

IMPACT OF SUBSTRATE DIVERSITY ON LICHEN SPECIES STRUCTURE IN CENTRAL KAZAKHSTAN

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ABSTRACT

The Betpak-Dala floristic region of Kazakhstan includes the Betpak-Dala clay desert, the deserts of the northern shore of Lake Balkhash, and the low hills of the western shore of Lake Balkhash. This region is the most sparsely populated and least studied. Our research aimed to review all available data and compile an up-to-date list of lichenobiota species in the Betpak-Dala floristic region, based on specimens from the Herbarium of the Institute of Botany and Phytointroduction, the authors' own collections, the iNaturalist database, and other accessible sources. We collected lichen samples within the Betpak-Dala floristic region in 2024. We compiled an annotated list of lichenobiota species from the floristic region, including 115 species from 54 genera, 19 families, 12 orders, and 3 classes. Forty-two species are reported for this territory for the first time. The largest genus, *Acarospora*, includes 11 species (10% of the total); *Lecanora*, 9 species (8%); *Circinaria*, 8 species (7%); *Physcia*, 6 species (5%); and *Aspicilia*, 6 species (5%). Three genera are represented by 4 species each, three by 3 species, 11 genera by 2 species, and 32 genera by one species each. Most identified lichen species are associated with rock outcrops (70 species, 56% of the total), soil (22 species, 18%), and crushed stones (17 species, 13%). Two species (1%) were observed on mosses. Three species (2%) were found on the bark of branches of *Artemisia* sp., *Oreosalsola laricifolia*, and *Salsola* sp.; six species (5%) were found on plant debris. Two species (1%) occur on fragments of old slate, and two can exist as free-living forms. The species *Acarospora stapfiana* develops on another lichen, *Golubkovia trachyphylla*. The most widespread forms in the studied area are crustose areolate and narrow-lobed foliose lichens. This study significantly expands knowledge of Central Asian desert lichenobiota by providing a thorough, integrative evaluation of lichen diversity and substrate specificity across the Betpak-Dala floristic region. The discovery of new species in the area emphasizes the importance of systematic surveys in understudied deserts and highlights the underappreciated biodiversity of arid landscapes. For future research, these results provide a crucial baseline for biogeographical, ecological, and conservation-focused studies in Kazakhstan's desert ecosystems. The research is valuable for documenting lichen diversity in the Betpak-Dala floristic region.

Keywords: Betpak-Dala desert, Lichen, Life form, Substrate affiliation, Taxonomic spectrum.

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1. INTRODUCTION

Lichens form through symbiotic partnerships between algae or cyanobacteria and fungi. Lichens play an important role in maintaining natural systems. They contribute to global biological diversity. Good air quality, suitable substrates, habitat continuity, and a favorable climate all support lichen diversity (Bukabayeva et al., 2024; Kolita & Gogoi, 2024; Evankow et al., 2025). In desert environments, algae and lichens also play important roles as primary producers. They are frequently found in biological soil crusts. These crusts help to stabilize soil, reduce erosion, and increase soil fertilityVol-26-59-68-2026-ABR-26-248 by fixing nitrogen and carbon from the atmosphere. Algae and lichens can photosynthesize, making them critical to desert ecosystem resilience and long-term sustainability. Their ability to survive and function in such conditions demonstrates the different tactics primary producers use to thrive in deserts. Because they are sensitive to ambient moisture and temperature and cannot actively regulate water intake and storage, lichens have become reliable bioindicators of climate change and extreme conditions (Rawat et al., 2025; Kanyungulu & Farkas, 2026; Möller, 2026). These poikilohydric organisms show significant intraspecific and interspecific variation in thallus physiology, anatomy, morphology, and architecture, allowing lichens to adapt to a wide range of environmental conditions (Phinney et al., 2021; Nugroho et al., 2025; Tumor et al., 2025). Desert plant communities play an important role in boosting desert ecosystem production and stability, but they are very

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susceptible to environmental changes because of their weak resilience and tolerance to perturbations. Studies have reported lichen diversity across deserts, with some showing strong correlations with abiotic factors such as water and temperature (Temina, 2021; Tu et al., 2024; Zhumaniyazova et al., 2025).

