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The Indicative Potential of the Forest-Tundra Landscape Component

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Abstract

In order to expand the possibilities of soil-cover remote monitoring and improve prognostic models of active-layer depth dynamics in connection with global climatic changes, the verification of correspondence between plant and soil components of subarctic landscapes is necessary. This is most relevant for the forest-tundra zone, where the variety and mosaicity of soils and vegetation is great due to its ecotonic position. The purpose of this work was to study the relationship of vegetation with the characteristics of cryogenic soils and the dynamics of the active layer in forest-tundra landscapes. Data were obtained during monitoring studies at key sites in diverse landscapes of forest-tundra in the vicinity of Labytnangi. It was revealed that the thickness of the organogenic horizons, as well as the value of the moss phytomass, determine the active-layer thickness. A close connection with relief and soils allows the use of vegetation as an indicator of the soil texture and the depth of active-layer occurrence and features.

Keywords: plant communities, cryogenic soils, active layer, landscape, forest-tundra, Western Siberia

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1. Introduction

Vegetation is a physiognomic element of the landscape. The potential for a more accurate assessment of hidden landscape component states, in particular soils, over vast spaces using vegetation is increasing with the development and improvement of satellite surveillance systems. As a result of numerous studies [1–6], a close relationship between vegetation and the topography, soils and active layer thickness was established. This allows us to use vegetation as an informative indicator of edaphic factors, depth and the peculiarities of the active layer in permafrost distribution. This is important for the forest-tundra zone for two reasons: the great variety and mosaic of both soils and vegetation and the zone's particular vulnerability to climate changes.

The purpose of our research is to study the relationship of vegetation with the characteristics of cryogenic soils and the dynamics of the seasonal layer in various forest-tundra landscapes of Western Siberia. Research objectives: i – to identify the relationship between vegetation and soils in different landscapes of the forest-tundra ecotone; ii – to verify the indicative potential of vegetation for assessing the status and depth of the cryogenic soil active layer. Verification of the correspondence between plant and soil components of forest-tundra landscapes can, on one hand, contribute to the expansion of soil cover remote monitoring possibilities: on the other hand, it can improve the prognostic models of the dynamics of exogenous processes occurring in subarctic landscapes, including in connection with global climate changes [7].

2. Methods

2.1. Studied area

The objects of research were the vegetation and soils of the western part of the West Siberian plain on the left bank of the Ob River in the Labytnangi area (Yamalo-Nenets Autonomous District, 66°39′25″ N; 66°25′05″ E). According to climatic division, the key sites are within the Atlantic–Arctic moderately cold humid area [8]. The average annual temperature of the territory is –7.1°C, the sum of the temperatures more than 10°C is equal to 800°C and the annual precipitation is near 400 mm. The studied area belongs to the forest-tundra zone. The relief is a flat-sloping, hilly ridge with deep river valleys. Soil-forming rocks are sandy, clay and largely rocky. The zonal vegetation is typical for forest-tundra: a combination of dwarf birch moss-lichen (lichen-moss) and grass-moss tundras and bogs, often with individual larches and open forests of larch, spruce or spruce-larch dwarf birch. Tundra vegetation is confined to the plains and gentle slopes, while open forests and thickets of dwarf birch with willows are limited to depressions and the valleys of streams and rivers. Lichen tundra is typical to well-drained areas with little snow in winter.

2.2. Sites and plots

Three key sites each equal to 1 km^2 were studied so that they can be deciphered by remote methods according to the type of vegetation (Figure 1). The key sites were selected in accordance with the three main types of vegetation (tundra, peatbog and forest) and different parent rock textures (sand (sandy loam) and clay (loam)). The altitude above sea level of all key areas varies slightly (from 90 to 110 m). The sites are located on a line from the northwest to the southeast. The key site vegetation cover was mapped at a scale of 1:10 000.

The elementary chorological unit is a plant unit, conjugated on the area with a characteristic element of mesorelief. After the analysis of the geobotanical maps of the key sites, the most representative typical vegetation was chosen in each of them: stationary monitoring plots (SMP) were selected with exact geographical coordinates. In key site № 2, two stationary monitoring plots were established. Thus, all four SMPs were placed in typical forest-tundra landscapes, differing in terms of the location in the relief, soil-forming rocks, soil and vegetation type and type of tundra [9]. SMP size was 10x10 m in tundra (without forest stand) and 20x20 m in open forests.

