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Algoflora of the northern littoral part of the Azerbaijani sector of the Caspian Sea (Siyazan and Shabran districts)

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Although studies on the algoflora of the Azerbaijani sector of the Caspian Sea have been conducted since the 60s of the 20th century, very little information is available about the diversity and distribution areals of algae in this sea. The paper presents the results of the study of the diversity, taxonomic structure, and ecological characteristics of marine macrophytes and microscopic algal flora of the Caspian Sea shores in the northeastern part of the Azerbaijan Republic (the territory of Siyazan and Shabran regions). 28 species of algae belonging to 4 divisions, 14 orders, 16 families, and 21 genera were identified in the research area. Their belonging to divisions *Bacillariophyta* (13 species), *Chlorophyta* (6 species), *Cyanophyta* (5 species), and *Charophyta* (4 species) was established. The *Bacillariophyta* division is the dominant group in the composition of the studied algal flora with 46.4%, *Chlorophyta* constitutes 21.4%, *Cyanophyta* -18%, and *Charophyta*-4.2%. *Naviculaceae, Oscillatoriaceae, Spirogyraceae,* and *Cladophoraceae* were found to be the leading families in algal flora. Out of 28 algae species detected, 22 species were found to be new to the research area.

Keywords: *Agoflora, ecological groups, algae, taxonomic analysis, ecological analysis*

INTRODUCTION

Using light energy, algae that are a significant part of the photoautotrophic organisms of the aquatic environment, perform the biosynthesis of cell components, including those involved in energy exchange for their reproduction. Algae are mainly typical aquatic organisms[1], distributed in fresh and salt water basins and hot springs. They include macrophyte and microscopic algae (microalgae), which are representatives of green (*Chlorophyta*), blue-green (*Cyanophyta*), yellow-green (*Xanthophyta*), red (*Rhodophyta*), diatom (*Bacillaryphyta*), golden (*Chrysophyta*), and brown (*Ochrophyta*) algae divisions (Pienaar and Pieterse, 1990). Representatives of all divisions are eukaryotes, except cyanobacteria, which are prokaryotes. Algae actively participate in the cycle of sulfur, nitrogen, carbon, and other biogenic elements. They are also primary producers of organic matter in aquatic ecosystems. Algae synthesize proteins, lipids, and carbohydrates, valuable biologically active substances, and are rich in mineral elements. Due to their photosynthesizing abilities, they play an important role as one of the main sources of oxygen in the atmosphere. This, in turn, draws attention to the study of the issues of biology, ecology, systematics, physiology, and biochemistry of algae (Vozjinskaya and Kamnev, 1994).

Because the physical and geochemical properties of water systems depend on the water

[1] Some algae are mixotropic or facultative heterotrophs, some have lost their ability to photosynthesize and become obligate heterotrophs, and some exist in the soil environment.

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flowing into them, they change significantly as a result of urbanization, industrial waste, agriculture, and human activity (Bornette və Puijalon, 2011; Chappuis et al., 2014; Carle et al., 2005). These activities affect the quality and quantity of water, the distribution and diversity of aquatic organisms, primary production and thus, the balance of the aquatic ecosystem (Bornette və Puijalon, 2011).

Depending on the degree of pollution of reservoirs, it is important to study the species that make up the sampling system of reservoirs (Barinova et al., 2019). The following zones differing in the degree of water pollution in the saprobe system are distinguished: catarob (c), xenosaprob (x), oligosaprob (o), α-mesosaprob (α), β-mesosaprob (β), polysaprob (p), isosaprob (i), metasaprob (m), hipersaprob (h), ultrasaprob (u), antisaprobic (a), radiosaprob (r), and kryptosaprob (k) (Barinova and Medvedeva, 1996; Barinova et al., 2006). Catarobic and xenosaprob zones are characterized by a very pure water mass. Oligosaprob zone is considered a completely clean zone of water reservoirs. The water of the oliqosaprob zone is usually saturated with oxygen. In the mesosaprob zone, the degree of water pollution is relatively small, proteins are completely dissolved, and hydrogen sulfide and carbon dioxide are in small quantities.

The physicochemical characteristics of the water system and the socio-ecological characteristics of the water basin also have a significant effect on the species composition of algae in different places along the stream water and lake systems. As the impact of anthropogenic factors on aquatic ecosystems is constantly increasing due to the rapid development of industry, it is necessary to evaluate the species composition and vital activity of algae in rivers, seas, and lakes exposed to anthropogenic influences in order to assess the biological diversity, protection, and sustainable use of algae, the driving forces affecting them and the quality of life of people in a multidisciplinary context.

