ISSN 2079-0961, Arid Ecosystems, 2015, Vol. 5, No. 3, pp. 169–175. © Pleiades Publishing, Ltd., 2015.
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APPLIED PROBLEMS OF ARID LANDS DEVELOPMENT

Contribution of Lichens in the Formation of Biological Soil Crusts in the Steppes of the Khangai Upland (Mongolia)

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Received February 24, 2015

Abstract—Biological soil crusts in the biogeocenoses of the dry steppes of the Khangai upland are formed by combinations of complexes of terricolous lichen synusiums composed of different lichen species and life forms. Lichens of seven life forms are represented in the studied lichen synusiums. The synusium of *Xanthoparmelia camtschadalis* vagrant lichen occurs most often in the studied biogeocenoses.

Keywords: biological soil crusts, lichens, biogeocenosis, structure, synusium, dry steppes, Mongolia

DOI: 10.1134/S2079096115030038

INTRODUCTION

In hot and cold deserts and steppes, where the surface is slightly covered by vascular plants, organisms of different taxonomic groups—cyanobacteria, algae, lichens, mosses, microscopic fungi, and bacteria—are often seen between higher plants. These organisms and other biota representatives form biological soil crusts (BSC) as a result of their interaction with ground particles of the surface soil layer several millimeters thick. The extracellular polysaccharides released by cyanobacteria, algae, and fungi hyphae adhere to the smallest soil particles and facilitate the attachment of lichens and mosses to the substrate (*Biological…,* 2003). They occur in almost all of the biomes of the Earth in which the competition of the vascular plants is low. Crusts formed by cyanobacteria are usually allocated to infertile sand soils, while the lichen proportion rises on substrates with carbonates and clay particles (Evans and Johansen, 1999). Most lichen species are adapted for long droughts, which enables them to inhabit cold and hot deserts and semiarid areas of plain and mountain steppes (Biazrov et al., 1989; *Lichen*…, 2004). Here, they form lichen synusiums, which are combinations of lichen groups within particular spatially isolated plant communities developed under uniform environmental conditions; lichens in the synusium are similar in species composition and life forms (Biazrov, 1990). Some well-known researchers point out that BSCs are formed by representatives of various taxonomic groups of macroscopic and microscopic organisms, which may be autotrophic or heterotrophic (Evans and Johansen, 1999; *Biological*…, 2003). This concept of BSC is similar to our understanding of lichen synusium as a biogeocenotic synusium of the level of endostratosynusium (Biazrov, 1975). This signifies that the groups specified with respect to specific features of a combination of lichen species and life forms include invertebrates, microorganisms, ground, and air. Therefore, a synusium of terricolous lichens may be considered an integrated part of a BSC community.

The vegetation in arid regions of Eurasia is actively investigated by Russian scientists (Abaturov and Nukhimovskaya, 2013; Bananova and Lazareva, 2014; Novikova et al., 2010; Tulokhonov et al., 2014), but BSCs very rarely become research objects. When part of Central Asia was within the former Soviet Union, the role of cyanobacteria, algae, and lichens in the formation of desert biogeocenoses was studied there (Dzhuraeva, 1980; Novichkova-Ivanova, 1980). Thus, the aim of this issue is to reveal the role of lichen synusiums in BSC formation on the example of some steppe biogeocenoses of the Khangai upland (Mongolia).

REGION AND OBJECTS OF STUDY

The study was performed on the Eastern Khangai upland (the Arakhangaiskii aimak, the Tevshrulekh somon). It is located in the central part of the western Mongolia. The upland stretches from the west to the east, between 92° and 106° E; the extreme southern point is situated to the south of 46° N, and the extreme northern point is at some distance to the north of 50° N. The upland is in general a typical middle-mountain area represented by a combination of ridges (2000–3500 m above sea level) and mountain depressions of various widths at altitudes 1000 m above sea level or lower (*Geomorfologiya*…, 1982). The highest altitudes of the main ridge of the upland, representing a part of the continental watershed, are located in the Otgon-Khairkhan-nuru mountain group. The Otgon-Tenger mountain with an altitude of 3905 m above sea level is the highest summit. A deep snow layer is preserved on its slopes above an altitude of 3500 m for dozens of years.