According to the floristic region zoning developed for the "Flora of Kazakhstan" (Alibekov et al., 2025), the Betpak-Dala floristic region includes the clay desert of Betpak-Dala, the deserts of the northern shore of Lake Balkhash and the low hills of the western shore of Lake Balkhash (Fig. 1). The Betpak-Dala desert is located almost in the center of Kazakhstan, between the lower reaches of the Chu (Shu) and Sarysu rivers and the western shore of Lake Balkhash. Betpak-Dala is a flat and gently undulating plain with an area of about 75,000 km², stretching from west to east for about 500 km, from north to south up to 170 km, with an absolute altitude of 450–500 m in the northeast, 200 m – in the southwest, and the highest point – Mount Zhambyl (972 m above sea level). The average altitude of the desert is around 300 m. The eastern part is a plain with low ridges alternating with depressions, while the western part features a plain with closed depressions and dry basins. In the central part of the desert lies the Kogashik stow, characterized by diverse relief such as low mountains, hilly plains, and plains with takyrs, salt flats, and solonchaks. In Betpak-Dala, the predominant soils are brown and desert grey-brown, often saline or subsaline. Takyrs and salt marshes are frequently found in depressions. Stabilized and hummocky-ridge sands are observed near the Sarysu and Chu rivers. Lakes and rivers are generally saline and seasonal. Freshwater lakes are few and small. Groundwater lies at depths of 2 to 30 meters (Geosfera, 2025).



Fig. 1: Floristic Regions of Kazakhstan: 1 – Obshchy Syrt's spurs, 2 – Tobol-Ishim, 3 – Irtysh, 4 – Semipalatinsk pine forest, 5 – Kokshetau, 6 – Caspian, 6a – Bukeyev, 7 – Aktobe, 7a – Mugodzhaz, 8 – Emba, 9 – Turgay, 10 – West low mountains, 10a – Ulytau, 11 – East low mountains, 11a – Karkaraly, 12 – Zaysan, 13 – North Ust-Urt, 13a – Buzachi, 13b – Mangyshlak, 14 – Aral, 15 – Kyzyl-Orda, 16 – Betpak-dala, 17 – Muiyunkum, 18 – Balkhash-Alakul, 19 – South Ust-Urt, 20 – Kyzylkum, 21 – Turkistan, 22 – Altai, 23 – Tarbagatai, 24 – Zhongar Alatau, 25 – Trans-Ile, Kungey Alatau, 25a – Ketmen, Terskey Alatau, 26 – Chu-Ile Mountains, 27 – Kyrghyz Alatau, 28 – Karatau, 29 – West Tien-Shan.

The climate is continental, with dry and hot summers and moderately cold, low-snowfall winters (snow cover depth does not exceed 10–15 cm). The average annual air temperature reaches 3.6–5°C, with January averaging –12 to –14°C and July 24–26°C. Annual precipitation amounts to 100–150 mm, with the highest levels occurring in spring. These circumstances are advantageous because deserts are a natural setting for researching ecological processes. Their harsh, resource-constrained conditions, which act as potent environmental filters, drive this state. Compared to more complex, resource-rich environments, this strong selection pressure simplifies the ecosystem, making the relationships between organisms and their surroundings, as well as the ensuing community dynamics, more obvious and simpler to study (Qu et al., 2020; Jiang et al., 2021). Recent research on deserts in China, Mongolia, and the Middle East supports this idea (Tumur et al., 2021; Kherlenchimeg et al., 2024).

Vegetation cover in the Betpak-Dala desert varies from north to south. The main ecological-physiognomic desert types include sagebrush (dominant), perennial saltwort, psammophytic-sagebrush and psammophytic-grass communities, psammophytic-shrub formations, and black saxaul stands (Dimeyeva et al., 2018). In desert depressions, the relict ornamental shrub *Spiraeanthus schrenckianus* (C. A. Mey.) Maxim. is found. The Kogashik tract is characterized by a diverse range of plant communities: sagebrush-anabasis, *Calligonum*-sagebrush, anabasis, black-sagebrush-*Salsola*, *Anabasis salsa*, shrub, *Glycyrrhiza-Atriplex*, *Petrosimonia*, *Halostachys*, and *Halocnemum* associations.

The chemistry and texture of their substrates often strongly influence desert lichen communities. In a survey of Kazakhstan's Betpak-Dala desert, most lichens (56%) were saxicolous (on rock), with much smaller fractions on soil, debris, or bark. In the Kalahari region of South Africa, rock-dwelling lichens showed noticeably greater diversity than bark-dwellers, reflecting this pattern (Ward et al., 2024). Studies also found that saxicolous species outnumbered corticolous or terricolous lichens in China's arid Tian Shan. Overall, these and other data show that substrate type (plant litter, soil texture, bedrock geochemistry) and lithology serve as powerful filters, producing substrate-specific lichen assemblages in desert environments (Tumur et al., 2025).

