2006)	
	Oncorhynchus mykiss	Aquaculture	Özçelep (2009)	
Apiosoma piscicolum Blanchard, 1885	*Oncorhynchus mykiss*	Aquaculture	Ögüt and Akyol (2007)	Eurasia
Apiosoma sp.	*Oncorhynchus mykiss*	Aquaculture	Burgu et al. (1988)	ld/u
			Altunay (2006)	
			Altunay and Yıldız (2008)	
			Özçelep (2009)	
Epistylis sp.	*Morone saxatilis*	Aquaculture	Tokşen (2006)	ld/u
	Oncorhynchus mykiss	Aquaculture	Ögüt and Akyol (2003)	
			Altunay (2006)	
			Altunay and Yıldız (2008)	
			Özçelep (2009)	
	Hybrid bass	Aquaculture	Tokşen (2006)	
Ichthyophthirius multifiliis Fouquet, 1876	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	Eurasia
	Salvelinus fontinalis	Aquaculture	Balta et al. (2008)	
	Hybrid bass	Aquaculture	Tokşen (2006)	
	Morone saxatilis	Aquaculture	Tokşen (2006)	
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988)	
			Ögüt et al. (2005)	
			Ögüt and Akyol (2007)	
			Balta et al. (2008)	
			Çevrimel and Soylu (2017)	
			Özer et al. (2010)	
			Balta et al. (2019)	
			Tokşen (2002)	
			Uzbilek and Yıldız (2002)	
			Tabakoğlu (2004)	
			Mefut et al. (2007)	
			Özçelep (2009)	

Table 2c: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Ciliophora, Oligohymenophorea				
Ichthyophthirius sp.	*Oncorhynchus mykiss*	Aquaculture	Soylu (1996)	ld/u
Trichodina acuta Lom, 1961	*Oreochromis niloticus*	Aquaculture	Cengizler and Can (1999)	Eurasia
Trichodina claviformis Dobberstein and Palm, 2000	*Oncorhynchus mykiss*	Aquaculture	Ögüt and Akyol (2007)	Europe
Trichodina domerquei (Wallengren, 1897)	*Oncorhynchus mykiss*	Aquaculture	Burgu et al. (1988) Ince and Uslu (2017)	Europe
Trichodina sp.	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	ld/u
	Morone saxatilis	Aquaculture	Tokşen (2006)	
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988) Soylu (1996) Altunay (2006) Altunay and Yıldız (2008) Çevrimel and Soylu (2017) Balta et al. (2008) Balta et al. (2019) Özçelep (2009) Ögüt and Akyol (2003)	
	Salvelinus fontinalis	Aquaculture	Balta et al. (2008)	
Trichodina nigra Lom, 1960	*Oncorhynchus mykiss*	Aquaculture	Özer et al. (2010) Burgu et al. (1988) Dal (2006)	Eurasia
Trichodinella sp.	*Oncorhynchus mykiss*	Aquaculture	Burgu et al. (1988)	ld/u
Tripartiella sp.	*Oncorhynchus mykiss*	Aquaculture	Altunay (2006) Altunay and Yıldız (2008)	ld/u

Table 2d: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Ciliophora, Phyllopharyngea				
Chilodonella cyprinid (Moroff, 1902) Strand, 1928	*Oreochromis aureus*	Aquaculture	Cengizler and Can (1999)	Eurasia
	Oreochromis niloticus	Aquaculture	Cengizler and Sarıhan (1992)	
			Cengizler and Can (1999)	
	Sarotherodon galileus	Aquaculture	Cengizler and Sarıhan (1992)	
	Tilapia rendalli	Aquaculture	Cengizler and Sarıhan (1992)	
	Tilapia zilli	Aquaculture	Cengizler and Sarıhan (1992)	
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988)	
			Soylu (1996)	
			Ögüt and Akyol (2007)	
Chilodonella sp.	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	ld/u
	Oncorhynchus mykiss	Aquaculture	Altunay (2006)	ld/u
			Altunay and Yıldız (2008)	
			Balta et al. (2019)	
			Özer et al. (2010)	

Table 2e: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Myxozoa				
Eimeria truttae (Leger and Hesse, 1919) Stankovitch, 1924	*Oncorhynchus mykiss*	Aquaculture	Sağlam and Pala (2008)	ld/u
Platyhelminthes, Monogenea				
Dactylogyrus anchoratus (Dujardin, 1845) Wagener, 1857	*Carassius auratus*	Enne Dam Lake	Koyun (2001)	Asia
		Enne Dam Lake	Koyun and Altunel (2007)	
		Emre Dam Lake	Öztürk (2011)	
	Carassius gibelio	Ömerli Dam Lake	Kırcalar (2013)	
		Seyitler Dam Lake	Öztürk (2010)	
		Karacaören II Dam Lake	Kır and Samancı (2012)	
		Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
		Emre Dam Lake	Öztürk (2011)	
		Marmara Lake	Demir and Karakişi (2016)	
Dactylogyrus baueri Gussev, 1955	*Carassius gibelio*	Ömerli Dam Lake	Kırcalar (2013)	Japan
		Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
Dactylogyrus inexpectatus Isjumova, 1955	*Carassius gibelio*	Ömerli Dam Lake	Kırcalar (2013)	Southeast Asia
		Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
Dactylogyrus minutes Kulwièc, 1927	*Carassius gibelio*	Karacaören II Dam Lake	Kır and Samancı (2012)	Eurasia
Dactylogyrus sphyrna Linstow, 1878	*Oncorhynchus mykiss*	Aquaculture	Ince and Uslu (2017)	Eurasia

Table 2e: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Myxozoa				
Dactylogyrus vastator Nybelin, 1924	*Carassius gibelio*	Sığırcı Lake	Çolak (2013)	Asia
		Gala Lake	Soylu (2014)	
	Oreochromis niloticus	Aquaculture	Cengizler and Can (1999)	
Dactylogyrus sp.	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	ld/u
	Oncorhynchus mykiss	Aquaculture	Burgu et al (1988)	
	Carassius gibelio	Ömerli Dam Lake	Kırcalar (2013)	
Diplozoon paradoxum von Nordmann, 1832	*Tilapia zilli*	Tigem Pond	Zeren (2008)	Asia
Gyrodactylus carassii Malmberg, 1957	*Carassius gibelio*	Seyitler Dam Lake	Öztürk (2010)	Europe
Gyrodactylus elegans von Nordmann, 1832	*Carassius auratus*	Karagöl Lake	Geldiay and Balık (1974)	Asia
Gyrodactylus katharineri Malmberg, 1964	*Carassius auratus*	Enne Dam Lake	Koyun and Altunel (2007)	Asia
Gyrodactylus sp.	*Carassius auratus*	Emre Dam Lake	Öztürk (2011)	ld/u
	Carassius gibelio	Ömerli Dam Lake	Kırcalar (2013)	
		Gala Lake	Soylu (2014)	
		Sığırcı Lake	Çolak (2013)	
		Marmara Lake	Demir and Karakişi (2016)	
	Oncorhynchus mykiss	Aquaculture	Ögüt and Akyol (2007)	
	Lepomis gibbosus	Sığırcı Lake	Çolak (2013)	
Tetraonchus sp.	*Tilapia zilli*	Tigem Pond	Zeren (2008)	ld/u
Onchocleidus similis syn. *Urocleidus similis* Mueller, 1936	*Lepomis gibbosus*	Sığırcı Lake	Çolak (2013)	North America
		Gala Lake	Soylu (2014)	
	Carassius gibelio	Gala Lake	Soylu (2014)	

Table 2f: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Platyhelminthes, Cestoda				
Caryophyllaeus fimbriceps Annenkova-Chlopina, 1919	*Carassius gibelio*	Gala Lake	Soylu (2014)	Ponto-Caspian region
Ligula intestinalis (Linnaeus, 1758)	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	Europe
	Pseudorasbora parva	Hirfanlı Dam Lake	Benzer (2020)	
Schyzocotyle acheilognathi (Yamaguti, 1934)	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	Asia
	Carassius gibelio	Bafra fish lakes	Öztürk and Özer (2014)	
	Gambusia holbrooki			
Platyhelminthes, Digenea				
Clinostomum complanatum (Rudolphi, 1814) Braun, 1899	*Oncorhynchus mykiss*	Aquaculture	Burgu et al (1988)	ld/u
	Lepomis gibbosus	Sığırcı Lake	Çolak (2013)	
Crepidostomum farionis (Müller, 1780) Lühe, 1909	*Oncorhynchus mykiss*	Aquaculture	Dörücü (2000)	Europe
Diplostomum sp.	*Carassius gibelio*	Ömerli Dam Lake	Kırcalar (2013)	ld/u
	Oncorhynchus mykiss	Aquaculture	Çevrimel and Soylu (2017)	
	Carassius gibelio	Gala Lake	Soylu (2014)	
		Sığırcı Lake	Çolak (2013)	
	Lepomis gibbosus	Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
Tylodelphys clavata (von Nordmann, 1832) Diesing, 1850	*Lepomis gibbosus*	Sığırcı Lake	Çolak (2013)	Eurasia
Tetracotyle spp.	*Lepomis gibbosus*	Sığırcı Lake	Çolak (2013)	ld/u

Table 2g: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Acanthocephala				
Acanthocephalus sp.	*Lepomis gibbosus*	Gala Lake	Soylu (2014)	ld/u
Pomphorhynchus laevis (Zoega in Müller, 1776) Porta, 1908	*Carassius auratus*	Enne Dam Lake	Koyun (2001)	Ponto-Caspian region
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988)	
		Aquaculture	Çevrimel and Soylu (2017)	
Nematoda				
Contracaecum sp.	*Carassius auratus*	Enne Dam Lake	Koyun and Altunel (2007)	ld/u
	Carassius gibelio	Marmara Lake	Demir and Karakişi (2016)	
Contracaecum rudolphii Hartwich, 1964	*Carassius gibelio*	Karataş Lake	Innal et al. (2020)	ld/u
Eustrongylides excisus Jägerskiöld, 1909	*Lepomis gibbosus*	Gala Lake	Soylu (2014)	ld/u
	Carassius gibelio	Marmara Lake	Demir and Karakişi (2016)	
Hysterothylacium aduncum (Rudolphi, 1802)	*Carassius gibelio*	Karacaören II Dam Lake	Kır and Samancı (2012)	ld/u
	Oncorhynchus mykiss	Aquaculture	Pekmezci and Umur (2015)	ld/u
Hysterothylacium sp.	*Carassius auratus*	Enne Dam Lake	Koyun (2001)	ld/u
Pseudocapillaria tomentosa (Dujardin, 1845) Moravec, 1987	*Carassius gibelio*	Marmara Lake	Demir and Karakişi (2016)	ld/u
Raphidascaris acus (Bloch, 1779)	*Carassius gibelio*	Büyükçekmece Dam Lake	Yardımcı et al. (2018)	Ponto-Caspian region
Schulmanela petruschewskii (Shulman, 1948)	*Oncorhynchus mykiss*	Aquaculture	Pekmezci and Umur (2015)	Europe
Annelida, Hirudinea				
Piscicola geometra (Linnaeus, 1761)	*Carassius gibelio*	Uluabat Lake	Arslan and Emiroğlu (2011)	Eurasia

Table 2h: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Mollusca, Bivalvia				
Glochidia (larvae)	*Lepomis gibbosus*	Gala Lake	Soylu (2014)	Asia
	Carassius gibelio	Gala Lake	Soylu (2014)	
Crustacea, Maxillopoda				
Argulus foliaceus (Linnaeus, 1758)	*Carassius auratus*	Aquarium conditions	Yıldız and Kumantaş (2002)	Europe
		Emre Dam Lake	Öztürk (2012)	
	Carassius gibelio	Emre Dam Lake	Öztürk (2012)	
		Aquaculture condition	Tabakoğlu (2006)	
	Oncorhynchus mykiss	Aquaculture	Öktener and Ünal 2020	
Crustacea, Copepoda				
Lernaea cyprinacea (Linnaeus, 1758)	*Carassius gibelio*	Karacaören II Dam Lake	Kır and Samancı (2012)	Asia
		Marmara Lake	Demir and Karakişi (2016)	
		Onaç Reservoir	Innal (2020)	
		Çanaklı Reservoir		
		Soğanlı Reservoir		
		Karataş Lake		
		Beyşehir Lake		
	Gambusia holbrooki	Kundu River Estuary	Innal and Avenant-Oldewage (2012)	
		Düger Creek	Innal et al. (2017)	
	Lepomis gibbosus	Gala Lake	Soylu (2014)	
	Pseudorasbora parva	Onaç Reservoir	Innal (2020)	
	Oncorhynchus mykiss	Aquaculture	Tokşen et al. (2015)	
		Sarı Mehmet Dam Lake	Urku and Onalan (2018)	
Ergasilus sp.	*Carassius gibelio*	Büyükçe-kmece Lake	Yardımcı et al. (2018)	ld/u

CONCLUSIONS

The data of the present survey suggest that human activities, particularly aquaculture have led to the introduction of non-indigenous fish along with their parasites which could negatively influence the native and endemic ichthyofauna of Turkey. Some parasites such as *Anguillicoloides crassus*, *Schyzocotyle acheilognathi*, and *Onchocleidus similis* have increased in dispersal areas and nowadays affect the native hosts.

Chilodonella cyprini, identified in six alien fish species, and *Ichthyophthirius multifiliis,* found in five species, are believed to be the most generalist parasites; both of these protozoan parasites are of Eurasian origin. For a large number of parasites related to non-native fish species, there are still limited data on their area of origin.

Oncorhynchus mykiss was the alien host with the highest number of reported parasites, including protozoans, mixozoans, digeneans, acanthocephalans, nematodes, and crustaceans. Since there are so many parasite species reported for trout rearing, aquaculture owners should concentrate more on management strategies.

As the invasive fish species continues to have a major impact on the diversity of indigenous fish populations of Turkey, careful monitoring of their parasites is required in further studies, especially for the alien species, originated in Asia or North America. However, it is worth noting that non-indigenous fishes may be infected with native Eurasian parasites.

ACKNOWLEDGEMENTS

The authors are thankful to reviewer's comments and suggestions and also to Dr. Yuriy Kvach (Institute of Marine Biology of the NAS of Ukraine) for his valuable contribution to improve the manuscript.

REFERENCES

1. Altunay S., 2006 – Ectoparasitological examination of rainbow trout (Oncorhynchus mykiss Walbaum, 1792) cage-cultured in Kesikköprü Dam Lake, Ankara University, Institute of Science, Master Thesis, 43.
2. Altunay S. and Yıldız H. J., 2008 – Ectoparasitological examination of rainbow trout (Oncorhynchus mykiss Walbaum, 1792) cage-cultured in Kesikköprü Dam Lake, *Ankara University Journal of Agricultural Sciences*, 14, 154-162. (in Turkish)
3. Arkush K. D., Mendoza L., Adkison M. A. and Hedrick R. P., 2003 – Observations on the life stages of Sphaerothecum destruens n. g., n. sp., a mesomycetozoean fish pathogen formally referred to as the rosette agent, *Journal of Eukaryotic Microbiology*, 50, 430-438.
4. Arslan N. and Emiroglu O., 2011 – First record of parasitic Annelida-Hirudinea (Piscicola geometra Linnaeus, 1761) on Carassius gibelio (Bloch, 1782) in Lake Uluabat (Turkey), *Kafkas Universitesi Veteriner Fakultesi Dergisi*, 17, 1, 131-133.
5. Balta F., Kayis S. and Altinok I., 2008 – External protozoan parasites in three trout species in the Eastern Black Sea region of the Turkey: intensity, seasonality, and their treatments, *Bulletin of the European Association of Fish Pathologists*, 28, 157-162.
6. Balta F. and Dengiz Balta Z., 2018 – Identification and treatment of hexamitiasis observed in rainbow trout (Oncorhynchus mykiss), *Fry Journal of Anatolian Environmental and Animal Sciences*, 3, 1, 4-8.
7. Balta F., Balta Z. D. and Akhan S., 2019 – Seasonal distribution of protozoan parasite infections in rainbow trout (Oncorhynchus mykiss) farms in the Eastern Black Sea of Turkey, *Bulletin of the European Association of Fish Pathologists*, 39, 1, 31-39.
8. Benzer S., 2020 – Ligula intestinalis infection of Pseudorasbora parva in Hirfanlı Dam Lake, Kırşehir, Turkey, *Journal of Fisheries*, 8, 1, 762-767.
9. Kumar B. A., 2000 – Exotic fishes and freshwater fish diversity, *Zoo's Print Journal*, 15, 363-367.
10. Bunkley-Williams L. and Williams E. H., 1994 – Parasites of Puerto Rican freshwater sport fishes, Puerto Rico Department of Natural and Environmental Resources, San Juan, P. R. and Department of Marine Sciences, University of Puerto Rico, Mayaguez, PR, 168.
11. Burgu A., Oğuz T., Korting W. and Güralp N., 1988 – Parasites of freshwater fishes in some areas of Central Anatolia, *Journal of Etlik Veterinary Microbiology*, 6, 143-165. (in Turkish)
12. Canning-Clode J., 2015 – Biological invasions in changing ecosystems, vectors, ecological impacts, management and predictions, De Gruyter Open, 488, https://doi.org/10.1515/9783110438666.
13. Cengizler İ. and Sarıhan E., 1992 – A study on Chilodoniasis encountered in Tipalias, *Ege Journal of Fisheries and Aquatic Sciences*, 9, 33-36, 60-65. (in Turkish)
14. Cenigizler İ. and Can R., 1999 – İki Tilapia Türünde (Oreochromis niloticus L., 1758 ve Oreochromis aureus Steindacher, 1864) *Ektoparazitlerin Belirlenmesi, Su Ürünleri Dergisi*, 6, Sayı, 3-4, 345-352, İzmir, Bornova. (in Turkish)
15. Çetinkaya O., 2006 – Exotic and native fish species that introduced or stocked into Turkish waters, their impacts on Aquaculture, fisheries, wild populations and aquatic ecosystems: A preliminary study on constructing a database (in Turkish with English Summary), Symposium on Management of Reservoirs and Fish Stocking, MARA, Mediterranean Fisheries.
16. Çevrimel D. S. and Soylu E., 2017 – The occurrence of Pomphorhynchus laevis (Acanthocephala) in cage reared rainbow trout (Oncorhynchus mykiss) from Işıklı Spring, Çivril, Turkey, *Ege Journal of Fisheries and Aquatic Sciences*, 34, 3, 255-260.
17. Çolak H. S. 2013 – Metazoan parasites of fish species from Lake Sığırcı (Edirne, Turkey), *Turkish Journal of Veterinary and Animal Sciences*, 37, 200-205.
18. Çolak S. Ö., Soylu E., Erdoğan F. and Erdoğan M., 2012 – Metazoan parasites of European eel (Anguilla anguilla) from the Köyceğiz Dalyan Estuarine channel system, Turkey, *Bulletin of the European Association of Fish Pathologists*, 32, 5, 159-163.

