Changes in the Effect of Tree Stand Competition on the *Pinus sibirica* Undergrowth during Post-fire Successions in Mid-Taiga Birch Forests of the Urals

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Abstract. The effect of light and root competition of the tree stand on the growth of the *Pinus sibirica* Du Tour undergrowth in post-fire birch forests of different ages is investigated using the example of mid-taiga forests of the Middle Urals. The studies were carried out on the basis of a microecosystem approach, using indices of light competition of the tree stand (*Ilsc*), root competition of the tree stand (*Irsc*) and integral competition of the tree stand (*Irlsc*). At the stage of the 13-year-old young birch stand with almost full illumination, the main factor determining the growth and development of *Pinus sibirica* undergrowth is root competition for soil nutrition. In the 32-year-old middle-aged birch stand, a joint, almost identical, effect of the factors of light and root competition on the growth of *Pinus sibirica* undergrowth is observed. In the mature 70-year-old birch stand, the main factor, influencing the growth of *Pinus sibirica* undergrowth, is the level of interception of photosynthetically active radiation by its canopy (light competition) with root competition is not expressed. In our opinion, this is due to the adaptive abilities and characteristics of the soil nutrition of the *Pinus sibirica* undergrowth and a change in the degree of soil saturation with organic compounds during the development of the post-fire birch forest.

1 Introduction

The problem of plant community dynamics is one of the most pressing in modern forest ecology and forestry [1–5, etc.]. A significant number of works are devoted to the processes of regeneration of dark coniferous forests with the participation of *Pinus sibirica* Du Tour through the soft-leaf stage [6, 7, etc.]. The formation of derivative soft-leaf forest stands in place of native dark-coniferous forests is currently considered as the most promising direction and objective stage of their restoration [8, 9]. The soft-leaf forest stands themselves with an abundance of *Pinus sibirica* undergrowth under the canopy are considered as potential Siberian stone pine forests [7]. Presumably, the vast majority of

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post-fire Siberian stone pine forests in the Urals and Western Siberia have passed through the soft-leaf stage in their development. When studying the restoration of Siberian stone pine forests, the main attention was paid to the species composition, quantity and vitality of the woody plants undergrowth and other components, changes in the species composition and parameters of forest stands according to their developmental stages. In some cases, only average statistical parameters of environmental conditions were considered.

The purpose of this work is to analyse the changes in the factors of light and root competition in a post-fire berry-green moss birch forest stand with changing age in relation to the *Pinus sibirica* undergrowth.

2 Materials and Methods

The study of the structural and functional relationships of *Pinus sibirica* undergrowth with an edificator birch stand dominated by *Betula pendula* Roth was carried out in the middle taiga subzone of the northern foothills and low mountains (250 m above sea level) of the eastern macroslope of the Middle Urals (Novolyalinskoe Forestry, Sverdlovsk Region. 59ºN, 59ºE). The experimental plots, which are considered as elements of one genetic series of development of a potential Siberian stone pine forest [6], are located in post-fire berry-green moss birch forests of 13, 32 and 70 years of age. A combined assessment of forest stand parameters, environmental conditions and *Pinus sibirica* undergrowth was carried out on a series of circular registered plots. The radius of the registered plots is determined by the length of the lateral roots of the *Betula pendula* model trees in the stand of the corresponding age (Table 1). In the centre of the registered plot there is a model sample of *Pinus sibirica* undergrowth of a certain age (Table 1).

Table 1. Characteristics of trial plots.

Birch forest stand				R, m	N r.p.	A.m.s., years old	Z, years
Age, years old	Species composition	H, m	S, m^2/ha				
13	*Betula pendula* - 60% *Pinus silvestris* - 20% *Populus tremula* - 20%	2	-	1.5	50	10-11	3
32	*Betula pendula* - 70% *Pinus silvestris* - 20% *Larix sibirica* - 10%	10	11.4	3	47	25-30	5
70	*Betula pendula* - 90% *Populus tremula* - 10% *Pinus silvestris* - single	23	21.6	7	80	23-35	5

Note: H – average tree stand height, m; S - the basal area m^2/ha; R - radius of circular registered plots, m; N r.p. - number of circular registered plots on the trial plot; A.m.s. - age of a model specimen of *Pinus sibirica* undergrowth, years; Z - period of average vertical growth of the terminal shoot of undergrowth and the corresponding growth of trees by volume, years

In the 32- and 70-year-old birch forest, cores were taken from all trees it each circular registered plot, using an age drill. In a 13-year-old birch forest, cross-cuts were taken at the base of all tree stems. In addition, the distance from each tree to a model specimen of *Pinus sibirica* undergrowth sample was measured in each circular registered plot. The height and diameter of all trees were measured at a height of 1.3 m, and in a 13-year-old birch forest - at the base of the stem. At the same time, the penetrating relative photosynthetically active radiation (PAR) was measured with a luxmeter in the center of the registered plots and in the open place, during the period of most intensive growth in mid-June on cloudy days.