Within the Betpak-Dala desert, there are two state nature reserves: the Betpakdala State Nature Reserve of local

significance, covering 1,415,861 hectares, and the Kogashik State Nature Reserve (Botanical), covering 150 km². The Betpak-Dala floristic region is the most sparsely populated and least studied area. A preliminary list of lichens from the Betpak-Dala desert included 72 species: 51 were found in the Kogashik tract, 16 in the vicinity of the city of Karazhal (Nurkenova & Sadykova, 2012), and 5 species were shared between both locations. Despite being understudied, recent surveys show that Central Asian deserts have high lichen diversity. Systematic sampling in a single reserve in arid northwest China (Western Tianshan, Xinjiang) revealed 596 lichen taxa (580 species plus subspecies) (Tumur et al., 2025). Similarly, Mongolia's flora includes more than 1000 known lichen species (Hauck et al., 2013b). These studies show that Central Asian deserts may host a variety of endemic and widespread lichens, many of which had not previously been identified. The aim of our research was to revise all existing data and compile an up-to-date list of lichenobiota species in the Betpak-Dala floristic region of Kazakhstan, based on herbarium specimens from the Institute of Botany and Phytointroduction, the authors' own collections, the iNaturalist database (iNaturalist, 2025) and other available sources.

2. MATERIALS AND METHODS

2.1. Sample Collection

Lichen samples were collected within the territory of the Betpak-Dala floristic region of Kazakhstan in 2024 (Fig. 2). The geographic coordinates of the sampling points were recorded using a GPS device (Garmin). Most of the samples were collected from rock outcrops, soil and crushed stones; significantly fewer were found on shrub and semi-shrub branches and other substrates.

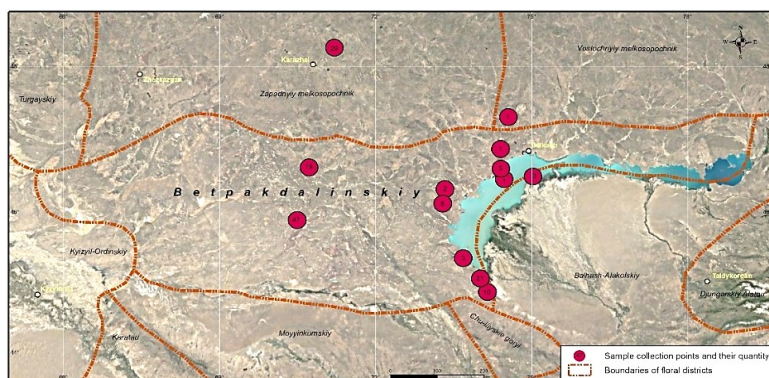


Fig. 2: Map of the Betpak-Dala floristic region with sample collection points marked.

2.2. Light Microscopy

Morphological and anatomical characteristics of the lichens were studied using a Levenhuk MED D45T LSD light microscope. The following morphological features were evaluated: growth form; color and texture of the upper and lower surfaces of the thallus; presence, type, and location of attachment organs; type, size, and location of fruiting bodies, soralia, isidia, pycnidia, etc. (Tsurikov & Korchikov, 2018). Anatomical features were studied by examining thin sections of the thallus and fruiting bodies (either fresh or fixed). These sections were used to assess thallus type, the structure and taxonomic identity of the photobiont, internal structure of the fruiting bodies, shape and size of asci, presence and structure of paraphyses, and type, color, size, and number of spores per ascus.

2.3. Chemical Staining

Staining was performed using a 10% aqueous solution of potassium hydroxide, a saturated aqueous solution of calcium hypochlorite, a 10% aqueous solution of hydrochloric acid, and an alcohol solution of iodine.

2.4. Identification

Species identification was based on key diagnostic features including morphological, anatomical, and biochemical characteristics specific to lichens. Identification was conducted using relevant taxonomic keys (Tsurikov & Korchikov, 2018). The species list was verified against the MYCOBANK Database (2025) and arranged following the classification system by Hyde (2024).

3. RESULTS

3.1. Taxonomic Analysis of the Lichenobiota in the Betpak-Dala Floristic Region of Kazakhstan

The annotated list of lichenobiota species for the Betpak-Dala floristic region includes 115 taxa (Table 1), arranged in systematic order according to Hyde (2024). Of these, 42 species are recorded for the first time in this area.

