Comparative analysis of the competition of stands of different species composition in relation to the Siberian stone pine undergrowth

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Abstract. Under the canopy of the parent native berry-green-moss Siberian stone pine forest and derivatives berry-green-moss pine and birch forests on the Urals, using the previously proposed complex of light, root, and integral competition indices of the stand, a comparative analysis of the parameters of the Siberian stone pine undergrowth is carried out. Under the canopy of Siberian stone pine forest two main determining factors have a negative complex effect on the growth of the Siberian stone pine undergrowth: the light competition of the stand (the level of photosynthetically active radiation interception by its canopy) and, almost equal to it, the root competition for soil nutrition. Under the pine forest canopy with the combined negative effect of factors of light and root competition of the stand on the development of Siberian stone pine undergrowth, light competition is decisive. The effect of the root competition is less than almost two times. Under the birch forest canopy the main factor determining the development of Siberian stone pine undergrowth is the light competition of the stand. The connection with the root competition of stand is not expressed.

1 Introduction

The solution to the problem of sustainable forest reproduction is based on a comprehensive study of complex structural and functional relationships with external environmental factors and between all components of forest ecosystems. Until recently, when studying the processes of Siberian stone pine (*Pinus sibirica* Du Tour) regeneration and development of its forests, the main attention was paid to the number and vitality of its undergrowth and the parameters of the stand. In some cases, despite the heterogeneity and parcellar structure of forest ecosystems [1], only the average statistical parameters of environmental conditions, primarily the level of penetrating photosynthetically active radiation (PAR) were considered. Moreover, the lack of light caused by the interception of PAR by the canopy of the stand is considered the main determining factor in limiting the growth and development of all plants of the lower tiers in all forest ecosystems [2-5 et. al]. More intensive growth of Siberian stone pine undergrowth was repeatedly noted in the glades of stands than under the closed canopy, where it is in a depressed state [6-9 et. al.]. At the same time, the influence

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of root competition of stands (RSC) of different species composition for soil nutrition, which in some cases may be a priority [10, 11], was almost not considered.

The purpose of this work is a comparative analysis using the previously proposed and tested [10, 11] complex of indices of light (*Ilcs*), root (*Ircs*) and integral (*Irlcs*) competition of the stand against the Siberian stone pine undergrowth in the same type of forest growing conditions under the canopy of the native parental Siberian stone pine forest and of the derivatives pine and birch forests.

2 Materials and Methods

The study of the structural and functional relationships of Siberian stone pine undergrowth with the edificator tree stand on the microecosystem approach [12] was carried out on the border of the Middle and Northern Urals in the foothill-low-mountain part (250 m above sea level) of its eastern macroslope of the middle taiga subzone (Novolyalinsk forestry Sverdlovsk region). The test plots were established in relatively similar forest growing conditions of the berry-green moss type in the postfires native 220-year-old Siberian stone pine forest and in the derivatives 75-year-old pine forest and 70-year-old birch forest. A coupled accounting of the parameters of the stand, environmental conditions and 23-35-year-old Siberian stone pine undergrowth was carried out on 80–107 systematically placed circular registered plots with a radius of 7 m, with a model specimen of undergrowth in the center. As a model, a specimen without mechanical damage was selected, growing separately no closer than 2.5-3 m from other undergrowth or shrubs to exclude their influence [13, 14]. At each registered plot, the diameter of all trees at a height of 1.3 m, their height and distance from them to the model specimen of undergrowth in its center were determined. Using the LinTab-6 equipment, the cores taken from all trees on the plots with an age drill were used to determine their age and radial growth over the last five years, on the basis of which their average volume growth was calculated. For each model specimen of Siberian stone pine undergrowth the age, the main parameters and the average vertical increase of the terminal shoot over the last five years was determined. In the center of the plots during the most intensive growth period, the penetrating relative light intensity was determined using a luxmeter. The assessment of the stand competition in the centers of the registered plots was carried out according to the method developed by N.S. Sannikova [10-12] using the indices of light (*Ilsc*), root (*Irsc*) and integral (*Irlsc*) stand competition.

3 Results and Discussion

In the Siberian stone pine forest, the stand with an average height of 24 m (the sum of the cross-sectional areas (∑csa) is 39.5 m^2/ha), is dominated by *Pinus sibirica* trees (70%) with an average diameter of 40 cm at the height of 1.3 m. The proportion of *Picea obovata* trees and *Abies sibirica* trees with an average diameter of 22 cm at the height of 1.3 m does not exceed 20% and 10%, respectively. The pine forest stand with a height of 23 m (∑csa is 36.2 m^2/ha) is represented only by *Pinus sylvestris* (100%). The stand of a birch forest with a height of 23 m (∑csa is 21.6 m^2/ha) mainly consists of *Betula pendula* (90%), partly *Populus tremula* (10%) and singly *Pinus sylvestris*. Siberian stone pine undergrowth of different ages in the studied forests is equally found both in glades and under a closed canopy, where the penetrating PAR does not exceed 10-20%.