The Caspian Sea also has a great diversity of algae. It is attributed to its weak connection with other seas and lakes. Besides, it is a closed water basin to some extent. Algae monitoring in the Azerbaijani sector of the sea began in the middle of the 20th century. Previously, in the research conducted in the Caspian Sea, a total of 76 species of algae belonging to 4 divisions, 6 classes, 15 orders, 21 families, and 42 genera were found, of which 38 species and 1 subspecies were found to belong to Baku Bay, and 12 species (8 green, 3 red and 1 black) to the southern shores of the Caspian Sea (Zaberzhinskaya, 1968). As a result of other studies, 309 species and an intraspecific taxon belonging to two classes, three orders, three sub-orders, and eight families of diatoms were recorded in the Caspian Sea (Karayeva, 1972). Multi-year original studies and literature data related to phytoplankton - blue-green algae of the Caspian Sea revealed 85 species and intraspecies taxa, of which only 18 taxa were shown to belong to the Azerbaijani sector of the sea (Zaberzhinskaya, 1968).

In recent years, as a result of the intensification of navigation and the increase in transportation, the discharge of chemical, industrial, agricultural, and domestic wastes, the Caspian Sea, including littoral areas and small water bodies close to these areas, is exposed to pollution, which has a negative impact on water quality, ecosystems and the environment (Shah və Shah, 2013; Niraula, 2012). This pollution may seriously affect the algal biodiversity and bioresources of the aquatic environment. Since monitoring of the Azerbaijani sector of the Caspian Sea has not been carried out for a very long period or has been carried out superficially, it is impossible to obtain sufficiently accurate information on new and rare species of algae, as well as on extinct species.

This article provides information on the taxonomic structure, rare and new species of algae biodiversity identified by monitoring the littoral areas of the Caspian Sea in the Siyazan and Shabran districts of the Republic of Azerbaijan. Ecobiological analysis of the studied species was carried out.

MATERIALS AND METHODS

Algological samples for the study were taken from littoral areas of the Caspian Sea in the Siyazan and Shabran districts located in the northeastern part of the Greater Caucasus. The Siyazan district is located in the north part of Azerbaijan, 103 km north of Baku city in the

Samur-Davachi lowland, on the shore of the Caspian Sea near the Greater Caucasus. It borders Shabran to the west and northwest, the Khizi district to the southeast, and the Caspian Sea to the east. The Shabran district is located in the northeast of the Greater Caucasus, 123 km from Baku, and is surrounded by the Caspian Sea at a distance of 24 km from the east.

In May-September 2023, a total of 40 samples of plankton, benthos, and epiphyte (species attached to the substrate or stones) were collected from 13 sampling points of the Caspian coast of the Siyazan and Shabran districts. The coordinates of the sampling points were determined. Maps showing sampling points are illustrated in Figure 1.

