Plant & Fungal Research (2025) 8 (2): 46-54
https://doi.org/10.30546/2664-5297.2025.8.2.1029
ISSN 2617-8001 (print), ISSN 2664-5297 (online)

The algoflora of forest springs in Basgal (Ismayilli, Azerbaijan)

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Abstract: This study investigates the algal flora of seven forest springs in Basgal settlement of Ismayilli district (southern Greater Caucasus), emphasizing their ecological structure and bioindicator potential. Seasonal sampling was conducted during 2024 (May, July, September) in both planktonic and benthic habitats. Water temperature, pH, electrical conductivity and total dissolved solids were measured *in situ*, and algal samples were analyzed using light and electron microscopy. Taxonomic identification followed standard phycological keys and was verified via AlgaeBase. Water quality and organic pollution were evaluated using the Palmer Pollution Index and saprobity analysis. The mean temperature of the springs ranged from 7°C to 12°C, with pH values between 7.6 and 8.5, electrical conductivity from 162 to 322 µS/cm, and total dissolved solids from 105 to 209 mg/L, indicating neutral to slightly alkaline and moderately mineralized waters. A total of 25 taxa belonging to five divisions were identified: Charophyta, Chlorophyta, Cyanobacteria, Euglenophyta and Heterokontophyta. Palmer Index values (10–22) and saprobic assessments confirmed mostly oligosaprobic to β-mesosaprobic conditions. The results show that algal diversity and distribution in Basgal forest springs are closely linked to hydrological regime and forest vegetation, reflecting high ecological stability. These findings highlight the importance of algal monitoring for assessing and conserving freshwater ecosystems in mountainous forests of Azerbaijan.

Keywords: *diversity, electrical conductivity, freshwater algae, Palmer pollution index, physicochemical parameters, total dissolved solids*

INTRODUCTION

The study of algal communities in forest springs is particularly important for understanding the ecological integrity of these habitats. Algae respond rapidly to changes in environmental factors such as light regime, water chemistry, and hydrological conditions, and they are considered reliable bioindicators of ecosystem health [Round, 1984; Dubey et al., 2022; Naselli-Flores, Padisak, 2023]. Algae represent one of the most ecologically diverse groups of photo autotrophs in freshwater environments [Graham et al., 2009]. In forested areas, leaf litter decomposition, shading, and the breakdown of organic matter significantly influence the structure and species composition of algal communities [Sánchez et al., 2013]. The interaction between terrestrial and aquatic components contributes to the overall biodiversity and functionality of forest ecosystems [Akar, Şahin, 2014; Barinova, Kukhaleishvili, 2017].

Basgal settlement is located on the southern slopes of the Greater Caucasus mountains and is distinguished by its unique nature. The area is ecologically significant due to its rich diversity of flora and fauna as well as the presence of clean freshwater sources [Museyibov, 1998]. This forest ecosystem mainly consists of mixed forests dominated by hornbeam (*Carpinus betulus*), chestnut-leaved oak (*Quercus castaneifolia*) and Caucasian oak (*Quercus macranthera*). The shading effect of tree species such as oak and hornbeam regulates both water temperature and illumination regime, which are directly linked to the structural organization of algal communities. These forests play a crucial role in regulating the hydrological cycle, preventing soil erosion, and maintaining the local microclimate, thereby contributing significantly to ecosystem stability, biodiversity conservation, and the sustainability of surrounding human settlements. Springs have both ecological and socio-economic importance. In addition to serving as sources of drinking water for local communities, they also provide habitats for rare aquatic biotopes. These biotopes create favorable conditions for the development of various algal groups, particularly diatoms [Wehr et al., 2015]. Diatoms are recognized as key bioindicators of ecosystem health, and the investigation of their species composition is essential for water quality monitoring [Glevitzky et al., 2025;

Received: 07.08.2025; Received in revised form: 12.09.2025; Accepted: 22.12.2025
Citation: Malikli Y.M., Mukhtarova Sh.J. (2025) The algoflora of forest springs in Basgal (Ismayilli, Azerbaijan). *Plant & Fungal Research*, 8(2): 46-54.