The lichen species of the Betpak-Dala floristic region belong to three classes. The class Lichinomycetes includes only five species: *Lichinella nigritella* (order Lichinales, family Lichinellaceae), *Candelariella aggregata*, *C. aurella*, *C. oleifera*, and *C. vitellina* (order Candelariales, family Candelariaceae). The latter three species are associated with rock outcrops, with *C. vitellina* being the most frequently encountered. *C. aggregata* has been found on plant debris. The class Eurotiomycetes comprises six species from the genera *Dermatocarpon*, *Endocarpon*, *Endopyrenium*, and *Verrucaria* (subclass Chaetothyriomycetidae, order Verrucariales, family Verrucariaceae). All members of this class are relatively rare.

Table 1: Taxonomic spectrum of lichenobiota of Betpak-Dala floristic region of Kazakhstan

Class/subclass	Order	Family	Genus	Number of species	% of total number of species
Eurotiomycetes/ Chaetothyriomycetidae	Verrucariales	Verrucariaceae	<i>Dermatocarpon</i>	1	0.87
			<i>Endocarpon</i>	2	1.74
			<i>Endopyrenium</i>	1	0.87
			<i>Verrucaria</i>	2	1.74
Lecanoromycetes/ Acarosporomycetidae	Acarosporales	Acarosporaceae	<i>Acarospora</i>	11	9.56
			<i>Myriospora</i>	1	0.87
			<i>Sarcogyne</i>	1	0.87
/Lecanoromycetidae	Caliciales	Caliciaceae	<i>Amandinea</i>	1	0.87
			<i>Dimelaena</i>	1	0.87
			<i>Diplotomma</i>	1	0.87
		Physciaceae	<i>Kudratovia</i>	1	0.87
			<i>Physcia</i>	6	5.22
			<i>Physconia</i>	1	0.87
			<i>Rinodina</i>	3	2.61
			<i>Cladonia</i>	1	0.87
			<i>Squamarina</i>	1	0.87
	Lecanorales	Lecanoraceae	<i>Chlorangium</i>	1	0.87
			<i>Lecanora</i>	9	7.82
			<i>Lecidella</i>	2	1.74
			<i>Myriolectis</i>	1	0.87
			<i>Polyozosia</i>	2	1.74
			<i>Protoparmeliopsis</i>	2	1.74
			<i>Rhizoplaca</i>	3	2.61
		Parmeliaceae	<i>Melanelia</i>	1	0.87
			<i>Parmelia</i>	1	0.87
			<i>Protoparmelia</i>	1	0.87
			<i>Xanthoparmelia</i>	4	3.48
		Pilocarpaceae	<i>Micarea</i>	1	0.87
		Psoraceae	<i>Psora</i>	1	0.87
		Ramalinaceae	<i>Ramalina</i>	1	0.87
			<i>Thalloidima</i>	3	2.61
			<i>Toninia</i>	1	0.87
	Lecideales	Lecideaceae	<i>Lecidea</i>	1	0.87
	Peltigerales	Collemataceae	<i>Enchylium</i>	1	0.87
	Rhizocarpales	Rhizocarpaceae	<i>Rhizocarpon</i>	2	1.74
	Teloschistales	Teloschistaceae	<i>Bryoplaca</i>	1	0.87
			<i>Calogaya</i>	2	1.74
			<i>Caloplaca</i>	1	0.87
			<i>Golubkovia</i>	1	0.87
			<i>Gyalolechia</i>	2	1.74
			<i>Placodium</i>	1	0.87
			<i>Pyrenodesmia</i>	2	1.74
			<i>Rusavskia</i>	1	0.87
			<i>Seiophora</i>	1	0.87
			<i>Xanthocarpia</i>	1	0.87
			<i>Xanthoria</i>	2	1.74
			<i>Zeroviella</i>	1	0.87
/Ostropomycetidae	Graphidales	Diploschistaceae	<i>Diploschistes</i>	2	1.74
	Pertusariales	Megasporeaceae	<i>Aspicilia</i>	6	5.22
			<i>Circinaria</i>	8	6.96
			<i>Lobothallia</i>	4	3.48
		Pertusariaceae	<i>Pertusaria</i>	1	0.87
Lichinomycetes	Candelariales	Candelariaceae	<i>Candelariella</i>	4	3.48
	Lichinales	Lichinellaceae	<i>Lichinella</i>	1	0.87
3/4	12	19	54	115	100

