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RESEARCH ARTICLE

Changes in lichen cover composition on plateau palsas in Western Siberia under the impact of fires

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Abstract

This paper presents a cumulative list of lichen species recorded in key undisturbed and fire-disturbed sites of plateau palsas located along the latitudinal gradient in the ecological conditions of the permafrost zone of Western Siberia. Data on changes in the structure of the lichen cover under the impact of fires that occurred 8, 17, and 36 years ago are provided. Analysis of field research materials and aerial images from unmanned aerial vehicles revealed significant changes in lichen biodiversity and the structure of the lichen cover. The greatest number of species was observed in the 36-year-old plateau palsas, yet the lichen cover has not fully recovered over the long post-fire period, and most of the area is covered by a dense crust of burned lichen.

Keywords

Ground lichens, species composition, projected cover

Introduction

Plateau palsas, which extend from typical tundra to the southern border of the permafrost zone, occupy significant areas in Western Siberia (Pyavchenko 1955; Tyrtikov 1979; Ilyina et al. 1985). The surface of frozen hillocks is covered by a continuous lichen carpet (Tyrtikov 1979; Ilyina et al. 1985; Lapshina et al. 2023), yet few studies have investigated the lichen cover of this territory (Sedelnikova 2009). Some general information is known on lichens of Western Siberia, including lichens of tundras (Andreev 1984; Meltser 1985; Valeeva and Blum 1994; Magomedova 1994; Pristiazhnyuk 1998, 2001), middle taiga (Makarova et al. 2002; Kataeva et al. 2005), the Nether-Polar Urals (Magomedova 2003), tundras of the highlands of the Altai-Sayan mountain country (Sedelnikova, Sedelnikov 2016), and specially protected natural areas (Sedelnikova and Taran 2000; Sedelnikova 2010; Tolpysheva and Shishkonakova 2019). A number of studies analyze the species composition and quantitative structure of ground lichen communities of raised bogs and plateau palsas (Lapshina and Koneva 2010; Koneva 2014; Tolpysheva and Shishkonakova 2023); in addition, commonly known species of the genus *Cladonia* are frequently referenced in geobotanical literature pertinent to the study area (Shishkonakova et al. 2016; Koneva 2023). Territorial heterogeneity of lichen biodiversity in Western Siberia is analyzed by N.V. Sedelnikova (2009) and Sedelnikova et al. (2018). The most complete analysis of lichens from the Purovsky District of Yamal-Nenets Autonomous Area is reported by N.A. Alekseeva and N.V. Khozyainova (2008). The vegetation of palsas in mire complexes of the north of Western Siberia and the Taymyr Peninsula is described by E.D. Lapshina et al. (2023).

Vast areas of plateau palsas in Western Siberia have been affected by recurrent fires, with an increasing frequency and intensity in recent decades due to climatic changes (Moskovchenko et al. 2020; Cunningham et al. 2024). Fires reduce soil acidity, increase the content of ash elements, change the energy balance of cryogenic soils and terrestrial vegetation, and are therefore considered an evolutionary factor (Scotter 1971; Sukachev 1972; Chevychelov 2002: Tsvetkov 2004; Bret-Harte et al. 2013; Jones et al. 2015; Li et al. 2019; Miller et al. 2018). Under fire, however, the lichen cover either disappears entirely or its properties change significantly, affecting the nutrient, hydrothermal and gas regimes of peatlands and the state of permafrost (Tyrtikov 1979; Klein 1982; Coxson and Marsh 2001; Boudreault et al. 2009; Miller 2018; Lapshina et al. 2023). Pyrogenesis, which has an effect on lichen distribution and abundance, is one of the primary factors affecting successional processes (Sukachev 1972; Coxson and Marsh 2001). The effect of fires on biodiversity, particularly lichen diversity, remains poorly understood (Smith et al. 2017; Miller et al. 2022). The majority of studies are restricted to local areas and employ small sample sizes (Mistry 1998; Romagni and Gries 2000; Miller et al. 2018) A limited number of studies have investigated the rate and dynamics of lichen recovery in plateau palsas of Western Siberia (Zamaraeva 2011; 2012; Abdulmanova and Ektova 2015; Lapshina et al. 2023).

The aim of the study was to assess changes in species composition and the structure of the lichen cover on plateau palsas of the cryolithozone in Western Siberia under the impact of fires that occurred at different times, in comparison with their undisturbed counterparts.

