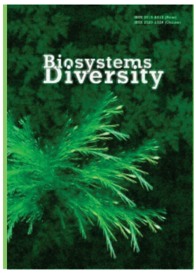

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The impact of climate aridification on rare lichen communities

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The global diversity of approximately 25,000 lichen species (e.g., from the genera *Usnea*, *Cladonia*, and *Peltigera*), including rare and endangered ones, highlights the importance of preserving their population in the State National Nature Park "Burabay". The objective of this study was to investigate the distribution of rare lichen species in the territory of the State National Nature Park "Burabay," located in the Akmola region of Kazakhstan, in the period from 2018 to 2022, with a particular focus on understanding how aridification may have influenced their presence and abundance. In the course of the study, methods such as route expeditions, the comparative morphological method, as well as some other special methods were used. The collection of information to systematize the taxonomic composition of lichens (genera *Lobaria*, *Rhizocarpon*, and *Xanthoria*) was carried out during route expeditions. The study identified 56 lichen species, with a focus on rare and protected species. Established in 2000, the park's rich biodiversity is showcased, including the discovery of three very rare species (*Dermatocarpon miniatum*, *Psora lurida*, and *Verrucaria nigrescens*) and four species requiring protection (*Peltigera spuria*, *Cladonia coccifera*, *Haematomma ventosum*, and *Caloplaca aurantiaca*). These findings are significant, considering the absence of data on these species since the 1982 Red Book of Kazakhstan (including genera such as *Lecanora*, *Lecidea*, and *Pertusaria*). The sensitivity of lichens to environmental changes (indicated by genera like *Alectoria*, *Bryoria*, and *Cetraria*) makes them ideal for monitoring ecological health through a cost-effective method known as lichen indication. The increase in the species count over the past five years (highlighting genera such as *Stereocaulon*, *Solorina*, and *Thamnolia*) suggests effective conservation efforts and underlines the park's ecological importance. The study's findings reveal that aridification is reshaping lichen communities in the park, emphasizing their sensitivity to climate change and the need for conservation strategies to address these changes and ensure the preservation of lichen biodiversity in the face of global climate change. The research contributes valuable data for future conservation planning and environmental assessments in the region, emphasizing the need to protect diverse lichen genera (e.g., *Evernia*, *Ramalina*, and *Parmotrema*) for ecological monitoring and conservation.

Keywords: natural ecosystems; Drude scale; thallus; lichen biodiversity; symbiotic relationships; environmental indicators.

Introduction

Globally, the study of lichens is gaining increasing importance in ecological research due to their role as sensitive bioindicators of environmental health (Orlov et al., 2022). Lichens, with their unique symbiotic nature, respond acutely to changes in atmospheric conditions, making them valuable in assessing air quality and the impact of pollutants (Sinigla et al., 2021; Fazan et al., 2022; Lawal et al., 2023). This sensitivity is heightened by their structural characteristics, such as the lack of a protective cuticle, allowing direct exposure to environmental factors (Floqi et al., 2009). Current global trends show a growing concern for lichen diversity in various ecosystems, ranging from pristine natural habitats to those heavily influenced by human activities (Lyubchyk et al., 2019; Langbehn et al., 2021; Manzitto-Tripp et al., 2022; Lõhmus et al., 2023). This focus is not only driven by the need to understand their ecological role but also to use their responses to forecast environmental changes, including those induced by climate change. The loss of lichen diversity is increasingly being recognized as an indicator of broader ecological shifts, prompting a need for comprehensive studies in diverse geographical regions (Brunialti et al., 2021; Steinová et al., 2022; Lukashchuk et al., 2023). Such research is critical for developing conservation strategies and understanding the dynamic interplay between lichens and their environments on a global scale. The study also underscores the pressing need to investigate aridification within this context, as arid conditions can significantly impact lichen populations and their responses to environmental changes (Pikovska, 2020; Zhumadilova et al., 2023). Understanding how aridification affects lichens globally is crucial for a comprehensive assessment of their ecological role and the development of effective conservation strategies. Of particular interest is the study of lichen populations due to their high sensitivity to environmental pollution, which allows us to speak of them as natural bioindicators. This property was discussed in the article by Khastini et al. (2019). In particular, the authors of the article conducted a comparative analysis of the populations of various lichen species in three ecosystems: a residential zone, a primary (primitive) forest, a secondary (restored after destruction) forest of the Rawa-Danau Nature Reserve in Indonesia, which made it possible to assess the current state of the natural environment in the Rava-Danau Nature Reserve. The sensitivity of lichens to various kinds of influences of biotic and abiotic origin is due to a number of features of their structure. First of all, lichens are a symbiotic organism consisting of fungi (mycobiont) and green algae (photobiont) or cyanobacteria (phycobiont) (Brazhnikova et al., 2022). Inside the thallus formed by the mycobiont, there are cells of the photobiont or phycobiont. The absence of a cuticle in lichens (a layer of cutin – a protective wax-like substance) leads to the fact that gas and water exchange occurs through the entire surface of the body without any purification from pollutants. In addition, unlike angiosperms of deciduous plants, lichens are not able to get rid of toxic substances formed during the growing season that accumulate in the leaves (Bahatska et al., 2023). The specifics of the interaction of a mycobiont with a photobandage (phycobiont) were also described in the monograph by Honegger (2022). In particular, the work studied the mycobiont-photobiont interface, as well as the process of accumulation of heavy metals and radionuclides. Similar studies are being carried out in European countries, in particular, Serbian researchers Ristic et al. (2021) study of lichens as the main indicators of the composition of atmospheric air. Separately, it should be noted that the study considered not only natural ecosystems, but also semi-natural communities, as well as ecosystems subjected to anthropogenic influence. It should be noted that the work of Mallen-Cooper et al. (2022) on the study of the impact of climate change on the state of lichens, also provides forecasts regarding the possibility of their migration. A similar study was carried out on the basis of material collected in the Southern Appalachians by Allen & Lendemer (2016). The authors of the article came to the conclusion that global warming can lead to the loss of approximately 93% of the biological diversity of lichens.