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The largest class represented is Lecanoromycetes, which includes three subclasses. The subclass Acarosporomycetidae accounts for 13 species in the genera *Acarospora*, *Myriospora*, and *Sarcogyne* (order Acarosporales, family Acarosporaceae). The subclass Lecanoromycetidae is the most diverse, comprising 6 orders, 12 families, 40 genera, and 70 species. Notable species include *Collema tenax*, common on soil, and *Rusavskia elegans*, which is widely distributed across both hemispheres and typically found on rocks and boulders in well-lit conditions (Yatsyna et al., 2012; Ezhkin, 2020). Also noteworthy is *Xanthoparmelia camtschadalis*, which initially attaches to substrates but later becomes free-living. This species is characteristic of southern dry steppe and northern desert habitats. The subclass Ostropomycetidae is represented by two orders, three families, five genera and 21 species. Among them, *Circinaria caesiocinerea* is the most frequently encountered species. The most species-rich genera are: *Acarospora* with 11 species (10% of the total number of species), *Lecanora* with 9 species (8%), *Circinaria* with 8 species (7%), *Physcia* with 6 species (5%) and *Aspicilia* with 6 species (5%) (Fig. 3). Three genera are represented by 4 species each, three – by 3 species, 11 – by 2 species, and 32 genera – by a single species each.

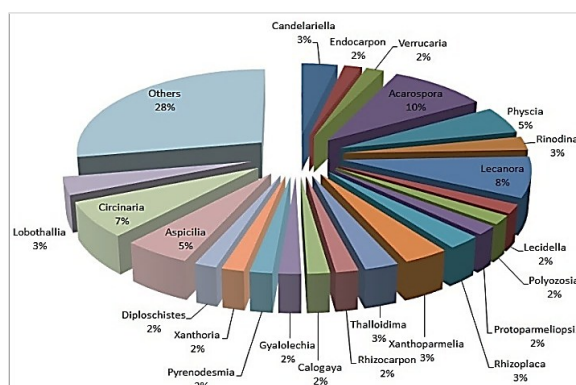


Fig. 3: Quantitative evaluation of lichen genera of the Betpak-Dala floristic region.

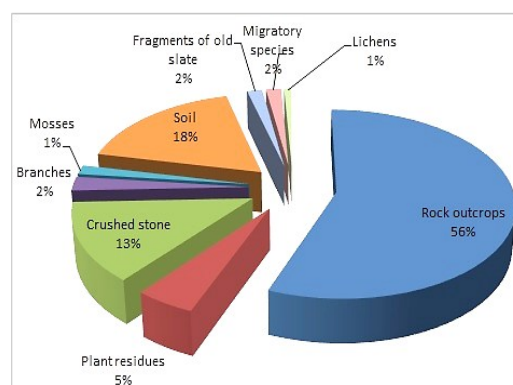


Fig. 4: Substrate specificity of lichens in the Betpak-Dala floristic region.

3.2. Substrate Specificity of Lichens in the Betpak-Dala Floristic Region

Most identified lichen species are associated with rock outcrops (70 species, 56% of the total; Fig. 4). Another 22 species (18%) grow on soil, and 17 species (13%) on gravel. Two species (1%) were found on mosses. Three species (2%) were observed on the bark of *Artemisia* sp., *Oreosalsola laricifolia* and *Salsola* sp. Six species (5%) were found on plant debris. Two species (1%) occur on fragments of old slate, and two others can exist as free-living forms. The species *Acarospora stapfiana* develops on another lichen, *Golubkovia trachyphylla*.

3.3. Lichen Life Forms in the Betpak-Dala Floristic Region

Two life forms characterize the lichens in this region. Only one species represents the endogenous type (Table 2). The life form spectrum in the region is dominated by crustose, tightly adhering, and narrow-lobed foliose lichens (Figs. 1A-16A). The vast majority of species (98.2%) are xerophytes, while xeromesophytes occur only on northern, shaded exposures of rock outcrops.



Fig. 1A: *Acarospora cervina*



Fig. 2A: *Dimelaena oreina*



Fig. 3A: *Diplotomma venustum*


Fig. 4A: *Lecanora argopholis*

Fig. 5A: *Protoparmeliopsis peltata*

Fig. 6A: *Rhizoplaca chrysoleuca*

Fig. 7A: *Rhizoplaca melanophthalma*

Fig. 8A: *Xanthoparmelia conspersa*

Fig. 9A: *Xanthoparmelia pulla*

Fig. 10A: *Psora decipiens*

Fig. 11A: *Lecidea atrobrunnea*

Fig. 12A: *Rhizocarpon disporum*
Table 2: Lichen life forms in the Betpak-Dala floristic region (Tsurikov 2020, with changes)