19. Colorni A., Diamant A., Woo P. and Bruno D., 2014 – Infectious diseases of warm water fish in marine and brackish waters, Diseases and disorders of finfish in cage culture, 2nd edition, Woo P. T. K. and Bruno D. W. (eds), Wallingford, UK, CABI Publishing, 155-192.
20. Copp G. H., Bianco P. G., Bogutskaya N. G., Erös T., Falka I., Ferreira M. T., Fox M. G., Freyhof J., Gozlan R. E., Grabowska J., Kováč V., Moreno-Amich R., Naseka A. M., Peňáz M., Povž M., Przybylski M., Robillard M., Russell I. C., Stakenas S., Šumer S., Vila-Gispert A. and Wiesner C., 2005a – To be, or not to be, a non-native freshwater fish? *Journal of Applied Ichthyology*, 21, 242-262.
21. Copp G. H., Garthwaite R. and Gozlan R. E., 2005b – Risk identification and assessment of non-native freshwater fishes: a summary of concepts and perspectives on protocols for the UK, *Journal of Applied Ichthyology*, 21, 371-373.
22. Cowx I. G. and Collares-Pereira M. J., 2002 – Freshwater fish conservation: options for the future, in Collares M. J., Pereira M., Coelho I. and Cowx G., (eds), Conservation of freshwater fishes: options for the future, Blackwell Science, Oxford, 443-452.
23. Dal A., 2006 – Parasitological research on rainbow trout (Oncorhynchus mykiss) farming in Atatürk Dam Lake, Çukurova University, Institute of Science, Master thesis, 52.
24. Demir S. and Karakişi H., 2016 – Metazoan parasite fauna of the Prussian carp, Carassius gibelio (Bloch, 1782) (Cyprinidae), from Marmara Lake, Turkey, *Acta Zoologica Bulgarica*, 68, 2, 265-268.
25. Dörücü M., 2000 – Occurence and first record of Crepidostomum farionis, Müler 1784 (Trematoda: Digenea) in Rainbow trout (Oncorhynchus mykiss) in a Fish Farm (Elazığ, Turkey), *Furat University Journal of Science and Engineering*, 12, 1, 323-327.
26. Emiroğlu Ö., 2011 – Alien fish species in upper Sakarya River and their distribution, *African Journal of Biotechnology*, 10, 73, 16674-16681.
27. Emiroğlu Ö., Ekmekçi F. G., Aksu S., Başkurt S., Atalay A. and Tarkan A. S., 2016 – Introduction and establishment of tropical ornamental fish, Pterygoplichthys spp. (Actinopterygii: Siluriformes: Loricariidae) in hot springs: Aquarium trade as a potential risk for biodiversity in Turkey, *Acta Ichthyologica et Piscatoria*, 46, 4, 351-356.
28. Ercan D., Andreou D., Sana S., Öntaş C., Baba E., Top N., Karakus U., Tarkan A. S. and Gozlan R. E., 2015 – Evidence of threat to European economy and biodiversity following the introduction of an alien pathogen on the fungal-animal boundary, *Emerging Microbes and Infections*, 4, 1, 1-6.
29. Froese R. and D. Pauly., 2021 – FishBase, World Wide Web electronic publication, www.fishbase.org, version (08/2021).
30. Geldiay R. and Balık S., 1974 – Türkiye tatlı su balıklarında rastlanan başlıca iç ve dış parazitler, *Ege Üniversitesi Fen Fakültesi Monografiler Serisi*, 14, İzmir, Turkey, Ege University. (in Turkish)
31. Genç E., 2005 – Occurrence of the swimbladder parasite Anguillicola crassus (Nematoda, Dracunculoidea) in European Eels (Anguilla anguilla) in Ceyhan River, Turkey, *Turkish Journal of Veterinary and Animal Sciences*, 29, 661-663.
32. Gozlan R. E., Peeler E. J., Longshaw M., St-Hilaire S. and Feist S. W., 2006 – Effect of microbial pathogens on the diversity of aquatic populations, notably in Europe, *Microbes and Infection*, 8, 1358-1364.
33. Hansen H. and Alarcón M., 2019 – First record of the Asian fish tapeworm Schyzocotyle (Bothriocephalus) acheilognathi (Yamaguti, 1934) in Scandinavia, *BioInvasions Records*, 8, 2, 437-441.
34. Ince H. and Uslu U., 2017 – Determination of parasites at cultured and captured fishes in Seyhan Dam Lake in Adana, *Eurasian Journal of Veterinary Sciences*, 33, 2, 89-96.
35. Innal D., 2020 – Detection of ectoparasite Lernaea cyprinacea (Copepoda: Lernaeidae) on some Cypriniformes fish from the Mediterranean region of Turkey, *Kommagene Biyoloji Dergisi*, 4, 2, 121-125.

36. Innal D. and Erk'akan F., 2006 – Effects of exotic and translocated fish species in the inland waters of Turkey, *Reviews in Fish Biology and Fisheries*, 16, 39-50.
37. Innal D. and Avenant-Oldewage A., 2012 – Occurrence of Lernaea cyprinacea on mosquito fish (Gambusia affinis) from Kundu Estuary (Antalya-Turkey), *Bulletin of the European Association of Fish Pathologists*, 32, 4, 140-147.
38. Innal D., Aydogdu A. and Guclu S. S., 2016 – Invasion of Schyzocotyle acheilognathi (Yamaguti, 1934) (Cestoda: Bothriocephalidea) in Turkey, *Acta Biologica Turcica*, 29, 1, 20-25.
39. Innal D., Avenant-Oldewage A., Dogangil B., Stavrescu-Bedivan M. M., Ozmen O. and Mavruk S., 2017 – Susceptibility of endemic and non-indigenous fish to Lernaea cyprinacea (Copepoda: Lernaeidae): a case study from Düger Spring Creek (Burdur-Turkey), *Bulletin of the European Association of Fish Pathologists*, 37, 3, 100-109.
40. Innal D., Ozemen O. and Genc E., 2018 – Infection of European Eel, Anguilla anguilla with the Nematode Anguillicoloides crassus from Some Estuarine Systems in Turkey, *Turkish Journal of Fisheries and Aquatic Sciences*, 19, 11, 899-905.
41. Innal D., Stavrescu-Bedivan M., Öztürk M. O. and Özmen Ö., 2020 – First record of Contracaecum rudolphii Hartwich, 1964 in Carassius gibelio (Bloch, 1782) from Turkey, *Aquatic Sciences and Engineerin*g, 35, 1, 1-5.
42. Kayış Ş., 2006 – Infestation and treatment of Ichthyobodo necator in trout (Onchorhynchus mykiss, Salvelinus fontinalis and Salmo trutta fario) farms of the eastern Black Sea region of Turkey, Karadeniz Technical University, Institute of Science, PhD Thesis, 68. (in Turkish)
43. Kayış Ş., Balta F., Serezli R. and Er A., 2013 – Parasites on different ornamental fish species in Turkey, *Journal of Fisheries Sciences*, 7, 2, 114-120.
44. Kennedy C. R., Hartvıgsen R. and Halvorsen O., 1991 – The importance of fish stocking in the dissemination of parasites throughout a group of reservoirs, *Journal of Fish Biology*, 38, 541-552.
45. Kennedy C. R., 1994 – The ecology of introductions, in parasitic diseases of fish, Pike A. W. and Lewis J. W. (eds), Dyfed, UK, Samara Publishing, 189-208.
46. Kennedy C. R., 2006 – Ecology of the Acanthocephala, Cambridge University Press, 260, https://doi.org/10.1017/CBO9780511541902.
47. Kır I. and Samanci I., 2012 – The parasite fauna of crucian carp (Carassius gibelio Bloch, 1782) inhabiting Karacaören II Dam Lake (Burdur, Isparta), *Journal of Eğirdir Fisheries Faculty*, 8, 2, 38-42. (in Turkish)
48. Kırcalar F., 2013 – The metazoan parasites of the invasive fish species Carassius gibelio from Omerli Dam Lake, Istambul, Turkey, *Journal of Fisheries and Aquatic Sciences*, 28, 23-38. (in Turkish)
49. Kirjušina M. and Vismanis K., 2007 – Checklist of the parasites of fishes of Latvia, *FAO Fishery Technical Papers*, 369/3, FAO, Rome, 106.
50. Koyun M., 2001 – The helminthofauna of some fishes in Enne Dam lake, Uludag University, Science Institution, PhD Thesis, 119.
51. Koyun M. and Altunel F. N., 2007 – Metazoan parasites of bleak (Alburnus alburnus), crucian carp (Carassius carassius) and golden carp (Carassius auratus) in Enne Dam Lake, Turkey, *International Journal of Zoological Research*, 3, 2, 94-100.
52. Mefut A, Emre Y., Diler Ö., Altun S. and İnce I., 2007 – Identification and controlling of bacterial patogens in some rainbow trout (Oncorhynchus mykiss) farms in the Mediterranean Region, Symposium of National Water Days, Antalya, 16-18 May 2007, 9-17.
53. Öğüt H, Akyol A and Cılız S., 2003 – Examination on external parasites cultured trout, XII, Symposium of National Aquatic Products, Elazığ, 2-5 September 2003, 192.
54. Mefut A., Emre Y., Diler Ö., Altun S. and İnce I., 2007 – Identification and controlling of bacterial patogens in some rainbow trout (Oncorhynchus mykiss) farms in the Mediterranean Region, Symposium of National Water Days, Antalya, 16-18 May 2007, 9-17.

55. Öğüt H, Akyol A and Cılız S., 2003 – Examination on external parasites cultured trout, XII, Symposium of National Aquatic Products, Elazığ, 2-5 September 2003, 192.
56. Öğüt H. and Akyol A., 2005 – Prevalence and intensity of Hexamita salmonis in rainbow trout farms in the Southeastern Black Sea and their relationship to environmental factors, *The Israeli Journal of Aquaculture*, 57, 2, 97-104.
57. Ogut H. and Akyol A., 2007 – Prevalence and intensity of ectoparasites in rainbow trout (Oncorhynchus mykiss) from larvae stage to market size in Turkey, *Israeli Journal of Aquaculture*, 59, 23-31.
58. Ogut H., Akyol A. and Alkan M. Z., 2005 – Seasonality of Ichthyophthirius muliiliis in the trout (Oncorhynchus mykiss) farms of the eastern black sea region of Turkey, *Turkish Journal of Fisheries and Aquatic Sciences*, 5, 23-27.
59. Öktener A., 2014 – Revision of parasitic helminths reported in freshwater fish from Turkey with new records, *Transylvanian Review of Systematical and Ecological Research*, 16.1, 1-56.
60. Özer S., Koyuncu E., Dönmez E., Bulduklu P. S. and Erdoğan S., 2010 – Protozoan ectoparasites of rainbow trout (Oncorhynchus mykiss, Walbaum, 1792) cultivated in Mersin, *Journal of Pendik Veterinary Microbiolgy*, 37, 1, 43-52. (in Turkish)
61. Öztürk M. O., 2010 – A research on plathelminth parasites of Carassius gibelio (Bloch, 1782) in Lake Dam Seyitler, *Journal of Science*s, AKÜ, 02, 91-97.
62. Öztürk M. O., 2012 – A research on Argulus foliaceus infection of three Cyprinid fish species in Lake Dam Emre, (Afyonkarahisar), *İstanbul Üniversitesi Veteriner Fakültesi Dergisi*, 38, 2, 183-190.
63. Öztürk M. O., 2011 – A research on helminth fauna of three cyprinid fish species in Emre Dam Lake, Afyonkarahisar, AKÜ, *Journal of Sciences*, 11, 23-29.
64. Öztürk T. and Özer A., 2014 – Comparative invasive Asian tapeworm Bothriocephalus acheilognathi infections on the Lower Kizilirmak delta fishes, *Journal of Academic Documents for Fisheries and Aquaculture*, 1, 1, 1-7.
65. Pekmezci G. Z. and Umur S., 2015 – Presence of Hysterothylacium gadi aduncum (Rudolphi, 1802) (Anisakidae) in cultured Rainbow trout (Oncorhynchus mykiss Walbaum, 1792) in fresh water farms from Turkey and its mortality, *Iranian Journal of Fisheries Sciences*, 14, 1, 150-157.
66. Rauque C., Viozzi G., Flores V., Vega R., Waicheim A. and Salgado-Maldonado G., 2018 – Helminth parasites of alien fresh-water fishes in Patagonia (Argentina), *International Journal for Parasitology: Parasites and Wildlife*, 7, 369-379.
67. Reading A. J., Britton J. R., Davies G. D., Shinn A. P. and Williams C. F., 2011 – Introduction and spread of non-native parasites with Silurus glanis L. (Teleostei: Siluridae) in UK fisheries, *Journal of Helminthology*, 1, 1-4.
68. Sağlam N. and Pala M., 2008 – Coccidiosis and its treatment in a rainbow trout (Oncorhynchus mykiss) farm, *Journal of Fisheries Sciences*, 2, 343-349.
69. Sana S., Hardouin E. A., Gozlan R. E., Ercan D., Tarkan A. S., Zhang T. and Andreou D., 2017 – Origin and invasion of the emerging infectious pathogen Sphaerothecum destruens, Emerging *Microbes and Infections*, 6, e76.
70. Sheath D. J., Williams C. F., Reading A. J. and Robert Britton J., 2015 – Parasites of non-native freshwater fishes introduced into England and Wales suggest enemy release and parasite acquisition, *Biological Invasions*, 17, 2235-2246.
71. Soylu E., 1985 – Studies of fish diseases in Sapanca Fish Production Station, İstanbul University, College of Aquatic Products, Publication 7, 22.
72. Soylu E., 1996 – Protozoan ectoparasites of Oncorhynchus mykiss recorded from farms in Marmara Region, Turkey, *Anadolu University Journal of Science and Technology*, 1, 19-26.

