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The Living Ground Cover of Mountain Tundra in the Northern and Southern Urals During an Invasion of *Juniperus sibirica*

S. U. Sokovnina[1], O. V. Erokhina[1], and D. V. Veselkin[1,2]

[1]Institute of Plant and Animal Ecology, Ural Branch of the Russian Academy of Sciences, 620144 Ekaterinburg, Russia
[2]Institute of Natural Sciences and Mathematics, Ural Federal University, 620002 Ekaterinburg, Russia

Abstract

In this work, the authors estimate the species abundance and the characteristics of ground cover (herb-dwarf-shrub and moss-lichen layers) structure in mountain tundra communities. They study mountain tundra communities that have significant differences in the degree of *Juniperus sibirica* Burgsd cover. Species richness and the abundance of plants were estimated on 40 plots (10x10 m) in mountain tundra communities of the Northern (the Kvarkush ridge) and Southern (the Zigalga and Nurgush ridges) Urals. Study plots were chosen with different degree of *J. sibirica* coverage, from lack of cover to dominance: the groups were 0%, 30–40% and 80–95%. *J. sibirica* invasion of mountain tundra communities in the Northern and Southern Urals has led to a decrease in the abundance of herbs and mosses on plots dominated by *J. sibirica*. The authors could not reveal other changes in the mountain tundra structure caused by the *J. sibirica* invasion. The α-biodiversity of plants and lichens and the ratio of functional and ecological plant groups do not depend on the degree of *J. sibirica* cover.

Keywords: shrubs, tundra communities, herb-dwarf-shrub layer, lichens, forest upper limit

Corresponding Author:
S. U. Sokovnina
sokovnina_su@ipae.uran.ru

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1. Introduction

A common trend in the Ural Mountains and other regions was a considerable expansion of woody and shrub vegetation into mountain tundra communities in the 20th and the beginning of the 21st centuries [1, 2]. However, areas covered by mountain tundra communities are quite small in the Northern and Southern Urals [3]. This expansion of woody and shrub vegetation may have grave consequences. Thus, studies into woody

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plants on the upper limits of mountainous terrain are already numerous, but research into shrub vegetation dynamics is not comprehensive [4, 5]. The invasion of deciduous trees and shrubs leads to changes in tundra communities [6–8]. Microclimatic conditions change under the shrub cover. The shrub layer keeps the snow cover longer, decreases the influence of wind and shades the ground surface: as a result, air and soil humidity increase [8, 9].

Juniperus sibirica Burgsd. shrubs form the upper limit of woody vegetation on the western slope of the Ural Mountains. The biotic effects of *J. sibirica* have not been studied before. We suggest that the invasion of *J. sibirica* into mountain tundra communities may be the cause of changes in the abundance of vascular plant and lichens. It may also change the ecological structure of tundra communities, possibly by causing an increase in the abundance of mesophytes.

The aim of our investigation is to evaluate the abundance and structural features of the living ground cover (herb-dwarf-shrub and moss-lichen layers) in mountain tundra communities with different degree of *J. sibirica* cover in the Northern and Southern Urals.

2. Methods

2.1. Area

Mountain tundra communities of the Northern (the Kvarkush ridge) and Southern (the Zigalga and Nurgush ridges) Urals were researched. The characteristics of the Kvarkush ridge: flat top of mountain in the upper reaches of the Zhigalan -2 (N 60°08′; E 58°44′); 880–933 m above sea level; rock percentage cover 1–40%; lichen-moss-herb tundra. The characteristics of the Nurgush ridge: mountain Northern (Big) Nurgush (N 54°48′; E 59°08′); 1300–1336 m above sea level; southern-eastern slope 3–5°; rock percentage cover 1–20%; moss-herb tundra. The characteristics of the Zigalga ridge: mountain Poperechnaya (N 54°39′; E 58°39′); 1257–1293 m above sea level; southern-eastern slope 3°; rock percentage cover 2–25%; lichen-herb tundra.

2.2. Study plots and relevés

Study plots were chosen with different degree of *J. sibirica* cover. There were three groups of *J. sibirica* abundance from lack of cover to dominance: 0% (sign *J. sibirica* 0); 30–40% (*J. sibirica* +) and 80–95% (*J. sibirica* ++). Study plots were chosen at random.

The plots did not have common boundaries. Study plots were 100 square meters. We used 3–8 special plots (0.625 square meters) for moss-lichen synusie characteristics [10].

We estimated the number of vascular plant and lichen species on each study plot (species density) and the percentage cover of the herb-dwarf-shrub layer (vascular plants), mosses and lichens. Vascular plant and lichen species abundance was evaluated via the Drude scale. We estimated rock percentage cover on each study plot. We conducted fieldwork during June and July in 2016 and 2017: the Kvarkush ridge – the first 10-day period in July 2017; the Nurgush ridge – the last 10-day period in June 2017; and the Zigalga ridge – the last 10-day period in June 2016. The number of relevés were: the Zigalga ridge – 18 plots and 47 special plots; the Nurgush ridge – 12 and 47; the Kvarkush ridge – 15 and 79.

