Botany

Cryptogam Diversity Associated with Xerophilous Shrubs in Semiarid Habitats of Georgia, South Caucasus

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(Presented by Academy Member George Nakhutsrishvili)

Abstract. Shrubs of semi-arid vegetation, as reserves for biocrust-associated cryptogams, are extremely important in the restoration of biocrusts and, consequently, soil and herbaceous cover. The present study aimed at revealing diversity of cryptogams (bryophytes, lichens and macrofungi) in the semi-arid regions of Georgia, determine their affinity to micro-habitats of hemi-xerophilous shrublands, and examine participation of target organisms in biological soil crusts. We studied the diversity of bryophytes, lichens, and macrofungi in three main types of semi-arid shrubland of the southern slope of the Kvernaki Range and Iori Plateau and recorded cryptogams under ten individual shrubs within each community. In total, 20 bryophytes species, 23 lichens species and 15 macrofungial species occurring in shrub projections were found. *Paliurus spina-christi* microhabitat exhibited the highest species richness of terrestrial cryptogams, while *Spiraea hypericifolia* microhabitat had the poorest. Hemi-xerophilous shrubs influence both composition and spatial distribution of cryptogam communities, while the affinity between shrubs and cryptogam species was not clearly observable. © *2025 Bull. Georg. Natl. Acad. Sci.*

Keywords: cryptogam diversity, bryophytes, lichens, macro-fungi, biological soil crusts, semiarid, xerophilous shrubs

Introduction

Drylands cover ~41% of the Earth's surface and constitute one of the largest biomes on the planet (Delgado-Baquerizo et al., 2016; Ladrón de Guevara et al., 2022). Under conditions of sparse vegetation cover, 70% of the dryland ground cover contains specialized organisms: cyanobacteria, eukaryotic algae, fungi, bacteria, lichens, and mosses composing so-called biological soil crusts, or simply biocrusts (Panigada et al., 2019; Weber et al., 2022). Biocrusts do not develop under dense canopies of vascular plants. They may occur in any climatic zone after disturbance of vegetation cover. They mostly appear in arid and semiarid areas, where plant individuals grow far apart (Belnap & Lange, 2013).

Biocrusts are fundamental components of ecosystems and control their key processes such as nitrogen and carbon cycle, water cycle, soil stabilization, vegetation cover restoration and maintenance, formation of habitats for nematodes, insects and other organisms. Biocrusts are very sensitive to mechanical stress, in particular trampling (Delgado-Baquerizo et al., 2016; Panigada et al., 2019; Maestre et al., 2016). Biocrusts are threatened by global changes, especially the combined effects of land use intensification and climate change at local, regional and global scales (Weber et al., 2022; Ferrenberg et al., 2015; Rodriguez-Caballero et al., 2018). Consequences of their loss should be incorporated into global change analyses and models (Ferrenberg et al., 2012;

Rodriguez-Caballero et al., 2021; Ferrenberg et al., 2017; López-Rodríguez et al., 2020). Biocrusts need to be protected to maintain the ecosystem services they provide (e.g., Bowker et al., 2018).

Materials and Methods

In Georgia, semiarid habitats mainly occur in eastern Georgia: on the Iori plateau in Kakheti, and foothills and plains of the mountains of Shida and Kvemo Kartli (Ketskhoveli, 1960; Nakhutsrishvili, 2013).

The study was conducted in Gareji, the Iori plateau, Kakheti and on the south-facing slopes of the Kvernaki range, Shida Kartli. The vegetation of the study area is mainly represented by steppe and shrubland. The shrubland is formed by various species of xerophilous species: *Paliurus spina-christi, Spiraea hypericifolia, Juniperus* spp., *Rosa* spp., *Carpinus orientalis, Rhamnus pallasii, Berberis vulgaris*, and *Cotynus coggygria*, with dominance of *Paliurus spina-christi*. The vegetation cover includes three functional groups: (A) shrub "islands", (B) herbaceous areas between the shrub "islands", and (C) the cover created by biological crusts of cryptogamic organisms between shrubs and herbs.

We conducted observations under ten individual shrubs in each of three communities of shrubland made up of: (a) *Spiraea hypericifolia*, (b) *Paliurus spina-christi*, and (c) *Juniperus* sp. and *Juniperus* sp.-*Paliurus spina-christi*. In these communities, we distinguished four different habitat subtypes: (i) stone-and-rock surface, (ii) bare soil fragments without vascular plants, (iii) segments covered with herbaceous vascular plants, and (iv) soil surface under xerophilous shrub canopies. We described species composition of cryptogamic organisms of each type of shrub habitat subtype.