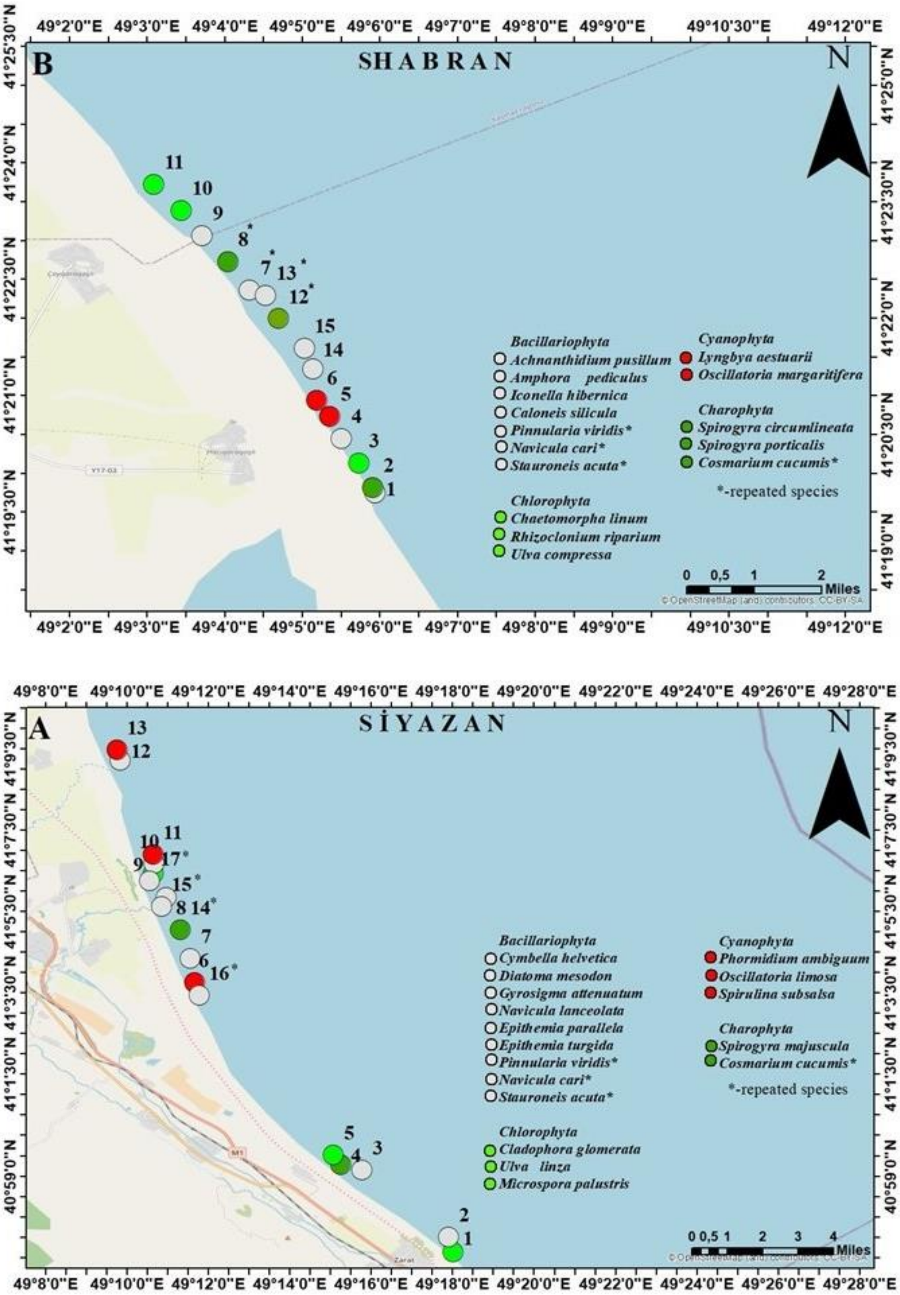

Fig. 1. Algae distribution in littoral areas of the Siyazan and Shabran districts of the Caspian Sea.

Plankton nets (silk gas 25/77) and "Jeddi" nets were used to collect plankton samples. A 3-liter glass container and a bathometer were used for benthic sampling. Epiphytic algae were collected by scraping off the solid substrate with a lancet and transferred to plastic containers (Yashnov, 1934; Arenshteyn, 1961; Boqorov, 1965). To study epilithic diatoms, bottom sediments were sampled 2-3 m from shore using an 8 mm diameter and 1 m long glass tube and transferred to plastic containers. For preservation and detailed study, 10% and 4% formaldehyde was added to epiphytic algae and other ecological group algae, respectively (Tash and Okush, 2006).

The epilithic samples precipitated, the water was drained and the sediment was transferred to Petri dishes. To remove acid and organic matter it was boiled and centrifuged after adding H_2O_2. Permanent samples were prepared from the cleaned materials for diatom identification (Gollerbax and Polyanskiy, 1951; Van Der Werff, 1999). A scanning electron microscope (JSM-35, Japan) was used to study diatoms, and an optical microscope (Nikon E100) was used to identify other algae divisions.

Water temperature was measured with a laboratory thermometer, pH was determined with a portable WTW-3110 pH meter (Germany). The map-scheme of the researched districts was prepared with ArcGIS version 10.7. Literature data were used for morphological characterization and identification of algae (Williams, 1985; Schmid, 1994; Stenina, 2009; Fourtanier and Kociolek, 2011; Seckbach and Kociolek 2011; Kulikovski et al., 2014; Afanasyev et al., 2016; Mukhtarova and Jafarova, 2020; Nuriyeva, 2019; Afanasyev et al., 2020; Volkova et al., 2020).

AlgaeBase (Guiry and Guiry, 2022), "California Academy" (www.calacademy.org), and "Alga Terra" (www.algaterra.org) websites were used to specify the names of algae species, referring to the latest nomenclature.

RESULTS AND DISCUSSION

Taxonomic analysis. As a result of the analysis of algae samples taken from the sampling points along the coast of the Caspian Sea, 28 species belonging to 4 divisions, 14 orders, 16 families, and 21 genera were identified for those areas. These species belong to the following divisions: *Bacillariophyta* (13 species), *Chlorophyta* (6 species), *Cyanophyta* (5 species), and *Charophyta* (4 species). The distribution of the points where algae samples were found along the coast, the coordinates where they were found are shown in Figure 1, Table 1, and Table 3. Microphotographs of algae samples collected using optical and electron microscopes, respectively, from the coasts of Shabran and Siyazan are shown in Figures 2 and 3.