73. Soylu E., 2014 – Metazoan parasites of fish species from Lake Gala (Edirne, Turkey), *Ege Journal of Fisheries Aquatic Sciences*, 31, 4, 187-193.
74. Soylu E. and Soylu M. P., 2012 – First record of the nonindigenous parasitic copepod Neoergasilus japonicus (Harada, 1930) in Turkey, *Turkish Journal of Zoology*, 36, 5, 662-667.
75. Tabakoğlu Ş., 2004 – Investıgatıon of parasites in some fish cultured in regional directorate of state hydraulic works, Master Thesis, Science Institution, Çukurova University, Adana, Turkey, 47. (in Turkish)
76. Tarkan A. S., Marr S. M. and Ekmekçi F. G., 2015 – Non-native and translocated freshwater fish species in Turkey, *FiSHMED Fishes in Mediterranean Environments*, 003, 28.
77. Tokşen E., 2002 – Ichthyophthirius multifilis Fouget, 1876 infection of cultured rainbow trout in Aegean Region and its terapy, *Journal of Bornova Veterinary Control and Research Institution*, 25, 39, 59-64.
78. Tokşen E, 2006 – Disease of Striped Bass (Morone saxatilis) and hybrids, fish stocking and reservoir Management, Symposium Book, 07-09, February 2006, Antalya, Turkey. (in Turkish)
79. Tokşen E., Zoral M. A. and Şirin C., 2015 – Occurrence of Lernaea cyprinacea infection in rainbow trout farmed in Turkey, *Bulletin of the European Association Fish Pathologists*, 35, 1, 8-14.
80. Urku C. and Onalan S., 2018 – First report of Lernaea cyprinacea (Copepoda: Lernaeidae) on rainbow trout (Oncorhynchus mykiss) from the Sarı Mehmet Dam Lake in Van-Turkey, *European Journal of Biology*, 77, 1, 42-5.
81. Uzbilek M. K. and Yıldız H. Y., 2002 – A report on spontaneous diseases in the culture of grass carp (Ctenopharyngodon idella Val. 1844), Turkey, *Turkish Journal of Veterinary and Animal Sciences*, 26, 2, 407-410.
82. Welcomme R. L., 1988 – International introduction of inland aquatic species, *FAO Fish Technical Paper*, 294, 318.
83. Woo P. T., Leatherland J. F. and Bruno D. W. (eds), 1995 – Fish diseases and disorders: Protozoan and Metazoan infections, 1, CAB international, 800.
84. Wootten R., 2012 – The parasitology of teleosts, Fish pathology, 292-338, in Fish pathology Ronald J. Roberts (ed.), 4th edition.
85. Yardımcı R. E., Çiğdem Ü. and Yardımcı C. H., 2018 – Parasite fauna of fish in Büyükçekmece Dam Lake, *Erzincan University Journal of Science and Technology*, 11, 2, 158-167.
86. Yıldız K. and Kumantaş A., 2002 – Argulus foliaceus infection in goldfish (Carassius auratus), *Israel Journal Veterinary Medicine*, 57, 3, 118-120.
87. Yuryshynets V., Ondračková M., Kvach Y. and Masson G., 2019 – Trichodinid ectoparasites (Ciliophora: Peritrichia) of non-native pumpkinseed (Lepomis gibbosus) in Europe, *Acta Protozoologica*, 58, 69-79.
88. Zeren A., 2008 – Parasitological investigation on some aquatic species collected from the Tigem Reservoirs (Yeniyurt, Dörtyol, Hatay), Mustafa Kemal University, Institute of Science, MSc Thesis, 66.

A COMPARISON OF THE EFFECT OF BLAST CHILLING AND ELECTRICAL STUNNING ON SOME HEMOLYMPH PARAMETERS IN RED SWAMP CRAYFISH (*PROCAMBARUS CLARKII*)

*Alexander ATANASOFF *, Faik Sertel SECER **, Dimitrinka ZAPRYANOVA ***, Cigdem URKU ***** and *Ferhat CAGILTAY ******

* Trakia University, Faculty of Veterinary Medicine, Department of Animal Husbandry, Students campus Stara Zagora, Bulgaria, BG-6014, hmi_atanasoff@mail.bg, ORCID: 0000-0003-3460-9589.
** Ankara University, Faculty of Agriculture, Department of Fisheries and Aquaculture, Ankara, Turkey, TR-06110, sertelsecer@yahoo.com, ORCID: 0000-0002-1940-7949.
*** Trakia University, Faculty of Veterinary Medicine, Department of Biochemistry, Students campus, Stara Zagora, Bulgaria, BG-6014, zaprianowa@abv.bg, ORCID: 0000-0002-0430-1690.
**** Istanbul University, Faculty of Aquatic Science, Department of Aquaculture and Fish Diseases, Ordu Street 200, Istanbul, Turkey, TR-34134, curku@istanbul.edu.tr, ORCID: 0000-0003-0381-9321, ferfez@istanbul.edu.tr, ORCID: 0000-0001-9866-083X.
***** Akdeniz University, Faculty of Fisheries, Department of Aquaculture, Dumlupinar Boulevard, Antalya, Turkey, TR-07058, ferhatcagiltay@akdeniz.edu.tr, ORCID: 0000-0001-9866-083X.

DOI: 10.2478/trser-2022-0005

KEYWORDS: crayfish, anestesia, blast chill, electrical stun, hemolymph parameters.

ABSTRACT

The aim of the present investigation is to compare the effect of standard method and electrical stunning on some hemolymph biochemical parameters in mid-sized Red Swamp Crayfish. The results showed that electrical stunning time of induction was significantly shorter and recovery was longer than chilling stun. Parameters of an electrical field that stuns crayfish beyond the point of recovery without causing damage have been identified. Based on this experiment, it seems that electrical stunning would be preferable to the other method.

RÉSUMÉ: Comparaison des effets du refroidissement par explosion et de l’étourdissement électrique sur certains paramètres hémolympiques de l’écrevisse rouge des marais (*Procambarus clarkii*).

Le but de la présente étude était de comparer l’effet de la méthode standard et de l’étourdissement électrique sur certains paramètres biochimiques de l’hémolymphe d’écrevisses rouges des marais de taille moyenne. Les résultats ont montré que le temps d’induction de l’étourdissement électrique était significativement plus court et que la récupération était plus longue que l’étourdissement à froid. Les paramètres d’un champ électrique qui étourdit les écrevisses au-delà du point de récupération sans causer de dommages ont été identifiés. Sur la base de cette expérience, il semble que l’étourdissement électrique soit préférable à l’autre method.

REZUMAT: O comparație a efectelor răcirii rapide și a asomării electrice asupra unor parametrii hemolimfatici la racii roșii de mlaștină (*Procambarus clarkii*).

Scopul prezentei investigații este de a compara efectul metodei standard și al asomării electrice asupra unor parametri biochimici hemolimfatici la racii roșii de mlaștină de dimensiuni medii. Rezultatele au arătat că timpul de inducție în cazul asomării electrice a fost semnificativ mai scurt, iar recuperarea a fost mai lungă comparativ cu anestezierea prin răcire. Au fost identificați parametrii unui câmp electric care anesteziază racii dincolo de punctul de recuperare, fără a provoca vătămări. Pe baza acestui experiment, se pare că asomarea electrică ar fi preferabilă celeilalte metode.

INTRODUCTION

The anesthesia of crustaceans is mainly used to lower the stress, avoid body damage such as autotomy or for different diagnosis procedures (Fotedar and Evans, 2011; Roth and Grimsbø, 2016). In recent decades, in edible crustaceans (crabs, lobsters, crayfishs, shrimps, etc.) various anesthetizing methods and techniques have been examined (Roth and Øines, 2010; Fregin and Bickmeyer, 2016). Most of the methods used are similar to those used in commercial fish. The most widely used methods for anaesthsia in crustaceans are chilling (air or ice slurry) and water cooling (tap water 0°C, sea water –1.8°C) (Tang et al., 2012; Fregin and Bickmeyer, 2016). However, it should be noted that the nervous system of crustaceans is able to retain nerve impulses even in extremely low temperatures (Tang et al., 2012) which makes the method not very effective. In general, cooling or chilling are recommended for tropical species of crustaceans that are sensitive to low temperatures (Weineck et al., 2018). On the other hand, the need to explore alternatives for other species required a series of subject of specific studies. Researchers from several universities concluded that electrical stunning can render the animal unconscious for seconds, making it the most humane approach for crustacean anaesthesia. This conclusion is based on electrophysiological readings of exposed nerves, heart rate, behaviour, and changes in the levels of biogenic amines within the hemolymph in model crustaceans (Neil, 2012; Neil and Thompson, 2012).

The purpose of the present study is to investigate the effect of two anesthetic protocols on some hemolymph parameters in mid-sized *Procambarus clarkii* (Girard, 1852).

MATERIAL AND METHODS

Crayfish preparation

This study was conducted in accordance with the Guidelines of the European Union (2010/63/UE) and Law on Veterinary and Medical Activities and Animal Welfare Act. Thirty mid-sized *Procambarus clarkii* individuals (42.91 ± 1.18 g; 55.81 ± 0.65 mm) were transferred to the Ankara University, Faculty of Agriculture, Aquaculture Base, in Turkey. Two experimental groups of crayfish were established – electrical stunning (ES) and blast chilling (BC), each containing fifteen crayfish individually housed in glass aquariums (30 cm × 20 cm × 20 cm, water depth aprox. 10 cm) with fresh water. The crayfish in ES group were subjected to an electrical stunning with different voltage (50-300V) for three seconds and after 10 seconds of recovery to a second (three seconds) stun. The crayfish in BC group were exposed for different period of time (1-5 minutes) to a blast chilling stun, which was in freezer (–18°C).

The crayfish were fed four times (8:00; 10:00; 13:00; 15:00) a day with commercial pellets at a ratio of 1% of body weight. Prior to anesthesia, feed was withheld for 24 hours.

A mobile device developed by members of the research team (Fig. 1) consisting of a capacitor (low capacity 47 µF) and two electrodes (copper). The electrodes were immersed into the water tank and each crayfish was subjected to a current of 4.7 mA (DC) by applying voltage from 50V to 300V for period of three seconds. The BC crayfish were placed in plastic boxes for five minutes in a freezer (–18°C), after that they were moved to the previous tanks for further examinations. The behavior of the crayfish (tail reflex) was used to monitored anesthetic depth. The induction time was recorded from the applying electrical stunning to the water and blast chilling until a weak response to strong tactile stimuli was observed. Recovery time is recorded from the time when the crayfish' normal reflex was restored and begins to move normally.

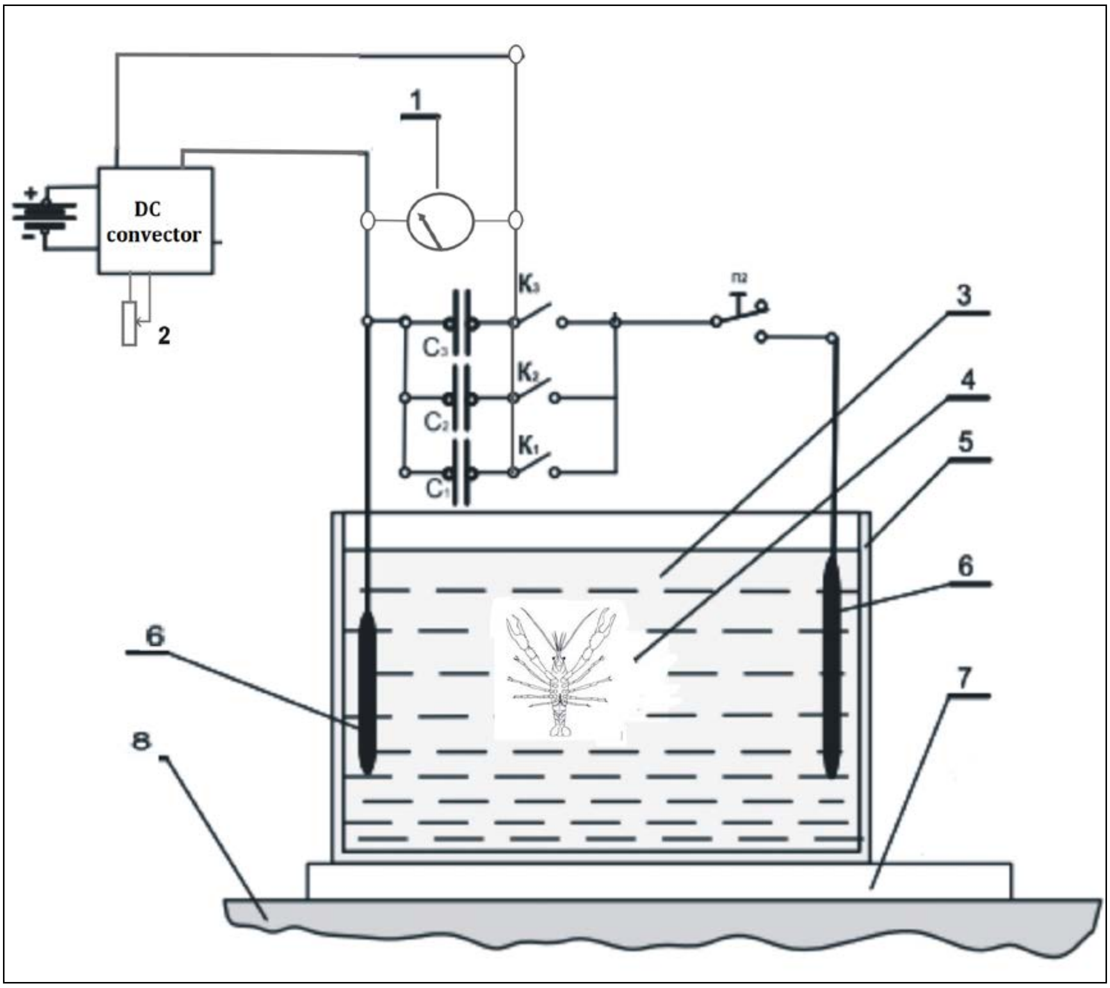


Figure 1: Technical scheme of the mobile electric stunning device: 1. voltage level indicator, 2. voltage regulator, 3. aquatic environment, 4. biological object, 5. insulating vessel, 6. electrodes, insulating surface, 8. table.

Tweezers were used for catching and after induction the crayfish were placed on a non-abrasive surface. Out of water, the crayfish were handled with medical gloves to reduce the risk of damage, and the measurements were made with digital caliper (G01489, Geko Corp., China).

The total length, cephalotorax, carapace, and body weight were recorded (Tab. 1).

Table 1: The growth parameters of *Procambarus clarkii* (Mean ± SE; n = 30).

Parameter	Value
Total length, mm	55.81 ± 0.65
Cephalotorax, mm	26.81 ± 0.43
Carapace, mm	11.75 ± 0.34
Body weight, g	42.91 ± 1.18

Hydrochemical parameters

Water temperature (°C), dissolved oxygen (mg/L), salinity (ppt), total dissolved solids (mg/L), specific conductance (μS/cm), conductance (μS/cm), NH4-N (mg/L), and pH were determined by the portable multi meter (YSI Pro Plus, Xylem Inc., USA).

Biochemical parameters

The crayfish were not separated by sex. Hemolymph was drawn from the pericardial sinus using a needle (18G) in a container with citrate/EDTA buffer at low pH (pH = 4.6) as an anticoagulant (Söderhäll and Smith, 1983). Each sample (50 μl) centrifuged (3,500 rpm for 10 minutes, Ohaus FC5515, Ohaus Corp., USA centrifuge). The levels of total protein (TP), albumin (Alb), globulins (Glb), calcium (Ca), phosphorus (P), urea (Ur) and creatinine (Cr) were determined with commercial kits (Giesse Diagnostics, Italy) on a Semi-auto Chemistry Analyzer (Mindray BA-88, Mindray Bio-Medical Electronics, China). The concentration of aspartate aminotransferase (AST) and alanine aminotransferase (ALT) were measured using a Chema Diagnostica (Italy) kits.

Statistical analysis

The statistical analysis was performed using one way analysis of variance (ANOVA). The results were processed with software Statistica v.10 (StatSoft Inc., 2002). All results are presented as mean and standard error of the mean (Mean ± SE). The statistical significance of parameters was determined in the LSD test at $P < 0.05$.

RESULTS AND DISCUSSION

Hydrochemical parameters

During the examination, the mean water temperature was 24.03 ± 0.10°C, dissolved oxygen (4.72 ± 0.51 mg/L), salinity (0.47 ± 0.03 ppt), total dissolved solids (625.43 ± 34.41 mg/L), specific conductance (963.00 ± 50.75 μS/cm), conductance (945.43 ± 51.14 μS/cm), NH4-N (0.02 ± 0.03 mg/L), and pH (7.41 ± 0.15) respectively. Water quality and values were within the technologically tolerance range of the crayfish.

Anaesthesia application

Induction time for all voltages was recorded as followed: for ES150V – 6.46 ± 0.31 sec., for ES220V – 6.02 ± 0.28 sec., and for ES300V – 5.03 ± 0.48 sec. Out of water period for all groups during linear measurement for growth performances was approximatelly five minutes On completion of the last procedure all crayfish were returned in tanks and motion and behavior of the crayfish (tail reflex) were closely monitored during recovery. Recovery time for all voltages was recorded as follows: for ES150V – 36.51 ± 6.81 sec., for ES220V – 138.18 ± 2.43 sec., and for ES300V – 328.98 ± 17.15 sec. In another group (BC), the recovery time – 13.48 ± 0.13 sec., was recorded at only five minutes of exposure to blast chilling stuning and was significantly different than ES (Tab. 2).

