Online Journal of Biological Sciences

Research Article

Species Diversity of Lichens in the Burabay State National Park, Kazakhstan

Aizhan Baubekova[1], Zhanilxan Bukabayeva[2], Assemgul Sarsenova[3], Talshen Darbayeva[3], Alexander Korolev[4], Nurziya Karipbayeva[5] and Ukibayeva Lazzat[1]

[1]*M.Kh.Dulaty Taraz Regional University, Kazakhstan*
[2]*Alikhan Bokeikhan University, Semey, Kazakhstan*
[3]*Makhambet Utemisov West Kazakhstan University, Oral, Kazakhstan*
[4]*Omsk State Agrarian University named after P.A. Stolypin, Omsk, Russia*
[5]*Almaty humanitarian-economic university, Almaty, Kazakhstan*

Article history
Received: 23-09-2024
Revised: 20-01-2025
Accepted: 27-01-2025

Corresponding Author:
Zhanilxan Bukabayeva
Alikhan Bokeikhan University,
Nur-Sultan, Kazakhstan
Email: zhanylxan79@mail.ru

Abstract: Lichens constitute essential components of terrestrial ecosystems, and comprehensive documentation of lichen diversity is fundamental for conservation and ecosystem management. This study investigated the species composition and ecological distribution of lichens in Burabay State National Nature Park, northern Kazakhstan. Established in 2000, the park encompasses over 100,000 hectares representing a unique forest-steppe ecotone surrounded by extensive steppe landscapes, supporting approximately 700 vascular plant species and diverse recreational facilities. During 2018-2019, intensive surveys were conducted at 11 representative sites throughout the park. A total of 44 lichen species belonging to 19 genera and 9 families were identified. The families Parmeliaceae (14 species, 31.8%) and Cladoniaceae (13 species, 29.5%) exhibited the highest species richness, while Dermatocarpaceae, Verrucariaceae, and Lecanoraceae were each represented by single species. Ecological substrate analysis revealed nine distinct groups, with epiphytic lichens comprising the dominant ecological guild. These findings establish a baseline inventory of lichen diversity in Burabay National Park, contributing to the broader understanding of lichen biogeography in Central Asian forest-steppe ecosystems. The documented species assemblage provides essential data for monitoring ecosystem health and informing conservation strategies in this protected area of Kazakhstan.

Keywords: Lichen Diversity, Burabay National Park, Kazakhstan, Parmeliaceae, Cladoniaceae, Epiphytic Lichens, Forest-Steppe, Biodiversity Inventory

Introduction

Lichens have been used in traditional foods and medicines for millennia and are crucial for ecosystem function and human well -bei (Kumar et al., 2024).

Amid ongoing environmental changes, protected natural areas are gaining increasing significance for the preservation and maintenance of key natural landscapes, vegetation types, and overall biodiversity (Kumar et al., 2016; Berteaux et al., 2018; Aldibekova et al., 2023). Lichens play a vital role in boreal ecosystems and are highly sensitive to environmental conditions.

Lichens are the symbiotic outcomes of open, interspecies relationships, central to which are afungus and a phototroph, typically an alga and/or cyanobacterium. The evolutionary processesthat led to the global success of lichens are poorly understood. Lichen fungal symbionts count among the onlyfilamentous fungi that expose most of their mycelium to an aerial environment (Spribille et al., 2022).

The presence of certain types of substrates in plant communities, a combination of environmental factors, and the recency of disturbance are crucial for the survival of this group of organisms (Lücking et al., 2021). Under certain environmental conditions, the diversity and biomass of lichens increase; therefore, they can be used as indicators of the degree of ecosystem transformation

SCIENCE Publications

© 2025 Aizhan Baubekova, Zhanilxan Bukabayeva, Assemgul Sarsenova, Talshen Darbayeva, Alexander Korolev, Nurziya Karipbayeva, Ukibayeva Lazzat. This open-access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license

(Miranda-González and McCune, 2020).

Lichenological research in specially protected environmental areas traditionally causes considerable interest among specialists, owing to the high degree of preservation of natural communities and their critical role in sustaining a rich assemblage of species, including rare and protected taxa. (Palmroos et al., 2023). Lichen species diversity represents an effective metric for monitoring the ecological status of protected areas (Frati and Brunialti, 2023), can be utilized to evaluate the extent of dynamic processes driven by both global and regional factors.