Mukhtarova, Muradova, 2021; Nobre et al., 2025; Taurozzi et al., 2024]. In recent decades, climate change, anthropogenic pressures, and intensive tourism activities have imposed additional stress on the region's aquatic ecosystems [Glibert, 2020; Cottingham et al., 2021; Bellino, Baldantoni, 2023]. Therefore, studying the biodiversity of Basgal's forest-spring ecosystems is of both theoretical and practical significance.

Phycological investigations indicate that diatoms (Heterokontophyta), green algae (Chlorophyta), and cyanobacteria (Cyanoprokaryota) are the most frequently encountered taxa in springs [Aysel, 2005; Jafarova, Mukhtarova, 2018]. The limited light availability and stable water temperature characteristic of forest-enclosed springs promote the dominance of diatoms [Butterwick et al., 2005; Sánchez et al., 2013].

Consequently, the vegetation cover, soil properties, and climatic conditions of Basgal forest exert a direct influence on the ecological state of its springs and the composition of their algal communities. A comprehensive study of these interrelationships holds substantial scientific and practical value for regional bioindication and water quality monitoring. Primary objective of this research is to conduct a detailed analysis of the algal flora of forest springs in Basgal, to determine their taxonomic structure and ecological group distribution, and to explore their ecological interactions with surrounding forest ecosystems. This approach provides a deeper understanding of the role of algae in maintaining ecological balance within the mountain-forest ecosystems of the Greater Caucasus.

MATERIALS AND METHODS

Algal samples were collected during May, July and September of 2024. Both planktonic and benthic (periphytic) forms were recorded at each sampling station. The samples were placed in sterile glass flasks, tightly sealed, and preserved with a 4% formalin solution [APHA, 2005]. Each sample was individually labeled, and the GPS coordinates of the collection sites were accurately recorded. Water temperature was measured *in situ* using a mercury thermometer, while pH values were determined with a portable pH meter (ATO-PH-02, Germany). The geographic locations of the sampling sites are shown in the corresponding map (Fig. 1). The map was produced in ArcGIS 10.8.2 (Esri) using the geographic coordinates of the study sites.

Samples of diatoms were examined using scanning electron microscopy (SEM, JSM-35SEM, JEOL, Japan), blue-green and green algae by using optical microscope

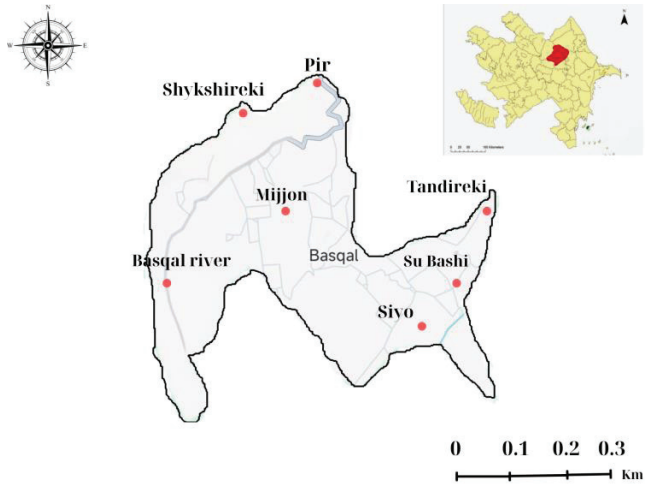

Figure 1. The map of the studied water bodies in Basgal settlement of Ismayilli district.

(Nikon E 100 Japan). Euglenophyta taxa were identified using the identification guide by K. Wotowski and F. Hindak [2005]. Prior to microscopic examination, all materials underwent standard cleaning and mounting procedures [Mukhtarova, Muradova, 2021]. Taxonomic identification was carried out in accordance with modern systematic principles, and species names were verified using the AlgaeBase database [Fourtanier, Kociolek, 2009; Guiry, Guiry, 2022].