Type	Division	Class	Group	Subgroup	Species
Endogenous	Plagiotropic	Crustose	Endolithic		<i>Sarcogyne lapponica</i>
Epigenous	Plagiotropic	Crustose	Uniform-crustose	Granular-warty	<i>Candelariella aurella</i> , <i>C. vitellina</i> , <i>Xanthocarpia tominii</i>
				Densely crusted	<i>Aspicilia maculata</i> , <i>A. arida</i> , <i>A. desertorum</i> var. <i>semivagans</i> , <i>A. goettweigensis</i> , <i>Circinaria calcarea</i> , <i>C. caesiocinerea</i> , <i>Diplotomma venustum</i> , <i>Lecanora argopholis</i> , <i>L. baicalensis</i> , <i>L. chlorophthalma</i> , <i>L. desertorum</i> , <i>L. frustulosa</i> , <i>L. gangaleoides</i> , <i>L. hagenii</i> var. <i>umbrina</i> , <i>L. lithophila</i> , <i>L. substellaris</i>
				Rimose	<i>Verrucaria muralis</i> , <i>V. nigrescens</i>
				Fissured-areolated	<i>Diploschistes diacapsis</i> , <i>D. scruposus</i> , <i>Kudratovia terrestris</i> , <i>Rinodina archaea</i> , <i>R. bischoffii</i> , <i>R. calcarea</i>

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		Areolated	<i>Acarospora badiofusca</i> , <i>A. bullata</i> , <i>A. cervina</i> , <i>A. stapfiana</i> , <i>A. veronensis</i> , <i>Aspicilia cinerea</i> , <i>Myriospora molybdina</i> , <i>Pyrenodesmia chalybaea</i> , <i>P. variabilis</i> , <i>Rhizocarpon disporum</i> , <i>Rh. geographicum</i> , <i>Lecidella carpathica</i> , <i>L. stigmatea</i>
		Placodioid	<i>Dimelaena oreina</i> , <i>Calogaya lobulata</i>
	Dimorphic	Lobed	<i>Protoparmeliopsis muralis</i> , <i>Lobothallia farinosa</i> , <i>L. melanaspis</i>
		Rosetted	<i>Calogaya saxicola</i> , <i>Caloplaca coronata</i>
	Scabious	Uniform-scaly	<i>Endocarpon halophilum</i> , <i>E. subfoliaceum</i>
		Scaly-areolated	<i>Acarospora glaucocarpa</i> , <i>A. fuscata</i> , <i>A. laqueata</i> , <i>A. macrospora</i> , <i>A. schleicheri</i> , <i>A. tominiana</i>
		Scaly-lobed	<i>Psora decipiens</i>
		<i>Toninia</i> -shaped	<i>Thalloidima candidum</i> , <i>T. sedifolium</i> , <i>T. tabacinum</i> , <i>Toninia coeruleonigricans</i>
		Subfoliate	<i>Lobothallia alphoplaca</i>
		radial-foliosed	
	Umblicate	Umblicate-foliose	<i>Dermatocarpon desertorum</i>
	Foliose	Narrow-lobed	<i>Gyalolechia bracteata</i> , <i>G. desertorum</i> , <i>Placodium paulsenii</i> , <i>Placolecanora albescens</i> , <i>Protoparmeliopsis peltata</i> , <i>Rhizoplaca chrysouleuca</i> , <i>Rh. melanophthalma</i> , <i>Rh. subdiscrepans</i> , <i>Squamarina lentigera</i> , <i>X. calcicola</i> , <i>Xanthoria parietina</i> , <i>Zeroviella papillifera</i>
		Medium- to broad-lobed	<i>Melanelia stygia</i> , <i>Parmelia aurantiaca</i> , <i>Protoparmelia badia</i> , <i>Xanthoparmelia conspersa</i> , <i>X. pulla</i> , <i>X. stenophylla</i>
		Dissected rhizoidal	<i>Golubkovia trachyphylla</i> , <i>Physcia adscendens</i> , <i>Ph.aipolia</i> , <i>Ph.aipolia</i> subsp.
		Gelatinous	<i>scopulorum</i> , <i>Ph.caesia</i> , <i>Ph. stellaris</i> , <i>P. tenella</i> , <i>Rusavskia elegans</i>
Monotropic	Fruticose	Upright	<i>Collema tenax</i>
		Pendant	<i>Circinaria hispida</i>
		Pulvinate	<i>Ramalina</i> sp., <i>Seiophora lacunosa</i>
		Flat-lobed	<i>Circinaria transbaicalica</i>
Free-living	Crustose	Aegagropilous	<i>Circinaria esculenta</i> , <i>C. lacunosa</i>
	Foliose	Dissected	<i>Borreria camtschadalis</i> , <i>Endocarpon vagans</i>
	Fruticose	Radial-angular-bladed	<i>Circinaria affinis</i> , <i>C. fruticulosa</i>