The restoration of vegetation is concentrated in the urban core area and mountainous area, while the degradation of vegetation is mainly concentrated in the suburbs. In recent years, the vegetation in most mountainous areas has changed from restoration to significant restoration, indicating that the growth of mountain vegetation has continued to restore (Niepsch et al., 2023; Yerezhepova et al., 2024), as well as to forecast ecosystem conditions and formulate effective conservation measures (Grimm et al., 2021; Li et al., 2020).

In Kazakhstan, lichen research has been conducted irregularly, mainly by florists and geobotanists. The lack of information on species composition hinders their conservation and rational use as a significant component of ecosystems. Within the territory of Kazakhstan, 29 geobotanical zones have been identified, encompassing several floristic regions. One of these zones is the Burabay State National Nature Park. It holds the status of a conservation and scientific institution and is included in the system of specially protected natural areas of national significance, established to protect biological and landscape diversity. (Nurkassimova et al., 2024; Khussainov et al., 2024).

The region's climate is characterized by sharply continental features: hot summers and harsh, low-snow winters, mitigated by the influence of hills, water bodies, and forested areas. From a geomorphological perspective, the territory represents the highest part of the northern edge of the Central Kazakh Upland.

The mountainous relief is most pronounced in the western part, where the Kokshetau mountain range lies between lakes, with its highest point located in the northern section of the range Mount Kokshetau reaches an absolute elevation of 1000 meters above sea level. To its south lie the Burabay and Zheke-Batyr mountains, with elevations of 700 and 827 meters, respectively. In the southern part of the range, mountain heights gradually decrease to 500 meters. Within the territory of Burabay National Park, there are several large lakes, including Borovoe, Shuchye, Maloe and Bolshoi Chebachye, Maybalyk, and Katarkol. Studying and preserving biodiversity is one of the foremost challenges of our time. Lichens, which are symbiotic organisms consisting of a fungus and an alga, are unique components of the surrounding world and ecosystems. Conservation and sustainable use of lichens, as a vital part of ecosystems, are impossible without understanding their species composition (Bukabayeva et al., 2024).

The purpose of the present work was to conduct a complete survey of the lichen flora of the environs of the Burabay State National Nature Park and to establish the taxonomic affiliation of species.

Materials and Methods

The material collection was conducted in the spring, summer, and autumn of 2019 in the natural plant communities of the Burabay State National Natural Park, using the route reconnaissance survey. The study area was divided into plots, where all potential lichen habitats were examined: tree bark, soil, rocky areas, and other substrates.

The study was aimed at examining the species diversity and distribution of lichens in different plant communities of the Burabay State National Natural Park.

The occurrence of epiphleoid lichens was recorded at the following sampling plots.

The collected material was labeled and prepared to be stored in a herbarium. Herbarium material was identified using a comparative morphological method and several field guides. The nomenclature of taxa is given according to the latest reports from Austria (Atni et al., 2024), Norway and Sweden (Simon et al., 2020), Canada and the USA, and in case of cetrarioid lichens, according to T. Randlane and A. Saag. The vegetation survey was carried out according to the methods adopted in phytocenology and widely used in geobotanical research. The collected material was deposited in the herbarium of the Department of General Biology and Genomics of the Faculty of Natural Sciences of the Eurasian National University named after L.N. Gumilev.

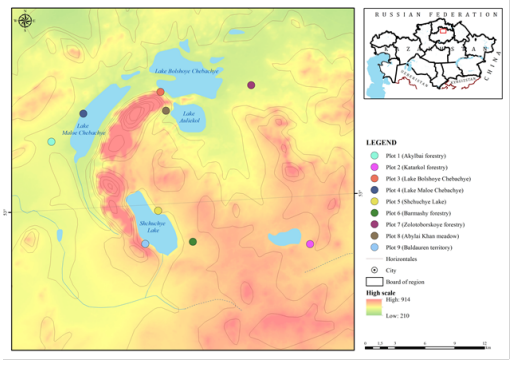

Fig. 1: Study area of the Burabay National Park

To achieve the set goals, the following methods were used: Route method researchers moved across park areas, recording the occurrence of lichens. Plot method the park area was divided into 11 sections, and a detailed inventory of lichens was conducted at each site. Collection and herbarium preparation: collected lichen samples were carefully labeled and placed in the herbarium for further study. Comparative-morphological method lichen species identification was carried out by comparing their morphological traits with descriptions in field guides. Use of field guides modern lichen identification guides from various regions of the world were used for accurate species identification.