The necessity of this research stems from the urgent need to understand and preserve the biodiversity of rare lichen species, which are crucial indicators of ecological health and balance in the State National Nature Park "Burabay." Thus, the study of the species diversity and ecology of lichens growing on the territory of the State National Nature Park "Burabay" aims to fix the current state of its ecosystems and systematize the information received. On the one hand, this can serve as the basis for the development of measures aimed at the conservation of rare and endangered species. On the other hand, the dynamics of changes in the species diversity of lichen flora may indicate changes in biotic and abiotic environmental conditions.

Materials and methods

The study's methodology adheres to ecological research ethics, utilizing non-invasive techniques such as route expeditions and scanning electron microscopy, and systematically identifying lichen species based on established scales and international reports, ensuring minimal environmental impact and data reliability. The study of lichen flora in the territory of the State National Nature Park "Burabay", located in the Akmola region of the Republic of Kazakhstan, was carried out during 2018–2022. Utilizing an integrative methodological approach, the study combined extensive field surveys, satellite imagery analysis for historical climate data, and microclimatic monitoring to assess changes in humidity, temperature, and precipitation patterns within the park's territory. These methods provided a robust framework for understanding the direct and indirect effects of aridification on lichen biodiversity. Field surveys were systematically carried out across various habitats within the park, employing the route method to ensure comprehensive coverage of the lichen populations. Satellite imagery from the past two decades was analyzed to identify long-term trends in vegetation cover and moisture availability, which served as proxies for assessing the degree of aridification. Microclimatic monitoring stations were strategically placed in selected study sites to record real-time data on environmental conditions affecting lichen habitats. This multifaceted approach allowed the climate data to be correlated with observed changes in lichen communities.

The study area was previously divided into squares (sections) for the most thorough study of lichen populations. At the same time, out of the eleven squares received, seven fell within the territory of the Burabay Reserve, and four plots in the territory immediately adjacent to it. The collected material was labelled. The identification of species was carried out on the basis of a comparative morphological method, a number of determinants and images obtained using a low-vacuum scanning electron microscope – JSM-6390 LV JEOL (made in Japan). Scanning microscopy is based on the interaction of an electron beam with the object under study. This principle of operation makes it possible to obtain not only a magnification many times greater than the capabilities of optical analogues, but also information about the structure and composition of the layers directly adjacent to the surface. Although the use of a low-vacuum system leads to a decrease in resolution in comparison with high-vacuum devices, for the tasks set, this is quite acceptable. The taxa were identified on the basis of reports of lichens from Austria (Hafellner & Turk, 2001), Norway and Sweden (Westberg et al., 2021), Canada and the USA (Esslinger, 1997).

To determine the quantitative ratio of species, identify rare species and species in need of protection, the Drude scale was used, which is a classical system for determining the abundance of species based on visual counting. In accordance with the Drude scale, five main points are distinguished depending on the number of individuals of each species per unit area or volume: Socials (Soc.) – Background (F): plants that form a common background, usually in contact with each other. Copiosae (Cop.) – Abundant (Ob.), plants are very common, but not so much as to merge into the general background. Depending on the number of plants, this score is divided into three subgroups in the direction of decreasing abundance of individuals of each species: Cop.3 (Ob.-3), Cop.2 (Ob.-2), Cop.1 (Ob.-1). Sparsae (Sp.) – Occasional (Isr.), plants are not common, individuals are scattered. Solitariae (Sol.) – Rare (R) plants are rare, present in a few specimens. Unicum (Un.) – Solitary (Unit), the plant is represented by a single individual in the study area.

Results

As a result of the studies carried out on the territory of the State National Nature Park "Burabay", 3 species of very rare lichens (Solitaries according to the Drude scale) were found growing in four of the eleven sites where the studies were carried out. At the same time, the total number of species identified during the study is 56. Very rare species include: *Dermatocarpon miniatum*, *Psora lurida* and *Verrucaria nigrescens*. The abundance of these species can be characterized as low in large areas. At the same time, such species as *Peltigera spuria*, *Cladonia coccifera*, *Haematomma ventosum* and *Caloplaca aurantiaca* belong to the Unicum category according to the Drude scale, i.e. are in need of protection. However, these species were not included in the Red Book of the Republic of Kazakhstan, published in 1982, which may indicate that they could be distributed to other territories of the Republic of Kazakhstan. But during the forty years that have passed since the publication of the Red Book, there have been no reliable data on the distribution of the above species in scientific papers devoted to similar studies. Very rare lichens, as well as lichens in need of protection, were classified according to their position in the substrate into epilithic (growing on stony and rocky soils, while, as a rule, certain types of lichens are confined to a certain type of rock, depending on their chemical composition), epiphytic (growing on other plants) and epigeic (ground forms) ecological groups (Fig. 1). The distribution of the studied lichen species is shown in Table 1.

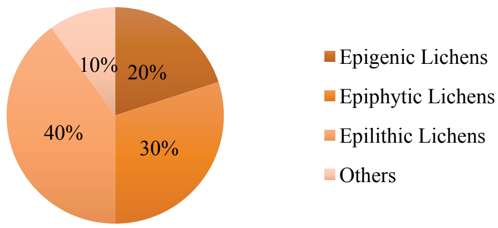

Fig. 1. The distribution of lichen species in the Burabay area

Table 1
Ecological groups of very rare and protected lichen species

Very rare species	Environmental group	Species in need of protection	Environmental group
Family: Dermatocarpaceae – *Dermatocarpon miniatum*	epilithic	Family: Peltigeraceae – *Peltigera spuria*	epigeic
Family: Lecideaceae – *Psora lurida*	epilithic	Family: Cladoniaceae – *Cladonia coccifera*	epigeic
Family: Verrucariaceae – *Verrucaria nigrescens*	epilithic	Family: Lecanoraceae – *Haematomma ventosum*	epigeic
		Family: Caloplacaceae – *Caloplaca aurantiaca*	epigeic

Table 1 shows that the only lichen species that belongs to very rare species is *Psora lurida*, which belongs to the ecological group of epiphytes, while this lichen grows exclusively on birch trunks. The distribution of the studied lichen species is determined by the peculiarities of the structure of their thallus. Below is a detailed description of the lichens found during the study on the territory of the State National Nature Park "Burabay".