2.3. Data analysis

We analyzed the following data: (i) the common abundance of each layer and species richness (species density – number of vascular plants, mosses and lichens on each plot); (ii) the abundance of different functional and ecological groups.

The functional groups of vascular plants were: (i) forbs; (ii) grasses; and (iii) others (*Diphasiastrum*, *Dryopteris*, *Empetrum*, *Rubus*, *Vaccinium* species). The ecological groups of vascular plants were: (i) psychrophyte; (ii) mesophyte; and (iii) hygrophyte. The lichen morphological groups were: (i) shrub-fruticose (*Cladonia* sp.); (ii) tubulose (*Cladonia* sp.); (iii) cup-shaped (*Cladonia* sp.); (iv) foliose (*Peltigera* sp.); and (v) others (*Cetraria* sp.; *Cladonia* sp.; *Flavocetraria* sp.).

The Drude data abundance of each plant and lichen species was converted into a percentage: 0 – 0%; un – 0.1%; un-sol – 0.4%; sol-un – 0.7%; sol – 1%; sol-sp – 3%; sp-sol – 5%; sp – 7%; sp-cop$_1$ – 11%; sp-cop$_{1-2}$ – 15%; cop$_1$ – 20%; cop$_{1-2}$ – 27%; cop$_{1-3}$ – 35%; cop$_2$ – 40%; cop$_3$ – 65%; soc – 90%. Afterward, we counted total percentage cover of vascular plants and lichens and also the cover portion of different groups of vascular plants and lichens in the total cover.

We used general linear models (*GLM*) for statistical analysis. We used a scheme with discrete and continuous predictors, factor interaction and hierarchically nested effects. The discrete factors were: (i) *J. sibirica* percentage cover (*J. sibirica* 0; *J. sibirica* + and *J. sibirica* ++); (ii) area (the Northern or Southern Urals); (iii) 'mountain' (Kvarkush, Nurgush, Poperechnaya) was a nested predictor within area; and (iv) *J. sibirica* – area interaction. The continuous factors were: (v) altitude above sea level; (vi) rock percentage cover. We state the mean ± standard error. We used STATISTICA 10.0 for analysis.

3. Results

We detected 23 vascular plant and 43 lichen species in the Northern Urals (the Kvarkush ridge). There were 30 vascular plant and 33 lichen species on the Nurgush ridge, and 38 and 23 species, respectively, on Poperechnaya Mountain in the Southern Urals. So γ-biodiversity of vascular plants is higher in the Southern Urals then the Northern Urals. However, lichen γ-biodiversity is much higher in the Northern Urals. Vascular plant species density varies from 9 to 15 species per 100 square meters (Table 1). Lichen species density is 5–11 species per plot (Table 1). The range of vascular plant percentage cover is about 68–77% on plots with *J. sibirica* 0–40% cover. Plots with *J. sibirica* dominance are characterized by 20–34% vascular plant cover. The abundance of mosses and lichens decreases as one moves from the Northern to the Southern Urals.

The estimations of the main variability factors that lead to plant community structure change are presented in Table 2. The abundance of the herb-dwarf-shrub layer depends on *J. sibirica* percentage cover. Moss percentage cover is affected by *J. sibirica* abundance. The common tendency for moss cover is to decline on plots with *J. sibirica* dominance. However, an important feature is that the moss cover has a significantly different response to *J. sibirica* abundance in the tundra communities of the Northern and Southern Urals.

Lichen species abundance depends on abiotic (altitude above sea level and rock percentage cover) and geographical (area and mountain) conditions. All of these factors do not have any effect on the α- biodiversity (species density) of vascular plants and lichens. The ratios of different functional and ecological groups of vascular plants and morphological and ecological groups of lichens are independent of biotic, abiotic and geographical factors (we do not demonstrate these tundra community parameters in Table 2).

The upper shift of woody vegetation in different parts of the Ural Mountains is connected with *J. sibirica* invasion into tundra communities. This process leads to a decrease in vascular plant and moss abundance on plots with *J. sibirica* dominance. However, the reorganization of the internal structure of mountain tundra communities during *J. sibirica* invasion was not detected. We could not determine the relationship between the ratio of different groups of plants and lichens and *J. sibirica* percentage

Table 1: Abundance and species richness of living ground cover in Ural mountain tundra communities with different percentage cover of *Juniperus sibirica* (m ± SE).