Materials and methods

Study area

The studies were conducted at three key sites of the plateau palsa in the Nadym-Pur interfluve, undisturbed and disturbed by fires (Figs 1, 2). The sites are located within the Ob-Taz region of frozen peat bogs (Meltser 1985). Plateau palsa is a complex formation comprising elongated or ridge-shaped peat hillocks and wet lowlands (Richter 1963). Peat deposit thickness exhibits considerable variability (0.2–4 m), while the depth of seasonal thawing ranges within 0.3–0.6 m (Lapshina et al. 2023). The vegetation of plateau palsa on hillocks is represented by ledum-lichen, shrubby-sphagnum-lichen and shrubby-cloudberry-sphagnum communities; sedge and cottonsedge thrive in hollows along with sphagnum (Richter 1963; Lapshina et al. 2023). The study area is located in the region with a sharply continental climate, with significant temperature fluctuations throughout the year, harsh and prolonged winters, extended periods of snow cover, and rather cold and short summers (Richter 1963). General characteristics of the studied peatlands and meteorological data from the nearby meteorological stations in Urengoy and Tarko-Sale, in accordance with SP 131.13330.2020, are summarized in Table 1.

Table 1. General characteristics of the studied peatlands and meteorological data

Site	Fire year (age)	Natural zone	Average annual temperature, °C	Average temperature in January, °C	Average temperature in July, °C	Precipitation in April–October	Precipitation in November–March
Novy Urengoy	2016 (8)	Forest-tundra	-7	-26.5	+15.5	360	136
Severo-Komsomolsky	2007 (17)	Northern taiga	-5.6	-25.2	16.4	371	150
Muravlenko	1988 (36)	Northern taiga	-5.6	-25.2	16.4	371	150

The year of the fire was determined by comparing multi-temporal satellite images using Normalized Burned Ratio (NBR) based on near infrared and shortwave infrared bands:

$$NBR = (NIR–SWIR)/(NIR+SWIR),$$

where

NIR: near infrared,

SWIR: short-wave infrared (Lopez-García and Caselles 1991).

The lichen cover structure was analyzed using aerial images taken via the DJI 3 UAV. The georeferencing, interpretation and reclassification of vegetation types and determination of the proportion of different phytocoenoses were conducted using ArcGIS software (Fig. 3).

In both disturbed and undisturbed sites, geobotanical descriptions were conducted in August 2023 and 2024 using standard methods.

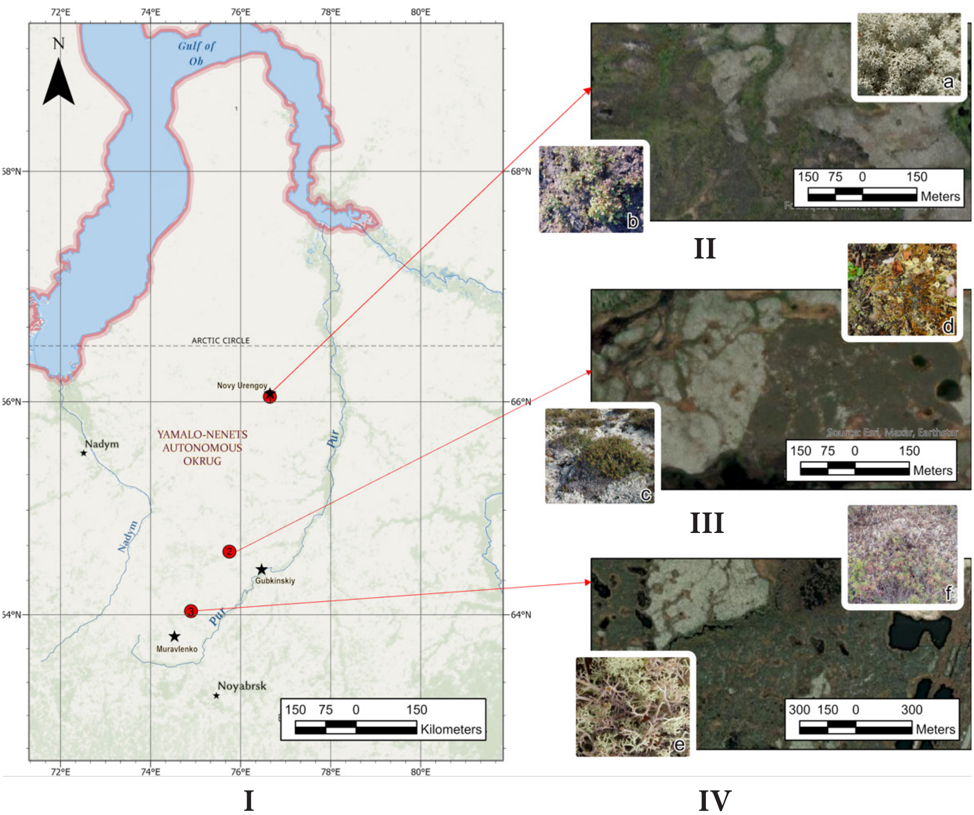

Figure 1. Location of the key sites: research points (I), satellite image of the Novy Urengoy site (II), satellite image of the Severo-Komsomolsky site (III), satellite image of the Muravlenko site (IV); a – vegetation of undisturbed palsa at the Novy Urengoy site, b – vegetation of disturbed palsa at the Novy Urengoy site, c – vegetation of undisturbed palsa at the Severo-Komsomolsky site, d – vegetation of disturbed palsa at the Severo-Komsomolsky site, e – vegetation of undisturbed palsa at the Muravlenko site, f – vegetation of disturbed palsa at the Muravlenko site.