Table 2: Anesthesia monitoring parameters of *Procambarus clarkii* (Mean ± SE; n = 30); * $P < 0.05$; *** $P < 0.001$.

Parameter	Group ES (electrical stun)					Group BC (blast chill)				
	50V	100V	150V	220V	300V	1 min.	2 min.	3 min.	4 min.	5 min.
Induction time, sec.	n.d	n.d	6.46 ± 0.31	6.02 ± 0.28	5.03 ± 0.48	n.d	n.d	n.d	n.d	n.d
Recovery time, sec.	n.d	n.d	36.51 ±6.81*	138.18 ±2.43***	328.98 ±17.15***	n.d	n.d	n.d	n.d	13.48 ±0.13

Survey of hemolymph biochemical changes in the crayfishes exposed to two different anesthetic agents can be used in the assessment of anesthesia's effects of hemostasis of those species. The obtained results are shown in table 3.

Table 3: Effect of anesthesia on some biochemical indices of *Procambarus clarkii* hemolymph (Mean ± SE; n = 30); * *P*<0.05.

Parameter	Group ES (electrical stun/300V)	Group BC (blast chill/5 min)	Reference values
Aspartate aminotransferase, IU	26.64 ± 3.42	17.33 ± 4.50	8 – 28
Alanine aminotransferase, IU	10.00 ± 5.29	29.00 ± 2.10	10 – 40
Creatinine, µmol/L	883.86 ± 26.3	877.9 ± 50.2	523 – 1216
Urea, mmol/L	1.10 ± 0.11	0.62 ± 0.11*	0.58 – 1.10
Total protein, g/L	20.00 ± 3.00	19.66 ± 1.52	10 – 30
Glucose, mmol/L	29.92 ± 5.2	24.42 ± 8.9	10 – 20
Albumine, g/L	13.34 ± 5.7	9.67 ± 3.78	8 – 19
Globulins, g/L	6.67 ± 1.2	9.99 ± 1.56	6 – 14
A/G ration	2/1	0.97/1	0.96/1
Calcium, mmol/L	1.28 ± 0.14	1.74 ± 0.12	1.39 – 2.19
Phosphorus, mmol/L	0.75 ± 0.02	1.08 ± 0.7	0.48 – 1.52

Over the last decade, various means have been used to enable the diagnosis procedures or the slaughtering of crustaceans such as ice, boiling, carbon dioxide, chemical solutions, or electricality. One of the most widely used method for crayfish is chilling, which is readily available, low cost, and without any risk to operator (Yue, 2008). As crayfish are cold-blooded animals, chilling helps reduce nerve function and metabolic activity. After subjected to this method, crayfish do not demonstrate behavioural signs of discomfort or pain, such as autotomy. However, there is no evidence to suggest that this is true anaesthesia rather than just paralysis. The amount of time required to introduction and recovery time by chilling varies depending on species, size, metabolic state, etc. In the present case, the data revealed that exposition of five minutes blast chilling in mid-sized *Procambarus clarkii* showed rapid time of recovery (13.48 ± 0.13s) and none of the crayfish died from the acute cold exposure. Our results about basic parameters for monitoring anesthesia in blast chilling were the same as those described by a number of authors (Roth and Øines, 2010; Weineck et al., 2018), with the relative difference may be attributed to different crayfish species.

There are few published studies assessing electircal stunning in crustaceans (Roth and Øines, 2010; Neil, 2012; Fregin and Bickmeyer, 2016; Roth and Grimsbø, 2016; Weineck et al., 2018). It was reported that electronarcosis is considered safe and effective in freshwater and marine crustaceans at voltages ranging from 110 V to 220 V at 50 Hz AC and varying between two to five Amps. The duration of the stunning ranges between five to 10 seconds for crabs and lobsters and should not exceed 20 seconds to avoid local injuries (Neil, 2012; Neil and Thompson, 2012). The results of this experiment are consistent with data of Roth and Grimsbø (2016) and is supported by the finding that no tissue damage (autotomy) followed to exposure, provided a rapid induction, and short time of recovery (five to six minutes). In the groups ES150V, ES220V, and ES300V, time of induction was statistically significantly shorter and recovery was longer in comparison with group BC5, exposed to a blast chilling stun. The anesthetic time for ES300V group was about three to four minutes and allowed to take hemolymph samples and measure the growth performance of crayfish.

Hemolymph of crustaceans, similar to fish and animal blood, is a highly valuable tissue as an indicator for monitoring of environmental stressors and is a sensitive response to many disorder states in wild or cultured crustaceans (Lorenzon et al., 2011). The most used hemolymph biochemical markers of hepatocellular damage are aspartate- and alanine aminotransferases (AST and ALT). Activity changes in these enzymes are the main sensitive indicators reflecting the physiological status of hepatocytes and protein metabolism (Cheng and Wu, 2019). In the current study the activity of AST showed not statistically increased levels after anesthesia with electrical stunning compared to the standard method whereas ALT were significantly lower than blast chilling. Therefore, the values in both groups were close to the levels reported by Cheng and Wu (2019).

Furthermore, the estimation of creatinine and urea is used to determine injured kidney function and to detect renal diseases (Toffaletti and McDonnell, 2008; Banaee et al., 2012). In our study, the levels of creatinine did not change after administration of either type of anesthetics. On the other hand, the urea concentration is almost doubled compared to cooling. By analogy with fish which produced small quantity of urea and the gills are the important organ of urea excretion for some of them, may be elevated levels indicated branchial epithelial disease instead renal dysfunction.

Furthermore, studies were performed on the total protein concentration in seven species of crustacea and must take into account the fact that various factors (nutrition, reproduction, stress, and infections) can affect the levels of hemolymph proteins. Hemocyanin is the major hemolymph constituent (> 60%); the remaining proteins (in order of concentration) include coagulogen, apohemocyanin, hormones, and lipoproteins (Lorenzon et al., 2011). Also, the values of this predominant protein in hemolymph can be use as a biological criterion of osmotic stress (Sepici-Dinçel et al., 2013). Different stressors may reduce hemocyanin reserves, but in this case the protein concentrations in both groups are the same and no deviations are observed. On other hand, it is possible when animals are under stress to mobilize proteins to respond to increased energy needs, which is important for maintaining homeostasis with increased physiological activity (Martinez et al., 2004). In an investigation, *Procambarus clarkii* hemolymph protein levels from normoxic areas raised during the spring and summer which may be due to increased photoperiod, temperatures, and food availability (Sladkova and Kholodkevich, 2011). These authors found that the total protein concentrations are around 45-50 mg/mL, but if the animals lived in hypoxic areas, the values are much lower (around 25-30 mg/mL), and in this conditons they are close to our results.

Moreover, according to some researches in crustaceans, their main energy source are proteins, and also in haemolymph the main circulating carbohydrate is glucose (Sánchez-Paz et al., 2007). A slight hyperglycemic response was also observed in our survey, but this was not significant, probably because of a stress response triggered by stunning. Furthermore, the crayfish showed no alteration in total protein concentrations in both of groups. Thus, it may be due to the fact that observed hyperglycemia is enough to supply the enhanced energy requirements increasing from the anaestasia stress.

Principally, the determination of electrolytes can evolve as environmental monitoring markers and as indices of crustaceans' welfare (Noga, 2000). Calcium is a macroelement which is absorbed from the external environment, as well as by the gills and guts and then delivered to the cuticle for calcification, or can be stored in the hemolymph or in other tissues (Li and Cheng, 2012). In decapods, which represent the largest group of crustaceans, calcium translocation between an endogenous or exogenous source and the cuticle occurs via the haemolymph and can vary and its transport between the haemolymph and the storage site is accomplished by a specialized epithelium (Luquet and Marin, 2004). Calcium enters the epidermal cells from the molting fluid incorporated into intracellular, extracellular or small granules (released into the haemolymph) (Greenaway and Farrelly, 1991). Also, it is possible, in the freshwater crab, the amount of calcium in haemolymph to be enhanced in pre-molting period (Sparkes and Greenaway, 1984). Li and Cheng (2012) examined haemolymph, hepatopancreas, cuticle, and muscle in *Litopenaeus vannamei*, have observed much higher levels of calcium in haemolymph than our results but we must take into account that the calcium content in the natural freshwater is lower than in marine water. It is also possible to have a low heamolymph calcium levels because the animals are lived in water with small content of this mineral. Nevertheless, we found no significant changes in the concentration of calcium and phosphorus in *Procambarus clarkii* following both methods of anesthesia.

CONCLUSIONS

This investigation provides practical and useful information about the application of electrical stunning in Red Swamp Crayfish (*Procambarus clarkii*). The biochemical haemolymph measured ranges in the present work suggest that homeostasis of crayfishes were no changed after exposure to electrical stunning compared to the standard method of anaesthesia. The effects of electrical stunning did not significantly vary in any measured parameters in haemolymph. Therefore, on the basis of anesthetic effectiveness, ethical expectations and crayfish welfare, we recommend the anesthetic protocol using electrical stunning.

ACKNOWLEDGEMENTS

We would like to express our very great appreciation to Mr. Gerdzhikov L. from Etalon Ltd. Co. for his valuable and constructive suggestions during the planning and development of this research work and handling the device.

REFERENCES

1. Banaee M., Mirvaghefei A., Majazi Amiri B. and Rafei G., 2012 – Biochemical blood and histopathological study of experimental Diazinon poisoning in common carp fish (Cyprinus carpio), *Iranian Journal of Natural Resources*, 65, 2, 119-133.
2. Cheng Y. and Wu S., 2019 – Effect of dietary astaxanthin on the growth performance and nonspecific immunity of red swamp crayfish Procambarus clarkii, *Aquaculture*, 512, 734341.
3. Fotedar S. and Evans L., 2011 – Health management during handling and live transport of crustaceans: A review, *Journal of Invertebrates Pathology*, 106, 1, 143-152.
4. Fregin T. and Bickmeyer U., 2016 – Electrophysiological investigation of different methods of anesthesia in lobster and crayfish, *PLoS ONE*, 11, 9, e0162894.
5. Greenaway P. and Farrelly C., 1991 – Trans-epidermal transport and storage of calcium in Holthuisana transversa (Sundathelphusidae) during premoult, *Acta Zoologica*, 72, 1, 29-40.
6. Li C. and Cheng S., 2012 – Variation of calcium levels in the tissues and hemolymph oflitopenaeus vannamei at various molting stages and salinities, *Journal of Crustacean Biology*, 32, 1, 101-108.
7. Lorenzon S., Martinis M. and Ferrero E. A., 2011 – Ecological relevance of hemolymph total protein concentration in seven unrelated Crustacean species from different habitats measured predictively by a density-salinity refractometer, *Journal of Marine Biology*, 11, 7, Article ID 153654.

8. Luquet G. and Marin F., 2004 – Biomineralisations in crustaceans: storage strategies, *Comptes Rendus Palevol, General Palaeontology (Palaeobiochemistry)*, 3, 6-7, 515-534.
9. Martinez C. B. R., Nagae M. Y., Zaia C. T. and Zaia D. A. M., 2004 – Morphological and physiological acute effects of lead in the neotropical fish Prochilodus lineatus, *Brazilian Journal of Biology*, 64, 4, 797-807.
10. Neil D., 2012 – The effect of the Crustastun™ on nerve activity in crabs and lobsters, Scientific report, Institute of Biodiversity, Animal Health and Comparative Medicine at the School of Medical Veterinary and Life Sciences, University of Glasgow.
11. Neil D., and Thompson J., 2012 – The stress induced by the Crustastun™ process in two commercially important decapod crustaceans: the edible brown Cancer pagurus and the European lobster Homarus gammarus, Scientific report, Institute of Biodiversity, Animal Health and Comparative Medicine at the School of Medical Veterinary and Life Sciences, University of Glasgow.
12. Noga E., 2000 – Hemolymph biomarkers of custacean health, Immunobiology and Pathology, Science Publishers Inc., N. H., 125-163.
13. Roth B. and Øines S., 2010 – Stunning and killing of edible crabs (Cancer pagurus), *Animal Welfare*, 19, 3, 287-294.
14. Roth B. and Grimsbø E., 2016 – Electrical stunning of edible crabs (Cancer pagurus): From single experiments to commercial practice, *Animal Welfare*, 25, 4, 489-497.
15. Sánchez-Paz A., García-Carreño F., Hernández-López J., Muhlia Almazan A. and Yepiz-Plascencia G., 2007 – Effect of short-term starvation on hepatopancreas and plasma energy reserves of the Pacific white shrimp (Litopenaeus vannamei), *Journal of Experimental Marine Biology and Ecology*, 340, 2, 184-193.
16. Sepici-Dinçel A., Alparslan Z., Benli A., Selvi M., Sarikaya R., Ozkul I. and Erkoc F., 2013 – Hemolymph biochemical parameters reference intervals and total hemocyte counts of narrow clawed crayfish Astacus leptodactylus (Eschscholtz, 1823), *Ecological Indicators*, 24, 305-309.
17. Sladkova S. and Kholodkevich S., 2011 – Total protein in hemolymph of crawfish Pontastacus leptodactylus as a parameter of the functional state of animals and a biomarker of quality of habitat, *Journal of Evolutionary Biochemistry and Physiology*, 47, 2, 160-167.
18. Söderhäll K. and Smith V., 1983 – Separation of the haemocyte populations of Carcinus maenas and other marine decapods, and prophenoloxidase distribution, *Developmental and Comparative Immunology*, 7, 2, 229-239.
19. Sparkes S. and Greenaway P., 1984 – The hemolymph as a storage site for cuticular ions during pre-moult in the freshwater land crab Holthuisana transversa, *Journal of Experimental Biology*, 113, 43-54.
20. Tang L. S., Taylor A., Rinberg A. and Marder E., 2012 – Robustness of a rhythmic circuit to short- and long term temperature changes, *The Journal of Neuroscience*, 32, 10075-10085.
21. Toffaletti J. and McDonnell E., 2008 – Variation of serum creatinine, cystatin C and creatinine clearance tests in persons with normal renal function, *Clinica Chimica Acta*, 395, 1-2, 115-119.
22. Weineck K., Ray A. J., Fleckenstein L. J., Medley M., Dzubuk N., Piana E. and Cooper R., 2018 – Physiological changes as a measure of crustacean welfare under different standardized stunning techniques: Cooling and electroshock, *Animals*, 8, 9, 158.
23. Yue S., 2008 – The welfare of crustaceans at slaughter, HSUS Reports: Farm Industry Impacts on Animals, 4.

TAXONOMIC STATUS OF THE GENUS *SABANEJEWIA* (COBITIDAE) FROM KURA-ARAS RIVER SYSTEM (TURKEY)

Erdogan ÇIÇEK *, *Soheil EAGDERI* **, *Burak SECER* * and *Sevil SUNGUR* *** (c.a)

* Nevşehir Haci Bektaş Veli University, Faculty of Art and Sciences, Department of Biology, Nevşehir, Turkey, TR-50300, erdogancicek50@gmail.com, ORCID: 0000-0002-5334-5737; bsecer11@gmail.com, ORCID: 0000-0002-8763-131X.

** University of Tehran, Faculty of Natural Resources, Department of Fisheries, Karaj, Iran, soheil.eagderi@ut.ac.ir, ORCID: 0000-0002-1134-0356.

*** Nevşehir Haci Bektaş Veli University, Health Services Vocational School, Nevşehir, Turkey, TR-50300, sevilsungur@nevsehir.edu.tr, ORCID: 0000-0003-4018-6375 (corresponding author).

DOI: 10.2478/trser-2022-0006

KEYWORDS: inland freshwater, *Sabanejewia aurata*, taxonomy.

ABSTRACT

Sabanejewia is a member of the family Cobitidae found in Europe and Asia. In previous studies, *S. balcanica*, *S. caucasica*, *S. aurata* and *S. caspia* were reported from Turkey. Of these *S. aurata* and *S. caspia* were reported from the Kura-Aras Basin. We examined morphological characters and molecular data of the *Sabanejewia* specimens from Turkish parts of the Kura-Aras river system to determine their taxonomic status. We found no differences between the Kura and Aras rivers' populations in terms of morphology, but different populations showed a genetic distance of 0.1-1.9%. All the studied populations were identified as *S. aurata*. In addition, we could not find any evidence for the presence of *S. caucasica* and *S. caspia* in Turkey.

ZUSAMMENFASSUNG: Taxonomischer Status der Gattung *Sabanejewia* (Cobitidae) aus dem Einzugsgebiet des Kura-Aras Flusses (Türkei).