The climate of the area is extremely continental, which is explained by the position of the upland in the center of an powerful Asian anticyclone. The range of mean air temperatures of January and July is 32–43°C. The difference between the day and night temperature is also great. In the system of natural zones, the Khangai upland is assigned to the zone of dry steppes between the isohyets 200 and 350 mm and the isotherms of January –20° and –25° and that of July 16 and 18°C (Beresneva, 2006). Permafrost is also an important ecological factor. These general parameters are transformed by the relief of the area, which determines the specific natural conditions of particular parts of the upland and the motley pattern of the soil and plant cover (Biazrov et al., 1989; Beresneva, 2006). Several types of vertical belt sequence are specified in different natural zones here. With respect to the combination of zonality and vertical belts, a botanical-geographical zoning of the upland was conducted (Karamysheva and Banzragch, 1977). The studied area is assigned to the Eastern-Khangai low-mountain–medium-mountain region of the Northern-Khangai subprovince of forest and steppe. This region is distinguished among the other five regions by its higher proportion of forests and fragmentary high-mountain belt. The steppe belt is predominated by forbs-grass and meadow steppes, particularly their petrophyte variants (Karamysheva and Banzragch, 1977). Grass communities (meadows and steppes) predominate, and lichens play a particular, sometimes significant, role in them (Biazrov, 1986; Biazrov, 1990).

The object of investigation is represented by terricolous lichens of (1) the dry steppe plant community or plain–low-mountain belt at altitudes of 1350–1550 m above sea level and (2) the steppe plant community (1550–1700 m). The mesoclimate of the first belt is warm, dry, and extremely continental with a cold, dry winter (air temperature is from –30 to –35°C) characterized by large daytime temperature variations and the predominance of fine weather and a warm (16–18°C), very dry, and long summer. The growing period lasts up to 165 days, and the annual precipitation is 275–300 mm (Beresneva, 1983). The mesoclimate of the second belt is moderately warm, dry, and continental; the air temperature is about –30°C in winter and about 16°C in summer. The growing period lasts about 140 days, and the annual precipitation is 340–360 mm (Beresneva, 1983). In the dry-steppe belt, we studied the plant community (1-a) of dry *Caragana* feather-grass–bunchgrass and bunchgrass–feather-grass steppes (*Caragana microphylla* Lam.[1], *C. stenophylla* Pojak., *Stipa krylovii* Roshev., *Cleistogenes squarrosa* (Trin.) Keng., *Agropyron cristatum* (L.) P.B., and *Cymbaria daurica* L.) on chestnut deep-calcareous and carbonateless sandy soils of the high plains and pediments (five 50 × 50 m test plots). The projective cover of the fanerogamic plants in these communities is 52–65%, and the true cover is about 36%. Three test plots 40 × 60 m were set in communities of the petrophyte-forbs–bunchgrass-fescue steppes of plot 1-b, (*Festuca lenensis* Drob., *Cleistogenes squarrosa*, *Poa attenuate* Trin., *Agropyron cristatum* (L.) P.B., *Carex duriuscula* C.A. Mey., *Potentilla acaulis* L., *P. sericea* L., *Veronica incana* L., *Thalictrum petaloideum* L., *Arctogeron gramineum* (L.) DC., and *Ptilotrichum canescens* (DC.) C.A. Mey.) on chestnut and dark chestnut carbonateless stony soils on gentle slopes of the southern exposition. The projective cover of fanerogamic plant in these communities is 42–57%, and the true cover is about 45%. In communities of the third plot (1-c) of dwarf-semishrub–petrophyte-forbs–fescue (*Festuca lenensis*, *Chamaerhodos altaica* (Laxm.) Bunge, *Ch. erecta* (L.) Bunge, *Androsace incana* Lam., *Arenaria capillaries* Poir., and *Thymus gobicus* Tschern.) steppes on chestnut carbonateless poorly formed stony soils on flat tops of hills and convex parts of southern slopes, four test plots 50 × 50 m were set. The projective cover of fanerogamic plants in these communities is 50–60%, and the true cover is about 50%.