Very rare types of lichens (family: Dermatocarpaceae, *Dermatocarpon miniatum*). The lichen *D. miniatum* belongs to the ecological group of epiliths. Figure 2 shows photographs of *D. miniatum* in its natural habitat, as well as images taken with an electron microscope.

No other habitats were identified within the state national natural park "Burabay" for *D. miniatum*. The lichen is attached to the substrate by one or more gomfae, which are a thallus formation on the lower surface of the lichen. The thallus looks like a thin, smooth, leaf-like plate with a pointed edge and a notch towards the center. After drying, the edges of the thallus of this lichen become raised and fragile. The surface part of the thallus is covered with a powdery coating of a whitish-green colour, with a greenish-brown lower part. The perithecia (the reproductive part characteristic of fungi) can be white or black and are located on the thallus (family: Verrucariaceae, *Verrucaria nigrescens*). *Verrucaria nigrescens* is a very rare epilithic species. Figure 3 shows images of *V. nigrescens* on the substrate, as well as photographs of the upper and lower sides of the thallus with perithecia.

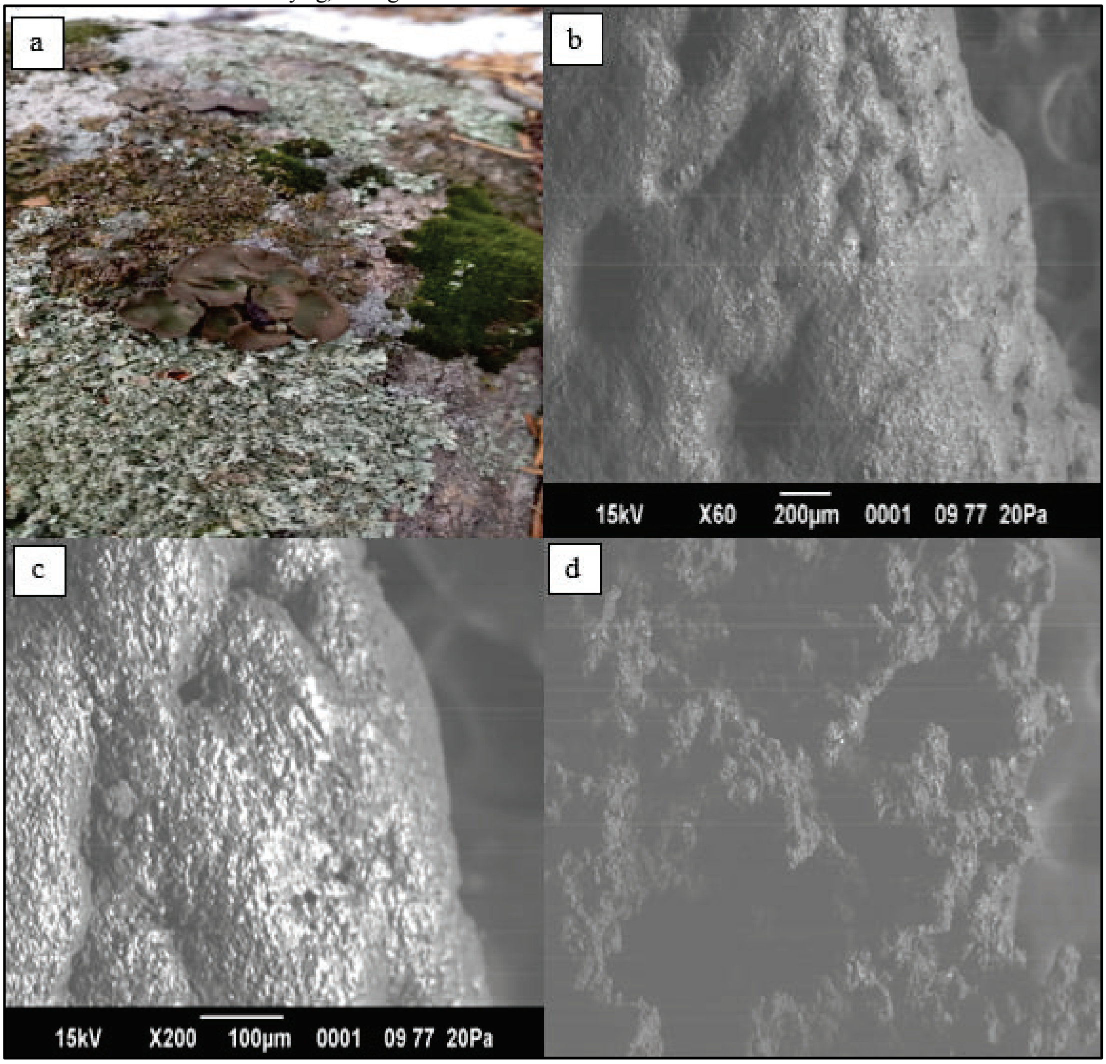

Fig. 2. *Dermatocarpon miniatum*: *a* – *D. miniatum* on a substrate; *b* – cortical layer of the thallus; *c* – marginal part of thallus with perithecia; *d* – gomfae on the underside of the thallus