As can be seen in Table 1 and Table 3, *Bacillariophyta* was the dominant group in the algal flora of the district with 46.4%, *Chlorophyta* with 21.4%, *Cyanophyta* with 18%, and *Charophyta* with 14.2% representatives. *Naviculaceae* Kützing, *Oscillatoriaceae* Engler, *Spirogyraceae* Bessey, *Cladophoraceae* Wille were the leading families in algae flora. 22 out of 28 algae species have been newly registered for this district. As seen in the table, algae can be found in various places on the sea coast - littoral areas, estuaries, rocks, in shells and plants (epiphytic), etc. Monitoring of the dynamics of the spread of detected algae by month showed that their spread was relatively higher in May compared to other months. This is likely due to the process of algal blooms that begin in the warmer months depending on environmental conditions.

Ecological analysis. The results of our research showed that 16 species of the detected algal samples are benthic for the algoflora of the Caspian Sea, 7 species are both planktonic and benthic, and 4 species are planktonic (Tables 2 and 3).

Depending on the degree of pollution, water basins are characterized by zones included in the saprob system (Barinova et al., 2019), and the detected algae species were analyzed according to this system. The species were evaluated based on the degree of water pollution in the saprobic system and one species of β-mesosaprobe, one species of xeno-β-mesosaprobe, one species of oligo-α-mesosaprobe, one species of oligo-β-saprobe, one species of xeno-saprobe, two species of oligo-β - mesosaprobe, two species of α-β-mesosaprobe, two species of oligo-xenosaprobe, and two species of oligosaprobe were identified. Such differences may be related to the changes in the geochemical properties of coastal waters and the properties of the water discharged into them.

Table 1. Algae sampling points on the shores of the Siyazan and Shabran districts of the Caspian Sea

Division	Species	Sampling points	Habitat
Bacillariophyta	*Cymbella helvetica* Kützing	40°57.506'N; 49°17.901'E	Estuaries
	Diatoma mesodon (Ehrenberg) Kützing	40°59.156'N; 49°15.775'E	Estuaries
	Gyrosigma attenuatum (Kützing) Rabenhorst	41°4.347'N; 49°11.558'E	Surfaces of mollusc shells
	Navicula lanceolata (C. Agardh) Ehrenb	41°5.850'N; 49°10.960'E	Estuaries
	Epithemia parallela (Grunow) Ruck & Nakov	41°6.687'N; 49°10.674'E	Sea foam
	Epithemia turgida (Ehrenberg) Kützing	41°9.228'N; 49°9.836'E	Sand
	Achnanthidium pusillum (Grunow) Czarnecki	41°19.346'N; 49°6.200'E	Littoral
	Amphora pediculus (Kützing) Grunow	41°20.453'N; 49°5.505'E	Macrophytic algae surface
	Iconella hibernica (Ehrenberg) Ruck & Nakov	41°22.365'N; 49°4.327'E	Littoral area
	Caloneis silicula (Ehrenberg) Cleve	41°23.071'N; 49°3.712'E	Littoral
Chlorophyta	*Chaetomorpha linum* (O.F.Müller) Kützing	41°20.136'N; 49°5.730'E	Littoral and upper sublittoral areas
	Cladophora glomerata (Linnaeus) Kützing	40°57.146'N; 49°18.007'E	Shell surfaces
	Microspora palustris Wichmann	41°6.451'N; 49°10.650'E	Sea foam
	Rhizoclonium riparium (Roth) Harvey	41°23.391'N; 49°3.446'E	On plants
	Ulva linza Linnaeus	40°59.530'N; 49°15.069'E	In the sublittoral zone, on stones and rocks
	Ulva compressa Linnaeus	41°23.732'N; 49°3.089'E	On the substrate, littoral
Cyanophyta	*Phormidium ambiguum* Gomont	41°3.765'N; 49°11.673'E	Littoral
	Oscillatoria limosa Agardh ex Gomont	41°6.910'N; 49°10.640'E	Rocks in littoral and upper sublittoral areas
	Spirulina subsalsa Oersted ex Gomont	41°9.470'N; 49°9.758'E	Shell surfaces
	Lyngbya aestuarii Liebman ex Gomont	41°20.737'N; 49°5.362'E	Littoral
	Oscillatoria margaritifera Kütz ex Gomont	41°20.947'N; 49°5.189'E	Rocks in littoral and upper sublittoral areas
Charophyta	*Spirogyra majuscula* Kützing	40°59.291'N; 49°15.252'E	The surface of macrophytic algae
	Spirogyra circumlineata Transeau	41°19.818'N; 49°5.913'E	Estuaries
	Spirogyra porticalis (O.F.Müller) Dumortier	41°22.739'N; 49°4.042'E	Sea foam

Thus, several small rivers (Devachichay, Shabranchay, Valvalechay, and Atachay), industrial and domestic waters flow into the research areas. Nevertheless, as seen in Tables 2 and 3, the waters of the studied area can be considered weakly or moderately polluted with organic matter and waste.