Vegetation descriptions were conducted in three plots at different stages of post-fire recovery and their undisturbed analogs. The area of description, depending on the size of the homogeneous contour, ranged from 70 to 120 m^2 (Yunatov 1964). In these plots, general geobotanical descriptions were performed, with approximately 20 descriptions completed for each site.

Within each plot, detailed geobotanical assessments were conducted on 1 × 1 m subplots, where photo documentation of vegetation cover was carried out, and lichen samples were collected to confirm and clarify species identification, with 3–4 samples collected per description. Descriptions and further data processing were carried out according to the Braun-Blanquet method (Braun-Blanquét 1964; Westhoff & Maarel 1978; Mirkin et al. 2000). The projective cover of species was assessed using the Braun-Blanquet scale: r – solitary specimen; + – less than 1%; 2a – 6–12%; 2b – 13–25%; 3 – 26– 50%; 4 – 51–75%; 5 – 76–50%. Species occurrence was calculated as the ratio of the number of plots where the species was recorded to the total number of plots, separately for natural and disturbed sites (Mirkin et al. 1989). Species frequency was evaluated using the scale: + – 0-5%; r – 5-10%; I – 11–20%; II – 21–40%; III – 41–60%; IV – 61–80%; V – 81–100%.

The majority of the samples were identified in the field, while ambiguous specimens were collected for laboratory identification. Taxon names were verified using electronic resources (Lichens of Belgium, Luxembourg and northern France, 2003–2024; Index Fungorum, 2024; Fungal Databases: Nomenclature and Species Banks, 2024). Two cetrarioid lichen species are presented as *Flavocetraria cucullata* (Bellardi) Kärnefelt & A. Thell and *Foveolaria nivalis* (L.) S. Chesnokov et al. in accordance with a recent publication (Chesnokov et al. 2023). Lichen species are listed in alphabetical order in table format.

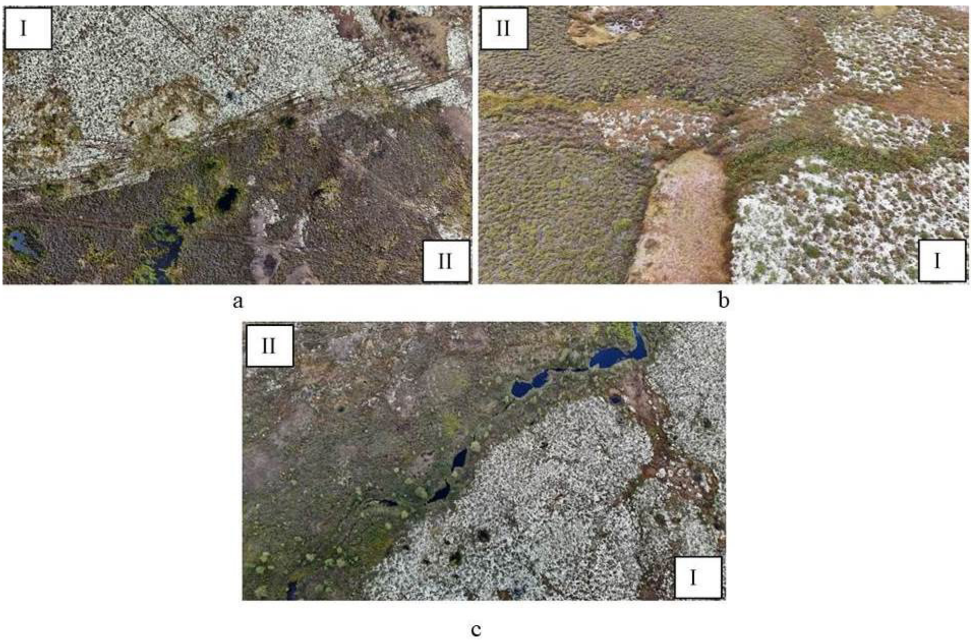

Figure 2. Landscapes of disturbed and undisturbed areas in the study area (UAV images): Novy Urengoy site (a), Severo-Komsomolsky site (b), Muravlenko site (c); I – undisturbed areas, II – disturbed areas.

