

# Diversity of *Pinus sibirica* forest types in different bioclimatic sectors of Sayan Mountains

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**Abstract.** The typological diversity of the three climatic facies of Siberian pine forests is considered in various bioclimatic sectors of the Priensiseysky Sayans. In each of the Sayan bioclimatic sectors, Siberian pine forests have a number of characteristic features of floristic composition and phytocenotic structure, restoration-age dynamics, productivity, and renewal process.

## 1 Introduction

The Siberian pine forests of the Western and Eastern Sayans are currently studied typologically, thanks to the works of Russian researchers, including botanists of Siberia [1-4]. A big step was taken at the end of the 20th and the beginning of the 21st centuries with the introduction of forest typological schemes to forest management, which was done by employees of academic institutes in Novosibirsk, Tomsk, Krasnoyarsk [5,6]. Databases on the biodiversity of Siberian pine forests have been created, and this allows us to study the diversity and natural relationships of Siberian pine forests in the Altai-Sayan Ecoregion at modern level [2, 7-10]. As one of the results of this work, based on the field materials of the authors and forest inventory materials, we consider the laws that govern the geography and dynamic trends in the formation of mountain dark coniferous forests after disturbances and anthropogenic interventions in the vast territory of the Priensiseysky Sayan Mountains. The typological diversity of the three climatic facies of Siberian pine forests represented in various bioclimatic sectors of the Priensiseysky Sayans is considered. The spectra of the mountain belt complexes (ABC) and the data of forest inventory based on the typology proposed by the Forest Institute of the SB RAS in 2006–2015 are analyzed with use statistical methods.

## 2 Siberian pine forests of Sayan in various bioclimatic sectors

The Siberian pine forests of the Western and Eastern Sayans are characterized by high floristic and typological diversity, in spite of composition of forest tree species is poor. In addition to Siberian pine, only 3-4 coniferous species (*Abies sibirica*, *Larix sibirica*, *Picea*

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*obovata*, *Pinus sylvestris*) are involved in the composition, with the latter 2 species being much less common in mountain Siberian pine forests compared to the plains of West Siberia. Of the small-leaved ones *Betula pendula*, *B. pubescens*, *Populus tremula* are included in the tree layer in case of disturbances by fires, logging, invasion of insect pests.

The main variety of floristic composition is revealed in the herb- shrub layer: 506 species in the dark coniferous forests of Yenisei Siberia, the smaller one is in the undergrowth (16), and moss layer is presented on the range of Siberian pine forests with the same composition of 3-7 dominant species and rarely more than 15 species else, with the participation of nemoral species.

The wide amplitude of the geographical and ecological range of Siberian pine in the Sayan Mountains allows us to distinguish within Sayans three bioclimatic sectors that differ in terms of continentality and moisture, the ratio of heat and moisture availability [8,9]: super-moist, moist, and moderately moist (or perhumid, humid and semi-humid according to Holdridge, 1967). In each of the Sayan bioclimatic sectors, Siberian pine forests have a number of characteristic features of floristic composition and phytocenotic structure, restoration-age dynamics, productivity, and renewal process [3,5,7,10]. Typological features of the Siberian pine forests in these various bioclimatic sectors will be briefly described below.

**The super-humid group of regions** (climate is perhumid and superhumid by Holdridge, 1967 [11]) with dominance of Siberian fir and Siberian pine-fir forests from 350–500 m up to 1300–1600 m above sea level are the most humid windward slopes of Priesseyevsky Sayans faced to Minusinsk depression. It is the north-eastern part of West Sayan and the western and south-western part of East Sayan. Siberian pine forest types are situated in the mountain chern ABC, the mountain-taiga perhumid ABC and in the subalpine ABC.