The littoral zone makes up 7% of the world's oceans, and seas, depending on the ecological characteristics, the structure of the organism, and the relationship between the organism and the environment. The main reasons for the abundance of fauna and flora in this zone are the rich vegetation consisting of algae from the shallow coasts entering the littoral and sufficient food products brought to the coastal zone by the continent waters. The second main reason for species richness is the diverse biotope of the littoral zone (gravelly, sandy, and clayey soils, fresh water at river sources, and dense forests with various plants). Based on the distribution of nutrients and environmental factors, the littoral zone is divided into 3 sub-zones (upper-, supra-, and sublittoral) that differ in terms of ecological conditions (Brauns et al., 2008). A comparative analysis of algae collection areas showed that 13 species of the discovered and studied ones can be attributed to the upper-, 9 species to the supra-, and 6 species to the sublittoral zone. The distribution of those species by subzones is shown in Tables 2 and 3.

Despite the closeness of their areas, the study of the materials collected from the coasts of Siyazan and Shabran revealed only 4 algae species – *Cosmarium curcumis, Pinnularia viridis, Navicula cari*, and *Stauroneis acuta* – in both districts. The characteristics of these species are shown in Table 3, and their images taken under the light and electron microscope are shown in Fig. 4. As seen in the table, these species were mainly benthic, thus, *Cosmarium curcumis* occurred in upper-, *Navicula cari* in supra-, *Pinnularia viridis* and *Stauroneis acuta* in sublittoral zones. It should also be noted that the *Pinnularia viridis* and *Stauroneis acuta* species have an oligo-xenosaprobic saprobic index.

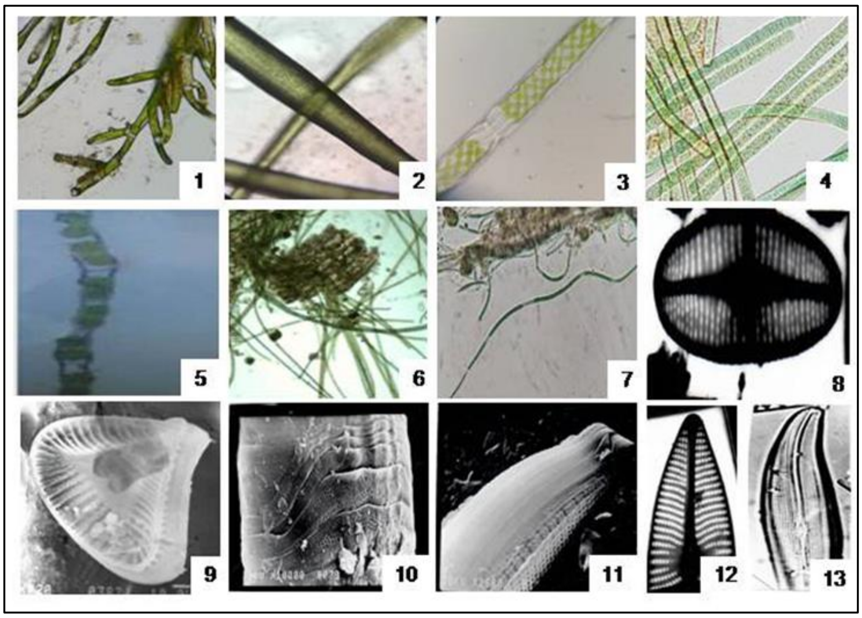

Fig. 2. View of species under the scanning electron microscope and light microscope (Siyazan district): 1. *Cladophora glomerata* (Linnaeus) Kützing, 2. *Ulva linza* Linnaeus, 3. *Spirogyra majuscula* Kützing, 4. *Phormidium ambiguum* Gomont, 5. *Microspora palustris* Wichmann, 6. *Oscillatoria limosa* Agardh ex Gomont, 7. *Spirulina subsalsa* Oersted ex Gomont, 8. *Cymbella helvetica* Kützing, 9. *Diatoma mesodon* (Ehrenberg) Kützing, 10. *Gyrosigma attenuatum* (Kützing) Rabenhorst, 11. *Navicula lanceolata* (C.Agardh) Ehrenb, 12. *Epithemia parallela* (Grunow) Ruck & Nakov, 13. *Epithemia turgida* (Ehrenberg) Kützing.