Processing of field materials and identification of species was conducted at the Department of Botany, BI TSU. Thalli and slices were studied using chemical reagents: potassium hydroxide (KOH) 10% solution, alcoholic solution of paraphenylenediamine $C_6H_4(NH)_2$. Lichens were identified using various Identifiers, Floras, monographs and reports by domestic and foreign authors (Kopaczevskaja et al. 1971; Golubkova et al. 1978; Purvis et al. 1992; Brodo et al. 2001; Andreev et al. 2023). To calculate the occurrence classes and average projective cover of species, the descriptions were entered into the IBISS 6.2 integrated botanical system database (Zverev 2007), from which verified lists and the requested data were obtained.

The lichen cover structure was analyzed using aerial images taken via the DJI 3 UAV. The georeferencing, interpretation and reclassification of vegetation types and determination of the proportion of different phytocoenoses were conducted using Reclassify and Zonal Statistics as Table (Spatial Analyst) ArcGIS software. Based on field studies and their comparison with UAV images, five classes of vegetation cover were identified for automatic interpretation. In complex cases, interpretation was carried out manually (Fig. 3).

Field studies performed using the equipment of the Unique Research Installation 'System of experimental bases located along the latitudinal gradient', Tomsk State University.

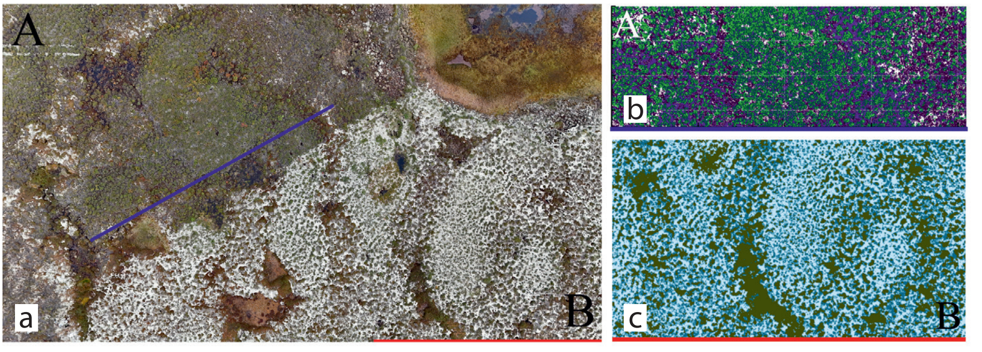

Figure 3. Fragment of assessment of changes in the projective cover of undisturbed and disturbed areas: natural colors (a), segmented and recolored image in the disturbed area (b), segmented and recolored image in the undisturbed area (c).

Results

The structure of the lichen cover of undisturbed plateau palsas is similar for all the studied sites. The ground cover is dominated by fruticose species: *Cladonia stellaris*, *Cl. stygia*, which form pure beautiful carpets. *Cladonia amaurocraea*, *Cl. uncialis*, *Foveolaria nivalis*, *Flavocetraria cucullata*, and *Gowardia nigricans* are abundant. *Bryocaulon divergens*, *Cetraria islandica*, *Cetrariella delisei*, Cl. Coccifera, *Cl. rangiferina*, and *Icmadophila ericetorum* are found sporadically. It should be noted that dominant carpets in undisturbed areas include a few species from a large number of genera (14 and 8, respectively) (*Bryocaulon*, *Cetraria*, *Cetrariella*, *Cladonia*, *Gowardia*, *Icmadophila, Flavocetraria* and *Foveolaria*). A total of 39 lichen species from 15 genera were identified in the plant communities of plateau palsas of two types.

Species distribution patterns in post-fire successions showed high variability (Fig. 4, Table 2). The largest areas were occupied by dead-covered plots or plots with bare peat. Dead-covered plots consist of charred thalli of *Cladonia stellaris* and *Cl. stygia*. In some cases, parts of the thalli survived and continue to grow. However, in most cases, a film of primary thalli of *Cladonia* species (*Cladonia cenotea*, *Cl. coccifera*, *Cl. deformis*, *Cl. sulphurina*) or crustose lichens begins to appear on the peat near the dead thalli. The dominance of species of the genus *Cladonia* together with typical bog and epiphytic species and genera has been reported by N.A. Alekseeva, N.V. Khozyainova (2008), N.V. Sidelnikova (2009), and V.V. Koneva (2014, 2023) for many habitats of Western Siberia.

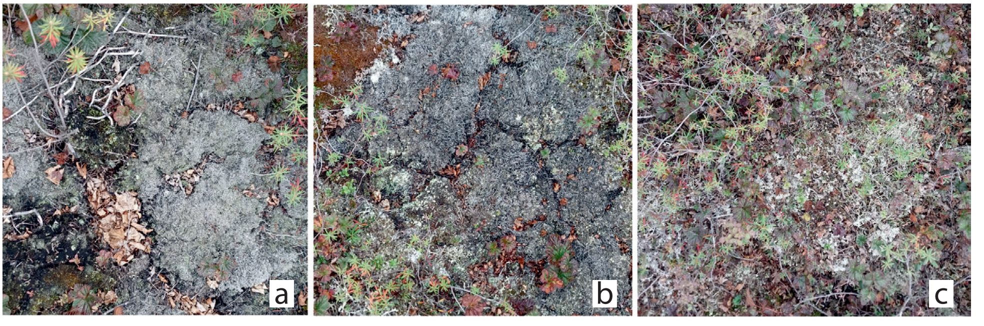

Figure 4. Typical terrestrial lichen cover of disturbed areas: Novy Urengoy site (a), Severo-Komsomolsky site (b), Muravlenko site (c).