During the study, key physicochemical parameters of water, including temperature, pH, electrical conductivity, and turbidity were measured, and mineralization levels were determined at certain stations. These indicators were used as the basic framework for evaluating the ecological status of the aquatic habitats [Muniz, 1990].

To determine the trophic state and pollution degree of the water bodies, bioindicator-based assessment methods were applied. The Palmer Pollution Index (PPI) was calculated to identify algal species tolerant to organic pollution, and the results were analyzed for each sampling station [Zahradkova, Soldan, 2008]. In addition, saprobic indicators were used to assess the biological quality of the waters. The integration of these two approaches made it possible to identify sites most affected by anthropogenic influence [Dubey et al., 2022].

For each sampling station, at least three parallel analyses were conducted to determine both qualitative and quantitative characteristics of the algal composition (Fig. 2). Microscopic observations were performed under 40× magnification, and species richness was evaluated following the methodological approach proposed by Round [1953].

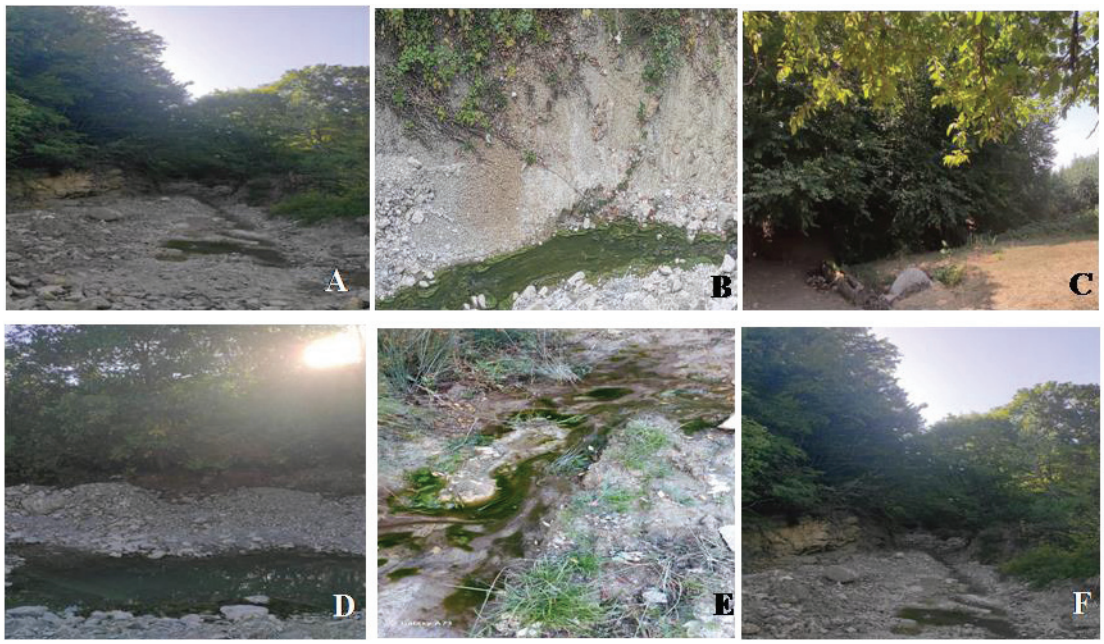

Figure 2. General view of water basins in the forest area. A, B. Basgal river (lower and upper part), C. Pir spring, D. Siyo spring, E. SuBashi, F. Tandiraki spring.

This methodological framework plays an important role in assessing the functional stability of forest ecosystems. The use of spring and stream ecosystems as bioindicators provides valuable insights into nutrient cycling intensity, organic matter decomposition processes, and the degree of anthropogenic impact on natural environments [Naselli-Flores, Padisák, 2023]. Moreover, silica utilization patterns in diatom frustule morphology reflect evolutionary adaptation to environmental gradients [Zoe, Benjamin, 2010]. Consequently, this approach establishes a reliable scientific basis for the long-term monitoring and evaluation of ecological stability within freshwater ecosystems.