Using LinTab-6 equipment, radial growth was determined from the last 3 years of cross cuts, and the last 5 years of cores. Based on these results, the average volume growth of the trees was calculated. For each model specimen of *Pinus sibirica* undergrowth, the age was determined by the number of vertical increments of the terminal shoot, the height, the diameter of the crown and the stem base, and the average vertical increment of the terminal shoot over three or five years.

The assessment of the tree stand competition in relation to *Pinus sibirica* undergrowth in the centres of the circular registered plots was carried out according to the microecosistem approach developed by N.S. Sannikova [10] using a system of indices of light (*Ilsc*), root (*Irsc*) and integral (*Irlsc*) tree stand competition.

3 Results and Discussion

In the centre of most of the circular registered plots of a 13-year-old birch forest, the value of the light competition index of the stand (*Ilsc*) does not exceed 5%. This corresponds to almost full illumination. The index (*Ilsc*) reflects the degree of interception of photosynthetically active radiation (PAR) by the forest stand canopy. Under these conditions, the average value of the vertical growth of the terminal shoot of *Pinus sibirica* 10-11-year-old undergrowth over the last three years (*Zh*) varies in a wide range from 3 cm to 26 cm (Fig. 1a). Thus, with almost complete penetrating PAR, the effect of light forest stand competition (LSC) on the growth of the undergrowth is almost not expressed here (R^2 = 0.23). At the same time, with an increase in the values of the index of root competition (*Irsc*) of the young birch stand from 0 to 2, the average vertical growth of the undergrowth decreases smoothly from 19.7 cm to 4.8 cm (almost 4 times) (Fig. 1b). This is confirmed by the relatively close negative relationship (R^2 = 0.66) of the average terminal shoot growth with *Irsc*. The empirical index of integral forest stand competition (*Irlsc*) reflects the joint effect of the factors LSC and root stand competition (RSC) on soil nutrition. The closeness of the relationship values (R^2 = 0.35) of the terminal shoot growth with *Irlsc* (Fig. 1c) is almost 2 times lower than the relationship with *Irsc*. This is probably due to the almost complete absence of LSC.

In a 32-year-old birch forest, the joint relatively equal effect of the LSC and RSC factors on the growth of 25–30-year-old *Pinus sibirica* undergrowth is manifested. With an increase in the value of *Ilsc* in the range of 3–80 (Fig. 1d) and *Irsc* in the range of 0.6–5.8 (Fig. 1e), the average vertical growth of the terminal shoot (*Zh*) over the last five years decreases relatively smoothly by ten times (from 30 cm to 3 cm). At the same time, there is a slightly closer relationship (almost 1.2 times) with *Ilsc* (R^2 = 0.62) than with *Irsc* (R^2 = 0.52). The closeness of the negative relationship (R^2 = 0.68) of the average current annual vertical shoot growth value of the undergrowth with *Irlsc* is slightly higher (1.1–1.3 times) than the relationship with their partial indices (Fig. 1f). The trend line with an increase in the value of *Irlsc* from 2 to 29 has a steeper shape, when the average growth values decrease sharply from 36 cm to 18 cm (2 times). This can clearly illustrate a certain joint effect of the LSC and RSC factors. Then, in the range of *Irlsc* values 30–338, the average growth gradually decreases to 5 cm (three times).

In a 70-year-old birch forest, as the canopy density and the value of *Ilsc* increase from 2-10 to 69, the average vertical growth of the terminal shoots of the 23-35-year-old *Pinus sibirica* undergrowth over the last five years decreases relatively smoothly by almost eight times (from 24.6 cm to 3.1 cm). This is confirmed by the close negative relationship (R^2 = 0.77) of growth with *Ilsc* for PAR (Fig. 1g). At the same time, the relationship with *Irsc* for soil nutrition is not expressed (Fig. 1h). The closeness of the relationship (R^2 = 0.65) of the average growth of the terminal shoot of undergrowth with *Irlsc* (Fig. 1i) almost 25% lower than the relationship with *Irsc*. This is probably due to the absence of the RSC effect.