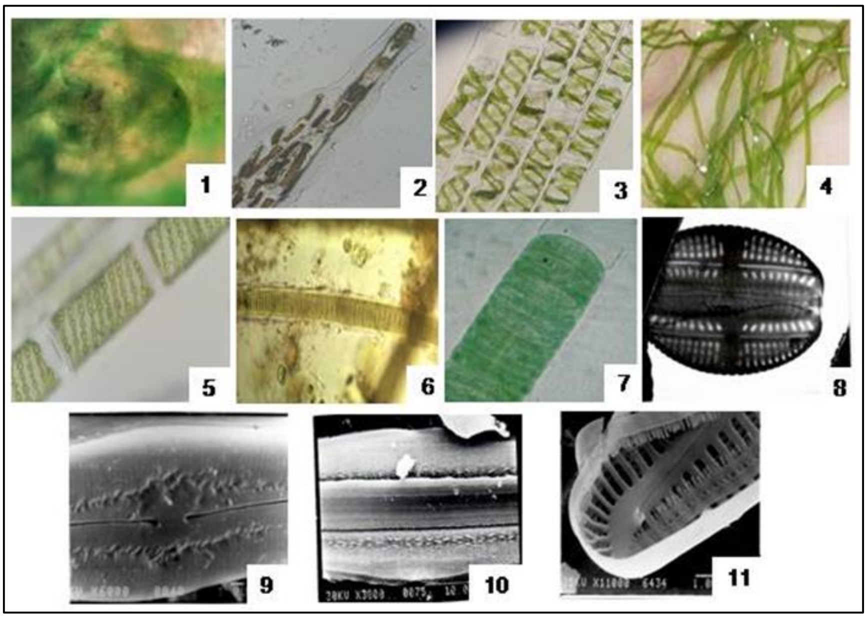

Fig. 3. View of species under the scanning electron microscope and light microscope (Shabran district): 1. *Chaetomorpha linum* (O.F.Müller) Kützing, 2. *Rhizoclonium riparium* (Roth) Harvey, 3. Spirogyra particalis (O.F.Müller), 4. *Ulva compressa* Linnaeus, 5. *Spirogyra circumlineata* Transeau, 6. *Lyngbya aestuarii* Liebman ex Gomont, 7. *Oscillatoria margaritifera* Kütz ex Gomont 8. *Achnanthidium pusillum* (Grunow) Czarnecki, 9. *Amphora pediculus* (Kützing) Grunow, 10. *Iconella hibernica* (Ehrenberg) Ruck & Nakov, 11. *Caloneis silicula* (Ehrenberg) Cleve.

Table 2. Ecological indicators of algae found on the shores of the Siyazan and Shabran districts of the Caspian Sea

Species	Saprob	Ecol. group	Ecological zone		
			Littoral zone (intertial)		
			Upperlittoral	Supra-	Sub-
Cymbella helvetica Kützing	–	ben.		+	
Diatoma mesodon (Ehrenberg) Kützing	o-β	ben.	+		
Gyrosigma attenuatum (Kützing) Rabenhorst	–	pl.		+	
Navicula lanceolata (C. Agardh) Ehrenb	x- β	ben.	+		
Epithemia parallela (Grunow) Ruck & Nakov	–	ben.		+	
Epithemia turgida (Ehrenberg) Kützing	o	ben.	+		
Achnanthidium pusillum (Grunow) Czarnecki	–	ben.	+		
Amphora pediculus (Kützing) Grunow	–	ben.		+	
Iconella hibernica (Ehrenberg) Ruck & Nakov	–	ben.	+		
Caloneis silicula (Ehrenberg) Cleve	x	ben.	+		
Chaetomorpha linum (O.F.Müller) Kützing	–	pl., ben.			+
Cladophora glomerata (Linnaeus) Kützing	β-o	pl., ben.	+		
Microspora palustris Wichmann		ben.		+	
Rhizoclonium riparium (Roth) Harvey	–	pl.		+	
Ulva linza Linnaeus	–	pl., ben.			+
Ulva compressa Linnaeus	–	pl., ben.	+		
Phormidium ambiguum Gomont		ben.	+		
Oscillatoria limosa Agardh ex Gomont	β	pl., ben.			+
Spirulina subsalsa Oersted ex Gomont	o-β	pl., ben.	+		
Lyngbya aestuarii Liebman ex Gomont	o	pl., ben.	+		
Oscillatoria margaritifera Kütz ex Gomont	–	pl.			+
Spirogyra majuscula Kützing	o-α	pl.		+	
Spirogyra circumlineata Transeau	α-β	ben.	+		
Spirogyra porticalis (O.F.Müller) Dumortier	α-β	ben.		+	