J. sibirica Percentage Cover	Percentage Cover, %			Species Number on 100 m^2	
	Vascular Plants	Mosses	Lichens	Vascular Plants	Lichens
The Northern Urals, Kvarkush ridge					
J. sibirica 0	68.0 ± 7.3	70.0 ± 4.5	10.0 ± 1.6	10.2 ± 1.2	8.6 ± 1.5
J. sibirica +	56.0 ± 5.1	64.0 ± 6.0	12.0 ± 1.2	9.6 ± 0.8	9.4 ± 1.5
J. sibirica ++	34.0 ± 2.4	40.0 ± 5.5	9.8 ± 1.8	8.8 ± 0.4	11.4 ± 1.3
The Southern Urals, Nurgush ridge					
J. sibirica 0	67.5 ± 9.2	35.0 ± 11.9	3.0 ± 2.3	13.0 ± 1.1	5.3 ± 1.9
J. sibirica +	65.0 ± 2.9	38.8 ± 10.1	5.8 ± 4.8	15.0 ± 0.4	7.8 ± 0.8
J. sibirica ++	23.8 ± 5.9	30.5 ± 10.4	2.8 ± 0.9	13.5 ± 1.2	8.3 ± 0.5
The Southern Urals, Poperechnaya mountain					
J. sibirica 0	76.7 ± 2.1	1.3 ± 0.8	8.7 ± 3.4	12.5 ± 1.2	7.0 ± 2.4
J. sibirica +	71.7 ± 3.1	3.0 ± 1.6	7.8 ± 2.1	10.8 ± 1.1	6.2 ± 1.7
J. sibirica ++	19.5 ± 9.0	5.5 ± 2.1	7.5 ± 2.1	11.5 ± 0.8	8.8 ± 1.9
Source: Authors' own work.					

cover. We cannot demonstrate significant differences of plant and lichen α-biodiversity on plot with various degree of *J. sibirica* cover.

Thus, our hypothesis is partially true that *J. sibirica* invasion leads to a decrease in vascular plant abundance. However, the hypothesis that *J. sibirica* invasion is the cause of the overgrowth of mesophyte plants in tundra communities is partially wrong.

Our results about the lack of influence of *J. sibirica* on the structure of Ural mountain tundra communities agree with the conclusions of some other researchers. These results demonstrate that shrub invasion does not have any influence on the herb-dwarf-shrub layer [11, 12]. However, in some cases the invasion of deciduous shrubs leads to an increase in the height and abundance of vascular plants and a decrease in total species biodiversity and moss and lichen abundance [6–8].

One of causes behind the weak reaction of mountain tundra communities to *J. sibirica* invasion may be their mosaic structure. Equally, different community components respond to environmental changes in different ways and at different rates. Generally, biotic ecosystem components respond to global changes more slowly than they do to abiotic components [11]. Also, the lack of plant community structure change on plots with various degree of *J. sibirica* cover may be caused by short-term invasion. The studied mountain tundra communities of the Northern and Southern Urals still retain their original features and characteristics. Significant differences in the moss and

Table 2: Value *F*-test in *GLM* and significance (*P*) of variation sources of living ground cover abundance and species richness in tundra communities in the Ural Mountains.

Variation Sources	Index	Percentage Cover, %			Species Number	
		Vascular Plants	Mosses	Lichens	Vascular Plants	Lichens
Juniperus sibirica percentage cover (dF = 2) [1]	*F*	37.22	4.51	1.29	0.43	0.60
	P	< 0.0001	0.0179	0.2882	0.6509	0.5542
Area (dF = 1) [2]	*F*	1.04	3.79	12.61	3.18	0.24
	P	0.3150	0.0593	0.0011	0.0828	0.6271
Interaction [1]×[2]	*F*	1.68	4.34	0.32	3.09	0.03
	P	0.2012	0.0206	0.7300	0.0576	0.9730
Mountain # (dF = 1)	*F*	0.18	9.02	15.37	5.41	0.09
	P	0.6782	0.0048	0.0004	0.0257	0.7690
Altitude above sea level ## (dF = 1)	*F*	0.99	1.86	11.36	1.43	0.14
	P	0.3267	0.1806	0.0018	0.2402	0.7145
Rock percentage cover ## (dF = 1)	*F*	1.86	0.96	6.04	1.17	1.13
	P	0.1814	0.3346	0.0190	0.2862	0.2956

Source: Authors' own work.

Notes. # in *GLM*, the factor 'Mountain' was hierarchically nested in the factor 'Area'; ## in *GLM*, these factors were analyzed like covariates without an estimation of interaction.

Source: Authors' own work.

lichen percentage covers of the tundra communities on each mountain demonstrate the preservation of their typical features and characteristics [3].

4. Conclusion

Juniperus sibirica invasion into mountain tundra communities of the Northern and Southern Ural leads to a decrease in vascular plant and moss abundance on plots with *J. sibirica* dominance. However, distinct changes in plant community structures after the invasion of *J. sibirica* are not demonstrated.

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