Results and Discussion

The conducted study of the lichen biota of the Burabay National Park revealed 44 lichen species belonging to 9 families (Peltigeraceae (3 species), Teloschistaceae (3), Lecideaceae (3), Physciaceae (5), Parmeliaceae (14), Cladoniaceae (13), and the families Dermatocarpaceae, Verrucariaceae, Lecanoraceae, each represented by one species) and 19 genera.

The dominance of epiphytic forms (14 species) and the combination of elements from arid and boreal lichen floras indicate the specific growing conditions for lichens in this region. Of the 44 lichen species, 11 species belong to the crustose life form, 17 to the foliose, and 16 to the fruticose. This distribution of life forms is due to the location of the study area in a temperate humid forest-steppe zone.

The discovery of the rare species *Cladonia rangiferina* highlights the need for further research and the protection of the park's unique lichen flora. The material collection was conducted in the spring, summer, and autumn. The results of the study are presented in Table 1.

The presented results are based on the system given in the 10th edition of the Dictionary of the Fungi (Anisworth et..., 2008). The nomenclature of taxa is given according to Index Fungorum. In the new version of the system, lichens and closely related fungi are assigned to five classes of Ascomycota and one class of Basidiomycota. All identified lichens belong to the class of *Ascolichenes* and two subclasses (*Pyrenocarpeae, Gymnocarpeae*); they can be presented in the following taxonomic order:

Kingdom true fungi (Mycota, Mycetalia)
Sub-kingdom – higher fungi (Dikarya)
Phylum Ascomycota (Berk.) Caval.Sm (2009)
Subdivision Pezizomycotina O.E. Erikss. & Winka, Myconet 1: 9 (1997)
Class Ascolichenes
Sub-class Pyrenocarpeae
Order Pyrenocarpales
Family Verrucariaceae; genus *Verrucaria*
Family Dermatocarpaceae*;* genus *Dermatocarpon*
Sub-class Gymnocarpeae
Order Cyclocarpales
Family Peltigeraceae; genus *Peltigera*
Family Lecideaceae*;* genera: Lecidea*; Psora; Rhizocarpon*
Family Cladoniaceae; genera: *Cladonia; Thamnolia*
Family Lecanoraceae*;* genus *Haematomma*
Family Parmeliaceae*; genera*: *Parmelia; Parmeliopsis; Cetraria; Hypogymnia; Evernia*
Family Teloschistaceae; genera: *Caloplaca; Xanthoria.*
Family Physciaceae*;* genera: *Gasparrinia; Gyrophora; Physcia*

The average number of genera in a family was 2.11. The family Parmeliaceae had the largest number of genera (six genera) followed by Lecideaceae and Physciaceae with three genera each. The family Teloschistaceae was represented by two genera. There were five families represented by one genus each (Cladoniaceae, Dermatocarpaceae, Lecanoraceae, Peltigeraceae, Verrucariaceae). The high position in the flora of the family Parmeliaceae brings it closer to the boreal flora of the Holarctic (Hurtado et al., 2019).

Specific features include the presence of the family Verrucariaceae*,* which is characteristic of the arid flora of the Holarctic. Thus, the floristic spectrum of lichens of the studied region combines features characteristic of arid and boreal flora of the Holarctic, which indicates the heterogeneity of the lichen flora of the region to a certain extent corresponding to its geographical location. Based on the relative role in the flora of the leading families and genera, the territory of the Burabay National Park can be characterized as boreal with pronounced arid features.

The average number of species in the genus was 2.32. Two genera with 19 species (43.2% of the total number) stand out. These are *Cladonia* (13 species) and *Parmellia* (6 species). The family Parmeliaceae with 14 species (31.8%) was the most species rich. In second place was the family Cladoniaceae with 13 species (29.5% of the total number of species). The family Physciaceae was represented by five species (11.4%), and the families Lecideaceae, Peltigeraceae and Teloschistaceae, by three species each (6.8%). The remaining families were represented by one species each, they accounted for 6.8% of all species identified.