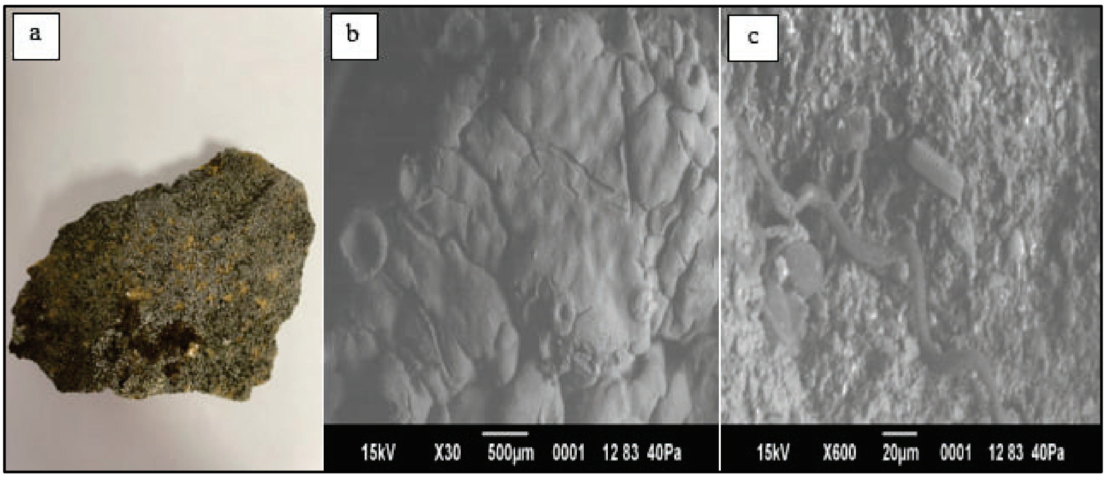

Fig. 3. *Verrucaria nigrescens*: *a* – *V. nigrescens* in a substrate; *b* – thallus with perithecia; *c* – lower part of the thallus

The surface of the thallus has a dark brown colour corresponding to the colour of the substrate on which it grows. Areola thalli are usually angular, often covered with cracks. The fruiting body is a perithecium without a stem, immersed in the lichen thallus (family: Lecideaceae, *Psora lurida*). This species is found in mixed forests on the trunks of young birches, where there is a lot of light and moisture. This species has a scaly greenish-brown thallus that adheres tightly to the birch bark. Apothecia (fruit body of an open type) of individuals of this species have edges bent upwards, and attachment to the substrate is carried out through a thickened folded central part. Figure 4 shows images of *P. lurida* directly on the substrate, as well as images taken with an electron microscope, giving an accurate representation of the surface of the lichen and the shape of the apothecia.

In the course of the study, among 56 lichen species identified in the study areas, both within the State National Nature Park "Burabay" and adjacent areas, *Peltigera spuria* (family: Peltigeraceae), *Cladonia coccifera* (family: Cladoniaceae), *Haematomma ventosum* (family: Lecanoraceae) and *Caloplaca aurantiaca* (family: Caloplacaceae) were classified according to the Drude scale as requiring protection. The biological characteristics and distribution of lichens in need of protection in the study area are described in detail (family: Peltigeraceae, *Peltigera spuria*). *Peltigera spuria* is an epigeic species that occurs in groups of no more than 1–3 individuals on the moss surface. The thallus is usually small, the length does not exceed 1.5–2.0 cm, and the width is from 1.0 to 1.2 cm. The upper part of the thallus is smooth, grey-green in colour. The underside of the lichen is pale pink with veins. Apothecia are located in the elongated part of the thallus. Figure 5 shows photographs of the *P. spuria* species taken directly in the habitat, as well as the thallus under an electron microscope magnification.

The lichen species *Cladonia coccifera* (family: Cladoniaceae), belonging to the epigeic ecological group, is very limited in numbers. In the individuals found, the primary thallus consists of small scales, while the secondary thallus (podetia) looks like a greenish-grey plate up to 2–5 cm in height. Apothecia are bright red, sometimes located singly, but more often collected in groups. The apothecium disc is convex, with clear margins. Figure 6 shows the appearance of the lichen *C. coccifera* both in its natural habitat on a moss substrate and images taken with an electron microscope.

An epilithic species of lichen *Haematomma ventosum* (family: Lecanoraceae) was found in very limited numbers. The substrate for this type of lichen is rocky surfaces, preferably calcareous or silicate. It was not found in other surveyed areas. The surface of the thallus is warty, wrinkled, with cracks. Numerous apothecia are sessile, brownish-red, collected in groups. Figure 7 shows *H. ventosum* at substrate in its natural habitat, and also shows separately sessile type apothecia.

This lichen *Caloplaca aurantiaca* (family: Caloplacaceae) has an orange-yellow colour and belongs to epilithic species. It grows on stony, well-heated surfaces in very small numbers. The thallus is a warty, bumpy formation of lemon-orange colour, usually has a round shape up to 15–17 cm in diameter. Apothecia are located in the middle part of the thallus and have a lemon-yellow colour. Apothecia are disc-shaped with slightly convex zigzag edges measuring 0.5 to 3.0 mm in diameter. Figure 8 shows the appearance of the lichen *C. aurantiaca* on the substrate, as well as enlarged images of the thallus and apothecia.