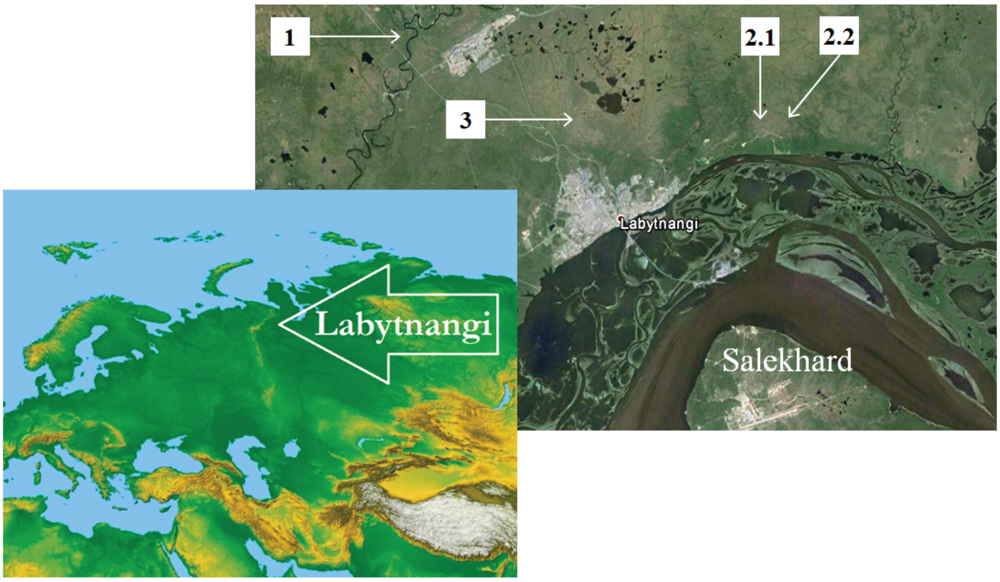

Figure 1: Location of standard monitoring plots (SMP).

2.3. Vegetation

The species composition and structure of vegetation were studied in all SMPs by the traditional method of geobotanical description during the maximum development of the grass and shrub layer. Plant associations were determined, the stocks and structure of the aboveground phytomass were studied and the state of vegetation and soils was characterized. The stock of the aboveground phytomass was determined by the method of bevels from the accounting areas 25x25 cm in length in a 16–25-fold repetition in each association. The aboveground phytomass was cut at the level of the boundary between living (green) and dead (brown) mosses. During the disassembly of bevels, fractions were isolated: cereals and sedges, forbs, shrubs, dwarf shrubs, lichens and mosses. The weighing of the fractions was carried out in an air-dry state with an accuracy of 0.1 g. The obtained numerical data were processed statistically using the program Statistics: stocks are given in the text in g/m^2.

2.4. Soils and active layer

At each key site, 5–8 soil sections were dug near the SMP in order to obtain the soil morphological characteristics and sampling necessary for soil diagnostics. The soils were classified in accordance with the World Reference Base [10]. Temperature and moisture sensors were installed in the soil near each SMPs. Measurements were performed throughout the period of field research. Automatic sensors, produced by Decagon Devices, were installed in one wall of the vertical soil section at depths of 2–10–20–50–100 cm when possible, and to the permafrost table when it was not. The depth of the STS in the SMP was measured with a probe with an accuracy of 1 cm on the same SMP area of 10×10 m in steps of 1 m at the same time in mid-August. A total of 121 measurements were made per year on each SMP.

3. Results

The variability of soil and vegetation cover at the key sites is caused by the diversity of their position in the relief and by the rocks (Table 1).

Table 1: Characteristics of key sites and stationary monitoring plots.

Characteristic	**Key site**			
	1	**2**		**3**
Position in mesorelief	Flat-sloping valley side of the bottom	Slightly inclined watershed area		Flat watershed area
Stationary monitoring plot, №	SMP1	SMP2.1	SMP2.2	SMP3
Rock texture	Sand	Sandy-loam	Silt-loam	Clay
Vegetation	Open birch-spruce-larch-forest dwarf shrub-moss-lichen	Mottled-medallion tundra dwarf shrub-moss-lichen	Hilly tundra ledum-dwarf birch-dwarf shrub-lichen and moss	Flat-knob bog dwarf birch-ledum-cloudberry-sphagnum

Characteristic	Key site			
	1		2	3
Synfolium edificators	*Larix sibirica, Betula tortuosa, Ledum palustre, Vaccinium uliginosum, V. vitis-idaea, Empetrum nigrum, Carex globularis, Hylocomium splendens, Polytrichum spp.,Cladonia gracilis, Cetraria laevigata, Stereocaulon glareosum, Cladina*	*Betula nana, Ledum decumbens, Vaccinium uliginosum, Empetrum hermaphroditum, Carex arctisibirica, Cladonia rangiferina, C. arbuscula, C. gracilis, Polytrichum ssp., Dicranum ssp*	*Betula nana, Ledum palustre, Vaccinium uliginosum, V. vitis-idaea, Empetrum nigrum, Carex tripartita*	*Betula nana, Ledum decumbens, Rubus chamaemorus, V. vitis-idaea, Eriophorum medium, Carex globularis.*
Phytomass stocks (excluding trees, g/m^2):				
Shrubs	0.7 ± 0.1	51.7 ± 6.6	183.8 ± 11.04	138.0 ± 8.2
Dwarf shrubs	172.2 ± 9.2	75.5 ± 3.6	106.3 ± 2.5	24.7 ± 1.3
Grasses	3.7 ± 0.3	2.9 ± 0.4	22.3 ± 1.4	73.6 ± 4.4
Mosses	94.1 ± 4.1	32.4 ± 1.7	238.8 ± 5.4	433.1 ± 7.7
Lycens	86.2 ± 6.3	107.6 ± 4.5	164.8 ± 10.0	28.3 ± 1.8
Total	356.9 ± 10.2	270.1 ± 9.8	716.0 ± 15.0	697.7 ± 14.6
Soil type	Albic Podzol	Albic Podzols Gelic	Histic Turbic Cryosol Reductaquic	Histic Cryosol
				