Despite that most researchers in relation to the substrate distinguish four main groups of lichens (epiphytic, epilyte, epigee, epixyl), in relation to other habitat conditions (soil specificity, waterlogging, biological residues, etc.), it is possible to expand this classification by distinguishing the following ecological-substrate groups (Oxner, 1974; Plant life., 1977; Rocha et al., 2022).

Table 1: Species composition of lichens of the Burabay National Park

Genus	Species	Life form	Substrate
Family Dermatocarpaceae			
1.Dermatocarpon	Dermatocarpon aquaticum (Weiss.) Zahlbr.	crustose	rocks submerged in water
Family Verrucariaceae			
2. Verrucaria	Verrucaria nigrescens (Ach.) Pers.	crustose	rocks
Family Peltigeraceae			
3. Peltigera	Peltigera spuria (Ach.) DC.	foliose	soil
	Peltigera canina (L.) Willd.	foliose	soil/stumps
	Peltiqera rufescens (Weis.) Humb.	crustose	rocks
Family Lecideaceae			
4. Psora	Hypocenomyce scalaris (Ach. ex Lilj.) M. Choisy (Psora ostreata)	crustose	bark/rocks
5. Rhizocarpon	Rhizocarpon geographicum (L.) DC.	crustose	rocks
6. Lecidea	Lecidea glomerulosa Steud.	crustose	bark
Family Cladoniaceae			
7. Cladonia	Cladonia fimbriata (L.) Fr.	fruticose	mossy stumps
	Cladonia gracilis (L.) Willd.	fruticose	soil
	Cladonia sylvatica (L.) Hoffm.	fruticose	soil
	Cladonia rangiferina (L.)	fruticose	stumps/soil
	Cladonia coccifera (L.) Willd.	fruticose	soil
	Cladonia alpicola (Flot.) Vain.	fruticose	soil
	Cladonia verticillata (Hoffm.) Schaer.	fruticose	sandy soil
	Cladonia deformis (L.)	fruticose	forest floor / stumps
	Cladonia crispate (Ach.) Flot.	fruticose	mossy stumps
	Cladonia cornuta (L.) Hoffm.	fruticose	mossy stumps
	Cladonia tenuis (F I k.) Harm.	fruticose	soil/stumps
	Cladonia coniocraea (Flk.) Spreng.	fruticose	tree trunk
	Cladonia alpestris (L.) Rabenh.	fruticose	sandy soil
Family Lecanoraceae			
8. Haematomma	Haematomma ventosum (L.)		limestone
Family Parmeliaceae			
9. Parmellia	Parmelia vegans Nyl.	foliose	soil
	Parmelia sulcata Taylor	foliose	tree trunk
	Parmelia caperata (L.) Ach.	foliose	bark
	Parmelia acetabulum (Neck.) Duby.	foliose	bark
	Parmelia saxatilis Linds.	crustose	rocks
	Parmelia olivacea (L.) Ach.	crustose	rocks
10. Hypogymnia	Hypogymnia physodes (L.) Nyl.	foliose	bark
11. Evernia	Evernia prunastri (L.) Ach.	fruticose	bark
	Evernia thamnodes (Flot.) Arnold. (син.: *Letharia thamnodes* (Flot.) Arnold.)	fruticose	bark
12. Xanthoparmelia	Xanthoparmelia conspersa (Ehrh.) Ach.	foliose	rocks
13. Parmeliopsis	Parmeliopsis hyperopta (Ach.) Vain.	foliose	bark
	Parmeliopsis pallescens (Hoffm.) Hillm.	foliose	bark
14. Cetraria	Cetraria glauca (L.) Ach.	foliose	bark
	Cetraria pinastri (Scop) S.F. Gray.	foliose	bark
Family Teloschistaceae			
15. Caloplaca	Caloplaca murorum (Hoffm.) Th. Fr.	crustose	rocks
	Caloplaca aurantiaca (Lightf.) Th. Fr.	crustose	bark
16. Xantoria	Xantoria candelaria (L.) Th. Fr.	foliose	bark
Family Physciaceae			
17. Physcia	Physcia aipolia (Ehrh.) Furnr.	foliose	bark
	Physcia stellaris (L.) Nyl.	foliose	bark
18. Gasparrinia	Gasparrinia elegans (Link.) Stein	crustose	rocks
19. Gyrophora	Gyrophora murina (Ach.)	foliose	rocks
	Gyrophora polyphylla (L.) Funck.	foliose	rocks