RESULTS AND DISCUSSION

Hydro chemical results. During the investigation of the continental water bodies in Basgal settlement, the main physicochemical parameters were analyzed seasonally across different hydrological stations. Parameters such as temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were considered key indicators for assessing the hydro-ecological condition of the aquatic ecosystems and understanding the factors influencing the development of microphytic benthos. The obtained data were systematizedand statistically processed to determine seasonal means (Tab. 1).

These data clearly illustrate the dynamics of seasonal ecological changes in the continental waters of Basgal and provide a reliable scientific basis for evaluating water quality in forest ecosystems.

The physicochemical characteristics of the spring waters, particularly pH, electrical conductivity (EC), and hardness (associated with the concentration of Ca^{2+} and Mg^{2+} ions) showed noticeable seasonal variability. These fluctuations are mainly attributed to differences in hydrological regime, climatic conditions, lithological composition, vegetation types, and anthropogenic factors. The pH values of the spring waters generally remained within a neutral range (7.2–8.7), exhibiting minor seasonal oscillations. During the spring, increased precipitation and snowmelt contributed to a slight decrease in pH values. EC in the spring waters is determined by the total concentration of dissolved ions – primarily Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2}, and HCO_3^{-}. In spring, enhanced precipitation and surface runoff lead to the dilution of ions, resulting in lower EC values. In summer, intensified evaporation and a decrease in water level increase the concentration of dissolved ions, whereas in autumn, the infiltration of mineral-rich groundwater stabilizes EC at a moderate level. Waterhardness is mainly associated with the concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. In areas rich in limestone, dolomite, and other carbonate rocks, spring waters tend to exhibit higher hardness levels. During spring, the increased

Table 1. Seasonal variation and mean values of physicochemical parameters in Basgal settlement.

1 / 2	spring				summer				autumn				mean values			
	T (°C)	pH	EC	TDS	T (°C)	pH	EC	TDS	T (°C)	pH	EC	TDS	T (°C)	pH	EC	TDS
Basgalriver	10	7.4	281	180	21	7.8	260	169	6	7.6	289	188	12	7.6	277	179
Shykshireki	10	7.6	326	212	16	7.9	318	206.7	2	7.7	321	209	9.3	7.7	322	209
Siyo	5.7	7.4	213	199	15	7.7	201	193	2	7.6	207	198	7.6	7.6	207	197
Mijjon	8.5	7	203	132	13	7.4	200	130	4	7.2	205	133	8.5	7.7	203	132
Tandireki	7	8.2	164	107	15	8.4	161	105	5	8.2	167	109	9	8.3	164	107
Pir	6	8.4	163	106	12	8.7	159	103	3	8.5	165	107	7	8.5	162	105
SuBashi	8	8.3	167	109	17	8.6	161	105	6	8.5	170	111	10.3	8.5	166	108

Note: 1– Freshwater bodies, 2– Physicochemical parameters, EC– electrical conductivity, TDS – total dissolved solids.

water volume leads to ion dilution and reduced hardness, while in summer, enhanced evaporation raises ion concentration, resulting in maximum hardness values. In autumn, the percolation of water through soil and decomposing plant litter enriches the water with additional minerals, maintaining hardness at an optimal level and influencing the chemical composition of nearby water bodies (Fig. 3).

Overall observations indicate that the physicochemical parameters of spring waters vary depending on seasonal and ecological processes. The dynamics of parameters such as pH, EC, and hardness are crucial for assessing hydro chemical stability, determining optimal habitat conditions for bioindicator species, and ensuring the continuous monitoring of water quality.

Taxonomic studies. The algal flora identified from the studied continental water bodies consisted of 25 taxa belonging to the following divisions: Charophyta (6), Chlorophyta (5), Cyanobacteria (5), Euglenophyta (2), and Heterokontophyta (7). The proportional composition of the algal community was as follows: Charophyta – approximately 24%, Chlorophyta – 20%, Cyanobacteria – 20, Euglenophyta – 8%, and Heterokontophyta – 28%. The floristic list of the recorded algal taxa is presented in Table 2, while the microphotographs of selected taxa are shown in the main text (Fig. 4).