Soil horizons	O-E-Bhs-Bg-BCg	O-E-Bhs-Br	H1-H2-Bg-Br-BCg	H1-H2-H3-Cg
Organogenic horizon (O, H) thickness, cm	4.3 ± 2.0	3.7 ± 2.4	18.7 ± 8.9	33.0 ± 7.1
Active layer depth, cm (2012–2017 yy.)	> 300	115–190	56–93	33–45
Source: Authors' own work.				

The data show that as the position in the relief changes from the valley side to the depression and/or the soil texture changes from sandy to clay, the active layer depth decreases. This is connected with the drainage weakening and the occurrence of moisture stagnation in this row. The rapid runoff of moisture in well drained soils intensifies the initially higher thermal conductivity of the solid phase of sandy soils compared to clayey soils [11], as a result of which the thermal regime of sandy, well-drained soils contrasts more than do clay soils (Figure 2(a)).

Sandy soils warm up in the summer faster than clay soils: under the cryolithozone forest-tundra conditions, this leads to a deeper active layer. Under such conditions, mainly open forests with a predominance of *Larix sibirica* are formed. In contrast, with poor drainage and moisture stagnation slight thawing occurs, and plant communities are formed with the predominance of *Betula nana, Ledum decumbens, Ledum palustre, Rubus chamaemorus* and *Eriophorum medium*, accumulating peat horizons of considerable thickness in the soils. The latter, in turn, strengthens moisture stagnation and serves as a thermal insulator (Figure 2(b)), further increasing the contrast between the thermal conductivity of the studied soils. Living phytomass also serves as an effective thermal insulator.

Thus, the composition of vegetation is quite clearly determined by the conditions of drainage. Woody (mainly larch) communities are confined to sandy soils and dissected reliefs with a good drain base. Mottled-medallion tundra is formed on sandy soils, while less dissected relief, mottled-medallion tundra is formed on the same elements of the relief, but on clay soils. Peat communities prefer depressions of the relief on clay rocks.

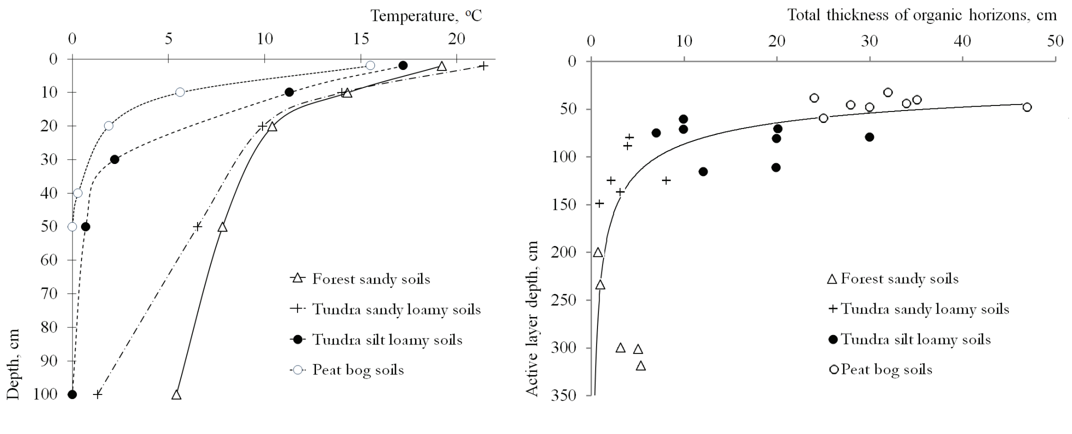

Figure 2: Temperature profile of the standard monitoring site soils (average values for July 2017 at 1 pm) and the relationship of active layer depth with soil organic horizon thickness. Source: Authors' own work.

4. Conclusion

Stable links between types of plant communities and edaphic factors have been established for the forest-tundra of the western part of the West Siberian plain. The edaphic components of the forest-tundra are extremely diverse in the landscapes under study, which is expressed in a variety of soil types and in the depth of the active layer: this is primarily due to the mesorelief and the texture of the soil-forming rocks. These factors determine the value of the territory's drainability, and, as a consequence, the vegetation community. In turn, vegetation through feedbacks largely determines the depth of the active layer due to the thickness of the organogenic horizons (peat) and the amount of phytomass, primarily mosses. For the purposes of remote permafrost monitoring and predicting its condition, the existing landscape diversity can be simplified to the four most typical and easily identifiable vegetation types (larch open forests, mottled-medallion lichen tundra, hilly tundra dwarf shrub-moss tundra and flat-knob bogs) contrasting in terms of the latent edaphic components.

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