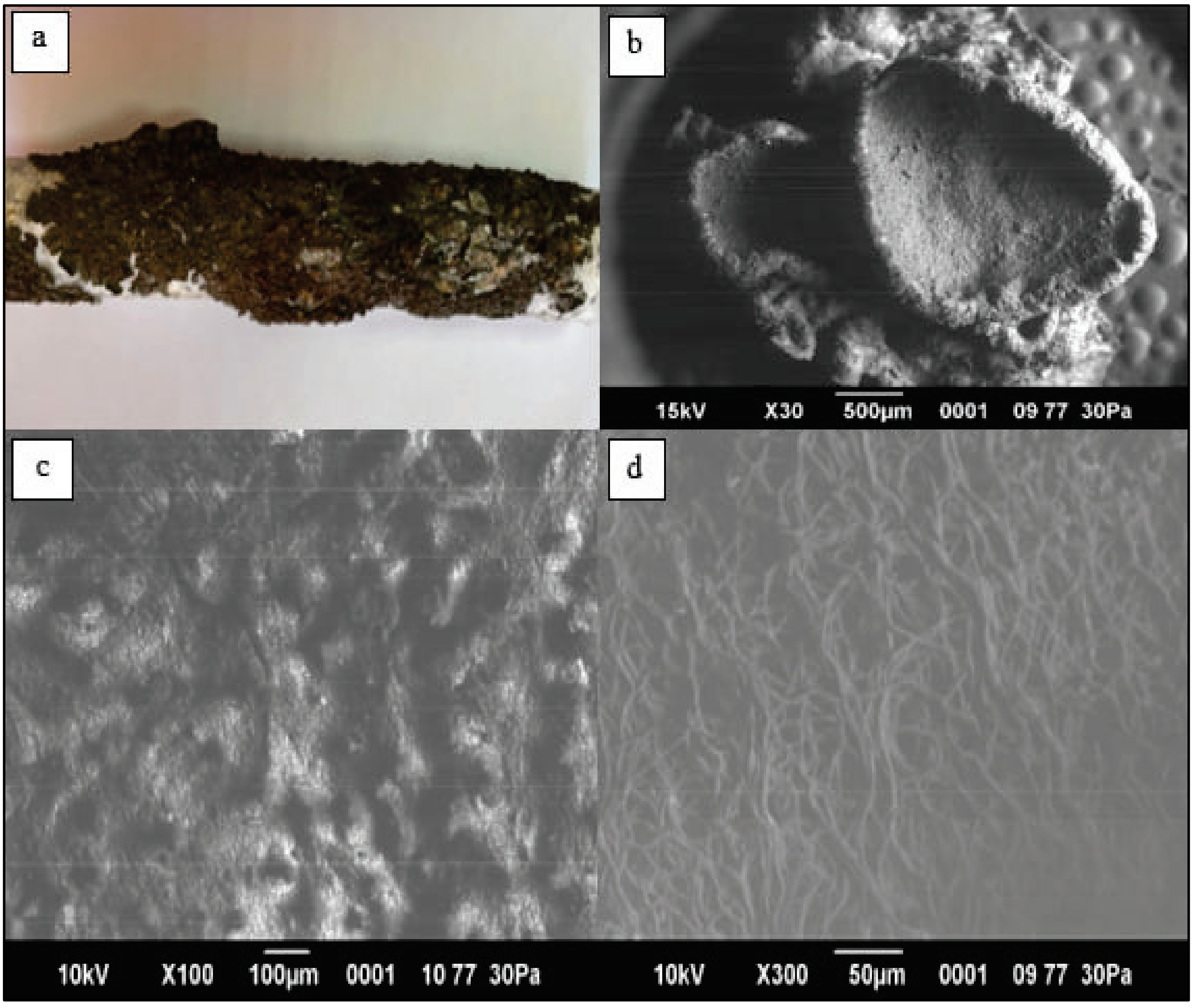

Fig. 4. *Psora lurida*: *a* – *P. lurida* on a substrate; *b* – form of apothecia; *c* – general view of the lichen surface; *d* – rhizine layer on the underside of the lichen

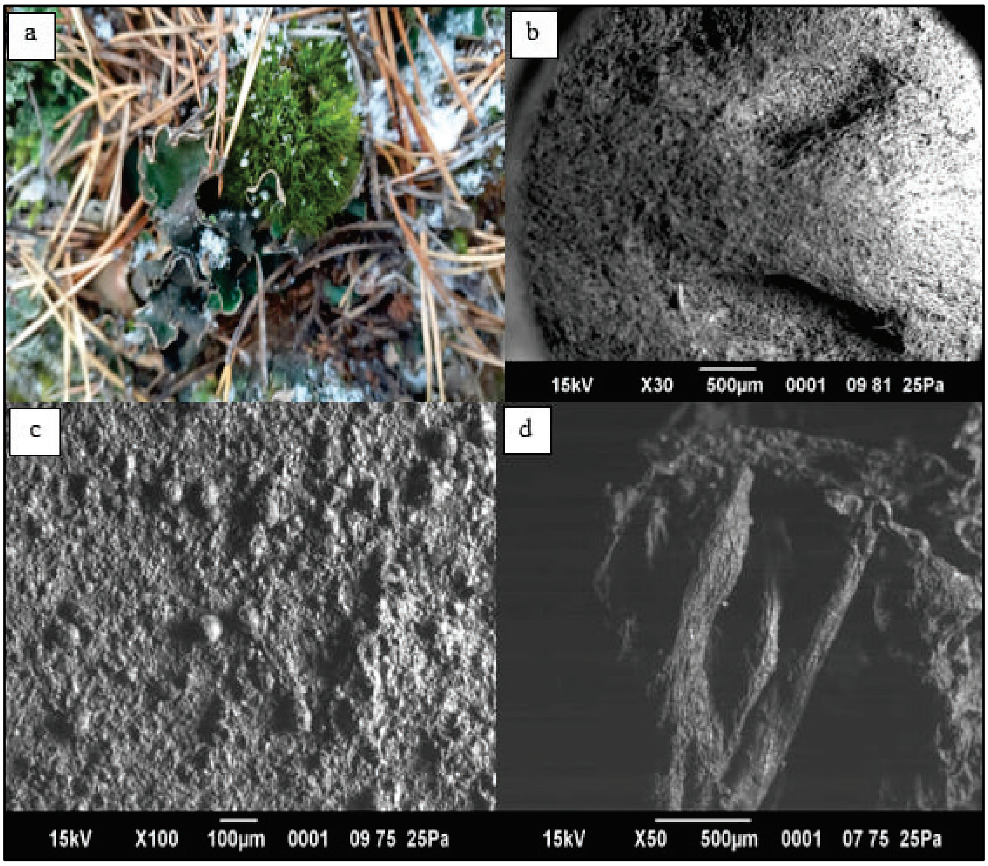

Fig. 5. *Peltigera spuria*: *a* – *P. spuria* on a substrate; *b* – veins in the lower part of the thallus; *c* – upper part of thallus (thallus) with apothecia; *d* – rhizine layer on the underside of the lichen