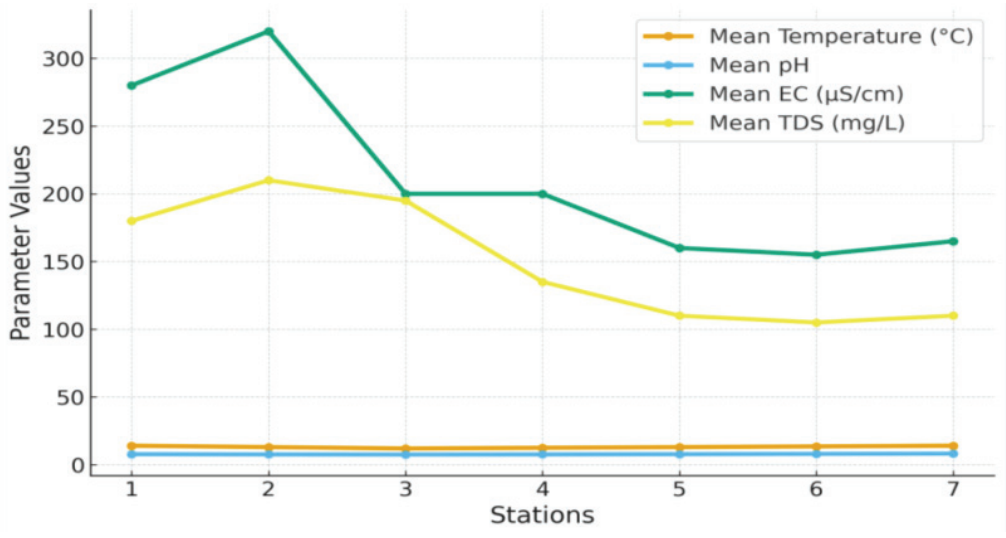

Figure 3. Mean physicochemical parameters (temperature, pH, EC, TDS) measured across the studied stations in Ismayilli district.

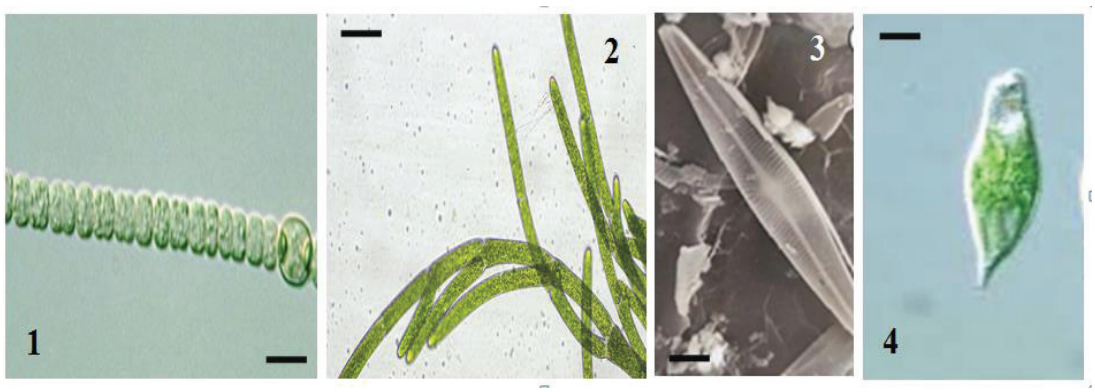

Figure 4. 1. *Anabaena* sp.Bory ex Bornet & Flahault, 2. *Cladophora glomerata* (Linnaeus) Kützing, 3. *Navicula radiosa* Kützing, 4. *Euglena viridis* O.F. Müller) Ehrenberg. Bar: 10 μm

Bioindicator assessment and ecological status. The dominance of Heterokontophyta, particularly species such as *Achnanthidium minutissimum* (Kützing) Czarnecki, *Navicula radiosa* Kützing, and *Nitzschia palea* (Kützing) W. Smith indicate β-mesosaprobic to α-mesosaprobic conditions, corresponding to moderate organic load and stable trophic status. Conversely, springs such as Pir and Siyo were characterized by high-quality, oligotrophic (low-nutrient) waters, while Basgal streams exhibited moderate saprobic indicators and higher abundance of Heterokontophyta species.