The main groups of forest types in the chern ABC are *Pinus sibirica* -and -*Abies sibirica* stands with large ferns and forbs. The bush layer is well developed (5-15%, with dominance of *Padus avium*, *Sorbus sibirica*, *Ribes nigrum*, *Ribes atropurpureum*, *Salix caprea*, *Spiraea chamaedryfolia*, *S. media*, *Caragana spp.*). The tree layer is composed of old-aged *Pinus sibirica* trees and various-aged *Abies sibirica*. The lower layer of ferns, tall herbs and grasses (70-95%, h =130-200 cm) is composed by large ferns (*Matteuccia struthiopteris*, *Athyrium filix-femina*, *Dryopteris carthusiana*, *D. filix-mas*, *D. expansa*, and *D. dilatata*), large herbs and forbs (*Aconitum septentrionale*, *Heracleum dissectum*, *Angelica sylvestris*, *Pleurospermum uralense*, *Crepis sibirica*) and grasses (*Calamagrostis langsdorffii*); boreal taiga species (*Oxalis acetosella* and others ); mesic herbs and grasses (*Pulmonaria mollis*, *Melica nutans*, *Milium effusum*, *Setellaria bungeana*), nemoral species (*Anemone baicalensis*, *Brunnera sibirica*, *Cruciata krylovii*, *Galium odoratum*) (45-60 species per 200 m<sup>2</sup>). A synusia of spring ephemerooids (*Anemone altaica*, *Anemone reflexa*, *Corydalis bracteata*, *Viola mirabilis*, *Viola uniflora* and others) are the feature of the spring season. Moss cover is poorly developed, but specific in composition, with the participation of nemoral species (*Plagiomnium cuspidatum*, *Cirriphyllum piliferum*, *Drepanocladus sp.*, *Mnium sp.*, *Bryum sp.* *Rhodobrium roseum*, *Climacium dendroides*), and *Rhytidiadelphus triquetrus*, *Rhytidiadelphus squarrosus*.

The *Pinus sibirica* -and -*Abies sibirica* forest types of the perhumid mountain taiga differ from the chern forest due to their structure (high density of stands, III-IV class of quality) and composition . The boreal taiga species absolutely dominate (*Calamagrostis obtusata*, *D. expansa*, *D. dilatata*, *Equisetum pratense*, *E. sylvaticum*, *Carex macroura*, *Oxalis acetosella*, *Thelypteris phegopteris*, *Cystopteris sudetica*, *Gymnocarpium dryopteris*, *Circea alpina*, *Cerastium pauciflora* and others (10–40 species per 200 m<sup>2</sup>) The only species of dwarf-shrubs is *Vaccinium myrtillus*. Among the other mountain taiga elements the lithophile *Bergenia crassifolia* is remarkable. The moss layer is well

developed and composed by *Hylocomium splendens*, *Pleurozium shreberii*, *Ptilium crista-castrensis*, *Rhytidiadelphus squarrosus*, *Plagiomnium cuspidatum*, *Mnium sp.*

Subalpine and subgoletz Siberian pine-and-Abies forest stands and open woodlands are characterized by lower layers of subalpine meadow-and-forest herbs and grasses as well as specific layer of shrubs (*Betula rotundifolia*, *Lonicera altaica*, *Rhododendron aureum* locally *Salix* spp. The species richness is high, 40-60 species per 200 m<sup>2</sup>.

**The humid climatic facies (B)** of taiga is mainly dark coniferous one, with a predominance of Siberian pine forests (from 600 to 1400–1600 m above sea level). They are located in the axis part of Western Sayan and in the bordering axis part of Eastern Sayan. Cyclonic activity here contributes to the formation of a climate with fairly high moisture supply and moderate continentality in the middle and high mountains, where the ABC complex is formed with a predominance of Siberian pine at altitudes of more than 700 m.

In the mountain-taiga ABC complex (700-1500, up to 1600 m) the Siberian pine forests are of III-IV class of quality. The ecosystems with some participation of *Abies sibirica* and *Picea obovata* form a wide belt, but locally, in contact with light coniferous subaiga belt, there is an admixture of larch, pine, and birch, due to frequent fires. An undergrowth is formed by *Sorbus sibirica*, *Lonicera altaica*, *Duschekia fruticosa*, *Spiraea media*, *Rubus ideaus*, in some places by the *Rhododendron ledebourii* and other species.

In different types of habitats (sites), different species of dwarf-shrubs dominate depending on moisture and soil richness, stony substrates, and other factors: *Vaccinium uliginosa*, *Ledum palustre*, *V. vitis-idea* but *V. myrtillus* is the main species among them; *Bergenia crassifolia* combines frequently with *Vaccinium myrtillus* in places of stony substrates; sometimes *Lycopodium annotinum*, *L. complanatum*, *Equisetum scirpoides*, *E. pratense*, and psichrophites small sedges *Carex iljini*, *C. globularis* (12-25 species per 200 m<sup>2</sup>).