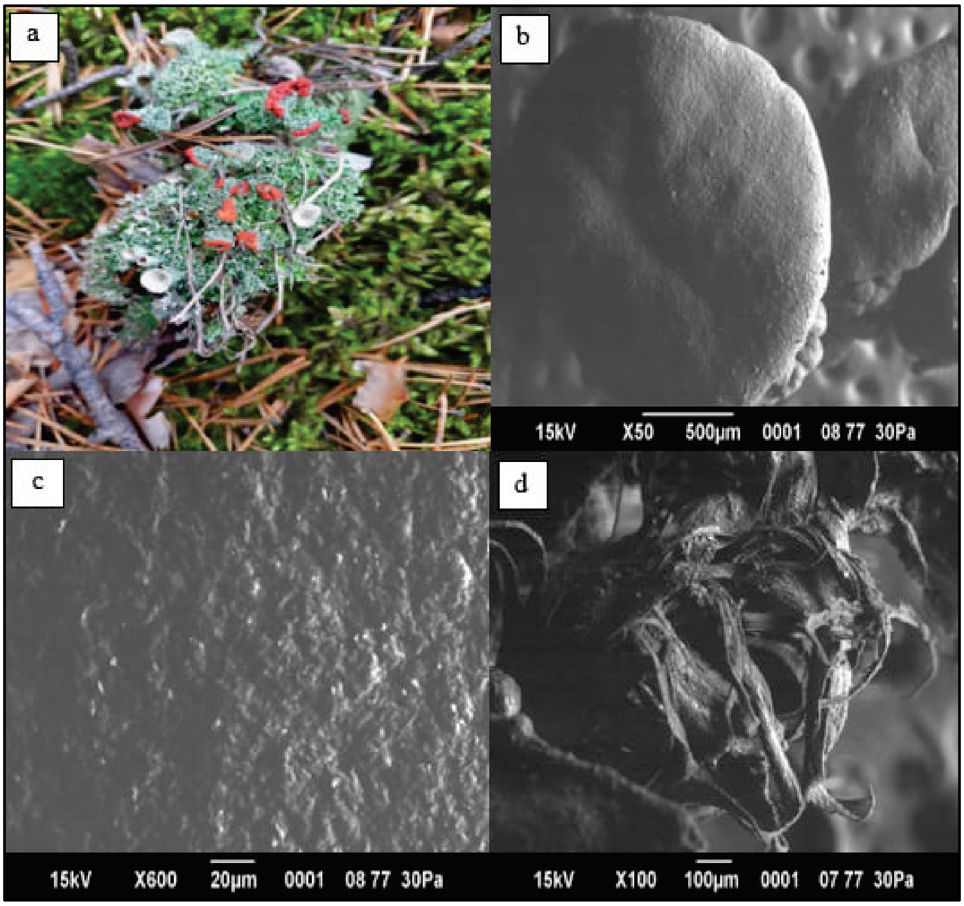

Fig. 6. *Cladonia coccifera*: *a* – *C. coccifera* on a substrate; *b* – form of apothecia; *c* – outer cortical verrucous layer of podetia; *d* – underside of the horizontal thallus associated with the substrate

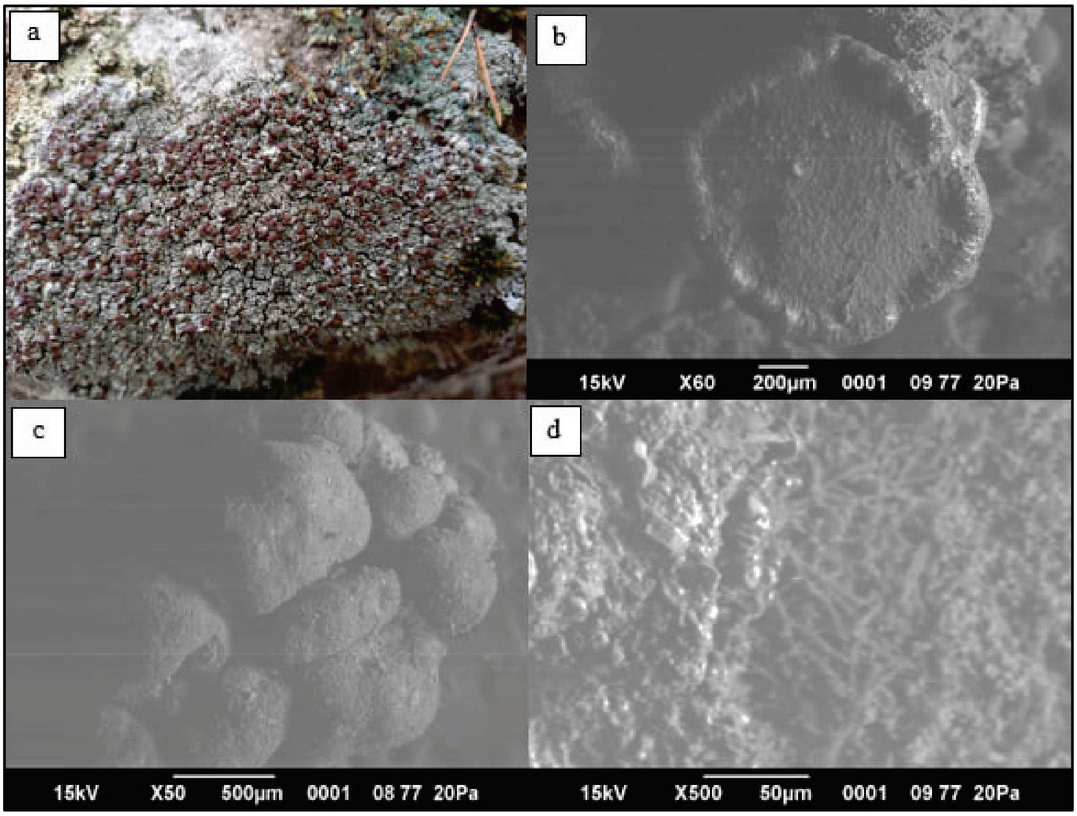

Fig. 7. *Haematomma ventosum*: *a* – *H. ventosum* on a substrate; *b* – sedentary apothecia; *c* – grouped apothecia; *d* – underside of the thallus