Table 2. Lichen species in plateau palsas of the permafrost zone of Western Siberia

No	Species	Novy Urengoy site		Severo-Komsomolsky site		Muravlenko site	
		UP*	**DP****	**UP***	**DP****	**UP***	**DP****
1	*Bryocaulon divergens* (Ach.) Kärnefelt	I/+	-	-	-	-	-
2	*Cetraria islandica* (L.) Ach.	IV/1	-	II/+	-	III/1	
3	*Cetraria sepincola* (Ehrh.) Ach.	-	-	-	+/+	-	+/+
4	*Cetraria elenkinii* Krog	II/+	+/+	-	-	-	-
5	*Cetraria laevigata* Rass.	III/1	I/+	II/+	-	II/+	III/+
6	*Cetrariella delisei* (Bory ex Schaer.) Kärnefelt & A. Thell	II/+	-	-	-	-	-
7	*Cladonia amaurocraea* (Flörke) Schaer.	IV/1	II/+	IV/+	III/+	III/1	III/1
8	*Cladonia arbuscula* (Wallr.) Flot.	I/1	+/+	-	III/+	III/1	II/+
9	*Cladonia botrytes* (K.G. Hagen) Willd.	-	-	-	-	-	+/+
10	*Cladonia cariosa* (Lilj.) Spreng.	-	-	-	+/+	-	+/+
11	*Cladonia cenotea* (Ach.) Schaer.	II/+	-	-	+/+	II/+	II/+

No	Species	Novy Urengoy site		Severo-Komsomolsky site		Muravlenko site	
		UP*	DP**	UP*	DP**	UP*	DP**
12	*Cladonia chlorophaea* (Flörke ex Sommerf.) Spreng.	-	-	-	+/+	-	-
13	*Cladonia coccifera* (L.) Willd.	III/+	-	II/+	II/+	II/+	IV/1
14	*Cladonia cornuta* (L.) Baumg.	III/+	-	+/+	+/+	II/+	II/+
15	*Cladonia crispata* (Ach.) Flot.	-	-	+/+	III/+	II/+	II/+
16	*Cladonia deformis* (L.) Hoffm.	-	+/+	+/+	+/+	II/+	+/+
17	*Cladonia floerkeana* (Fr.) Flörke	-	-	-	-	-	+/+
18	*Cladonia furcata* (Huds.) Baumg.	-	-	-	-	-	+/+
19	*Cladonia gracilis* (L.) Willd.	-	-	I/+	-	IV/+	+/+
20	*Cladonia mitis* Sandst.	III/1	I/+	III/1	II/+	III/+	II/1
21	*Cladonia rangiferina* (L.) Weber	II/+	-	+/+	+/+	+/+	+/+
22	*Cladonia rei* Schaer.	-	-	-	-	-	+/+
23	*Cladonia stellaris* (Opiz) Pouzar & Vězda	V/3	IV/+	V/3	IV/1	V/3	V/2a
24	*Cladonia stricta* (Nyl.) Nyl.	-	-	-	-	-	+/+
25	*Cladonia stygia* (Fr.) Ruoss	V/2b	IV/+	V/2b	V/1	V/2b	V/1
26	*Cladonia sulphurina* (Michx.) Fr	II/+	IV/+	II/+	IV/+	IV/+	IV/1
27	*Cladonia uncialis* (L.) F.H. Wigg.	IV/1	+/+	III/+	+/+	V/1	II/+
28	*Flavocetraria cucullata* (Bellardi) Kärnefelt & A. Thell	IV/1	I/+	IV/1	II/+	IV/1	I/+
29	*Foveolaria nivalis* (L.) S. Chesnokov et al.	IV/1	+/+	II/+	I/+	IV/1	+/+
30	*Gowardia nigricans* (Ach.) Halonen et al.	IV/1	-	II/1	-	IV/1	+/+
31	*Hypocenomyce scalaris* (Ach.) M. Choisy	-	-	-	-	-	+/+
32	*Icmadophila ericetorum* (L.) Zahlbr.	I/+	+/+	III/+	+/+	-	+/+
33	*Imshaugia aleurites* (Ach.) S.L.F. Mey.	-	-	-	-	-	+/+
34	*Parmeliopsis ambigua* (Hoffm.) Nyl.	-	-	-	-	-	+/+
35	*Parmeliopsis hyperopta* (Ach.) Vain.	-	-	-	-	-	+/+
36	*Placynthiella uliginosa* (Schrad.) Coppins & P. James	-	-	-	+/+	-	-
37	*Protomicarea alpestris* (Sommerf.) McCune	-	-	-	+/+	-	-
38	*Stereocaulon condensatum* Hoffm.	-	-	+/+	-	-	-
39	*Tuckermannopsis ciliaris* (Ach.) Gyeln.	-	-	-	-	-	+/+
	Total number of species	20	13	19	21	19	32

Note: *UP – undisturbed palsa, **DP – disturbed palsa.