Certain taxa, particularly representatives of Cyanobacteria, Euglenophyta, and Chlorophytascored high in the PPI, indicating their tolerance to organic contamination. In some sampling sites, the PPI exceeded 20, signifying moderate organic pollution, most likely associated with agricultural runoff and domestic wastewater influence (Tab. 2).

These results confirm that phytoplankton communities serve not only as indicators of species diversity but also as reliable bioindicators of water quality and pollution level. PPI was applied in the assessment (Palmer, 1969). This method evaluates the tolerance of algal genera- mainly Chlorophyta and Cyanobacteria to organic matter, expressed in scores: values ≥20 indicate moderate to heavy pollution, 15–19 indicate potential risk, and <10 represent clean water conditions.

Field observations from forest springs and streams underscore the importance of these algal communities as indicators of forest ecosystem health. Processes such as leaf decomposition, organic matter accumulation, and canopy shading directly influence the structure and abundance of phytoplankton. Hence, phytoplankton proves to be a highly sensitive component reflecting the biological balance within forest aquatic ecosystems. From an ecological standpoint, these results also allow for comparisons between areas with minimal anthropogenic disturbance and those under higher human impact. Such analyses are of strategic significance for forest ecosystem conservation, sustainable water management, and ecological risk mitigation.

Habitat Form. The algal species recorded in the continental waters of Basgal represent a wide range of ecological forms. The diatom algae primarily developed in benthic and periphytic forms. Genera such as *Navicula*

Table 2. Palmer Pollution Index for selected water sources.

№	Water source	Total score	Assessment
1	Basgal river	24	Moderately polluted
2	Shykshireki	16	Low pollution
3	Siyo	22	Moderately polluted
4	Mijjon	14	Clean (minor risk)
5	Tandireki	10	Clean
6	Pir	21	Moderately polluted
7	SuBashi	10	Clean

Table 3. List of algal species identified in the sampled water bodies.

Division	Species	Sampled water bodies						
		1	2	3	4	5	6	7
CYANOPROKARYOTA	*Anabaena* sp.Bory ex Bornet & Flahault	+				+	+	+
	Nostoc commune Vaucher ex Bornet&Flahault	+	+	+				
	Spirulina turpinex Gomont				+	+	+	+
	*Oscillatoria limosa C.*Agardh ex Gomont	+			+			+
	Leptolyngbya aeruginea (Kützing ex Hansgirg) Komárek					+		
CHLOROPHYTA	*Cladophora glomerata* (Linnaeus) Kützing	+			+		+	+
	Cladophora pulvinata (K.I.Meyer) K.I.Meyer				+		+	+
	Ulothrix Kützing		+			+		
	Oedogonium Link ex Hirn				+		+	
	Chlorella vulgaris Beijerinck	+						
CHAROPHYTA	*Chara vulgaris* Linnaeus	+			+	+		
	Chara contraria A.Braun ex Kützing			+		+		
	Nitella flexilis (Linnaeus) C.Agardh					+		
	Nitella opaca (*C.*Agardh ex Bruzelius) C.Agardh			+				+
	Tolypella nidifica (O.F.Müller) A.Braun	+			+			
	Spirogyra Link	+	+			+	+	
HETEROKONTOPHYTA	*Navicula radiosa* Kützing		+		+			+
	Pinnularia viridis (Nitzsch) Ehrenber	+						+
	Achnanthidium minutissimum (Kützing) Czarnecki	+	+	+			+	+
	Cymbella tumida (Brébisson) Van Heurck	+	+				+	
	Synedra ulna (Nitzsch) Ehrenberg				+			
	Surirella angusta Kützing	+			+			+
	Nitzschia amphibia Grunow	+						+
EUGLENOPHYTA	*Euglena viridis* (O.F.Müller) Ehrenberg					+		
	Trachelomonas hispida (Perty) F.Stein						+	