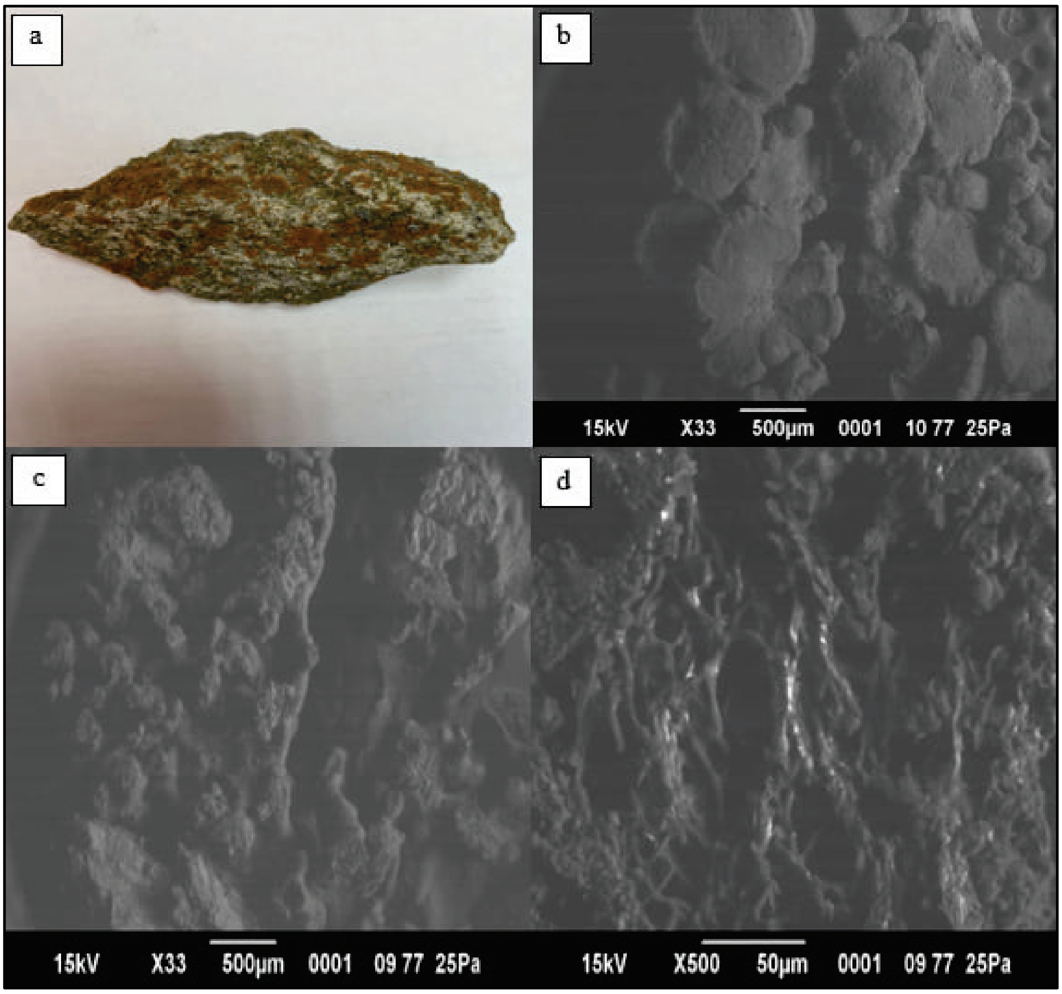

Fig. 8. *Caloplaca aurantiaca*: *a* – *C. aurantiaca* on a substrate; *b* – view of apothecia with zigzag edges; *c* – part of thallus with apothecia; *d* – view of apothecia with zigzag edges

As a result of the studies carried out on the territory of the State National Nature Park "Burabay", three species of lichens were found in three of the eleven surveyed territories, which, according to the Drude scale, can be classified as *Unicum* and need protection. These species include within the limits of the National Nature Park "Burabay": *Cladonia coccifera*, *Peltigera spuria* and *Haematomma ventosum*, as well as the species *Caloplaca aurantiaca*.

The results of the study revealed a discernible shift in the composition and distribution of lichen species across the park, with a notable decline in moisture-dependent species and an increase in those adapted to drier conditions. Specifically, species such as *Dermatocarpon miniatum*, *Psora lurida*, and *Verrucaria nigrescens*, which thrive in moist environments, exhibited reduced abundance and cover. Conversely, species with higher tolerance to dry conditions, such as *Cladonia coccifera* and *Caloplaca aurantiaca*, showed signs of expanded distribution. The analysis of microclimatic data confirmed a gradual increase in average temperatures and a decrease in precipitation levels over the study period, consistent with the patterns of climate aridification. These environmental changes have led to alterations in the microhabitats of lichens, affecting their growth, reproduction, and survival rates. The observed trends underscore the vulnerability of lichen communities to climate-induced stressors and highlight the necessity for targeted conservation efforts.

The findings from "Burabay" underscore the critical role of lichens as bioindicators of ecological health and climate change. The study's outcomes contribute to a growing body of evidence on the impacts of climate aridification on lichen communities, offering valuable insights for the development of adaptive conservation strategies. By documenting the changes in lichen biodiversity in response to aridification, this research not only enhances our understanding of lichen ecology in the context of climate change but also provides a model for similar studies in other regions facing the challenges of a changing climate.

Discussion

Studies of lichen flora are actively carried out around the world. This is primarily due to the need to study and record the current state of ecosystems in the face of constant environmental changes. The biodiversity of lichens is an excellent indicator of the state of ecosystems, both protected areas and areas subject to anthropogenic impact (Bidolakh, 2023). So, a number of articles by Bukabaeva & Abiyev (2020) have been devoted to the study of lichens in the territory of the State National Nature Park "Burabay". In the course of the research, all possible types of substrates were studied, such as wood, including living, rotten and dry, stony and rocky rocks, various types of soils. As a result of these studies, 44 lichen species were identified, which belong to 9 families (Peltigeraceae, Teloschistaceae, Lecideaceae, Physciaceae, Parmeliaceae, Cladoniaceae, Dermatocarpaceae, Verrucariaceae and Lecanoraceae) and 19 genera. Most of the lichen species found during the study belong to the ecological group epiphytes.

In the article by Abiyev et al. (2020) special attention was paid to the distribution of ecotope lichens (lichens that have the ability to adapt to the specifics of a particular set of environmental factors – an ecotope). The main ecological forms of lichens found on the territory of the State National Nature Park "Burabay" are considered, in particular, the researchers identified such forms as epiphytic, epigeic and epilithic forms, which is fully consistent with the results obtained by the authors of this article.