Discussion

Peat fires have a significant effect on the biodiversity of ground lichens of palsas in the permafrost zone of Western Siberia, which is reported by many authors for different habitats of both ground and epiphytic forms (Klein 1982; Antos et al. 1983; Mistry 1998; Johansson and Reich 2005; Boudreault et al. 2009; Zamaraeva 2011; 2012; Bret-Harte 2013; Abdulmanova and Ektova 2015; Giordani et al. 2015; Ray et al. 2015; Miller et al. 2018, 2020, 2022; Russell and Johnson 2019; Lapshina et al. 2023). UAV images and field research showed a significant change in the structure of the ground cover in fire-disturbed areas (Figs 5–7).

On undisturbed plateau palsas, 50 to 70% of the area is covered by a continuous lichen cover, while in burned areas, 46 to 65% remain dead-covered for many years, covered by a dense crust of burned lichen, which exhibits special physical properties (Kochetkova et al. 2023).

At the Novy Urengoy site disturbed by fire eight years ago, shrub vegetation, such as ledum, cloudberry, and green mosses, is primarily recovering. Crustose (*Icmadophila ericetorum*), and subulate and cup (*Cladonia amaurocraea*, *Cl. deformis*, *Cl. uncialis*) lichens are found occasionally, which is typical of the first years of lichen reproduction (Zamaraeva 2012; Abdulmanova and Ektova 2015; Arefiev and Kazantseva 2020). According to Zamaraeva (2012), the stage of subulate and cup lichen reproduction can last about forty years. In very humid areas near hollows, fruticose lichens (*Cl. stellaris*, *Cl. stygia*, *Cl. arbuscula*) are reproduced and occupy less than 1% of the total area, while the rest of the area is covered by a crust of burned lichen.

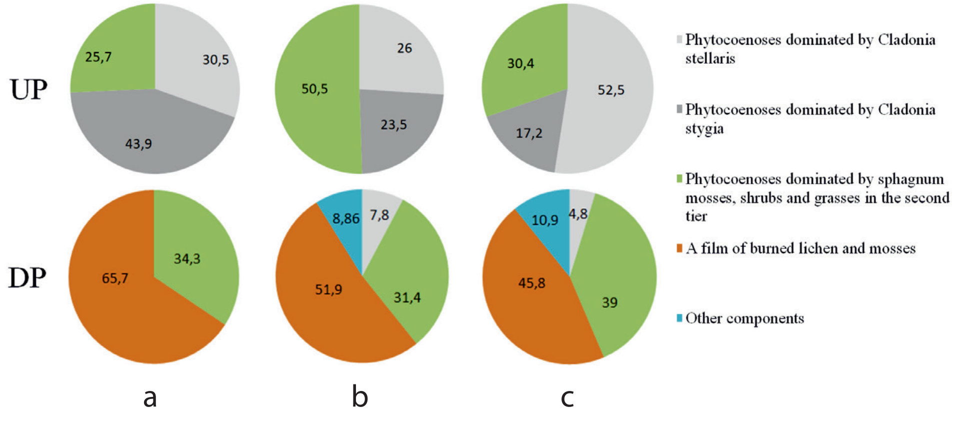

Figure 5. Structure of the ground cover in undisturbed and disturbed areas: undisturbed palsa (UP), disturbed palsa (DP); Novy Urengoy site (a), Severo-Komsomolsky site (b), Muravlenko site (c).

At the Severo-Komsomolsky site, in the area disturbed by fire 17 years ago, crustose lichen species (e.g., *Icmadophila ericetorum*) and species of the genus *Cladonia* represented by prothallus, subulate and cup lichens, including *Cl. cariosa*, *Cl. deformis*, *Cl. cenotea*, *Cl. chlorophaea*, *Cl. cornuta*, *Cl. crispata*, and *Cl. sulphurina*.

Cl. cariosa, *Cl. deformis*, *Cl. cenotea*, *Cl. chlorophaea*, *Cl. cornuta*, *Cl. crispata*, *Cl. stellaris*, *Cl. stygia* and *Cl. sulphurina* dominate among representatives of fruticose lichens, with participation of *Cl. amaurocraea*, *Cl. arbuscula*, *Cl. rangiferina* and *Cl. uncialis*. Recovery of typical Arctic fruticose lichens from other genera, e.g. *Flavocetraria cucullata*, was recorded in the area. No large foliose ground lichens were found.