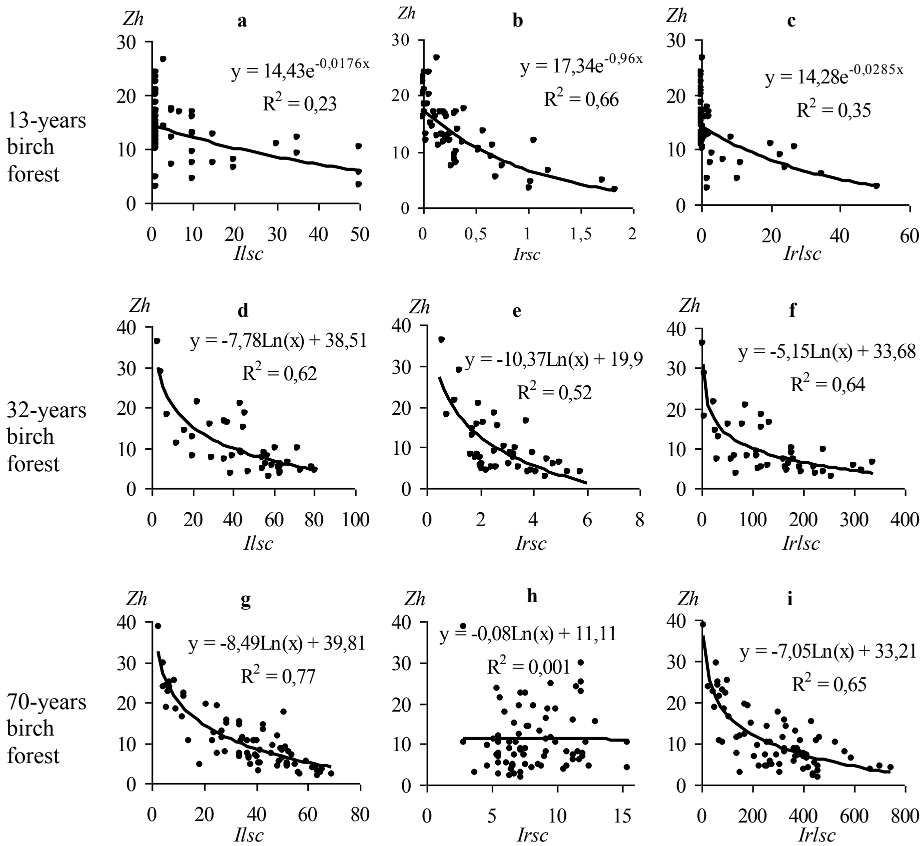

Fig. 1. Relationship of the average annual vertical growth of terminal shoots (*Zh*, cm) parameters of *Pinus sibirica* undergrowth with the indices of light (*Ilsc*) (**a, d, g**), root (*Irsc*) (**b, e, h**) and integral (*Irlsc*) (**c, f, i**) competition of green moss birch forest stands

We assume that the different degrees of RSC effect in the post-fire birch forest of different ages are caused by changes in the content of organic matter in the soil. The undergrowth of the *Pinus sibirica* successfully grows on the dead fallen tree stems, due to organic compounds formed during wood decomposition without soil mineral nutrition [11]. Birch roots are mainly located in the mineral horizons of the soil [12], and the root system of *Pinus sibirica* undergrowth is more superficial [13]. Perhaps, *Pinus sibirica* undergrowth under the canopy of a 70-year-old birch forest also has enough decomposition products of organic matter for its development in soil nutrition. In the event of a fire, the upper organic horizon of the soil is usually completely destroyed. It did not recover under the canopy of a 13-year-old birch forest. And in a 32-year-old birch forest, the organic content is apparently also insufficient. Soil nutrition of the *Pinus sibirica* undergrowth here, like that of the *Betula pendula* trees, is mainly mineral.

4 Conclusion

As the post-fire birch forest develops with its age, the effect of light forest stand competition (LSC) increases and that of root stand competition (RSC) decreases in relation to the *Pinus sibirica* undergrowth growing under the canopy. In our opinion, the different saturation of the soil with organic compounds may be the reason for the different effect of root competition of birch stands of different ages on the growth of *Pinus sibirica* undergrowth. Presumably, this may also be due to the different life strategies of the tree species, different zones and regimes of their soil nutrition, and the adaptive capacity of the *Pinus sibirica* undergrowth.

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