4. DISCUSSION

Comparing our data with previous studies (Nurkenova & Sadykova, 2012; Lichen Checklist & Identifier, 2025), we note an increase of 42 taxa in the lichen biota of the Betpak-Dala floristic region. This expansion is primarily attributed to the thoroughness of the mycological surveys conducted in the area. In earlier years (1961–1987), researchers studied only the Kogashik tract of the Betpak-Dala desert, and in 2012, research focused on the surroundings of Karazhal (Nurkenova & Sadykova, 2012). Our study encompassed the northern and eastern parts of the Betpak-Dala clay desert, the deserts of the northern shore of Lake Balkhash and low hills of the Balkhash western shore. It is also worth noting that the creation of two nature reserves in the Betpak-Dala desert – the Betpakdala State Nature Reserve of local significance (2024) and the Kogashik State Botanical Reserve (2006) – is likely to promote environmental conservation and increase biodiversity in the region.



Fig. 13A: *Calogaya lobulata* on *Salsola* sp.



Fig. 14A: *Diploschistes scruposus*

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The preliminary checklist of lichens of Kazakhstan (Wagner & Spribille, 2005) included 555 species. Eight years later, the list grew to 706 species (Sedelnikova, 2013) and eventually to 747 species (Hauck et al., 2013a), mainly because new taxa were discovered in the mountainous regions of the Altai and Saur systems (Table 3). Within the Betpak-Dala floristic region, 10 species were recorded (*Lichinella nigritella*, *Aspicilia goettweigensis*, *A. arida* (syn. *Circinaria arida*), *Gyalolechia bracteata*, *Ramalina* sp., *Rhizoplaca subdiscrepans*, *Physcia aipolia* subsp. *scopulorum* (syn. *Ph. mediterranea*), *Endocarpon vagans*, *Myriospora molybdina*, and *Acarospora laqueata*) that were previously unlisted in Kazakhstan's lichen biota (Wagner & Spribille, 2005; Hauck et al., 2013a; Sedelnikova, 2013; Lichen Checklist & Identifier, 2025).



Fig. 15A: *Lobothallia alphoplaca*



Fig. 16A: *Candelariella vitellina*

Table 3: Comparative analysis of species composition of lichenobiota of the Betpak-Dala floristic region of Kazakhstan and arid regions of other countries

Country/region	Number of lichen species	Number of lichen species shared with the Betpak-Dala floristic region of Kazakhstan	References
Betpak-Dala floristic region of Kazakhstan	115		present paper
Kazakhstan	747	102	Hauck et al., 2013b; Sedelnikova 2013; Wagner and Spribille 2005
Russia	3388	63	Urbanavichus, 2010
China (Xinjiang)	268	33	Abbas et al., 2001
Mongolia	736	55	Zhurbenko et al., 2019, 2020
Afghanistan	230	34	Mayrhofer et al., 2023
Turkey	1769	37	John 1996; John & Türk 2017; John et al., 2020

A comparison of the lichen species composition in the Betpak-Dala floristic region of Kazakhstan with arid territories in other countries (Table 3) reveals that 34 species are shared with Afghanistan's lichenobiota (Mayrhofer et al., 2023). All arid and semi-arid regions of Afghanistan are located in the southwestern part of the country, between 1000 and approximately 500 meters above sea level, across the provinces of Farah, Helmand, Kandahar, and Nimruz. These areas remain largely unexplored in terms of lichen diversity (Mayrhofer et al., 2023), even though Afghanistan's total known lichenobiota includes 230 species. Russia's lichen flora includes 3388 species, but only about 340 are associated with arid regions. Sixty-three species are common between Russian arid territories and the Betpak-Dala region. In China, the Xinjiang checklist includes 268 lichen species from the mountainous areas of the Altai, Tien Shan, Karakoram, and Kunlun, as well as the Taklamakan and Gurbantunggut deserts (Abbas et al., 2001). Unfortunately, the list does not specify which species were found in the deserts. Nonetheless, 33 species are shared with the Betpak-Dala floristic region.

An analysis of Mongolia's lichenobiota shows that its desert zones are characterized by a very poor and monotonous species composition. In the vast expanses of the Gobi's sandy and rocky deserts, lichens are often

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completely absent. In general, around 120 species have been recorded in the Gobi deserts of Mongolia, with the leading family being Acarosporaceae, which includes 19 species. Fifty-five species are common to both the Mongolian and Betpak-Dala lichen floras. In contrast, the dominant family in Kazakhstan's Betpak-Dala region is Lecanoraceae, with 20 species. Turkey's lichenobiota includes 1,769 species, reflecting the wide range of natural and climatic conditions in the country. In the Mediterranean coastal provinces alone, 459 species have been identified.