In the steppe belt, we studied the plant communities of plot 2-a of forbs–bunchgrass–feather-grass steppes (*Stipa krylovii*, *S. baicalensis* Roshev., *Koeleria cristata* (L.) Pers., *Poa attenuate* Trin., *Agropyron cristatum* (L.) P.B., *Androsace incana* Lam., *Artemisia commutate* Bess., *A. frigid* Willd., *Bupleurum scorzonerifolium* Willd., and *Potentilla sericea* (L.)) on dark-chestnut farinaceous-calcareous light loamy stony soils of the southeastern slope of the local ridge (3 test plots 50 × 60 m). The projective cover of fanerogamic plant in these communities is 45–65%, and the true cover is about 30%.

DATA SAMPLING AND TREATMENT

In order to reveal the composition of terricolous lichens and the association between lichen species, 50–100 0.5 × 0.5 m pots were set in the areas of the communities. The frame used for the study had 5 × 5 cm cells (each corresponded to 1% of the soil surface). All of the lichen species and the projective cover of their blastema (%) were determined for each plot. The description of each test plot was taken as a characteristic of a particular lichen group representing a part of the lichen synusium. Data on all the test plots assigned to the particular synusium were used as the basis for calculation of its mean characteristics (the species composition, projective cover of each species, and others). After the identification of lichen species, all of the descriptions of the plots assigned to the investi-

[1] The names of vascular plants are given according to V.I. Grubov (1982), and the names of lichens are determined by The List of Lichen Flora of Russia (*Spisok*..., 2010)

Table 1. Soil cover (%) by lichens in terricolous lichen synusiums in *Caragana* feather-grass–bunchgrass and bunchgrass–feather-grass steppes on chestnut deep-calcareous sandy soils (1-a)

Lichen	Life form	Lichen synusium*				
		1	2	3	4	5
Xanthoparmelia camtschadalis (Ach.) Hale	Lsl	0.3–14.6	1.8–13.0	1.6–5.0	0.7	5.0
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	Sc	–	0.6–1.2	2.7	–	1.0
Toninia tristis ssp. *asiaecentralis* (H. Magn.) Timdal	Sq	–	–	1.0–1.8	5.0	–
Heppia lutosa (Ach.) Nyl.	Sq	–	–	0.3	–	–
Collema minor (Pakh.) Tomin ap. Shapheev	S1	–	–	1.0–0.3	–	0.7
Peltigera rufescens (Weiss) Humb. var. incusa	L1	–	–	–	–	0.7
Number of species	6	1	2	5	2	4

* (1) *Xanthoparmelia camtschadalis*, SLF is 100Lsl; (2) *Xanthoparmelia camtschadalis–Cladonia chlorophaea*, SLF is 50Lsl50Sc; (3) *Xanthoparmelia camtschadalis–Cladonia chlorophaea–Toninia tristis*, SLF is 20Lsl20Sc40Sq20Sl; (4) *Xanthoparmelia camtschadalis–Toninia tristis*, SLF is 50Lsl50Sq; (5) *Xanthoparmelia camtschadalis–Cladonia chlorophaea–Peltigera rufescens*, SLF is 25Lsl25Sc25Ll25Sl.

gated community were separated into groups with similar species composition and life forms of lichens, i.e., by the type of association of representatives of different species and life forms of lichens. The life forms were specified according to the system proposed for the lichens of Mongolia (Golubkova and Biazrov, 1989). The lichen species revealed on the soils in the studied steppe communities are assigned to life forms as follows: uniform-crustose (Cr), crustose squamous (Sq), foliose broad-bladed rhizoid (Ll), foliose divide-bladed rhizoid (Sl), plagio-orthotropic awl-shaped and scypha-like (Sc), fruticose erect (Fe), and free-living foliose divide-bladed (Lsl). To characterize each of the specified lichen synusium, we determined the spectrum of life forms (SLF) as the proportion (%) of species of each life form in relation to the total species number.

RESULTS

In the communities (1-a) of *Caragana* feather-grass–bunchgrass and bunchgrass–feather-grass dry steppes of the dry-steppe belt, 8–32% of the soil surface is covered by lichens. Five lichen synusiums are revealed here (Table 1). Among them, the synusium of *Xanthoparmelia camtschadalis* is the best developed. It is formed by only one species (gregation type of association, according to V.V. Petrovskii (1960)) represented by free-living lichen that are typical for arid regions of the northern hemisphere and are not fixed to the substrate (Biazrov, 2012). The occurrence of this single-species synusium in the studied area varies from 5 to 100%, and the mass reserve is 22 kg/ha. This is practically a single lichen synusium, which occurs in the majority of plots in this community. The remaining terricolous lichen synusiums were only revealed on some plots (the occurrence was 5–15%). It should be mentioned that *X. camtschadalis* participates in all of the lichen synusiums specified in this steppe community. Its development obviously undergoes an adverse effect from *Caragana*: its occurrence on the soil surface under *Caragana* crowns is 8–9% and rises to 44–45% between the bushes.