1) Epilithic (stones, rocks)
2) Epiphytic (bark of trunks of woody plants and shrubs)
3) Epigee (soil, soil sediments)
4) Epigee-epilyte (sandstones, poor soils)
5) Epigee-calciophilic (on limestone)
6) Eurysubstrate (on two or more substrates)
7) Epiphytic-epixyl (on rotting wood, wet mossy soil)
8) Epibriophy (on mosses)
9) Epilichenophylic (on other lichens)
10) Epixyl (barkless trunks)
11) Epiphytic-relicvitic (on dead moss, forest residues)
12) Amfibic (on other substrates or substrates submerged in water)

Accordingly, nine ecological-substrate groups of lichens can be distinguished in the lichen flora of the vicinity of the Burabay National Park.

In relation to the substrate, the species diversity of lichens decreases in the following order: on soil > on bark > on stone. Thus, lichens from the epiphytic and epigeic groups dominate the studied area, making up about 60% of the total and totaling 26 species.

The biomorphological structure of lichens is the result of long-term evolutionary changes in the process of adaptation to environmental conditions. In continental, arid, arctic, and highland regions, crustose lichens predominate; in humid temperate and tropical climates, lichens are mostly foliose; more northern and mesic landscapes are characterized by the dominance of fruticose lichens. Of the 44 species of lichens identified in the Burabay National Park, 11 species belong to crustose, 17, to foliose, and 16, to fruticose lichens. This distribution of life forms is most likely due to the location of the study area in the temperate, moderately humid forest-steppe zone.

One species, *Cladonia rangiferina* (L.), is listed in the (Allen and Lendemer, 2022; Liu et al., 2020; Gheza et al., 2020).

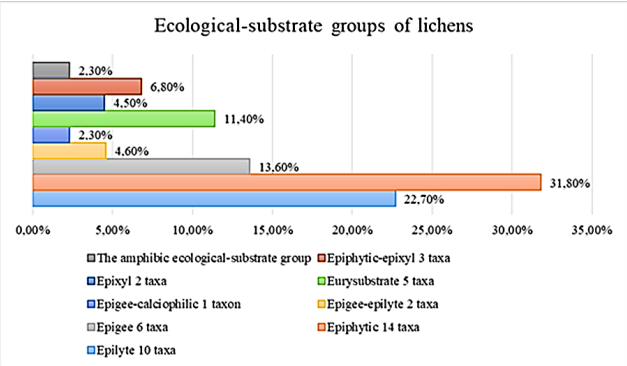

Fig. 2: Lichen flora of the vicinity of the Burabay National Park

Conclusion

In 2018-2019, a comprehensive study conducted in the vicinity of Burabay National Park, Kazakhstan, led to the identification of 44 species of lichens, representing 9 families and 19 genera. The taxonomic composition of the lichen biota was as follows: Peltigeraceae (3 species), Teloschistaceae (3), Lecideaceae (3), Physciaceae (5), Parmeliaceae (14), and Cladoniaceae (13). Additionally, the families Dermatocarpaceae, Verrucariaceae, and Lecanoraceae were each represented by a single species.

The distribution of these families within the lichen flora of the region suggests a unique combination of ecological features characteristic of both arid and boreal lichen floras found in the Holarctic region. Epiphytes represented the largest group in terms of species diversity, with 14 species identified. Among the 44 lichen species, 11 were crustose, 17 were foliose, and 16 were fruticose. This distribution of life forms is closely linked to the region's location in the temperate, moderately humid forest-steppe zone, where varying microhabitats support a wide range of lichen forms. Importantly, one species, *Cladonia rangiferina* (L.), is listed in the Red Book of Kazakhstan, emphasizing its vulnerable status and the need for conservation efforts to protect this rare species in the region. This study highlights the ecological richness of the Burabay National Park area, demonstrating a diverse lichen community that reflects the complex interplay of climatic conditions, habitat diversity, and regional flora. The findings also underscore the importance of preserving the lichen species found in the park, particularly those with conservation significance.