In the Siberian stone pine forest (Fig. 1a-c) a sharp twice decrease in the average of vertical increase of terminal shoots of Siberian stone pine undergrowth over the last five years is observed with an increase in the value of *Ilsc* (a decrease the penetrating PAR under the tree canopy) to 20 and of *Irsc* for soil nutrition in the range of values 0.04-0.06.

With a further increase in *Ilsc* in the range of 20-80 and in *Irsc* in the range from 0.04-0.05 to 0.15-0.17, the average growth of terminal shoots decreases from 7.8 to 0.5 cm/year (almost 15 times). In general, there is a negative relationship (R^2 = 0.54; p > 0.05) of the average annual growth of terminal shoots of undergrowth with the stand competition index for PAR (*Ilsc*) (Fig. 1a) and a close relationship (R^2 = 0.47; p > 0.05) with the RSC index (*Irsc*) for soil nutrition (Fig. 1b). At the same time, the tightness and reliability of the negative relationship (R^2 = 0.72; p > 0.05) of the average increase of terminal shoots with the complex index of integral stand competition (*Irlsc*) (Fig.1c), reflecting the combined influence of the factors of light and root competition, exceeds connections with these particular indices by 1.3–1.5 times. This is proved by the complex joint influence of these main factors, determine the growth and development of Siberian stone pine undergrowth.

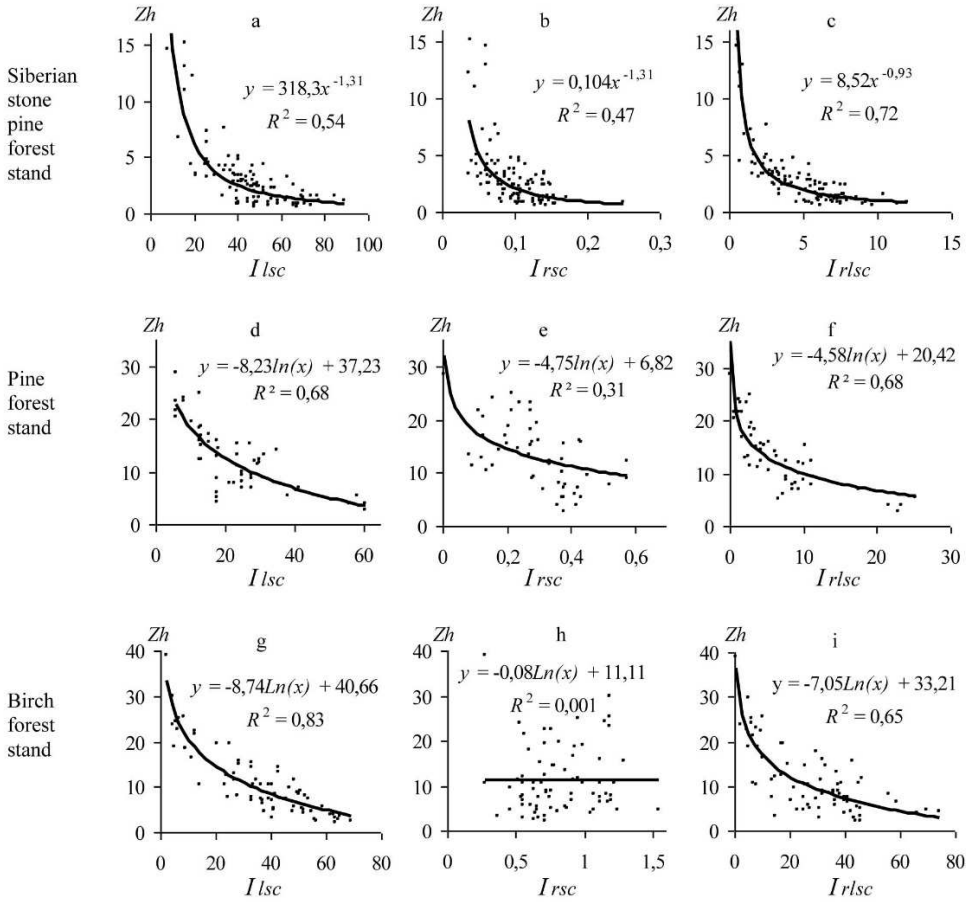

Fig. 1. Relationship of the parameters of the average annual vertical increase of terminal shoots (*Zh*, cm) of 23-35-year-old Siberian stone pine undergrowth with the indices of light (*Ilsc*), root (*Irsc*) and integral (*Irlsc*) competition of the tree stand-edificator