The nomenclature follows World Flora Online (2025) bryophytes, mainly Royal Botanic Gardens, Kew (2023) for fungi, mainly Inashvili et al. (2022) for lichens.

Results and Discussion

Twenty species of bryophytes, 13 species of macro-fungi and 23 species of lichens were identified under xerophilous shrub canopies (Table 1). They are:

(a) *Spiraea hypericifolia* shrub thickets mainly occur on the north- and west-facing slopes. The thickets are usually dense and mono-dominant. These are almost impassable for animals and do not suffer from mechanical damage. Under *S. hypericifolia*, humidity is apparently higher compared to other shrub communities and non-disrupted cover of cryptogams is developed. Bryophytes participate with a particularly high frequency. The carpet-like moss cover is made up of pleurocarpous species: *Abietinella abietina, Homalothecium lutescens, Hypnum cupressiforme*, sometimes *Rhytidium rugosum*. On the periphery of the thickets, where the shrub density is lower and slopes is well lit, the complex of the mentioned species is no longer found. Only well-formed cushions of acrocarpous species such as *Syntrichia ruralis* and *Tortella squarrosa* are observed. Of the macro-fungi *Geastrum floriforme*, and of the lichens *Cladonia convoluta, C. rangiformis* var. *foliosa* are recorded.

Table 1. Species of bryophytes under xerophilous shrub canopies in semiarid habitats of Georgia

Abietinella abietina (Hedw.) M.Fleish.	*Didymomodon rigidulus* Hedw.	*Rhytidium rugosum* (Ehrh. ex Hedw.) Kindb
Amblystegium serpens (Hedw.) Shimp.	*Didymomodon vinealis* (Brid.) R.H.Zander	*Pterigoneurum ovatum* (Hedw.) Dixon.
Barbula unguiculata Hedw.	*Entodon concinnus* (De Not) Paris	*Syntrichia caninervis* Mitt.
Bryum argenteum Hedw.	*Homalothecium lutescens* (Hedw.) H.Rob.	*Syntrichia ruralis* (Hedw.) F.Weber & D.Mohr.
Bryum caespiticium Hedw.	*Hypnum cupressiforme* Hedw.	*Tortella squarrosa* (Brid.) Limpr.
Dicranella varia (Hedw.) Shimp.	*Hypnum cupressiforme* var. *lacunosum* Brid.	*Tortula inermis* (Brid.) Mont.
Didymodon acutus (Brid.) K.Saito		

Table 2. Species of macro-fungi under xerophilous shrub canopies in semiarid habitats of Georgia

Chlorophyllum agaricoides (Czern.) Vellinga	*Geastrum campestre* Morgan	*Pisolithus arhizus* (Scop.) Rauschert
Cyathus olla (Batsch) Pers.	*Geastrum coronatum* Pers.	*Tulostoma brumale* Pers.
Cyathus striatus (Huds.) Willd.	*Geastrum fimbriatum* Fr.	*Tulostoma squamosum* (J.F. Gmel.) Pers.
Gastrosporium simplex Mattir.	*Geastrum minimum* Schwein.	
	Geastrum pectinatum Pers.	

Table 3. Species of lichens recorded under xerophilous shrub canopies in semiarid habitats of Georgia

Aspicilia esculenta (Pall.) Flagey	*Cladonia furcata* (Huds.) Schrad.	*Psora decipiens* (Hedw.)Hoffm.
Caloplaca sp.	*Cladonia rangiformis* Hoffm. var. *foliosa* Flk. ex Vain.	*Psora lurida* (Ach.) DC.
Catapyrenium squamulosum (Ach.) Breuss	*Collema tenax* (Swartz.) Ach. ex Degel	*Squamarina lentigera* (F.C.Weber) Poelt
Cetraria commixta (Nyl.) Th.Fr.	*Endocarpon pusillum* Hedw.	*Squamarina crassa* (Huds.) Poelt
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	*Endocarpon adscendens* (Anzi) Müll. Arg.	*Toninia sedifolia* (Scop.) Timdal.
Cladonia convoluta (Lam.) Anders	*Lecanora muralis* (Schaerb.) Rabenh. f. *albomarginata*	*Toninia squalida* (Schleich.) Mass.
Cladonia magyarica Vain.	*Lepraria* sp.	*Xanthoparmelia camtschodalis* (Ach.) Hale.
Cladonia fimbriata (L.) Fr.	*Parmelia vagans* (Nyl.) Nyl.	