Note: Sampled water bodies: 1.Basgal river, 2. Shykshireki spring. 3. Siyo spring, 4. Mijjon spring, 5. Tandireki spring, 6. Pir spring, 7. SuBashi spring.

radiosa Kützing, *Nitzschia palea* (Kützing) W. Smith, and *Achnanthidium minutissimum* (Kützing) Czarnecki were widely distributed on rock, plant, and algal surfaces in the springs and streams. Species of *Surirella* and *Synedra* genera dominated on epilithic substrates (rock surfaces). Among Chlorophyta, species like *Cladophora*, *Ulothrix* and *Chaetomorpha* were mainly benthic filamentous forms thriving in illuminated, fast-flowing waters, while *Chlorella vulgaris* and *Scenedesmus quadricauda* were typical planktonic species of stagnant or slow-moving waters. Charophyta species represented macroscopic benthic formsrecognized bioindicators of clean, mineral-rich waters. Cyanobacteria representatives occurred in both planktonic and periphytic environments, showing strong adaptability to organically enriched waters. Overall, benthic and periphytic forms predominated, indicating that the springs and streams of Basgal are substrate-rich and highly transparent environments.

The algal diversity of Basgal forest springs serves as a key indicator of the ecological health of forest ecosystems. The abundance of cyanobacteria and chlorophytes reflects sufficient light penetration and moderate nutrient levels in the water. The presence of *Chara vulgaris* Linnaeus and *Nitella opaca* (C. Agardh ex Bruzelius) C. Agardh confirms the oligotrophic nature of these waters. The high diversity of diatoms—particularly Navicula radiosa Kützing, *Nitzschia palea* (Kützing) W. Smith, and *Achnanthidium minutissimum* (Kützing) Czarnecki – represents a reliable bioindicator of good water quality. *Achnanthidium minutissimum* (Kützing) Czarnecki, typically found in clean and slightly polluted waters, confirms the favorable ecological status of Basgal springs, while the low abundance of tolerant species such as *Nitzschia palea* (Kützing) W. Smith suggests only localized nutrient enrichment.

In relation to forest dynamics, the algal communities are closely linked with processes such as leaf litter decomposition, forest canopy shading, and humic matter

input from soils. The infiltration of humic substances in deciduous forest zones stimulates moderate development of Euglenophyta, while filamentous chlorophytes form biofilms on rock surfaces, serving as substrate and food sources for macrofauna. The dominance of tree species such as *Betula* L., *Carpinus* L., *Fagus* L. and *Quercus* L. in Basgal forests enhances leaf litter input and microbial activity, promoting nutrient availability for algal growth. Thus, a strong mutual interaction exists between the forest ecosystem and spring algoflora, maintaining ecological balance within these aquatic environments.

CONCLUSIONS

The results of this study demonstrate that the forest springs of Basgal area sustain a diverse and ecologically balanced algal community, largely dominated by diatoms and chlorophytes. The variations in algal composition are closely associated with seasonal changes in water temperature, pH, electrical conductivity, and nutrient levels. The predominance of benthic and periphytic forms indicates that these springs are characterized by high water transparency and stable substrates.

The ecological assessment based on the Palmer Pollution Index and saprobity levels confirms that most of the studied springs maintain oligotrophic to moderately mesotrophic conditions, with only localized impacts from anthropogenic sources. The presence of clean-water indicators such as *Achnanthidium minutissimum* (Kützing) Czarnecki, *Chara vulgaris* Linnaeus, and *Nitella apaca* C. Agardh ex Bruzelius under scores the relatively undisturbed nature of these habitats.

Overall, the algal flora of Basgal forest springs reflects a well-preserved ecosystem, where interactions between aquatic and terrestrial components play a crucial role in maintaining ecological stability. This research highlights the importance of continuous monitoring of algal communities as reliable bioindicators for evaluating the ecological integrity of mountain forest ecosystems in the Greater Caucasus region.