Note: pl. – plankton, ben. – benthos, β – betamezosaprob, x-β – kseno-betasaprob, o – oliqosaprob, α-β – alfabetamezosaprob, o-α – oliqoalfamezosaprob, o-β – oliqobetamezosaprob, β-o – oliqobetasaprob, x – ksenosaprob.

Table 3. Characteristics of the same species found in the Siyazan and Shabran districts

Division	Species	Sampling point	Habitat	Saprob	Ecol. group	Ecological zone		
						Littoral zona (intertial)		
						Upper-	Supra-	Sub-
Charophyt	*Cosmarium curcumis* Corda ex Ralfs	41º5.065´N* 49º11.304´E 41º22.005´N** 49º4.695´E	Sea foam	–	ben.	+		
Bacillariophyta	*Pinnularia viridis* (Nitzch) Ehrenberg	41º5.625´N* 49º10.849´E 41º22.295´N** 49º4.534´E	At different depths of water	o-x	ben.			+
	Navicula cari Ehrenberg	41º3.446´N* 49º11.771´E 41º21.353´N** 49º5.138´E	Rock surfaces	–	eph. ben.		+	
	Stauroneis acuta W.Smith	41º6.262´N* 49º10.562´E 41º21.545´N* 49º4.987´E**	At different depths of water	o-x	ben.			+

Note: * – Siyazan district, ** – Shabran district, eph. – ephilitic, ben. – benthos, o-x – oligo-xenosaprobic.

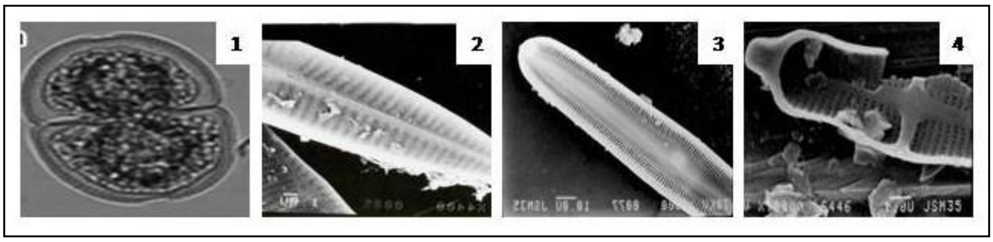

Fig. 4. View of species under the light microscope and scanning electron microscope (Siyazan, Shabran): 1. *Cosmarium cucumis* Corda ex Ralfs, 2. *Pinnularia viridis* (Nitzsch) Ehrenberg, *3*. *Navicula cari* Ehrenberg, 4. *Stauroneis acuta* W. Smith.