Acknowledgment

Thank you to the publisher for their support in the publication of this research article. We are grateful for the resources and platform provided by the publisher, which have enabled us to share our findings with a wider audience. We appreciate the efforts of the editorial team in reviewing and editing our work, and we are thankful for the opportunity to contribute to the field of research through this publication.

Funding information

The authors have not received any financial support or funding to report.

Authors Contributions

All authors have equally contributed to this research.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

References

Aldibekova, A., Kurmanbayeva, M., Aksoy, A., Permitina, V., Dimeyeva, L., & Zverev, N. (2023). Anatomical Structure and Phytochemical Composition of a Rare Species Fraxinus sogdiana Bunge (Oleaceae) Growing in Different Soils in Kazakhstan. Diversity, 15(6), 769. https://doi.org/10.3390/d15060769

Allen, J. L., & Lendemer, J. C. (2022). A call to reconceptualize lichen symbioses. Trends in Ecology & Evolution, 37(7), 582–589. https://doi.org/10.1016/j.tree.2022.03.004

Atni, O. K., Munir, E., Siregar, E. S., & Saleh, M. N. (2024). Lichen Diversity and Taxonomy in Bukit Barisan Grand Forest Park, North Sumatra, Indonesia. Biodiversitas Journal of Biological Diversity, 25(4), 1623–1630. https://doi.org/10.13057/biodiv/d250431

Berteaux, D., Ricard, M., St-Laurent, M.-H., Casajus, N., Périé, C., Beauregard, F., & de Blois, S. (2018). Northern protected areas will become important refuges for biodiversity tracking suitable climates. Scientific Reports, 8, 23050. https://doi.org/10.1038/s41598-018-23050-w

Bukabayeva, Z., Abiyev, S., Silybayeva, B., & Ivachshenko, O. (2024). The impact of climate aridification on rare lichen communities. Biosystems Diversity, 32(1), 142–149. https://doi.org/10.15421/012414

Frati, L., & Brunialti, G. (2023). Recent Trends and Future Challenges for Lichen Biomonitoring in Forests. Forests, 14(3), 647. https://doi.org/10.3390/f14030647

Gheza, G., Assini, S., Lelli, C., Marini, L., Mayrhofer, H., & Nascimbene, J. (2020). Biodiversity and conservation of terricolous lichens and bryophytes in continental lowlands of northern Italy: the role of different dry habitat types. Biodiversity and Conservation, 29(13), 3533–3550. https://doi.org/10.1007/s10531-020-02034-1

Grimm, M., Grube, M., Schiefelbein, U., Zühlke, D., Bernhardt, J., & Riedel, K. (2021). The Lichens' Microbiota, Still a Mystery? Frontiers in Microbiology, 12. https://doi.org/10.3389/fmicb.2021.623839

Hurtado, P., Prieto, M., Aragón, G., Escudero, A., & Martínez, I. (2019). Critical predictors of functional, phylogenetic and taxonomic diversity are geographically structured in lichen epiphytic communities. Journal of Ecology, 107(5), 2303–2316. https://doi.org/10.1111/1365-2745.13189

Khussainov, A. T., Shulembayeva, K. M., Durmekbayeva, S. N., Fakhrudenova, I. B., Khussainova, R. K., & Kakabayev, A. A. (2024). The Vascular Plant Flora Burabay National Park, Kazakhstan: Composition, Life Form Classification and Ecological Groups. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 94(3), 553–561. https://doi.org/10.1007/s40011-024-01550-2

Kumar, N., Rawat, S., Nayaka, S., & Singh Adhikari, R. (2024). Lichens of Tehri Garhwal: Exploring Diversity, Distribution, and Ethnobotanical Significance in the Western-Himalayan Region. Ethnobotany Research and Applications, 27, 1–12. https://doi.org/10.32859/era.27.41.1-12