The bryophyte species richness under *Spiraea hypericifolia* canopy is the lowest among the studied shrub community types, but cover is large and biomass is big.

(b) *Paliurus spina-christi* communities are characterized presence of admixture of *Rhamnus pallasii, Cotynus coggygria,* and in places *Berberis vulgaris*. They develop on the south-facing as well as south-east- and south-west-facing slopes and adjacent plain areas. The shrubs grow 3 to 7 meters apart. Among the shrubs of semi-arid regions, the cryptogams developing under *P. spina-christi* shrubs are distinguished by the highest species richness. Around the main stem of a shrub, bryophytes are arranged radially and their overall projection has the shape of an elongated oval towards the north. Within a shrub, where the air and soil retain moisture longer, pleurocarpous species develop: *Abietinella abietina, Homalothecium lutescens, Hypnum cupressiforme, H. Cupressiforme* var. *laconosum*, *Rhytidium rugosum*, rarely *Amblystegium serpens*, along the perimeter of the bush projection, in better light conditions, small and dense cushions of acrocarpous forms are found: *Barbula unguiculata, Bryum argenteum, B. Caespiticium, Dicranella varia, Didymodon acutus, D.*

rigidulus, D. vinealis, Syntrichia caninervis, S. ruralis, Tortula inermis, Tortella squarrosa, Pterigoneurum ovatum. Of lichens, the following are recorded: *Cladonia rangiformis, C. convoluta, C. magyarica, C. fimbriata, Collema tenax*. The biomass, frequency, cover and richness of bryophytes depend on the local topography, shrub frequency and their size. In conditions of high shrub frequency, the cover of mosses and lichens is almost continuous. In thin and low thickets, the cryptogam communities are poor. Of the bryophytes, the first to leave the disturbed community are pleurocarpous species. *Syntrichia ruralis* is a constant species in any conditions of the studied semi-arid habitats. It is often the only cryptogam species developing under shrubs. Of the macrofungi: *Cyathus olla, C. striatus, Gastrosporium simplex, Geastrum campestre, G. coronatum, Pisolithus arhizus, Tulostoma brumale, T. squamosum* are recorded.

(c) *Juniperus* spp. and *Juniperus* spp.-*Paliurus spina-christi* comminities are found on the north-facing and adjacent slopes. Shrubs are mostly scattered, growing 2-3 m apart and more. Under the shrubs, the cover of cryptogams, especially bryophytes, is well formed. In evergreen, spreading juniper canopies, where the relative humidity is higher, pleurocarpous forms of bryophytes: *Abietinella abietina, Homalothecium lutescens, Hypnum cupressiforme, Rhytidium rugosum* create a radially distributed, continuous carpet around the stems of the shrubs.

It has been experimentally proven that mosses and lichens in the open herbaceous areas experience a long-term decrease in photochemical efficiency in summer, which is avoided in the shade of juniper (Kalapos et al., 2001). Juniper shrubs influence the composition and small-scale spatial distribution of lichen and moss communities. In this type of shrub community, we first recorded the pleurocarpous form of *Entodon conncimus*. Among the acrocarpous bryophytes, the most frequent in the peripheral zone of a shrub projection are the low cushions of *Tortella squarrosa* and *Syntrichia ruralis*. Groups of *Didymodon acutus, D. rigidulus*, and *D. vinealis* are concentrated on the southern side. The other species: *Barbula unguiculata, Bryum argenteum, B. caespiticium* are scattered around the perimeter of a shrub projection.

Of the lichens, *Cladonia convoluta* and *C. furcata* occur under the junipers. Of the macrofungi, *Geastrum minimum* and *G. pectinatum* are found.