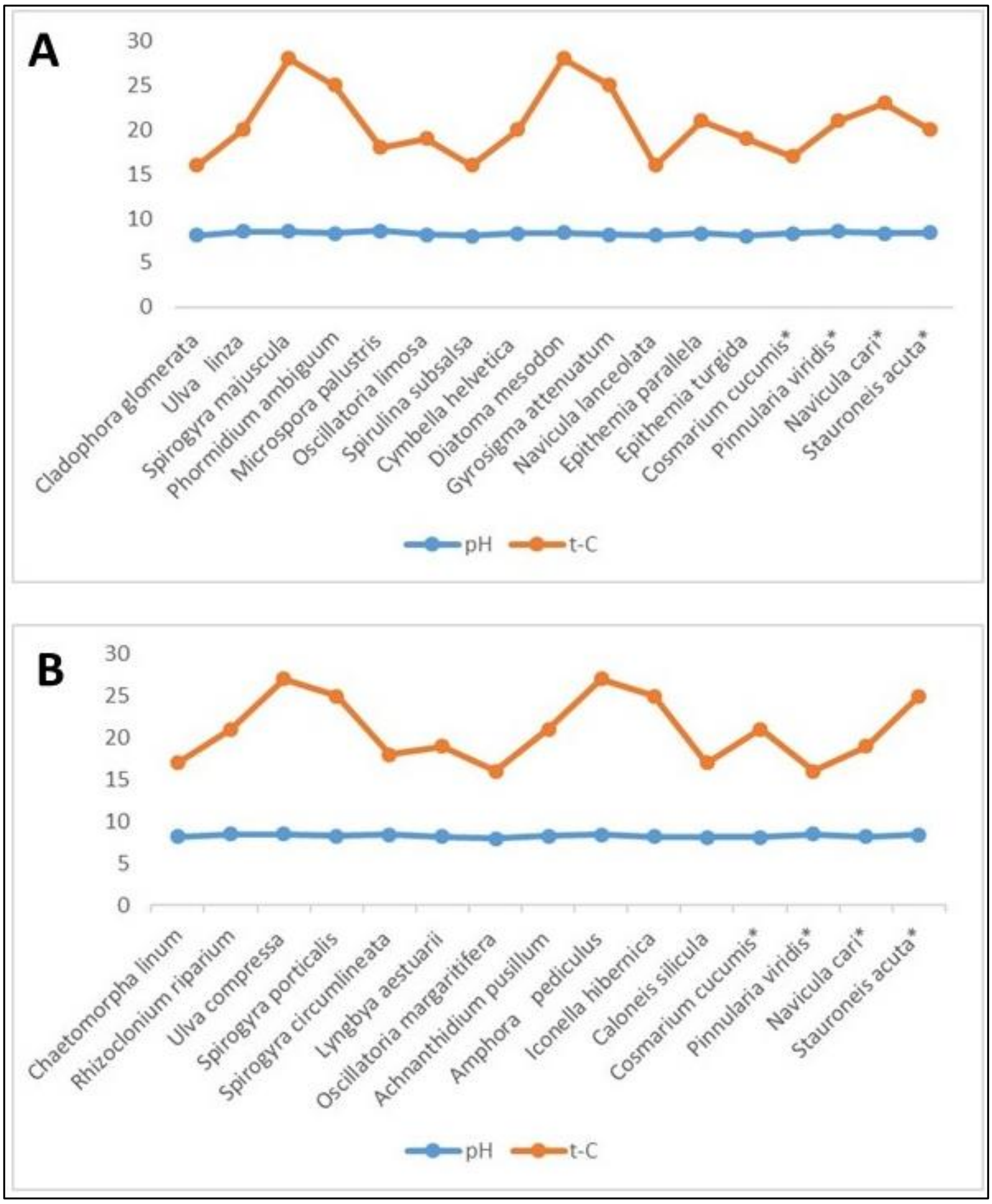

Fig. 5. Ecological conditions of the area where algae spread on the Siyazan (A) and Shabran (B) shores of the Caspian Sea.

Since algae samples were collected in different seasons, the temperature of the sea water in the areas where the species were collected (Figure 1) varied between 16 and 28℃. As seen in Figure 5, some species (*S. majuscula*, *N. lanceolata*, *E. parallela*, *A pediculus*, and *C. glomerata*) were detected at relatively low (16-20℃) temperatures, two of which – *C. cucumis* and *P. viridis* are common algal species. The average pH value of sea water in the areas where the experiments were conducted was 8.0 with slight differences. This indicator is close to the general pH indicator of the Caspian Sea (8.3). Thus, unlike other seas and oceans, the pH in the waters of the Caspian Sea is relatively high. The pH in the upper layers of seawater varies between 8.2 and 8.6, and in the deep layers between 7.9 and 8.1. Alkalinity in the Caspian Sea varies both seasonally and geographically, decreasing with increasing depth. It remains stable only in the open areas of the sea.

CONCLUSION

The Caspian Sea has a unique and rich fauna and flora. The uniqueness and variety of natural conditions, the weak connection with the sea and oceans have ensured the existence of many rare species of fauna and flora in the Caspian Sea. In the Azerbaijani sector, the water of two large rivers (Kur and Araz) and many small rivers, including industrial waste, are poured into the Caspian Sea. Both rivers pass through the territory of bordering countries, many polluted small rivers flow into them (Okhchuchay, Basitchay), and eventually enter the Azerbaijani sector of the Caspian Sea. This, in turn, is one of the factors that seriously affect the algae spectrum of the sea. Algae growth and reproduction are also affected by light, temperature, inorganic substances, and other factors. The fact that the research district is located outside the Kura River estuary and industrial regions and the relatively clean water affects the algal biodiversity of the area is also of interest. The discovery of new species that have not been recorded for this small area shows that the whole Caspian algoflora has been enriched in the last 50 years including the Azerbaijani sector. The study of the role of various abiotic factors in the formation of individual regions of the Caspian Sea, as well as the algoflora of the Caspian water area as a whole, has become one of the important regional issues and requires extensive research.

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CONFLICT OF INTEREST

There is no conflict of interest in the present study.

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