Turkey has only one sandy desert, Karapynar, with an area of 4,000 hectares, located in Konya Province. Lichens are practically absent in this area. A total of 37 species are shared between the Turkish and Betpak-Dala lichenobiotas. The Negev Desert in Israel contains about 81 lichen species, mostly saxicolous crusts and a few foliose cyanolichens, demonstrating that even small deserts can have unique flora (Temina, 2021). Larger floras are typically found in areas with different climates or relief, whereas hyperarid lowlands typically support fewer taxa. According to these results, Betpak-Dala's lichen richness is in this range: it is lower than mesic steppe areas but higher than extremely extreme deserts. These comparisons highlight biogeographic and climatic limits on species richness by showing that Betpak-Dala's diversity is lower than in lichen-rich montane areas and comparable to other Central Asian deserts. Because Betpak-Dala in Kazakhstan is situated where Siberian, Persian and Mongolian flora converge, its lichens probably include both regional species and a wide variety of Eurasian taxa. Although biogeographic surveys in Central Asia are still fragmentary overall, the data that is currently available points to a high turnover gradient from temperate (north) to arid (south). In this regard, Betpak-Dala's lichens connect Mongolian and Middle Eastern faunal elements within the broader Eurasian desert flora.

Conservation initiatives rarely focus on desert lichens, despite their ecological significance. National biodiversity reports and red-listing typically ignore lichens. According to recent reviews, IUCN assessments of lichens are difficult due to their small size and taxonomic complexity (Yahr et al., 2024). Few lichens found in arid regions have official conservation status. However, lichens are essential to desert ecosystems because they improve soil stability and nutrient cycling and dominate biological soil crusts that cover much of arid terrain (Zhang et al., 2023). By preserving ungrazed areas or stopping damaging off-road use, protecting lichen communities promotes the overall health of the landscape. Lichens can serve as biomarkers of ecosystem integrity in monitoring frameworks. For example, changes in soil crust cover or lichen functional diversity could indicate degradation. Monitoring vegetation can be aided by satellite or UAV mapping, but field surveys are necessary for lichens. Incorporating lichen conservation into biosurveys, as well as IUCN Red List initiatives that consider these mysterious but important desert organisms, would benefit arid regions.

Although the study provides a vital baseline for lichen biodiversity in Central Kazakhstan, its ecological and geographic limitations offer opportunities for further research. The vast western plains, which are characterized by distinctive closed depressions and dry basins, remain a significant geographic gap requiring comprehensive mycological surveys, even though the current research successfully expanded the known taxa by focusing on the northern and eastern clay deserts and the Lake Balkhash shores (Faleyev et al., 2024). Another significant drawback is the substrate distribution of the collected specimens, which strongly favors lithophilic and terricolous species over epiphytic ones. Future studies should conduct thorough surveys of arboreal substrates, especially since only 2% of identified species were found on desert shrubs like *Artemisia* and *Salsola*. Given that only 2% of identified species were found on desert shrubs like *Artemisia* and *Salsola*, future research should prioritize intensive surveys of arboreal substrates, particularly focusing on the relict shrub, which may harbor specialized or rare taxa (Manzitto-Tripp et al., 2022).

Methodologically, conventional morphological and chemical staining required outside expert help for "difficult species," suggesting that future research should use molecular phylogenetic analysis to resolve taxonomic ambiguities and potentially unearth cryptic species within the dominant genera *Acarospora* and *Lecanora*. Furthermore, the recent creation of nature reserves in the area offers a rare opportunity for long-term ecological monitoring to assess how these primarily xerophytic communities respond to rising salinity and climate change in the desert's "takyr" and salt flats. The lack of desert-specific data from nearby arid regions like Xinjiang and Afghanistan further limits comparative research, underscoring the need for more extensive international collaborative surveys to further understand trans-regional lichen migration and adaptation in Central Asia (Wang et al., 2024).

5. CONCLUSION

As a result of our study, we compiled an annotated list of lichen biota species in the Betpak-Dala floristic region of Kazakhstan. It includes 115 species from 54 genera, 19 families, 12 orders, and 3 classes. Forty-two species are recorded for this region for the first time. In our opinion, the increase in species numbers is primarily due to the comprehensiveness of the mycological research conducted. Most of the identified lichen species are associated with rock outcrops (70 species), soil (22 species), and gravel (17 species). The most widespread lichen types in the region are crustose, tightly adherent, and narrow-lobed foliose species. This research provides valuable data on lichen diversity in the Betpak-Dala floristic region.

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