The influence of the environment, in particular, pollutants in the atmospheric air, on the composition of the lichen flora of the State National Nature Park "Burabay" is described in the work of Bukabaeva & Abiyev (2020). The authors of the article noted that lichens *Cladonia* and *Parmelia* are very sensitive to the presence of pollutants in the environment, so they can serve as a reliable bioindicator. The State National Nature Park "Burabay" is a recreational area, therefore it is subject to anthropogenic impact and technogenic load. As a result, changes occur in abiotic natural factors, and lichens are the first to react to such changes.

Lichens are especially sensitive to the content of sulphur dioxide (SO_2), nitrogen oxide (NO_2), fluorine compounds and heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), zinc (Zn) in the atmospheric air. It is possible that the decrease in the abundance of the species *Cladonia coccifera* in the territory of the State National Nature Park "Burabay", revealed in the course of these studies to be at the level of Unicum on the Drude scale is associated with a deterioration in the state of the environment, namely air pollution, which corresponds to the conclusions of Sinigla et al. (2021), who described the properties of lichens of *Cladonia*, which are quite rare in the natural conditions of the Bakony mountain range and the Balaton Upland. Similar results when *C. coccifera* was categorized as Unicum were obtained in this study. The authors of the article came to the conclusion that the lichens of this family are very sensitive to changes in habitat conditions, which once again proves the possibility of their use for bioindication of the natural environment.

The article by Manzitto-Tripp et al. (2022) is devoted to the problem of lichen diversity. The authors analyse the factors of ecological distribution of lichen biodiversity based on the results obtained in the study of lichen populations in North America. At the same time, the authors concluded that most lichens are rare, this situation is associated with species that are photobionts (usually belonging to the group of green algae: *Trentepohlia* or *Trebouxia*), which are part of a symbiotic organism. In addition, the distribution of lichens is limited by the fact that in some cases only mycobionts reproduce.

The observed shifts in lichen communities in "Burabay" due to aridification mirror global patterns, indicating a widespread ecological response to climate change. Allen & Lendemer (2016) emphasized the vulnerability of high-elevation lichens to climate change, highlighting a trend also observed in our study, where rare lichen species exhibit significant sensitivity to changing moisture regimes. Similarly, Brunialti et al. (2021) and Fazan et al. (2022) explored the reproductive strategies of epiphytic lichens, providing a context for understanding how aridification might affect lichen reproduction and, consequently, their long-term survival and distribution. Honegger (2022) and Khastini et al. (2019) provided foundational knowledge on lichen biology and ecology, reinforcing the importance of studying lichen as indicators of environmental health. Our findings align with their observations, underscoring the utility of lichens in monitoring ecosystem changes due to climate aridification.

Research by Langbehn et al. (2021), Mallen-Cooper et al. (2022), and Lõhmus et al. (2023) further supports our results, showing how natural disturbance and climate change can significantly alter lichen communities. These studies, along with ours, suggest a global trend of shifting lichen populations in response to climate change, emphasizing the need for targeted conservation efforts. Ristic et al. (2021) and Manzitto-Tripp et al. (2022) discussed the rarity of lichens and their role as bioindicators, resonating with our observation of rare species' decline in "Burabay." This parallel underscores the global nature of the challenge faced by lichen conservationists. Sinigla et al. (2021) and Steinová et al. (2022) provided insights into the distribution and habitat preferences of lichens, which, when compared with our findings, suggest that aridification could lead to habitat fragmentation and loss for many lichen species.

Innovative modeling studies by Meyer et al. (2023) and Nikolić et al. (2024) present methodologies for predicting climate change impacts on lichens, offering a framework for future research in "Burabay" and beyond. Ås Hovind et al. (2020) and Di Nuzzo et al. (2022) explored life-stage dependent responses to climate, which could inform management strategies for preserving lichen diversity in changing climates. Studies by Munzi et al. (2019) and Yang et al. (2023) on the physiological responses of lichens to drying periods provide a mechanistic understanding of how aridification affects lichen biology, complementing our observations of community-level changes.

Overall, the congruence between our findings and the broader literature highlights the global significance of aridification impacts on lichen communities. It underscores the urgency of developing adaptive conservation strategies to mitigate climate change effects on these sensitive and ecologically important organisms.

Conclusion

As a result of the research, it was possible to collect and systematize information on rare species of lichens, as well as species in need of protection, on the territory of the State National Nature Park "Burabay", as well as the territories adjacent to it, located in the Akmola region of the Republic of Kazakhstan. Of the 56 species identified during the study, 3 species represented by ecological groups of epilithic and epiphytic organisms are classified as very rare species. Four species assigned to the ecological groups of epigeic and epilithic organisms are species subject to protection. It should be noted that rare and protected species were found only within four of the eleven sites in which the study was conducted. The distribution of lichens depends on the structural features of their thallus and the properties of the substrate. This information is of particular interest given the fact that for forty years since the publication of the Red Book of the Republic of Kazakhstan in 1982, there has been no reliable information on the populations of such lichen species as: *Dermatocarpon miniatum*, *Peltigera spuria*, *Psora lurida*, *Cladonia coccifera*, *Verrucaria nigrescens*, *Haematomma ventosum*, *Caloplaca aurantiaca*. The findings also indicate that aridification, characterized by increased temperatures and reduced precipitation, is altering the composition and distribution of lichen species within the park. Moisture-dependent species are experiencing a decline, while those adapted to drier conditions are expanding their presence. These shifts highlight the sensitivity of lichens to climate change and underscore the importance of implementing conservation strategies that account for the anticipated impacts of aridification. By focusing on the adaptability and resilience of lichen communities, we can better prepare for and mitigate the ecological consequences of a warming and drying climate. This study not only enriches our ecological knowledge but also serves as a crucial step towards the sustainable management and preservation of lichen biodiversity in the face of global climate change.

The data from the study in Burabay Nature Park, which serves both conservation and recreational purposes, suggest that lichen populations can serve as indicators of ecological health due to their sensitivity to environmental changes. This approach, known as lichen indication, is cost-effective and can complement or even replace traditional environmental monitoring methods. Future research could focus on developing lichen indication to minimize anthropogenic impacts on Burabay's flora and fauna.

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