The moss layer is strongly developed (60–95% moss pillow thickness is 8-10, up to 25-30 cm), composed of typically taiga species: *Pleurozium shreberii*, *Hylocomium splendens*, *Dicranum polysetum*, *D. scoparium*, *Ptilium crista-castrensis*, *Polytrichum commune*, *P. strictum*, etc. Lichens do not play meaningful role in *Pinus sibirica* old-aged taiga due to the surface (ground layer) is overlapped by dead stems and branches of trees, bushes and other mort organic mass.

Ecotone mountain taiga - mountain tundra forming the upper limit of forest (1600–1800 m above sea level) is composed by so called subgoletz-taiga forests and woodlands or pure subalpine Siberian pine woodlands without any mixture of the other tree species. The lower layers are dwarf-shrub-moss (with *Vaccinium myrtillus*, *V. uliginosa*, *Ledum palustre*), yernics (*Betula rotundifolia*), shrubbery (*Rhododendron aureum*), and lichen-moss and lichen moss. These forest types are combined with communities of mountain tundra, yernics, crumholtz and subalpine meadows.

**A moderately humid climatic facies of dark coniferous ecosystems** is represented in the **moderately humid** group of mountain taiga-forest-steppe regions [8] dominated by Siberian larch and Siberian pine forests (1200–2100 m above sea level). They occupy the southern macroslopes of the Western and Eastern Sayan ridges. The expositional asymmetry of landscapes is clearly expressed here due to a more continental and drier climate. Mountain taiga Siberian pine forests (with a mixture of *Larix sibirica* and *Picea obovata*) grow on the northern mesoslopes from heights of more than 900-1400 m above sea level and rise to abs. heights of 1700 m, keeping an admixture of larch up to 1-7 units of composition in stock. Comparing to above considered forest ecosystems these are the new ones, often post-fire, even-aged, less productive (IV-Va class of quality). At the same time, dominant species of the lower layers are similar to the previous Siberian pine forest types of the moist facies. The distribution of hypoarctic species of mosses and shrubs, *Betula rotundifolia*, and even sphagnum forest types is associated with permafrost, which is

developed more widely than in the forests of the humid facies. The undergrowth is unevenly developed (*Rhododendron ledebourii*, *Duschekia fruticosa*, *Lonicera altaica*, *Spiraea media*, etc.). The on-ground cover (40–80%) is formed from taiga dwarf-shrubs and grasses (*Vaccinium vitis-idaea*, *Pyrola incarnata*, *Linnaea borealis*, often *Calamagrostis pavlovii*, *C. obtusata*, *C. langsдорffii*) (10–30 species on 200 m<sup>2</sup>). Coverage of moss synusia is 30–100% (*Pleurozium shreberii*, *Hylocomium splendens*, *Dicranum spp.*, *Rhytidium rugosum*, *Aulacomnium palustre*).

The subalpine-taiga Siberian pine forests (often with a mixture of *Larix sibirica* and *Picea obovata*) can be distinguished as a special class of ABC. They are widespread in the moderately humid group of regions, sometimes penetrating into the insufficiently moist (semihumid) regions of Tuva over high watersheds and occupying heights from 1600–1800 to 2000–2100 m above sea level in the Prienisseysky part of Sayan.

At the upper boundary, which occasionally reaches 2200–2300 m above sea level, the yernik-moss, yernik-lichen, shrub-and-sedge, and grass-moss woodlands dominate. The local soil factors (rockiness, hydrothermal regime of substrates in high-mountainous landscapes) are especially powerful in extreme conditions and determine the differences between communities of Siberian pine forest types.

### 3 Conclusion

Typological diversity of Siberian pine forest ecosystems may be classified in three climatic facies each of them to be recognized by dominant species and life forms of the lower layers. The specificity of the species composition of the lower layers and the role of dominant species in various climatic facies of Siberian pine forests was characterized on the basis of our own information database with geobotanical descriptions for 1960–2019.

This work was supported by the Russian Foundation for Basic Research (18–05–00781 A).

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