Sabanejewia ist ein Vertreter der in Europa und Asien vorkommenden Cobitidae. In vorangegangenen Studien wurden *S. balcanica, S. caucasica, S. aurata* und *S. caspia* aus der Türkei gemeldet. Von diesen wurden *S. aurata* und *S. caspia* aus dem Entwässerungsgebiet des Kura-Aras-Flusses angegeben. Um ihren taxonomischen Status zu bestimmen wurden morphologische charakteristische Merkmale und molekulare Daten der Sabanejewia-Exemplare aus den türkischen Bereichen des Kura-Aras-Flusssystems untersucht, Dabei wurden in Bezug auf die Morphologie keine Unterschiede zwischen den Populationen der Flüsse Kura und Aras festgestellt, aber verschiedene Populationen zeigten einen hohen genetischen Abstand von 0,1-1,9%. Alle untersuchten Populationen wurden als *S. aurata* identifiziert. Außerdem konnten wir in der Türkei keine Hinweise auf das Vorkommen von *S. caucasica* und *S. caspia* finden.

REZUMAT: Statutul taxonomic al genului *Sabanejewia* (Cobitidae) din sistemul fluvial Kura-Aras (Turcia).

Sabanejewia este un membru al familiei Cobitidae prezent în Europa și Asia. În studiile anterioare, *S. balcanica*, *S. caucasica*, *S. aurata* și *S. caspia* au fost raportate în Turcia. Dintre acestea, *S. aurata și S. caspia* s-au raportat în bazinul sistemului Kura-Aras. Am examinat caracterele morfologice și datele moleculare ale specimenelor de *Sabanejewia* din zonele turcești ale sistemului fluvial Kura-Aras pentru a determina statutul lor taxonomic. Nu am găsit diferențe între populațiile râurilor Kura și Aras în ceea ce privește morfologia, dar populații diferite au arătat o distanță genetică ridicată de 0,1-1,9%. Toate populațiile studiate au fost identificate ca *S. aurata*. În plus, nu am putut găsi nicio dovadă pentru prezența speciilor *S. caucasica* și *S. caspia* în Turcia.

INTRODUCTION

Sabanejewia Vladykov, 1929 is an Eurasian genus of the Cobitidae family consisting of ten nominal species (Sayyadzadeh et al., 2018; van der Laan, 2019) with four species, *S. aurata*, *S. balcanica*, *S. caucasica*, and *S. caspia* reported from inland waters of Turkey (Kuru et al., 2014; Çiçek et al., 2015; Çiçek and Sungur-Birecikligil, 2016). *Sabanejewia balcanica* (Karaman, 1922), described from the Vardar River of Greece, is found in the Thrace region of Turkey. De Filippi (1863) described *S. aurata* from the Sefid River basin at the Sartschem (Sarcham) of Iran, and it is widespread in the Kura-Aras river system. *Sabanejewia caspia* (Eichwald, 1838) was described from the Caspian Sea at Lenkoran, Azerbaijan, and *S. caucasica* (Berg, 1906) listed as a member of Turkish freshwater ichthyofauna by Kuru et al. (2014) without providing any evidence of its distribution area. In this study, we present our findings regarding the *Sabanejewia* populations in the Turkish part of the Kura-Aras river system, where some authors have reported the presence of three species, *S. aurata*, *S. caspia*, and *S. caucasica*, by providing their morphometric characters and phylogeny using COI barcoding to gain a much better understanding of *Sabanejewia* species in the Turkish part of this complex river system.

MATERIAL AND METHODS

Sampling and morphological study

Samplings were done using a backpack electrofishing device (SAMUS 1000), and the specimens were fixed into buffered 5% formaldehyde or directly fixed in 96% ethanol for molecular works. Then those formaldehyde-fixed specimens were stored in 70% ethanol. All measurements are made point-to-point with digital callipers to the nearest 0.1 mm. Methods for counts and measurements follow Kottelat and Freyhof (2007).

DNA extraction and PCR

DNA was extracted from fin-clips of the collected specimens using a modified Phenol-chloroform method (Sambrook et al., 1989). The COI gene was amplified using primers FishF1 (5'-TCAACCAACCACAAAGACATTGGCAC-3') and FishR1 (5'-TAGACTTCTGGGTGGCCAAAGAATCA-3') (Ward et al., 2005). Polymerase chain reaction (PCR) conditions were as follows: a 50 µl final reaction volume containing 25 µl of Taq 2X Mastermix red, one µl (10 µm) of each primer, five µl of total DNA and 18 µl of H_2O. Amplification cycles were as follows: denaturation for 10 minutes at 94°C; 30 cycles at 94°C for one min., 58.5°C for one min., 72°C for one min., and a final extension for five min. at 72°C. PCR products were purified using a purification kit (Bioneer, Inc, Daejeon, Korea). The PCR products were sequenced using the Sanger method by a robotic ABI-3130xl sequencer using the manufacturer's protocol (Macrogen, Inc, Daejeon, Korea). The forward and reverse primers were used for single-strand sequencing.

Molecular data analysis

We newly generated four DNA barcodes, and the sequences were compared to the published *Sabanejewia* sequences using a basic local alignment search tool (BLASTn) (Altschul et al., 1990). The retrieved sequences of the other members of the genus *Sabanejewia* from GenBank database (NCBI) following blast search are shown in table 1. For phylogenetic reconstructions, the datasets were analysed by Bayesian Inference (BI) using MrBayes 3.1.2 (Ronquist et al., 2011) and the maximum likelihood (ML) method in IQTREE 1.6.0 (Hoang et al., 2018). We determined the best-fit model of molecular evolution for the given data and to reconstruct the mitochondrial relationships between the studied taxa using the Bayesian information criterion scores (BIC) in IQTREE 1.6.0 (Kalyaanamoorthy et al., 2017). MrBayes was run with six substitution types (nst = 6) and considered gamma-distributed rate variation across sites and a proportion of invariable sites (GTR) for the COI datasets. For BI, we ran four simultaneous Monte Carlo Markov Chains for 10,000,000 generations, sample frequency every 1,000 generations, chain temperature 0.2. Log-likelihood stability was attained after 10,000 generations, and we excluded the first 1,000 trees as burn-in. The remaining trees were used to compute a 50% majority-rule consensus tree. For ML analyses, we conducted heuristic searches (1,000 runs) according to TPM2+F+G4 model. The genetic distances were investigated based on Kimura two-parameter (K2P) distances (Kumar et al., 2008). As outgroups, *Cobitis saniae* and *Misgurnus fossilis* (accession numbers: KP050509 and KM286765, respectively) were retrieved from GenBank.

Table 1: List of species used for molecular analysis and their GenBank accession number.

No.	Species	Accession no.
1.	*Sabanejewia aurata*	MK377023
2.	*Sabanejewia aurata*	MK377024
3.	*Sabanejewia balcanica*	KJ55470
4.	*Sabanejewia balcanica*	KJ554693
5.	*Sabanejewia baltica*	KR477107
6.	*Sabanejewia baltica*	KM287070
7.	*Sabanejewia caspia*	MK377022
8.	*Sabanejewia caspia*	MK377021
9.	*Sabanejewia caspia*	MK377020
10.	*Sabanejewia larvata*	KJ554832
11.	*Sabanejewia larvata*	KJ554664
12.	*Cobitis saniae*	KP050509
13.	*Misgurnus fossilis*	KM286765

The Mantel test was used to test for correlation between COI sequence data from each population and their geographical coordinates. The Mantel test was performed in PAST.

Materials used for morphological study

Sabanejewia aurata, IMNRF-UT-1085, 6, 47.8-61.6 mm SL; Iran: Ardabil prov.: Balikhlochay River at Baligulu, tributary of Aras River drainage, Caspian Sea basin, 38°09'11"N 48°11'07"E. – NHVUIC 1707, 3, 63.0-63.4 mm SL; Turkey: Erzurum prov.: Övenler Stream at Pasinler, Caspian Sea basin, 39°58'38.5"N 41°38'28.8"E. – NHVUIC 1807, 2, 76.1-81.0 mm SL; Turkey: Ardahan prov.: Kura River at Altaş Village, Caspian Sea basin, 41°09'33.9"N 42°52'06.5"E. – NHVUIC 1808, 4, 59.9-66.6 mm SL; Turkey: Ardahan prov.: Kura River at Sugöze Village, Caspian Sea basin, 41°06'06.1"N 42°39'38.0"E.

Sabanejewia caspia: IMNRF-UT-1084, 2, 45.5-50.1 mm SL; Iran: Gilan prov.: Rasht city, Anzali Wetland, Caspian Sea basin, 37°29'13"N 49°21'2"E.

Materials used for molecular analyses

All from Turkey: *Sabanejewia aurata*: – NHVUIC 1707-2 fin, Turkey: Erzurum prov.: Övenler Stream at Pasinler, 39°58'38.5"N 41°38'28.8"E. – NHVUIC 1807-2 fin, Turkey: Ardahan prov.: Kura River at Altaş Village, Caspian Sea basin, 41°09'33.9"N 42°52'06.5"E. GeneBank Accession number (ON025669, ON025670, ON025671, ON025672).

RESULTS

The body shape of the collected *Sabanejewia* specimens from the Aras and Kura rivers are displayed in figure 1, and their morphometric and meristic data are provided in tables 2 and 3. The morphometric characters of the *Sabanejewia* specimens from these two rivers largely overlap except prepelvic length (46.3-49.0 (in Aras) vs. 49.2-51.4 (in Kura) %SL) and postorbital distance (42.5-46.9 (in Aras) vs. 48.2-52.0 (in Kura) %HL). In addition, there was no difference between the studied populations in terms of the colour pattern.

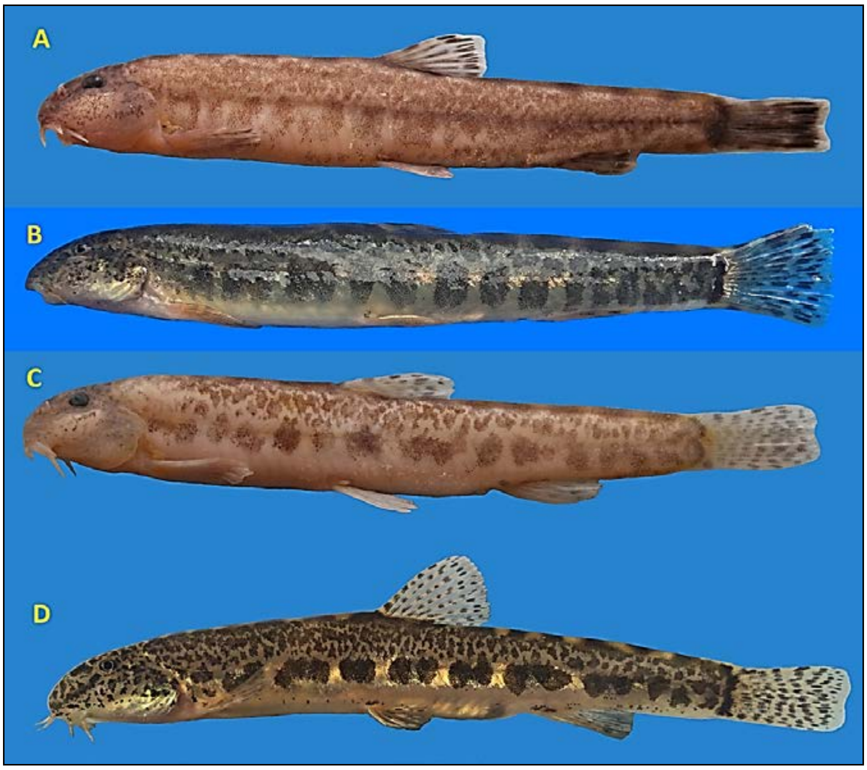


Figure 1: *Sabanejewia aurata* from the (A-B) Kura River, Turkey, (C) Aras River, Turkey, (D) Balikhlochay River, Iran.

Table 2: Morphometric data of the studied *Sabanejewia aurata* populations from the Kura and Aras rivers.

Morphometrics	Aras River (n = 3)		Kura River (n = 6)	
	Range	Mean±SD	Range	Mean±SD
Standard length (mm)	62.9-63.4	63.2±0.2	59.9-81.0	70.5±8.8
In percent of SL				
Head length	19.2-20.4	19.9 ± 0.6	19.1-21.1	20.1±0. 7
Body depth at dorsal-fin origin	16.0-17.0	16.53 ±0.5	14.8-16.5	15.7±0.7
Body width at dorsal-fin origin	8.7-10.2	9.2±0.9	8.2-9.3	8.6±0.4
Predorsal length	47.2-48. 9	47.95±0.8	48.5-50.7	49.6±0.8
Postdorsal length	40.3-43.4	42.2±1.7	39.1-42.8	41.5±1.3
Prepelvic length	46.3-49.0	46.8±1.0	49.2-51.4	50.1±0.8
Preanal length	71.3-73.6	71.5±0.1	72.3-76.4	74.9±1.3
Distance between pectoral and pelvic-fin origins	26.0-28.8	27.0±1.5	28.5-31.4	29.9±1.4
Distance between pelvic and anal-fin origins	22.6-24.3	23.7±0.9	23.7-26.7	25.2±1.0
Depth of caudal peduncle	10.4-10.7	10.59±0.1	9.1-10.8	9.5±0.5
Length of caudal peduncle	19.9-21.2	20.5±0.6	17.9-20.5	19.1±0.8
Dorsal-fin depth	16.7-16.9	16.8±0.1	16.2-17.3	16.7±0.5
Pectoral fin length	15.3-15.9	15.8±0.2	13.9-15.6	15.0±0.6
Pelvic fin length	12.6-13.7	13.1±0.6	11.6-13.9	12.9±0.8
In percent of HL				
Head depth at nape	65.9-67.9	66.9±1.0	62.1-73.7	69.0±4.6
Head depth at eye	47.1-49.3	48.4±1.1	48.6-58.8	52.5±3.9
Snout length	42.5-45.6	43.8±1.6	39.7-47.0	43.7±2.6
Eye diameter	16.9-17.8	17.4±0.4	14.4-18.9	15.8±1.6
Postorbital distance	42.5-46.9	45.0±2.3	48.2-52.0	50.0±1.6
Maximum head width	43.8-48.9	46.6±2.6	39.9-51.0	45.9±3.8
Interorbital width	19.1-21.1	20.0±1.0	14.5-19.5	17.3±1.3

Table 3: Meristic data of the studied *Sabanejewia aurata* populations from the Kura and Aras rivers.

	Branched dorsal-fin rays			
	N	6½	7½	mode
Sabanejewia aurata (Aras)	3	1	2	7
Sabanejewia aurata (Kura)	6	2	4	7
	Branched anal-fin rays			
	N	5½	6½	mode
Sabanejewia aurata (Aras)	3	3	–	5
Sabanejewia aurata (Kura)	6	6	–	5
	Pelvic-fin rays			
	N	6	7	mode
Sabanejewia aurata (Aras)	3	3	–	6
Sabanejewia aurata (Kura)	6	5	1	6
	Pectoral-fin rays			
	N	8	9	mode
Sabanejewia aurata (Aras)	3	1	2	9
Sabanejewia aurata (Kura)	6	2	4	9
	Caudal-fin rays			
	N	12	14	mode
Sabanejewia aurata (Aras)	3	3	–	12
Sabanejewia aurata (Kura)	6	6	–	12

According to the obtained results, *Sabanejewia* populations from the Aras and Kura rivers are nested in the same clade (Fig. 2).

The generated DNA barcode sequences of the *Sabanejewia* populations showed more than 98% similarity with the available sequences of *S. aurata*. In addition, a minimum K2P genetic distance between *S. aurata* from the Kura River and those from the Övenler Stream at Pasinler (a tributary of Aras River) and Balikhlochay River, entering to the Gharasu River, a tributary of the Aras River, were 1.3-1.5% and 1.6-1.9%, respectively. Furthermore, the distance between specimens from the Övenler stream and Balikhlochay River was 0.5-0.6%. The results revealed no correlation between the sequence data from each population and their geographical coordinates of the studied *S. aurata* ($P > 0.05$).