In the studied shrublands, in the projection of the shrubs, two forms of bryophytes are found: pleurocarpous and acrocarpous. The acrocarpous bryophyte species identified around the perimeter participate in the creation of biological crusts of semiarid vegetation; these are: *Barbula unguiculata, Bryum argenteum, B. caespiticium, Didymodon acutus, D. rigidulus, D. vinealis, Totella squarrosa, Syntrichia ruralis, S. caninervis, Tortula inermis*. The most frequent are: *Syntrichia ruralis, Didymodon rigidulus, D. vinealis, Tortella squarrosa* (Kalapos et al., 2021; Martínez-Sánchez et al., 1994; Seppelt et al., 2016; Warren et al., 2021). Pleurocarpous mosses never participate in biocrust associations of open places being attached to a specific habitat created under shrubs. Their thick carpet under xerophilous shrubs retains moisture for a relatively long time, reduces water evaporation from the soil, and resists water and wind erosion processes. Thus, a special microhabitat is created for the acrocarpous forms of xerophytic mosses as well growing around the perimeter of the shrubs, where they are relatively protected against the extreme effects of semi-arid conditions, animal grazing, or other types of disturbance, compared to biological crusts developed out of the shrub projection. The majority of acrocarpous moss species developing withinin the projection of xerophilous shrubs of the semi-arid vegetation in Georgia are, as mentioned, biocrust constituent species. Therefore, cryptogams developing under xerophilous shrubs represent biocrust reservoirs. In today's conditions, when steppe degradation and cryptogamic crust destruction occur due to cattle and sheep grazing, the survival strategy of biocrusts is associated with shrub-steppe, specifically with the shrub functional group. In turn, shrubs and biocrusts contribute to the biodiversity of semi-arid regions (Maestre et al., 2009). In semi-arid regions, they have a positive effect on soil productivity, restoration of grazed fields, biocrusts and vascular plants. The undisturbed cover of biological crusts determines the stability of the ecosystem, therefore they are called indicators of vegetation health (Kröpfl, 2022).

Biocrusts are characterized by the following main features: 1. physical structure, 2. functional parameters, 3. taxonomic composition (Weber et al., 2022). The process of biocrust formation is sequential and begins with cyanobacteria and eukaryotic algae. At the last stage of biocrust succession, bryophytes become their essential component. However, under stable conditions, their presence is possible even at earlier stages (Kröpfl et al., 2022). Such biocrusts are characterized by higher hygroscopic capacity and faster growth rates. Also, mosses-containing biocrusts are more resistant to climate changes, their multifunctionality increases with a positive effect on soil bacteria and fungi (Delgado-Baquerizo et al., 2016). Biocrusts, the composition of which includes mosses and lichens, have a rough surface, due to which their surface area and hygroscopic capacity increase, while water loss decreases. It was found that the two most common mosses of biological crusts in Spain, *Syntrichia ruralis* and *Tortella squarrosa*, had the ability to retain water for the longest time (Ladrón de Guevara et al., 2022). These species are the dominant species in our study area. This feature is determined by their morphological characteristics (Maestre et al., 2011).

It has been experimentally proven that moss and lichen biological soil crusts necessary space for vascular plant development. These processes create the space necessary for the development of vascular plants (Sepehr et al., 2022). The surface of the biological crust is a safe place for seed capture, germination and growth. At the same time, herbaceous plants had faster growth rates in the presence of moss biocrusts (Kröpfl, 2022). Thus, biological crusts are very important for herbaceous cover restoration. An experiment conducted by Tavili et al. (2017) showed that under the influence of biocrust cryptogams, germination and growth of herbaceous plants improved. In the semi-arid regions of northeastern Patagonia and southern Argentina, mossy biocrusts occur both under and outside shrubs (Kröpfl, 2022). Experimental evidence suggests that biocrusts improve soil moisture retention, herbaceous seed sorption, germination, growth, and the formation of resilient plant structures (Ladrón de Guevara, 2022; Kröpfl, 2022; Kröpfl et al., 2022; Viles, 2008). Similar findings have been reported in Israel (Kidron et al., 2010).

Conclusions

Under the canopies of xerophilous shrubs of the semiarid vegetation of Kvernaki range and Gareji, eastern Georgia, we identified 20 species of mosses, 23 species of lichens and 15 species of macro-fungi. The shrubs of *Paliurus spina-christi* shelter the richest communities of terricolous cryptogamic organisms, followed by *Juniperus* spp. / *Juniperus* spp.-*Paliurus spina-christi* comminities and further by *Spiraea hypericifolia* thickets. Affinity between the shrub species and the species of cryptogams is not clearly observable. The pleurocarpous species of bryophytes: *Homalothecium lutescens, Abietinella abietina, Hypnum cupressiforme* and the acrocarpous species: *Syntrichia ruralis, Tortella squarrosa, Didymodon vinealis, D. rigidulus* are found in the projection of almost all the dominant shrubs: *Spiraea hypericifolia*, *Juniperus oblonga, Rhamnus pallasi*, and *Cotinus coggygria*.