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Basqal meşə bulaqlarının alqoflorası (İsmayıllı, Azərbaycan)

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Bu tədqiqat Böyük Qafqazın cənub yamacında yerləşən Basqal meşə bulaqlarının yosun florasının tərkibini, ekoloji quruluşunu və bioindikator potensialını araşdırır. Mövsümi nümunələr 2024-cü ilin may-sentyabr aylarında plankton və bentos yaşayış mühitlərindən toplanmışdır. Su temperaturu, pH, elektrik keçiriciliyi və ümumi həll olmuş maddələr *in situ* şəraitdə ölçülmüş, yosun nümunələri işıq və elektron mikroskoplarında təhlil edilmişdir. Taksonomik identifikasiya standart alqoloji açarlara əsaslanaraq aparılmış və AlgaeBase məlumat bazası ilə təsdiqlənmişdir. Su keyfiyyəti və üzvi çirklənmə səviyyəsi Palmer çirklənmə indeksi və saprob səviyyə analizinə əsasən qiymətləndirilmişdir. Bulaqlarda orta temperatur 7–12°C, pH 7.6–8.5, EC 162–322 µS/cm, ümumi həll olmuş maddələr isə 105–209 mg/L aralığında dəyişmişdir. Ümumilikdə beş şöbəyə aid 25 takson müəyyən edilmişdir: Charophyta, Chlorophyta, Cyanobacteria, Euglenophyta və Heterokontophyta. Palmer indeksi (10–22) və saprob analizləri bulaqların əksəriyyətində oligosaprob və β-mezosaprob şəraitin üstünlük təşkil etdiyini göstərmişdir. Nəticələr Basqal meşə bulaqlarında yosun müxtəlifliyinin hidroloji rejim və meşə bitkiliyindən güclü şəkildə asılı olduğunu, ekoloji sabit sistem formalaşdırdığını sübut edir. Bu nəticələr Azərbaycanın dağ-meşə regionlarında şirin su ekosistemlərinin qiymətləndirilməsi və mühafizəsi üçün yosun monitorinqinin əhəmiyyətini vurğulayır.
Açar sözlər: *müxtəliflik, elektrik keçiriciliyi, şirin su yosunları, Palmer çirklənmə indeksi, fiziki-kimyəvi parametrlər, ümumi həll olunan bərk maddələr*

Альгофлора лесных родников на территории Басгал (Исмаиллинский район, Азербайджан)

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Данное исследование посвящено изучению альгофлоры семи лесных родников поселенка Басгал Исмаиллинского района расположенного на южных склонах Большого Кавказа с акцентом на их экологическую структуру и биоиндикаторный потенциа-

ла. Сезонный отбор проб проводился май-сентябре в 2024 году как в планктонных, так и в бентосных местообитаниях. Температура воды, pH, электропроводность и общее содержание растворённых веществ измерялись *in situ*, а образцы водорослей анализировались с использованием световой и электронной микроскопии. Таксономическая идентификация осуществлялась по стандартным альгологическим ключам и верифицировалась через базу данных AlgaeBase. Качество воды и органическое загрязнение оценивались с помощью индекса загрязнения Палмера и сапробиологического анализа. Средняя температура родников варьировала 7–12°C, значения pH 7.6–8.5, электропроводность 162–322 µS/см, а концентрация растворённых веществ 105 –209 мг/л, что указывает на нейтральные или слабощелочные и умеренно минерализованные воды. Всего выявлено 25 таксонов, относящихся к пяти отделам: Charophyta, Chlorophyta, Cyanobacteria, Euglenophyta и Heterokontophyta. Значения индекса Палмера (10–22) и сапробные оценки подтверждают преимущественно олигосапробные – β-мезосапробные условия. Результаты показывают, что разнообразие и распределение водорослей в лесных родниках Басгала тесно связаны с гидрологическим режимом и лесной растительностью, что отражает высокую экологическую устойчивость данных экосистем. Полученные данные подчёркивают важность альгомониторинга для оценки и сохранения пресноводных экосистем горных лесов Азербайджана.

Ключевые слова: *разнообразие, электропроводность, пресноводные водоросли, индекс загрязнения Палмера, физико-химические показатели, общее растворённые твёрдые вещества*