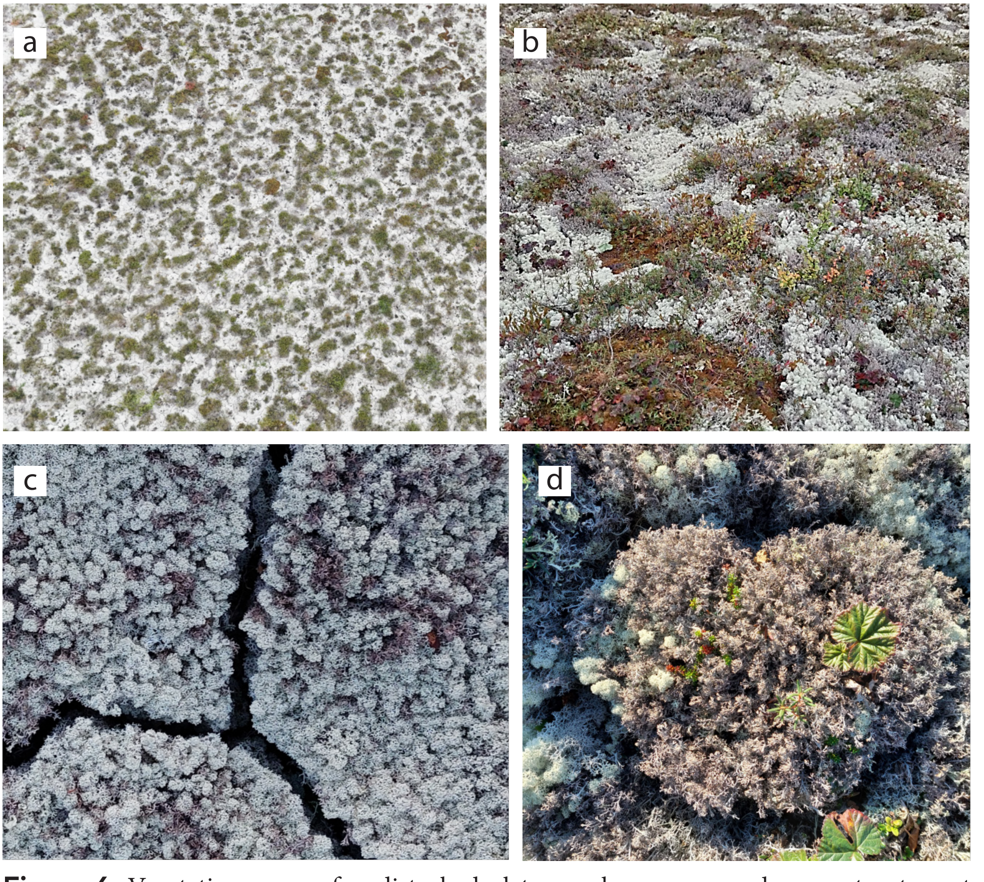

Figure 6. Vegetation cover of undisturbed plateau palsa: **a** – ground cover structure at the Severo-Komsomolsky site (UAV photo by S.N. Vorobyev), **b** – landscape of the Severo-Komsomolsky site (photo by L.G. Kolesnichenko), **c** – fragment of phytocoenosis dominated by *Cladonia stellaris* (Opiz) Pouzar & Vězda (photo by U.Yu. Shavrina), **d** – fragment of phytocoenosis dominated by *Cladonia stygia* (Fr.) Ruoss (photo by U.Yu. Shavrina).

Similar to many old-aged burned areas (Arefiev and Kazantseva 2020), the projective cover of the 36-year-old burned areas at the Muravlenko site was observed to increase significantly. In this area, fruticose lichens dominate and Arctic lichens *Cetraria laevigata*, *Flavocetraria cucullata*, *Foveolaria nivalis* and *Gowardia nigricans* can be encountered. The maximum biodiversity of lichens (32 species) was observed at this site. Similar to other studied sites, representatives of the genus *Cladonia* are primarily found in this area, with *Cl. stellaris* and *Cl. stygia* being dominant. In addition to species growing at the Severo-Komsomolsk site, *Cl. coccifera*, *Cl. floerkeana*, *Cl. furcata*, *Cl. gracilis*, *Cl. rangiferina*, and *Cl. stricta* were encountered in the area. A significant contribution to the biodiversity is made by woody debris such as sticks and pieces of wood, which are immediately colonized by typical epixylous and epiphytic species: *Cladonia botrytis*, *Imshaugia aleurites*, *Parmeliopsis ambigua*, *Parmeliopsis hyperopta*, *Tuckermannopsis ciliaris*. However, the lichen cover has not fully recovered in 36 years after fire, and despite high species diversity, these communities are transient and unstable under different impacts.