On plots of the petrophyte-forbs–bunchgrass–fescue community of the dry-steppe belt, the soil is about 12% covered by lichens, and six lichen synusiums are specified here (Table 2). The synusium formed by only one species—*Xanthoparmelia camtschadalis*—is also most widely represented here (its occurrence on the plots is 10–100%), and this species participates also in four synusiums.

The greatest diversity of terricolous lichen synusiums in communities of the dry-steppe belt—14 groups—is revealed on the plots of dwarf-semishrub–petrophyte-forbs–fescue steppes (Table 3), though the total soil coverage by lichens here is only about 5%. The synusium of *Xanthoparmelia camtschadalis* is also best developed here (the occurrence on the plots is 5–100%). Nevertheless, contrary to the aforementioned communities of the belt, this species participates only in three lichen groups.

On the plots of the forbs–bunchgrass–*Stipa krylovii* steppe with *Stipa baicalensis* of the steppe belt, terricolous lichens occur more rarely as compared to the dry-steppe belt. Their total occurrence is 53%, and the projective soil cover is about 5%. Five lichen synu-

Table 2. Soil cover (%) by lichens in terricolous lichen synusiums in petrophyte-forbs–bunchgrass–fescue steppes on chestnut and dark-chestnut carbonateless stony soils (1-b)

Lichen	Life form	Lichen synusium*					
		1	2	3	4	5	6
Xanthoparmelia camtschadalis	Lsl	1.0	0.5	1.0	0.3	1.2	–
Cladonia chlorophaea	Sc	–	0.3	–	0.5	–	0.5
Collema minor	S1	–	–	0.3	–	–	–
Toninia tristis ssp. *asiaecentralis*	Sq	–	–	–	1.5	1.2	–
Psora globifera (Ach.) Massal.	Sq	–	–	–	0.5	0.2	–
Number of species	5	1	2	2	4	3	1

* (1) *Xanthoparmelia camtschadalis*, SLF is 100Lsl; (2) *Xanthoparmelia camtschadalis–Cladonia chlorophaea*, SLF is 50Lsl50Sc; (3) *Xanthoparmelia camtschadalis–Collema minor*, SLF is 50Lsl50Sl; (4) *Xanthoparmelia camtschadalis–Cladonia chlorophaea–Toninia tristis*, SLF is 25Lsl25Sc50Sq; (5) *Xanthoparmelia camtschadalis–Toninia tristis*, SLF is 34Lsl66Sq; (6) *Cladonia chlorophaea*, SLF is 100Sc.

siums are revealed here (Table 4), and the synusium of *Xanthoparmelia camtschadalis* is also best developed (the occurrence is 40%). This species also participates in three synusiums with an occurrence of 1–5% on different plots.