In the pine forest (Fig. 1d-f), with an increase in *Ilsc* in the range of 6-60 (Fig. 1d), a relatively smooth decrease in the average growth values of terminal shoots of undergrowth is observed by almost five times (from 24.3 cm to 4.1 cm). With an increase in the RSC index (*Irsc*) in the range of 0.1-0.6 (Fig. 1e), their average value is reduced only twice (from 16.3 cm to 8.3 cm). At the same time, the average increase of terminal shoots is more closely negatively associated (more than 2 times) with the light competition index (R^2 =

0.68; $p > 0.05$) than the root competition index ($R^2 = 0.31$; $p > 0.05$). The tightness of the negative relationship between the average increase of terminal shoots with the index of integral competition (*Irlsc*) of the derivative pine forest ($R^2 = 0.68$; $p > 0.05$) remains equal to the light one (Fig. 1f). At the same time, the trend line, as in the Siberian stone pine forest, has a steeper shape, which can clearly illustrate a certain joint influence of light and root competition factors, especially when the *Irlsc* value increases from 0.7 to 7, when the average growth sharply decrease from 24.3 cm up to 9.3 cm. Subsequently, in the range of its values of 7-25, the average growth gradually decreases to 4.1 cm (two times).

In the birch forest (Fig. 1g-i), as the *Ilsc* value increases with the closeness of the tree canopy from 2-10 to 69, there is also a relatively smooth decrease in the value of the average growth of terminal shoots of undergrowth by almost 8 times (from 24.6 cm to 3.1 cm). At the same time, there is a very close negative relationship ($R^2 = 0.83$; $p > 0.05$) between their average values with *Ilsc* for PAR (Fig. 1g), and the relationship with *Irsc* for soil nutrition is not expressed (Fig. 1h). The tightness of the relationship ($R^2 = 0.67$; $p > 0.05$) of the average increase of the terminal shoot of undergrowth with the empirical index of integral stand competition (*Irlsc*) (Fig. 1i), reflecting the combined influence of the factors of light and root stand competition, is almost 25% lower than the relationship with *Ilsc*, which is probably caused by the lack of connection with RSC.

Thus, depending on the species composition of the stand, there is a decrease in the role of its root competition in the development of Siberian stone pine undergrowth. With the same ranges of *Ilsc* values in all cases, the parameters of relatively the same-age Siberian stone pine undergrowth under the canopy of the parent native Siberian stone pine forest are 1.5-2.8 times less than in a pine forest and 1.6-3.2 times less than in a birch forest, where the RSC is not expressed (table). At the same time, the average parameters of undergrowth in a birch forest exceed those of undergrowth by 1.1-1.6 times in a pine forest. This can clearly illustrate the additional significant negative impact on the growth of Siberian stone pine undergrowth by the root competition of the parent stand and the weaker pine forest.

Table 1. General parameters of 23-35-year-old Siberian stone pine undergrowth under the canopy of forest stands at the corresponding values of index of light stand competition (*Ilsc*)

Ranges of *Ilsc* values	**%**	**10-15**	**30-35**	**55-60**
Siberian stone pine forest stand	*h* *Zh*	178±20.8 12.1±1.35	89±9.5 4.0±0.53	59±8.3 1.5±0.25
	Dc *dbs*	65 2.4±0.31	40 1.3±0.12	20 1.0±0.1
Pine forest stand	*h* *Zh*	270±15.5 16.8±0.93	197±7.0 10.2±0.84	101±11.8 4.4±0.46
	Dc *dbs*	100 4.1±0.26	70 3.4±0.24	45 1.6±0.17
Birch forest stand	*h* *Zh*	424±44.7 19.1±1.96	258±19.6 10.7±1.02	163±7.0 4.8±0.58
	Dc *dbs*	110 5.6±0.46	90 3.7±0.38	50 2.6±0.21

Note: *h* – average height of the undergrowth, cm; *Zh* - average vertical increase of the terminal shoot of the undergrowth over the last five years, cm; *Dc* – average diameter of the crown of the undergrowth, cm; *dbs* – average diameter of the stem base of the undergrowth, cm

4 Conclusion

Thus, in the conditions of intraspecies competition under the canopy of the parent green-moss Siberian stone pine forest, a joint relatively equal negative effect of root and light

competition of the stand on the growth of Siberian stone pine undergrowth is manifested. With the combined influence of the factors of light and root competition of the stand of a derived pine forest on the growth of Siberian stone pine undergrowth under its canopy, the decisive factor is the interception of PAR (light competition of the stand). The influence of the root competition of the pine forest for soil nutrition is expressed to a much lesser extent (almost two times). The main factor limiting the growth and development of Siberian stone pine undergrowth under the canopy of a derivative green-moss birch forest is a lack of light (penetrating PAR), and root competition for soil nutrition is not expressed. Perhaps, in the conditions of interspecies competition, due to its ecological characteristics, the Siberian stone pine undergrowth is in a certain way adapted to the conditions of pine forests and especially birch forests, which is expressed, among other things, in the absence of visible root competition of the stand in relation to it.

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