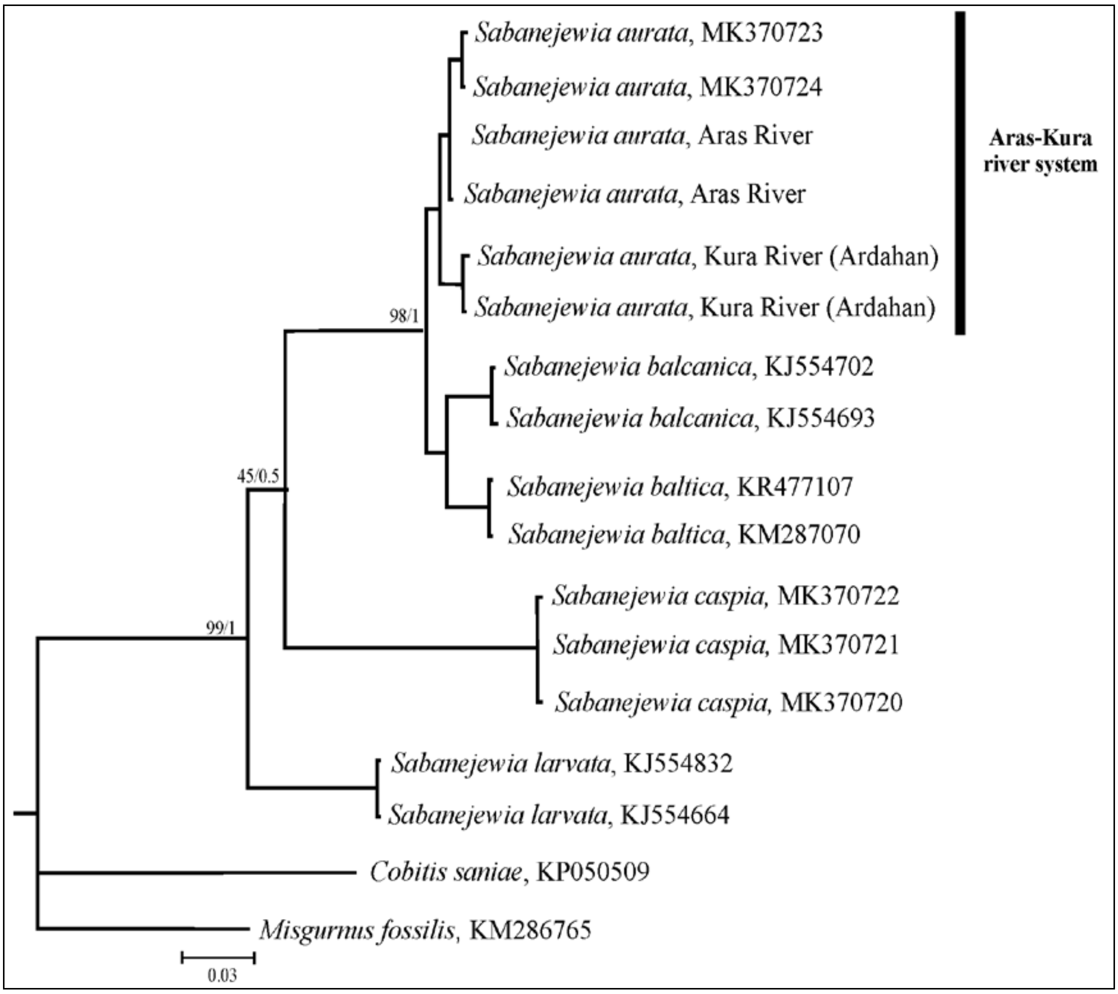


Figure 2: Maximum likelihood estimation of the phylogenetic relationships based on the mitochondrial COI barcode region. Values at nodes correspond to ML bootstrap /BI posterior probability.

DISCUSSION

We found only *S. aurata* in the Aras and Kura rivers and their morphometric and meristic data were largely overlapping, except prepelvic length and postorbital distance. In a species with a widespread distribution area, we expect small morphological differences between populations found in different environmental conditions (Marcil et al., 2006; Poorbagher et al., 2017; Radkhah et al., 2017). In addition, the results revealed that *Sabanejewia* specimens of the Turkish parts of the Aras and Kura rivers are nested with other *S. aurata* DNA data available in the GenBank. The generated DNA sequences in the global database (GenBank) provide a trustworthy platform for speedy and correct species identification providing a better understanding of biodiversity (Shen et al., 2013).

The report of *S. caucasica* in the Turkish parts of the Kura-Aras river system by Kuru (1975) is apparently an error. In addition, solely *S. aurata* has been reported from the lower parts of the Çoruh (Rioni) River in Georgia, a river draining to the Black Sea (Ninua and Japoshvili, 2008), and not found in the Turkish part (Bayçelebi et al., 2015). According to Berg (1949), *S. caucasica* is distributed in the Terek, upper reaches of Kuban River. Furthermore, our sampling in the Kura and Aras rivers had not led of collecting of any *S. caspia* in Turkish parts of these rivers. *S. caspia* is found in fresh and brackish waters of the southern Caspian Sea basin, reported in the lower part of the Kura River, Novogolsk (Damakh), Kumashi, Lenkoran, Anzali Wetland and some rivers' estuaries in the Mazanderan Province of Iran (Berg, 1949; Coad, 2019). Therefore, *S. caucasica* and *S. caspia* should be excluded from Turkish fish fauna till providing further confirmation by specimens.

The results also revealed a high genetic distance i.e. 0.5-1.9%, between different populations of *S. aurata* in the Kura-Aras river system. This distance was lower between the populations of the same river (0.1-0.6%), however, there was no correlation between the sequence data and geographical distance of the studied *S. aurata* populations. One of the main difficulties regarding the identification of the ichthyofauna of the Kura-Aras river system can be inaccessibility to the whole river system. The Kura-Aras river basin is an internationally significant river system that covers almost all of Armenia and Azerbaijan, and a sizeable part of the populated and urbanized parts of Georgia. These countries together with Iran and Turkey rely heavily on the Kura-Aras river system as a principal source of water for all sectors and users including industry, agriculture, energy, and, residential. The Aras River has its source near Erzurum in Anatolia, and it is the longest river in the southern Caspian Sea and drains the south side of the Lesser Caucasus Mountains and then joins the Kura River which drains the north side of those mountains. Its total length is 1,072 km covering an area of 102,000 km^2. The lower parts of this river system form small lakes with associated marshes e.g. Akh Gol and even the main canal has 0.5-4.0 m depth, with an average of 2.5 m (Zakeri, 1997). Therefore, high genetic distances between the isolated populations of the *S. aurata* can be due to the above-mentioned barriers in the lower parts of the river system, leading to habitat fragmentations. The nocturnal *Sabanejewia* species inhabit faster water in the upper and middle reaches of rivers and they prefer shallow and clear waters (Coad, 2019). This non-migrant *S. aurata* prefers similar habitat, therefore, they show similar morphological characteristics despite having a high genetic distance (Fig. 3).

Figure 3: The Kura River at Ardahan, habitat of *Sabanejewia aurata*.

CONCLUSIONS

We examined the collected *Sabanejewia* specimens from Turkish parts of the Kura-Aras river system that were *Sabanejewia aurata*.

Based on our findings, the populations of the Kura and Aras rivers have similar morphology, however, they showed a genetic distance of 0.1-1.9%.

We could not find any evidence for the presence of *Sabanejewia caucasica* and *Sabanejewia caspia* in the Turkish part of this river system, and their presence needs to be confirmed.

ACKNOWLEDGEMENTS

We are pleased to thank Nevsehir Haci Bektas Veli University and University of Tehran and Keivan Abbasi for providing *Sabanejewia caspia* specimens.

REFERENCES

1. Altschul S. F., Gish W., Miller W., Myers E. W. and Lipman D. J., 1990 – Basic local alignment search tool, *Journal of Molecular Biology*, 215, 3, 403-410.
2. Bayçelebi E., Turan D. and Japoshvili B., 2015 – Fish fauna of Çoruh River and two first records for Turkey, *Turkish Journal of Fisheries and Aquatic Sciences*, 15, 777-788, https://doi.org/10.4194/1303-2712-v15_4_01.
3. Berg L. S., 1949 – Freshwater fishes of the U.S.S.R. and adjacent countries, 4th edition, 2, English translation appeared in Israel Program of Scientific Translation, Jerusalem, 1964, 496.
4. Coad B. W., 2019 – Freshwater Fishes of Iran, retrieved from www.briancoad.com.
5. Çiçek E. and Sungur-Birecikligil S., 2016 – Ichthyofauna of the Turkish parts of Kura-Aras River Basin, *FishTaxa*, 1, 1, 14-26.
6. Çiçek E., Sungur-Birecikligil S. and Fricke R., 2015 – Freshwater fishes of Turkey: a revised and updated annotated checklist, *Biharean Biologist*, 9, 2, 141-157.
7. De Filippi F., 1863 – Nuove o poco note specie di animali vertebrati raccolte in un viaggio in Persia nell' estate dell' anno 1862, *Archivio per la Zoologia, l'Anatomia e la Fisiologia*, 2, 377-394. (in Italian)
8. Hoang D. T., Chernomor O., Von Haeseler A., Minh B. Q. and Vinh L. S., 2018 – UFBoot2: improving the ultrafast bootstrap approximation, *Molecular Biology and Evolotion*, 35, 2, 518-522, https://doi.org/10.1093/molbev/msx281.
9. Kalyaanamoorthy S., Minh B. Q., Wong T. K. F., von Haeseler V. and Jermiin L. S., 2017 – ModelFinder: fast model selection for accurate phylogenetic estimates, *Nature Methods*, 14, 587-589, https://doi.org/10.1038/nmeth.4285.
10. Kottelat M. and Freyhof J., 2007 – Handbook of European Freshwater Fishes, Cornol, Switzerland, 646.
11. Kumar S., Nei M., Dudldey J. and Tamura K., 2008 – MEGA: a biologist-centric software for evolutionary analysis of DNA and protein sequences, *Briefings in Bioinformatics*, 9, 299-306, https://doi.org/10.1093/bib/bbn017.
12. Kuru M., 1975 – Systematic and zoogeographic investigation of Pisces living in freshwater waters of Tigris-Euphrates, Kura-Aras, Van Lake and Black Sea Basin (Assoc. Prof. Thesis), Atatürk University, Erzurum, Turkey. (in Turkish)
13. Kuru M., Yerli S. V., Mangıt F., Ünlü E. and Alp A., 2014 – Fish biodiversity in inland waters of Turkey, *Journal of Academic Documents for Fisheries and Aquaculture*, 3, 93-120.
14. Marcil J., Swain D. P. and Hutchings J. A., 2006 – Countergradient variation in body shape between two populations of Atlantic cod (Gadus morhua), *Proceeding Biological Science*, 22, 273, 1583, 217-223, https://doi.org/10.1098/rspb.2005.3306.
15. Ninua N. S. and Japoshvili B. O., 2008 – Check list of fishes of Georgia, *Proceedings of the Institute of Zoology*, XXIII, 163-176.
16. Poorbagher H., Eagderi S. and Pirbeigi A., 2017 – Temperature-induced phenotypic plasticity in Aphanius arakensis Teimori, Esmaeili, Gholami, Zarei and Reichenbacher, 2012 (Teleostei: Aphaniidae), *European Journal of Biology*, 76, 1, 1-6, https://doi.org/10.5152/EurJBiol.2017.1701.
17. Radkhah A. R., Poorbagher H. and Eagderi S., 2017 – Habitat effects on morphological plasticity of Saw-belly (Hemiculter leucisculus) in the Zarrineh River (Urmia Lake basin, Iran), *Journal of BioScience and Biotechnology*, 6, 1, 37-41.

18. Ronquist F., Teslenko M., van der Mark P., Ayres D. L., Darling A., Höhna S., Larget B., Liu L., Suchard M. A. and Huelsenbeck J. P., 2012 ─ MrBayes 3.2, Efficient bayesian phylogenetic ınference and model choice across a large model space, *Bioinformatics*, 61, 539-542, https://doi.org/10.1093/sysbio/sys029.

19. Sambrook J., Fritsch E. F. and Maniatis T., 1989 ─ Molecular Cloning – A laboratory manual, 2nd edition, Cold Spring Harbor Press, Cold Spring Harbor, New York, 545.

20. Sayyadzadeh G., Abbasi K. and Esmaeili H. R., 2018 ─ Review and re-description of Sabanejewia species in Iran (Teleostei: Cobitidae), *Iranian Journal of Ichthyology*, 5, 4, 267-292, https://doi.org/10.22034/iji.v5i4.322.

21. Shen Y. Y., Chen X. and Murphy R. W., 2013 ─ Assessing DNA barcoding as a tool for species identification and data quality control, *PLoSONE*, 8, 2, e57125, https://doi.org/10.1371/journal.pone.0057125.

22. van der Laan R., 2019 ─ Freshwater Fish List (Online), 27th edition, Richard van der Laan, Almere, the Netherlands, 1086.

23. Ward R. D., Zemlak T. S., Innes B. H., Last P. R. and Hebert P. D., 2005 ─ DNA barcoding Australia’s fish species, *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 360, 1462, 1847-857, https://doi.org/10.1098/rstb.2005.1716.

24. Zakeri H., 1997 ─ Water catchment area of the Caspian Sea, Abangan, Student Quarterly of the Water Engineering Faculty of Khajeh Nassir ud-Din Tousi, 1997, 12, www.netiran.com/Htdocs/Clippings/Social/970700XXSO02.html.

A NEW CONCEPT OF FRONTAL MIGRATION SYSTEM FOR FISH – FOR OVERFLOW WEIRS AND RIVER SILLS

Răzvan VOICU *, *Liliana VOICU* *, *Artur RADECKI-PAWLIK* **, *Doru BĂNĂDUC* *** and *Karol PLESIŃSKI* **** (c.a.)

* National Institute of Hydrology and Water Management, București-Ploiești Street 97, București, Romania, RO-013686, getiiliberi@gmail.com, ORCID: 0000-0002-3459-173X, lilianavoicu80@gmail.com, ORCID: 0000-0001-9164-7042.
** Cracow University of Technology, Structural and Material Mechanics Division, Warszawska Street 24, Krakow, Poland, PL-31-155, rmradeck@cyf-kr.edu.pl, ORCID: 0000-0002-6486-1016.
*** Lucian Blaga University of Sibiu, Applied Ecology Research Center, Dr. Ion Raţiu Street 5-7, Sibiu, Romania, RO-550012, ad.banaduc@yahoo.com, ORCID: 0000-0003-0862-1437.
**** University of Agriculture in Krakow, Department of Hydraulic Engineering and Geotechnics, Mickiewicza Avenue 21, Krakow, Poland, PL-31-120, k.plesinski@ur.krakow.pl, ORCID: 0000-0003-2157-2502, (correspondence author).

DOI: 10.2478/trser-2022-0007

KEYWORDS: river sills, overflow weirs, fish pass hydraulic structure, migration.

ABSTRACT

In this paper we present a new frontal migration system for fish which could be used for overflow weirs and river sills. Since movement of fish is the most crucial thing in the healthy river environment fish passes are necessary to predict in any place where hydraulic structures are designed or any river engineering works are applied in the river channel. Thus in our paper we are giving a proposal of a new fish migration system when any river cross section weirs, sills or other low head hydraulic structures are planned. We hope our system would be built one day proving the advantage of using it.

RÉSUMÉ: Un nouveau concept de système de migration frontale des poissons – pour les déversoirs et les seuils des rivières.

Dans cet article, nous présentons un nouveau système de front de migration pour les poissons qui pourrait être utilisé pour les déversoirs et les seuils des rivières. Puisque le mouvement des poissons est la chose la plus cruciale dans l’environnement sain de rivière les passes de poissons sont nécessaires pour prévoir dans n’importe quel endroit où les structures hydrauliques sont conçues ou n’importe quels travaux d’ingénierie de rivière sont appliqués dans le canal de rivière. Ainsi, dans notre document, nous proposons un nouveau système de migration des poissons lorsque des barrages, des seuils ou d’autres structures hydrauliques à faible chute sont prévus. Nous espérons que notre système sera construit un jour pour démontrer l’avantage de l’utiliser.

REZUMAT: Un nou concept de sistem frontal de migrare pentru pești – pentru deversoare și praguri de râu.

În această lucrare vă prezentăm un nou sistem frontal de migrare a peștilor, care ar putea fi utilizat pentru deversoare și praguri de râu. Deoarece mișcarea peștilor este cel mai important lucru într-un mediu sănătos al râurilor, prevederea trecătorilor pentru pești este necesară în orice loc în care sunt proiectate structuri hidraulice sau orice lucrări de inginerie a râurilor aplicate în albia râului. În această lucrare oferim o propunere pentru un nou sistem pentru migrarea peștilor atunci când sunt planificate deversoare, praguri sau alte structuri hidraulice. Sperăm că sistemul nostru va fi construit într-o zi dovedind avantajul utilizării lui.