DISCUSSION

The number of terricolous lichen synusiums in the composition of complexes in BSC in the investigated types of steppe biogeocenoses of the Eastern Khangai upland varies from 5 to 14. They are formed by representatives of seven lichen life forms and are predominated by chloro-lichens (symbiosis of fungus and green alga). Ciano-lichens (the symbiosis of fungi and cyanobacteria) such as *Collema minor*, *Heppia lutosa*, and *Peltigera rufescens* are also present. A lichen synusium of gregation association type (formed by one species) is the most pronounced in all of the communities. It is formed by *Xanthoparmelia camtschadalis*, a vagrant foliose lichen, the area of which stretches over arid and semiarid regions of the northern hemisphere. This species participates in most other specified lichen synusiums of various association types (a mixed-gregation type formed by species of various life forms and a congregation type formed by lichens of different layers). A synusium of aggregation type (represented by different species of one life form (Petrovskii, 1960)) is described only once (Table 3, syn. 14). Thalli of *Xanthoparmelia camtschadalis* may be practically always revealed on the soil surface among feather grass, fescue, sedge, thyme, and other vascular plants. They are not fixed to the substrate, and they are dry and able to be transported by wind. It should be mentioned that vagrant lichens are typical not only for the BSCs of the steppes of the Khangai upland but are also represented in BSCs in other regions. The species *Xanthoparmelia camtschadalis* forms BSCs in the Northern America prairie, together with other vagrant lichen species (*X. chlorochroa*, *X. lipochlorochroa*, *X. neochlorochroa*, and *X. vagans*) (Rosentreter, 1993). A similar role is played by the *Xanthoparmelia semiviridis* vagrant foliose lichen in the arid region of Australia (Rogers, 1971) and the *Xanthomaculina convolute* vagrant foliose lichen in the Namib Desert (Lange et al., 1994). Representatives of other life forms of different genera and species of lichens (*Candelariella*, *Catapyrenium*, *Cladonia*, *Collema*, *Endocarpon*, *Heppia*, *Peltigera rufescens*, *Physconia*, *Psora*, and *Toninia*) found in BSCs of the studied steppes of the Khangai upland are typical for BSCs of other arid regions (Belnap and Lange, 2003). The high taxonomic similarity between lichens in the BSCs of the Khangai steppes and other regions of the Earth is evidence of the fact that ecological conditions suitable for the activity of representatives of lichen taxa forming BSCs exist on various continents.

The presence of a combination of terricolous lichen synusiums in each of the studied steppe biogeocenosis shows that BSC is formed by a mosaic of microareas of different structure that are not interrelated. The mosaic pattern depends on the distribution of fanerogamic plants and specific features of the soil and microrelief. The highest mosaic rate of the BSC of the studied steppes is typical for stony soils (Table 3). Therefore, significantly more data on specific features of BSC spatial patterns in the biogeocenose areas should be obtained in order to reveal the parameters to characterize BSCs.

The structural and functional roles of BSCs in biogeocenoses are important. First, they develop in the space unoccupied by fanerogamic plants. As a result, the structure of the community becomes more complicated, and the solar energy and other resources are used more efficiently. Biological soil crusts protect soil from wind and water erosion and affect the water and temperature regimes of communities, seed germination, and plant fixation on the soil. The biota represen-

Table 3. Soil cover (%) by lichens in terricolous lichen synusiums in dwarf-semishrub–petrophyte-forbs–fescue steppes on chestnut carbonateless very stony soils (1-c)

Lichen	Life form	Lichen synusium*													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Xanthoparmelia camtschadalis	Lsl	0.4	0.3	–	–	–	–	–	–	–	–	0.1	0.2	–	–
Cladonia chlorophaea	Sc	–	0.8	–	–	0.5	0.4	–	0.5	–	–	0.1	–	–	–
Candelariella aurella (Hoffm.) Zahlbr.	Cr	–	–	0.1	–	–	–	–	–	–	–	–	–	–	–
Endocarpon subfoliaceum Tomin	Sq	–	–	0.1	–	–	–	–	–	–	–	–	–	–	–
Toninia tristis ssp. *asiaecentralis*	Sq	–	–	1.0	0.7	–	–	–	–	–	0.1	–	–	–	0.1
Physconia muscigena (Ach.) Poelt	S1	–	–	1.5	–	0.5	–	–	–	–	–	0.1	–	0.1	–
Stereocaulon glareosum (Savicz) H. Magn.	Fe	–	–	–	–	–	0.7	0.5	–	0.5	–	–	0.5	–	–
Peltigera leptoderma Nyl.	L1	–	–	–	–	–	–	–	–	1.5	–	–	–	–	–
Caloplaca sp.	Cr	–	–	–	–	–	–	–	–	–	0.1	0.1	–	–	–
Heppia lutosa	Sq	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–
Cladonia pocillum (Ach.) Grognot	Sc	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–
Catapyrenium rufescens (Ach.) Breuss	Sq	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1
Number of species	12	1	2	4	1	2	2	1	17	2	3	5	2	1	2