It is known that recovery of lichen communities after high-intensity fires can take several decades (Coxson and Marsh, 2001; Boudreault et al. 2009; Miller et al. 2020, 2022). The time required for lichens to finally recover in fire-affected areas is assumed to range from 40 to 150 years, depending on fire intensity (Zamaraeva 2012; Russell and Johnson 2019). Since the lichen cover plays a critical role in soil formation (Jung et al. 2020), nitrogen fixation (Brodo et al. 2001), and hydrologic cycling (Rundel 1978), its significant post-fire changes over 30 or more years can affect soil and hydrologic regimes.

Conclusion

Thus, the projective cover and structure of lichen cover changes depending on the age of fire. Restoration of the lichen cover begins with the settlement of fruticose, cup and tubular *Cladonia* lichens. Fruticose-branched lichens show the minimal growth rate on burned areas within a period of up to 36 years. The maximum number of species was observed on 36-year-old palsas; yet the lichen cover has not fully recovered over a long post-fire period, and much of the affected area is covered by a dense crust of burned lichen. The lichen cover has not recovered to 100% projective cover anywhere in the study area. Recovery is much better due to bog shrubs (*Ledum palustre* L.), under the canopy of which 'pioneer cladonia' develop. The increased number of lichen species in post-fire areas, compared to natural communities, can be interpreted as an increase in biodiversity within the lichenobiota. However, despite high species diversity, these communities are transient and unstable under different impacts.

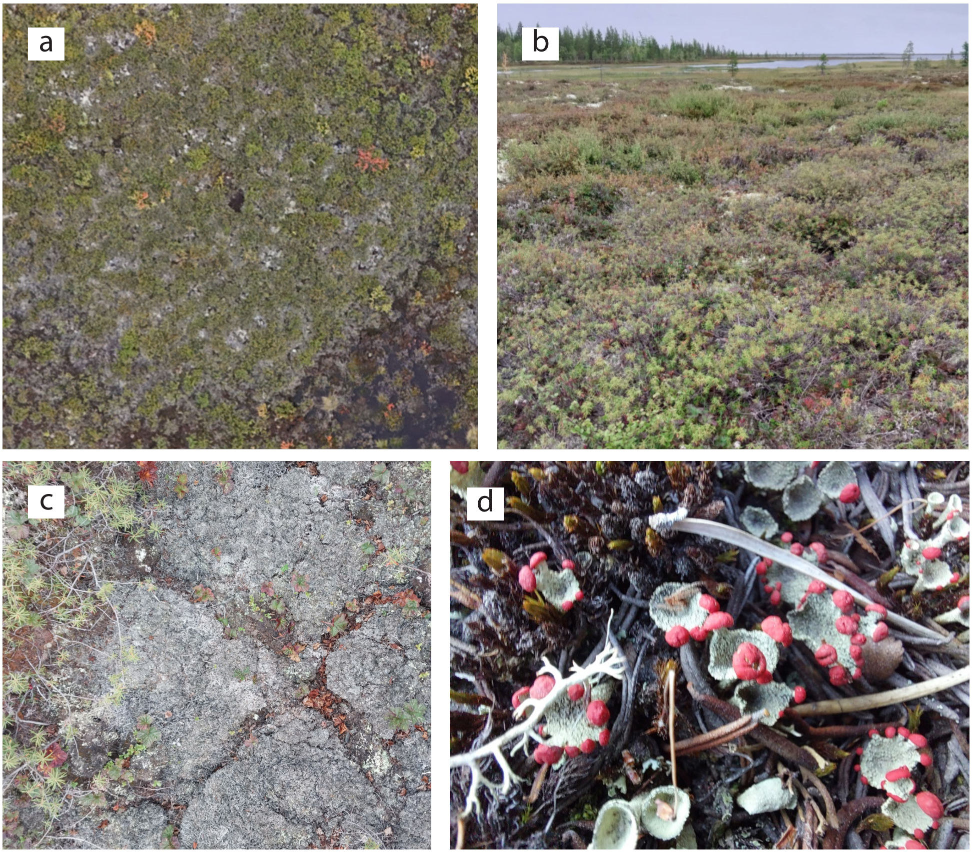

Figure 7. Vegetation cover of fire-disturbed areas: **a** – ground cover structure at the Severo-Komsomolsky site (UAV photo by S.N. Vorobyev), **b** – landscape of the Severo-Komsomolsky site (photo by L.G. Kolesnichenko), **c** – dense crust of burned lichen (photo by L.G. Kolesnichenko), **d** – recovery of *Cladonia coccifera* on a 36-year-old burned area (photo by U.Yu. Shavrina).

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