The acrocarpous moss *Syntrichia ruralis* and the lichen *Cladonia convoluta* are the most common species of the semiarid cryptogamous biota.

The main species of acrocarpous bryophytes that form biological crusts in the areas between shrubs are also associated with xerophilous shrubs of the shrub-steppe: *Barbula unguiculata, Bryum argenteum, B. caespiticium, Didymodon acutus, D. rigidulus, D. vinealis, Tortella squarrosa, Syntrichia ruralis, S. caninervis, Tortula inermis*. Bryophytes made up various communities around the stems of xerophilous shrubs depending on their life forms and location in the projection of the shrub. Cryptogams developing under shrubs are well-shaped due to the specific conditions of the microhabitat. Shrubs of semi-arid vegetation, as reserves of cryptogams associated with biocrusts, are of great importance in the restoration of biocrusts and, accordingly, semi-arid vegetation cover.

Given the urgency of the above issues, we see the necessity to conserve certain semi-arid ecosystems of background importance, such as certain areas on the south-facing slope of the Kvernaki range (e.g. the Kotsakhuri ravine near Kaspi).

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ბოტანიკა

საქართველოს სემიარიდული მცენარეულობის ქსეროფილურ ბუჩქებთან ასოცირებული კრიპტოგამების მრავალფეროვნება

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სემიარიდული მცენარეულობის ბუჩქებს, როგორც ბიოქერქებთან ასოცირებული კრიპტოგამების რეზერვატებს, დიდი მნიშვნელობა აქვს ბიოქერქების და, შესაბამისად, სემიარიდული მცენარეულობის ნიადაგისა და ბალახოვანი საფრის აღდგენისთვის. ნაშრომის მიზანი იყო საქართველოს სემიარიდული რეგიონების კრიპტოგამების (ბრიოფიტების, ლიქენების, მაკროსოკოების) სახეობრივი მრავალფეროვნების გამოვლენა, ჰემიქსეროფილური ბუჩქნარის მიკროჰაბიტატებთან მათი მიჯაჭვულობის ხარისხის დადგენა და ბრიოფიტების, ლიქენებისა და მაკროსოკოების მონაწილეობის შესწავლა კრიპტოგამული ორგანიზმების თანასაზოგადოე-

ზებში, კერძოდ, ნიადაგის ბიოლოგიურ ქერქებში. ბრიოფიტების, ლიქენებისა და მაკროსოკოების მრავალფეროვნებას ვიკვლევდით სემიარიდული ბუჩქნარის სამ ძირითად ტიპში: გრაკლიანში (*Spiraea hypericifolia* L.), ძეძვიანსა (*Paliurus spina-christi* Mill.) და ღვიიანში (Juniperus spp.). კრიპტოგამებზე დაკვირვება ხდებოდა აღნიშნული ფიტოცენოზების ათ-ათი ბუჩქის მაგალითზე. შესწავლილი რეგიონების (კვერნაქის სერის სამხრეთი ფერდობი და ივრის ზეგანი) სემიარიდული მცენარეულობის ჰემიქსეროფილური ბუჩქების პროექციაში გამოვლენილია 20 სახეობის ხავსი, 23 სახეობის ლიქენი და 15 სახეობის მაკროსოკო. კრიპტოგამების სახეობრივი მრავალფეროვნება, განსაკუთრებით ბრიოფიტების შემთხვევაში, კონცენტრირებულია ბუჩქების ვარჯთა პროექციაში შექმნილ მიკროჰაბიტატებში. ნიადაგის კრიპტოგამების მაღალი სახეობრივი სიმდიდრით გამოირჩევა ძეძვიანის მიკრო-ჰაბიტატი, სახეობებით ყველაზე ღარიბი კი გრაკლიანის მიკროჰაბიტატია. ჰემიქსეროფილური ბუჩქები გავლენას ახდენს კრიპტოგამების თანასაზოგადოებათა შემადგენლობასა და სივრცულ განაწილებაზე, თუმცა ბუჩქებისა და კრიპტოგამების სახეობებს შორის ნაკლებად არის გამოხატული მიჯაჭვულობა.

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