* (1) *Xanthoparmelia camtschadalis*, SLF is 100Lsl; (2) *Xanthoparmelia camtschadalis–Cladonia chlorophaea*, SLF is 50Lsl50Sc; (3) *Physconia muscigena–Toninia tristis–Candelariella aurella*, SLF is 25Sl0Sq25Cr; (4) *Toninia tristis*, SLF is 100Sq; (5) *Cladonia chlorophaea–Physconia muscigena*, SLF is 50Sc50Sl; (6) *Cladonia chlorophaea–Stereocaulon glareosum*, SLF is 50Sc50Fe; (7) *Stereocaulon glareosum*, SLF is 100Fe; (8) *Cladonia chlorophaea*, is 100Sc; (9) *Stereocaulon glareosum–Peltigera leptoderma*, SLF is 50Fe50Ll; (10) *Toninia tristis–Caloplaca* sp., SLF is 67Sq33Cr; (11) *Xanthoparmelia camtschadalis–Cladonia chlorophaea–Physconia muscigena–Caloplaca* sp., SLF is 20Lsl40Sc20Sl20Cr; (12) *Xanthoparmelia camtschadalis–Stereocaulon glareosum*, SLF is 50Lsl50Fe; (13) *Physconia muscigena*, SLF is 100Sl; (14) *Toninia tristis–Catapyrenium rufescens*, SLF is 100Sq.

Table 4. Soil cover (%) by lichens in terricolous lichen synusiums in forbs–bunchgrass– *Stipa krylovii* steppe with *S. baicalensis* on dark chestnut farinaceous-calcareous light-loamy stony soils

Lichen	Life form	Lichen synusium*				
		1	2	3	4	5
Xanthoparmelia camtschadalis	Lsl	2.5	1.0	0.7	0.3	–
Cladonia chlorophaea	Sc	–	0.5	–	–	–
Collema minor	S1	–	–	0.3	–	–
Heppia lutosa	Sq	–	–	–	0.5	0.2
Number of species	4	1	2	2	2	1

* (1) *Xanthoparmelia camtschadalis*, SLF is 100Lsl; (2) *Xanthoparmelia camtschadalis–Cladonia chlorophaea*, SLF is 50Lsl50Sc; (3) *Xanthoparmelia camtschadalis–Collema minor*, SLF is 50Lsl50Sl; (4) *Xanthoparmelia camtschadalis–Heppia lutosa*, SLF is 50Lsl50Sq; (5) *Heppia lutosa*, SLF is 100Sq.

tatives in BSCs produce the mass, which is supplied to biogeocenoses. Its volume depends on the development rate of organisms in particular habitats. In different grass biogeocenoses of the Khangai upland, the reserve of dry mass of *Xanthoparmelia camtschadalis* varied from 22 to 1010 kg (Biazrov, 1986). Some part of the initial production dies and is decomposed, enriching the soil with organic and mineral substances, which enter the biological turnover of the community. Cyanobacteria (for example, *Nostoc commune* Vauch., which is often revealed in the Mongolian steppes), cyano-lichens (*Collema*, *Heppia*, and *Peltigera*), and other organisms found in BSC are able to fix atmospheric nitrogen, and its compounds penetrate the soil. BSC producers provide the habitat and food for a number of invertebrate groups (Biazrov et al., 1976). This is proved by the fact that populations of microarthropods and nematodes in BSC areas are many times greater when compared to soil with a bare surface, all other conditions being equal (*Biological*..., 2003).

Lichen synusiums on the soil may be considered a stage of BSC development and an indicator of the community age. This complicated problem requires additional analysis. It may only indicate that the obtained data do not permit the conclusion that BSC development is a linear process, when simple groups of crustose lichens give way to communities of foliose and then fruticose lichens. The development of BSC is not a one-way process, and the formation of a more complicated structure is accompanied by its simplification. It may be assumed that the combination of lichen synusiums revealed in the community includes elements of the past and future BSC statuses. For example, the wide distribution of *Xanthoparmelia camtschadalis* vagrant species testifies to a long-term steppe stage in the landscape development, during which the plant cover was rather thin. This lichen synusium may be considered the climax. Dry and open habitats with sparse plant cover are also indicated by the presence of *Collema minor*, *Heppia lutosa*, and *Toninia tristis* ssp. *asiaecentralis*.

CONCLUSION

The data on the composition of terricolous lichen synusiums, which are considered structural parts of biogeocenoses, are valuable for the analysis of specific features of the formation and structure of BSCs in these biogeocenoses. Scientists who study arid communities should pay attention to biological soil crusts.

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Translated by I. Bel'chenko