Kumar, V., Upreti, D. K., & Nayaka, S. (2024). Morpho-taxonomic Revision of the Lichen Genus Psora Hoffm. (Psoraceae, Lecanorales) from India. Biology Bulletin, 51(4), 954–958. https://doi.org/10.1134/s1062359023606146

Li, C., Tang, X., Zheng, X., Ge, S., Wen, H., Lin, X., Chen, Z., & Lu, L. (2020). Global Prevalence and Incidence Estimates of Oral Lichen Planus. JAMA Dermatology, 156(2), 172–181. https://doi.org/10.1001/jamadermatol.2019.3797

Liu, J., Hao, J., Liu, Y., & Lallas, A. (2020). Dermoscopic features of lichen sclerosus in Asian patients: a prospective study. Journal of the European Academy of Dermatology and Venereology, 34(11). https://doi.org/10.1111/jdv.16540

Lücking, R., Leavitt, S. D., & Hawksworth, D. L. (2021). Species in lichen-forming fungi: balancing between conceptual and practical considerations, and between phenotype and phylogenomics. Fungal Diversity, 109(1), 99–154. https://doi.org/10.1007/s13225-021-00477-7

Miranda-González, R., & McCune, B. (2020). The weight of the crust: Biomass of crustose lichens in tropical dry forest represents more than half of foliar biomass. Biotropica, 52(6), 1298–1308. https://doi.org/10.1111/btp.12837

Niepsch, D., Clarke, L. J., Newton, J., Tzoulas, K., & Cavan, G. (2023). High spatial resolution assessment of air quality in urban centres using lichen carbon, nitrogen and sulfur contents and stable-isotope-ratio signatures. Environmental Science and Pollution Research, 30(20), 58731–58754. https://doi.org/10.1007/s11356-023-26652-8

Nurkassimova, M., Omarova, N., Zinicovscaia, I., Yushin, N., & Chaligava, O. (2024). Mosses as bioindicators of air pollution with potentially toxic elements in the Burabay State National Natural Park, Kazakhstan. Environmental Monitoring and Assessment, 196(5), 442. https://doi.org/10.1007/s10661-024-12602-5

Palmroos, I., Norros, V., Keski-Saari, S., Mäyrä, J., Tanhuanpää, T., Kivinen, S., Pykälä, J., Kullberg, P., Kumpula, T., & Vihervaara, P. (2023). Remote sensing in mapping biodiversity–a case study of epiphytic lichen communities. Forest Ecology and Management, 538, 120993. https://doi.org/10.1016/j.foreco.2023.120993

Rocha, B., Matos, P., Giordani, P., Piret, L., Branquinho, C., Casanelles-Abella, J., Aleixo, C., Deguines, N., Hallikma, T., Laanisto, L., Moretti, M., Alós Ortí, M., Samson, R., Tryjanowski, P., & Pinho, P. (2022). Modelling the response of urban lichens to broad-scale changes in air pollution and climate. Environmental Pollution, 315, 120330. https://doi.org/10.1016/j.envpol.2022.120330

Simon, A., Lücking, R., Moncada, B., Mercado-Díaz, J. A., Bungartz, F., da Silva Cáceres, M. E., Gumboski, E. L., de Azevedo Martins, S. M., Spielmann, A., Parker, D., & Goffinet, B. (2020). Emmanuelia, a new genus of lobarioid lichen-forming fungi (Ascomycota: Peltigerales): phylogeny and synopsis of accepted species. Plant and Fungal Systematics, 65(1), 76–94. https://doi.org/10.35535/pfsyst-2020-0004

Spribille, T., Resl, P., Stanton, D. E., & Tagirdzhanova, G. (2022). Evolutionary biology of lichen symbioses. New Phytologist, 234(5), 1566–1582. https://doi.org/10.1111/nph.18048

Yerezhepova, N., Kurmanbayeva, M., Terletskaya, N., Zhumagul, M., Kebert, M., Rašeta, M., Gafforov, Y., Jalmakhanbetova, R., & Razhanov, M. (2024). New Data on Phytochemical and Morphophysiological Characteristics of Platycladus orientalis L. Franco and Thuja occidentalis L. Conifer Trees in Polluted Urban Areas of Kazakhstan. Forests, 15(5), 790. https://doi.org/10.3390/f15050790