INTRODUCTION

The lotic systems suffered extremely variated modification types and degradations in the last decades all over the world due to a high number of variable factors (Curtean-Bănăduc and Farcaş, 2013; Gromova et al., 2013; Curtean-Bănăduc, 2014a, b, 2015; Barinova et al., 2016; Marić et al., 2017; Pacioglu et al., 2019; Piria et al., 2019; Barinova et al., 2020; Bănăduc D. and Curtean-Bănăduc A., 2020; Caleta M. et al., 2020; Kar and Khynriam, 2020; Kar et al., 2020; Najib et al., 2020; Radkhah and Eagderi, 2020; Radkhah et al., 2020; Schneider-Binder, 2020; Şahin et al., 2020; Valiallahi, 2020; Askeyev et al., 2021; Barinova, 2021; Barinova and Mamanazarova, 2021; Cianfaglione, 2021; Rios, 2021; Savenko and Kryvtsova, 2021) including due to the rivers engineering. River engineering is sometimes a necessity especially when the rivers or streams must be prevented against flooding, use for obtaining electric power, irrigations, etc. However any hydraulic structure built in the river channel could create ecological problems for lotic environments, including for the local or/and regional organisms, among them the one of the most important indicative for lotic systems ecological status taxonomic group, the fish, is a typical example (Voicu et al., 2014, 2020a; Popa et al., 2016; Radecki-Pawlik et al., 2019; Costea et al., 2021; Bănăduc et al., 2014, 2020, 2021). All fish species need a continuous free access to different habitats (feeding, sheltering, wintering, spawning, nursery, etc.) all along their life cycle. The occurrence of habitats fragmentation and degradation is significantly opposing them to reach the fish population optimum distribution and ecologic status, or even make them to vanish. Such fragmentations can be created including by all types of damming structures which need the best in situ adapted type of overflow weirs and river sills to be used in each specific case. That is why the enrichment with new concepts of these constructions global portfolio is not only a necessity but a must (Bylak et al., 2017).

The Water Framework Directive (Directive 2000/60/WE) was introduced to help conserve river geomorphical and ecological integrity across Europe. This Directive emphases on ensuring (or re-installing) the natural hydromorphic functioning of watercourses and helped set the challenge of finding new solutions to the long-standing problems caused by river engineering (Plesiński et al., 2021). This challenge requires multidisciplinary integrated researcher teams to bring into light new innovative concepts including for avoiding or repairing lotic systems fragmentation and degradation.

There are many impact types on fish habitats of barriers which block, disrupt or/and delay movements, inducing reduced fish fitness, ecological status and increase their mortality. In order to allow the fish to overpass abrupt level differences on rivers resulting from artificial damming by dams, weirs, drops, sills and other engineering structures, and also natural barrages formed by waterfalls, hydraulic technical structures called fish passes or fish ways, are or should be carefully built. There are relative numerous designs of such structures for fish spatial mobility and even migration: conventional pool passes, slot pool passes, denil (baffle) fish passes, modular meander-type fish passes, cascaded pool fish pass with boulder weirs – step-pool rock ramp fish way, ramp riffles, cascades, cascaded bypasses, bypass in the form of riffles, fish lifts, ropeways and railways, etc. (Tymiński and Kałuża, 2013; Mokwa and Tymiński, 2017).

Fish ladders and passages were found to be the most common means of passing fish upstream man made barriers (Čada and Jones, 1993). The design of a fish pass is one of the most challenging processes in water engineering, due to the technical problems to be solved in the conditions of the in situ environment related needed adaptations. This is because the designer is faced here with a problem that requires solving several interrelated tasks: the design work, the hydraulics of liquid and solid flow and the biological and ecological characteristics of the local and regional fish species. Therefore, the best solution would be the cooperation of hydrotechnical engineers and technicians with biologists and ecologists with expertise in aquatic ecology and ichthyology in the design, construction, and monitoring of these special created and adapted technical structures. The most common problems occurring during the operation of the fish pass are the lack of attracting current for fish at the exit of the fish pass (connections of the fish pass with the river bed), lack of monitoring (e.g. dislodging after extreme events), no positive reaction to changing natural and/or human induced hydrological conditions, and last but not least poaching (Bănăduc and Curtean-Bănăduc, 2019; Bartnik et al., 2010; Plesiński et al., 2020; Bănăduc et al., 2021).

When designing a fish pass, it is important to combine good engineering practice, good biological and ecological assessment and monitoring data, careful laboratory tests, and numerical simulations (Teppel and Tymiński, 2013).

Also an important aspect in the restoration of longitudinal connectivity in rivers and streams is the implementation of fish migration systems at the upstream of the functional hydraulic structures (weirs, drop structures, or river sills). The diversity of these existing structures as well as the different locations of these weirs within the lotic system, riparian zone, and watershed challenges the design engineers to find new holistic adaptative solutions for fish migration systems (Voicu et al., 2020b).

Thus in this work we present one of the fish-like pass systems which we call frontal fish migration system. It can be built for overflow weirs and sills and used in any hydraulic river engineering works. We hope our system will be built one day and prove its usefulness.

DESCRIPTION OF MIGRATION SYSTEM

Before making a ridge (migration channel) on approximately the entire length of the overflow weir, it will be increased in width by adding a layer of concrete both upstream and downstream of approximately 10 cm (Fig. 1).

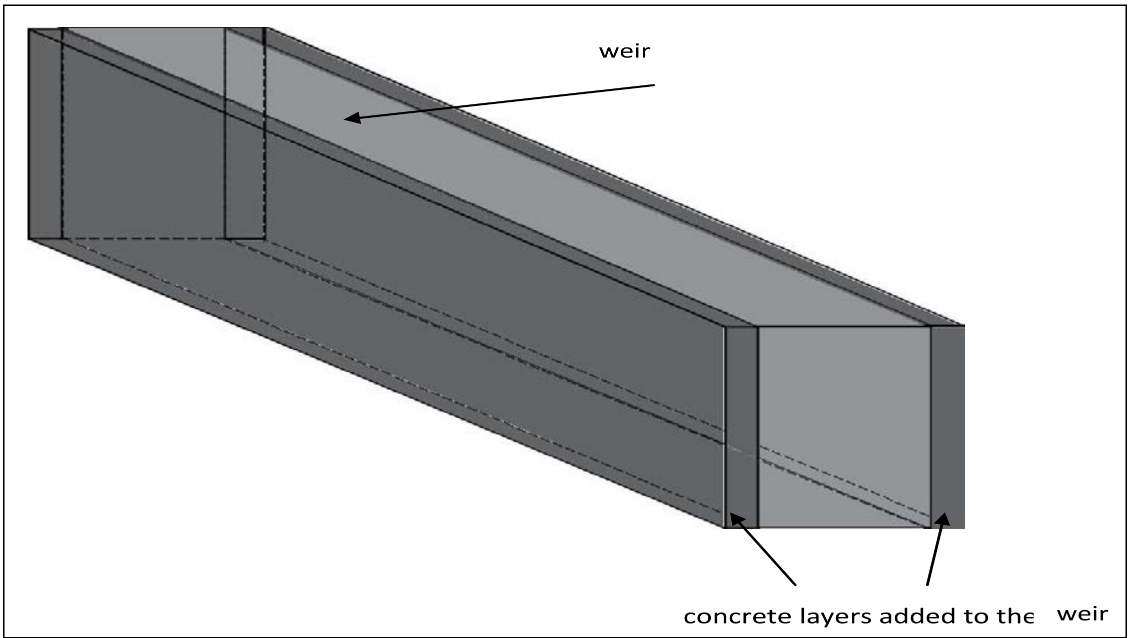


Figure 1: Positioning the concrete layers on the weir.

After the overflow weir has been lined with concrete on either side like it is shown in figure 1, a crenel is drilled perpendicular to it. Before approximately 10 cm to pierce the spillway weir, the battlement (crenel) will bend to the left or right depending on how the end of the crenel is positioned. In this case, the battlement (crenel) turns to the right (Fig. 2).

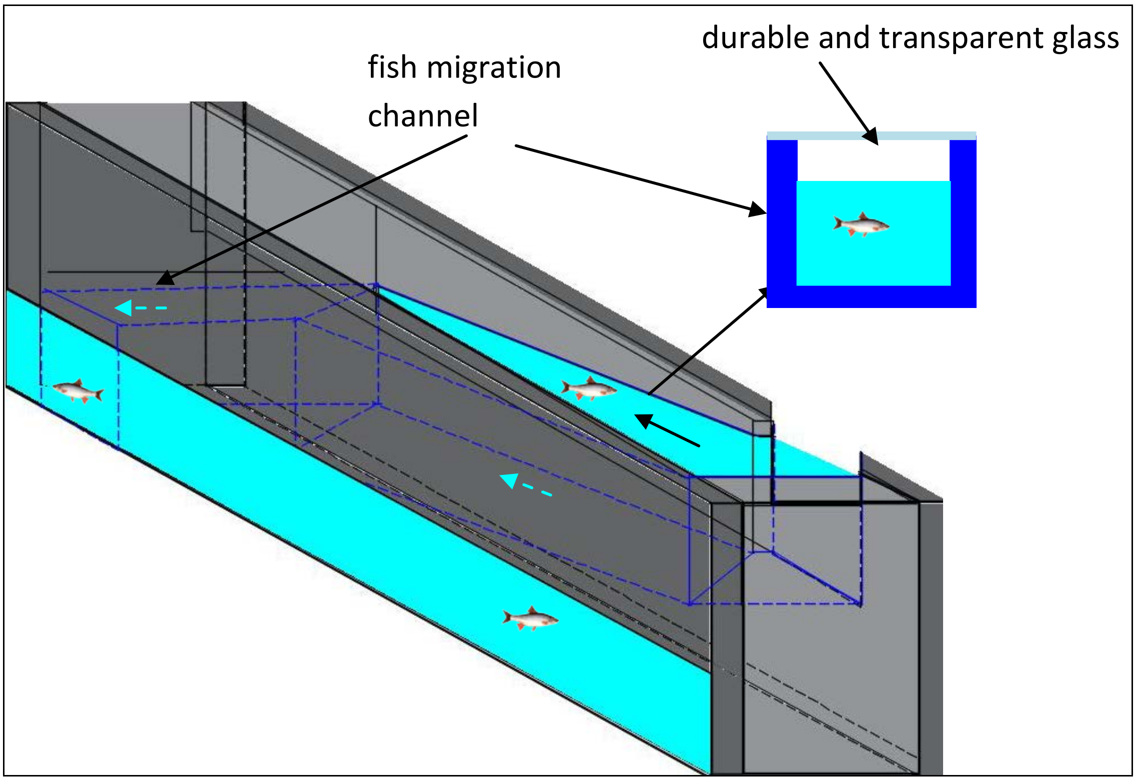


Figure 2: Positioning the battlement inside the weir.

After the battlement turns to the left or right, its slope will be chosen according to the biological and ecological characteristics migratory species in the river or stream of interest. The whole fish migration channel is covered by a resistant and transparent glass sheet (Fig. 2). Over this glass sheet, the stream will pass or not. But it will still protect the fish's migration channel so that water does not enter it. Being transparent glass, the fish will have enough light to be able to migrate. After the channel for migrating the fish has passed a portion of the weir (through it) it will turn left or right (Fig. 2). If the downstream end of the migration channel is below the water level by about two thirds then the end of the channel will not be extended (Fig. 2). If the downstream end of the fish migration channel is above the river water level, the channel will extend with the same slope outside the weir so as to reach the watercourse (Fig. 3).

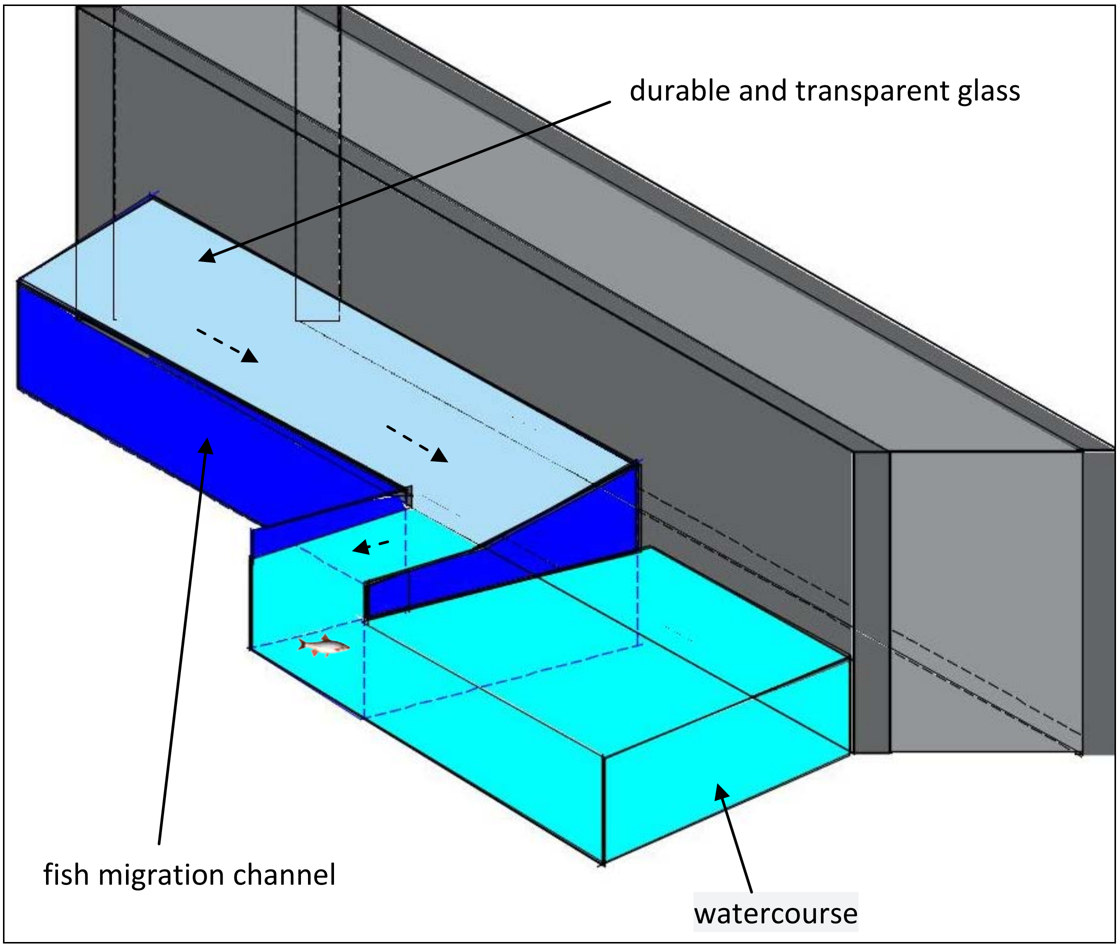


Figure 3: Extension of the canal to the watercourse.

The shape of the channel fixed to the weir will have a trapezoidal shape closing in the upper part with a resistant and transparent glass ceiling (Fig. 3). If the downstream end of the fish migration channel even in these conditions will not reach the watercourse then the downstream end will be connected to a basin, to two basins, three connection basins that have a direct connection with the river (Fig. 4).

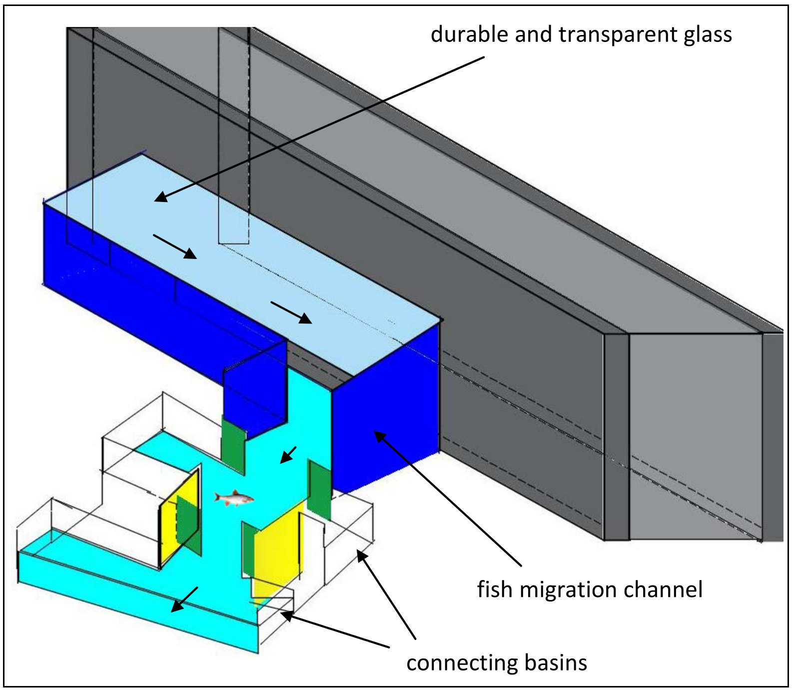


Figure 4: Positioning of connecting basins.

The system is functional at overflow thresholds of heights less than or equal to 2.5 m.

The advantage of this technical system is that during floods it can hardly be damaged. A semicircular metal bar fixed at the top will protect the channel from floats (Fig. 5).

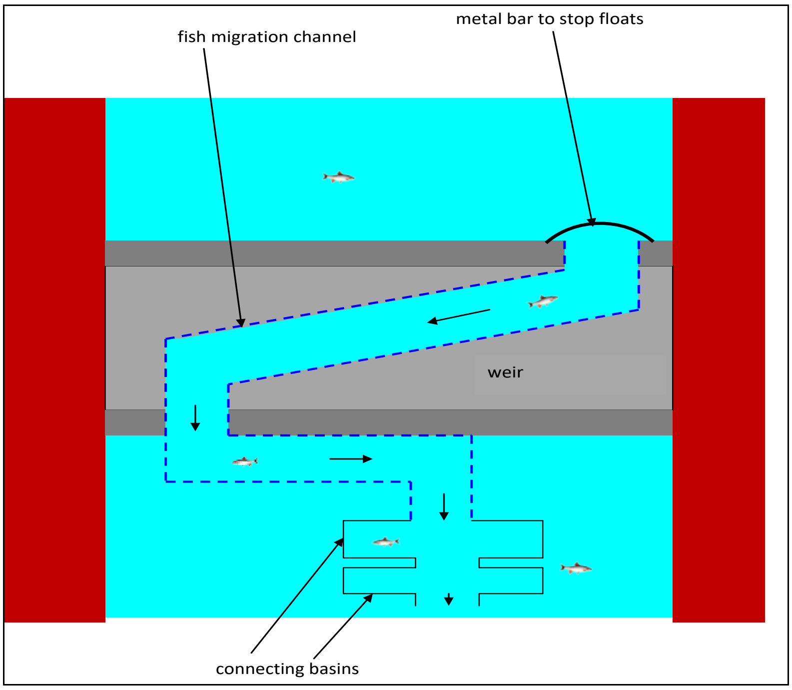


Figure 5: General scheme of the system for fish migration.

CONCLUSIONS

Fish ladders should be an integral part of weirs and dams, especially those that block the migration path for fish. Unfortunately, it is too often possible to find hydrotechnical structures in the riverbeds without elements supporting the migration of fish. Therefore, such facilities should be modernized and new ones should be constructed with fish passes.

The system proposed here has several advantages: relatively low cost of creation; taking up a small space (no influence on the external structure of the overflow threshold); protection against poaching (difficult access for outsiders); low costs of monitoring and operation; no impact of flood waters on the migration system; production of attracting current.

An additional advantage of the discussed system built of local and natural materials (stones, boulders – increasing the roughness of the surface of the walls and the bottom of the system elements, as well as imitating the natural conditions of the river bed bottom), macrozoobenthos will be able to be present in the system, and probably also migrate.

REFERENCES

1. Askeyev A., Askeyev O., Askeyev I. and Monakhov S., 2021 – Occurrence, abundance and distribution of Bleak, Common Spirlin, and Sunbleak in the environmental gradients of small rivers (Tatarstan), *Transylvanian Review of Systematical and Ecological Research*, 23.2, 51-62, DOI: https://doi.org/10.2478/trser-2021-0014.
2. Barinova S., Na L., Jiyang D., Yonglei A., Xueming Q. and Chenxin W., 2016 – Ecological assessment of water quality of the Songhua River upper reaches by algal communities, *Acta Ecologica Sinica*, 36, 3, 126-132, DOI: https://doi.org/10.1016/j.chnaes.2015.12.001.
3. Barinova S., 2021 – Plants, mosses, charophytes, protozoan, and bacteria water quality indicators for assessment of organic pollution and trophic status of continental water bodies, *Transylvanian Review of Systematical and Ecological Research*, 23.3, 17-36, DOI: https://doi.org/10.2478/trser-2021-0018.
4. Barinova S. and Mamanazarova K. 2021 – Diatom algae-indicators of water quality in the lower Zarafshan River, Uzbekistan, *Water*, 13, 358, DOI:doi.org/10.3390/w13030358.
5. Bartnik W., Książek L. and Wyrębek M., 2010 ─ Hydrauliczne warunki występowania prądu wabiącego dla przepławek ryglowych, *Infrastructure and Ecology of Rural Areas*, 9, 123-132, (in Polish).
6. Bănăduc D., Curtean-Bănăduc A., Lenhardt M. and Guti G., 2014 – "Porţile de Fier/Iron Gates" Gorges area (Danube) fish fauna, *Transylvanian Review of Systematical and Ecological Research*, special issue 16, The "Iron Gates" Natural Park, Edit. Universităţii "Lucian Blaga" din Sibiu, ISSN 1841-7051, 171-196, DOI: 10.1515/trser-2015-0041.
7. Bănăduc D. and Curtean-Bănăduc A., 2019 – Habitat changes impact on fish fauna – Scorei Dam lake study case (Olt River, Danube Basin), *Acta Oecologica Carpatica*, XII.I, 63-84.
8. Bănăduc D. and Curtean-Bănăduc A., 2020 – Human impact effects on Târnava River basin aquatic biodiversity (Transylvania, Romania), in Human impact on Danube Watershed biodiversity in the XXI Century, Bănăduc D., Curtean-Bănăduc A., Pedrotti F., Cianfaglione, Akeroyd J., (eds), Springer Nature Switzerland AG, 425-437, DOI: https://doi.org/10.1007/978-3-030-37242-2_20.
9. Bănăduc D., Voicu R. and Curtean-Bănăduc A., 2020 – Sediments as factor in the fate of the threatened endemic fish species Romanichthys valsanicola Dumitrescu, Bănărescu and Stoica, 1957 (Vâlsan River basin, Danube Basin), *Transylvanian Review of Systematical and Ecological Research*, 22.2, The Wetlands Diversity, 15-30, DOI: https://doi.org/10.2478/trser-2020-0008.

10. Bănăduc D., Voicu R., Voicu L., Baki A. B. M., Barb C., Serrano I. and Curtean-Bănăduc A., 2021 – Coştei hydrographic diversion node, a historical environment quality and biological resources accessibility game changer (Middle Danube Watershed); anthropogenic induced problems and sustainable solutions – An ichthyologic perspective, *Transylvanian Review of Systematical and Ecological Research*, 23.3, The Wetlands Diversity, 87-116, DOI: 10.2478/trser-2021-0021.
10. Bylak A., Kukuła K., Plesiński K. and Radecki-Pawlik A., 2017 – Effect of a baffled chute on stream habitat conditions and biological communities, *Ecological Engineering*, 106 A, 263-272.
11. Ćaleta M., Mustafić P., Zanella D., Buj I., Marčić Z. and Mrakovcic M., 2020 – Human impacts on the Dobra River (Croatia), in Human impact on Danube Watershed biodiversity in the XXI Century, Bănăduc D., Curtean-Bănăduc A., Pedrotti F., Cianfaglione, Akeroyd J., (eds), Springer Nature Switzerland AG, 151-168.
12. Čada G. F. and Jones D. W., 1993 – Benefits of fish passage and protection measures at hydroelectric projects, Report of Environmental Sciences Division and Energy Division, Oak Ridge National Laboratory, Work for Hydropwer Program, Office of Renewable Energy Conversion, U.S. Department of Energy, *Envirnmental Sciences Division Publication*, 4042, ORNL, 715-724.
13. Cianfaglione K., 2021 – Plant landscape and models of French Atlantic estuarine systems, Extended summary of the doctoral Thesis, *Transylvanian Review of Systematical Research*, 23.1, 15-36, DOI: https://doi.org/10.2478/trser-2021-0002.
14. Costea G., Push M. T., Bănăduc D., Cosmoiu D. and Curtean-Bănăduc A., 2021 – A review of hydropower plants in Romania: distribution, current knowledge, and their effects on fish in headwater streams, *Renewable and Sustainable Energy Reviews*, 54, 111003, DOI: 10.1016/j.rser.2021.111003.
15. Curtean-Bănăduc A. and Farcaş A., 2013 – Timiş River (Banat, Romania) benthic macroinvertebrate communities structure spatial dynamic, *Transylvanian Review of Systematical Research*, 15, special issue, 123-32, DOI: 10.2478/trser-2013-0038.
16. Curtean-Bănăduc A., 2014a – Diversity of Stonefly (Insecta, Plecoptera) communities in the Grădişte Watershed (Grădiştea Muncelului-Cioclovina Nature Park), *Acta Oecologica Carpatica*, VII, 61-72.
17. Curtean-Bănăduc A., 2014b – Benthic macroinvertebrate communities in the northern tributaries of the Iron Gates Gorge (Danube River), *Transylvanian Review of Systematical Research*, 16, 3, 151-164, DOI: https://doi.org/10.1515/trser-2015-0039.
18. Curtean-Bănăduc A., 2015 – Biotope determinants of EPT assamblages structure – Târnava Watershed (Transylvania, Romania) case study, *Transylvanian Review of Systematical Research*, 16, 3, 151-164, 17.2, 95-104, DOI: https://doi.org/10.1515/trser-2015-0067.
19. Directive 2000/60 European Commission of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32000L0060.
20. Gromova Y. F., Afanasyev S. and Shevtsova L.V. 2013 – Structural Organization of Zooplankton in Transformed Small Rivers, *Hydrobiological Journal*, 49, 1, 21-29.
21. Kar D. and Khynriam A. D. 2020 – On a recent pioneering taxonomic study of the fishes from Rivers Diyung, Vomvadung, Khualzangvadung, Tuikoi and Mahur in Dima Hasao District of Assam (India), *Transylvanian Review of Systematical Research*, 22.3, 83-106, DOI: 10.2478/trser-2020-0019.
22. Kar D., Khynriam D., Das B. and Das S., 2021 – A recent taxonomic study of the fish from the Jinam River in Dima Hasao biodiversity hotspot region of Assam (India); *Transylvanian Review of Systematical Research*, 87-102, DOI: https://doi.org/10.2478/trser-2020-0013.

23. Marić S., Stanković D., Wanzenböck J., Šanda R., Erős T., Takács P., Specziár A., Sekulić N., Bănăduc D., Ćaleta M., Trombitsky I., Galambos L., Sipos S. and Snoj A., 2017 – Phylogeography and population genetics of the European mudminnow (Umbra krameri) with a time-calibrated phylogeny for the family Umbridae, *Hydrobiologia*, 792, 151-168, DOI: https://doi.org/10.1007/s10750-016-3051-9.
24. Mokwa M. and Tymiński T., 2017 ─ Hydraulic calculations for fish passes, in Open channel hydraulics, river hydraulic structures and fluvial geomorphology for engineers, geomorphologists and physical geographers, Radecki-Pawlik A., Pagliara S., Hradecký J. and Erik Hendrickson, (eds), CRC Press, eBook ISBN 9781315120584, 51, DOI: 10.1201/9781315120584.
25. Najib S. A. M., Aliah S. and Hamidon H. N., 2020 – Suspended sediment concentration and sediment loading of Bernam River, (Perak, Malaysia); *Transylvanian Review of Systematical Research*, 22.2, 1-14, DOI: 10.2478/trser-2020-0007.
26. Pacioglu O., Satmari A., Milca P., Pîrvu M., Cîmpean M., Battes K. P., Lele S. F., Bănăduc A. and Pârvulescu L., 2019 – Flash-floods influence macroinvertebrate communities distribution in lotic ecosystems, *Transylvanian Review of Systematical Research*, 21.1, 45-56, DOI: 10.2478/trser-2019-0004.
27. Piria M., Simonović P., Zanella D., Ćaleta M., Šprem N., Paunović M., Tomljanović T., Gavrilović A., Pecina M., Špelić I., Matulić D., Rezić A., Aničić I., Safner R. and Treer, T. 2019 – Long-term analysis of fish assemblage structure in the middle section of the Sava River - The impact of pollution, flood protection and dam construction, *Science of The Total Environment*, 651, 1, 143-153, DOI: 10.1016/j.scitotenv.2018.09.149.
28. Plesiński K., Radecki-Pawlik A. and Suder K., 2020 ─ Analiza funkcjonalności przepławki komorowej dla ryb przy stopniu wodnym zlokalizowanym na potoku Porębianka (w:), Kałuża T., Radecki-Pawlik A., Wiatkowski M. and Hammerling M. (eds), Modelowanie procesów hydrologicznych. Zagadnienia modelowania w sektorze gospodarki wodnej, Wydawnictwo Naukowe Bogucki, Poznań, 69-86. (in Polish)
29. Plesiński K., Radecki-Pawlik A., Galia T. and Gibbins C., 2021 ─ Block ramp hydraulic structures in mountain streams and rivers: Design considerations, flow hydraulics and eco-geomorphic processes, Bogucki Wydawnictwo Naukowe, Poznań, ISBN 978-83-7986-345-7, 270.
30. Popa G.-O., Curtean-Bănăduc A., Bănăduc D., Florescu I. E., Burcea A., Dudu A., Georgescu S. E. and Costache M., 2016 – Molecular markers reveal reduced genetic diversity in Romanian populations of Brown trout, Salmo trutta L., 1758 (Salmonidae), *Acta Zoologica Bulgarica*, 68, 3, 399-406.
31. Radecki-Pawlik A., Voicu R., Plesiński K., Gajda G., Radecki-Pawlik B., Voicu L. and Książek L., 2019 ‒ Difficulties with existing fish passes and their renovation, The pool fish pass on Dłubnia river in Krakow, *Acta Scientiarum Polonorum*, Formatio Circumiectus, 18, 2, 109-119, https://doi.org/10.15576/ASP.FC/2019.18.2.109.
32. Radkhah A. R. and Eagderi S., 2020 – Investigation on the global distribution of invasive fish species, convict cichlid Amatitlania nigrofasciata (Perciformes, Cichlidae) over the past years with emphasis on Iranian inland waters, *Transylvanian Review of Systematical Research*, 22.3, 45-56, DOI: 10.2478/trser-2020-0017.
33. Radkhah A. R., Eagderi S. and Shams Y., 2020 – The fish fauna of the Zarineh River (Urmia Lake Basin) downstream sector – conservation and management; *Transylvanian Review of Systematical Research*, 22.1, 69-80, DOI: 10.2478/trser-2020-0005.
34. Rios J. M., 2021 – Predation by the nonnative rainbow trout, Oncorhynchus mykiss (Walbaum, 1792), on the native biota from freshwater environment of the central Andes (Argentina), *Transylvanian Review of Systematical Research*, 23.1, 67-72, DOI: 10.2478/trser-2021-0005.

35. Savenko M. and Kryvtsova M., 2021 – Urban aquatic ecosystems as a factor of the spread of antibiotic resistant microorganisms and resistance genes, *Transylvanian Review of Systematical Research*, 23.2, 1-12, DOI: 10.2478/trser-2021-0009.
36. Schneider-Binder E., 2020 – Riparian vegetation along the Scroafa Stream and its tributaries (Southern Transylvanian Tableland) under changing ecological conditions and human intervention; *Transylvanian Review of Systematical Research*, 22.2, 31-46, DOI: 10.2478/trser-2020-0009.
37. Şahin B., Akar B. and Barinova S. 2020 – Bioindication of water quality by diatom algae in high mountain lakes of the Natural Park of Artabel Lakes (Gümüşhane, Turkey), *Transylvanian Review of Systematical and Ecological Research*, 22.1, 1-28, DOI: https://doi.org/10.2478/trser-2020-0001.
38. Teppel A. and Tymiński T., 2013 – Hydraulic research for succesful fish migration improvement – “nature-like” Fishways, *Civil and Environmental Engineering Reports*, 10/2013.
39. Tymiński T. and Kałuża T., 2013 – Effect of vegetation on flow conditions in the “nature-like“ Fishways, *Annual Set the Environment Protection*, 15.
40. Valiallahi J., 2020 – Range map and distribution of Luciobarbus barbulus (Heckel, 1847) in the Tigris and Euphrates river basins; *Transylvanian Review of Systematical Research*, 22.1, 57-68, DOI: 10.2478/trser-2020-0004.
41. Voicu R. and Bănăduc D., 2014 – Restoring longitudinal connectivity of the Someşul Mic River near the dam in Măstirea Village (Transylvania, Romania), *Acta Oecologica Carpatica*, VII, 153-172.
42. Voicu R., Radecki-Pawlik A., Tymiński T., Mokwa M., Sotir R. and Voicu L., 2020a – A potential engineering solution to facilitate upstream movement of fish in mountain rivers with weirs: Southern Carpathians, the Azuga River, *Journal of Mountain Science*, 17, DOI: 10.1007/s11629-019-5572-y, 501-515.
43. Voicu R., Radecki-Pawlik A., Voicu L., Urbani J. D. and Bănăduc D., 2020b – Innovative on-site adapted system for fish migration with flow divider and glass collector basin, *Transylvanian Review of Systematical and Ecological Research*, 22.1, DOI: 10.2478/trser-2020-0006, 81-98.