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## The problem of drying up spruce stands and ways to solve it

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**Abstract.** The last decades has been witnessed of the mass spruce stands drying up problem in different countries of the world. The investigation purpose consists in establishing influence of the growth conditions and the bark beetle, on the drying up of spruce forests. Forest stands of the coniferous-broadleaved (mixed) zone forests in Russian Federation served as an object of our research. Based on the results of the acts of pathologic inspection, it is established that the share of drying up spruce forests decreases with increasing soil fertility and moisture. The influence of the bark beetle was investigated on the basis of materials of three sample plots in stands of the green-moss spruce type of forest. We did not find traces of vital activities of the bark beetle by the drying spruce trees with a diameter at altitudes of 1.3 m to 14 cm fully, as well as with a diameter of 14 to 22 cm partly. The fact revealed is explained by the fact that these spruce trees have a thin bark which is not enough for the beetle laying inside of it the mother gallery, and the brood bark for subsequent feeding. The bark beetle is not the primary reason of the spruce forests drying in the Permsky Kray. It is necessary to conduct a much deeper study on this problem.

The last decades has been witnessed of the mass spruce stands drying up problem in different countries of the world [1-3]. This problem entails a multiplicity of negative environmental consequences: the reduction of biodiversity, the destruction of forest biocenosis, the landscape modification, the forested area reduction, the forest fire danger increase, the large volume loss of quality wood and the reduction of ecological functions by forest stands. The drying of spruce forests threatens to cause an ecological catastrophe.

Various authors give significantly different reasons for the drying of spruce forests. In particular, many authors note that reason of spruce forests drying is dry conditions [4-5]. At the same time, a some authors [6-7] note that the mass drying of spruce stands is bound with the reproduction of the bark beetle (*Ips typographus* (L.)). In the opinion of A.M. Mezhibovsky [8], the main reason of spruce forests drying is the degree of infection of the soil with a pine fungus (*Heterobasidion annosum* (Fr.) Bref.). Other authors [9-10] link the mass drying of spruce forests with to natural evolutionary rearrangements of forest ecosystems and their centuries-old dynamics. Thus, scientists have not a unified view about the reasons of spruce stands drying. However, the most scientists think that the reasons of spruce forests drying are dry conditions and reproduction of the bark beetle.

There is a mass drying of spruce stands (Figure 1) in the central part of the Russian Federation, in the zone of coniferous-broadleaved (mixed) forests of the Permsky Kray. Investigations have not been



to study the reasons of spruce stands drying in last years in the territory of the Permsky Kray [11]. This fact determined the line of our research.



**Figure 1.** Spruce forest drying in Permsky Kray.

The investigation aim consisted in establishing forest site type's and bark beetle impact on spruce stands drying up in condition of coniferous-broadleaved (mixed) forests zone of Permsky Kray.

Spruce stands on the territory of the Ochersky and Tchaikovsky forest districts of Permsky kray (European part of the Russian Federation) has served as our research subject [12].

The acts of pathologic inspection of the Ochersky forest district for the period from 2010 to 2016 years were analyzed in the process of the investigations. Spruce forest drying was recorded with acts of pathologic inspection. Moreover, forest management materials and materials of sample plots (SP) were analyzed.

Distribution of drying spruce stands were compared as a whole for forest district and for acts of pathologic inspection for each forest site type for the purpose of establishing of influence of the forest site type on the spruce stands drying.

In forest pathologic investigations sample plots have been laid according to generally used and approved methods [13]. There are three sample plots in even-aged spruce forests of green-moss spruce forest type. All spruce stands have a IV class age, a I productivity class, a medium crop density. All spruce stands are mixed, with a pine admixture.

Continuous counting of trees was made, the category of sanitary state of all trees was determined, presence or absence of bark beetle gallery was noted for fresh and old dead standing trees within each SP.

There are the following state categories of trees: healthy, weakened, strongly weakened, drying off, fresh and old dead standing trees.

The area of drying spruce forests increased for the researched period according to the materials of the acts of pathologic inspection (Table 1). So, if in 2010 in the Ochersky forest district 183.5 hectares of spruce stands have dried up that there are in 2015 already 1021.1 hectares.

**Table 1.** Drying greenish spruce stands of the Ochersky forest district.

Year of investigation	Number of investigated stratums, pcs	Area of investigated stratums, ha
2010	15	183.5
2011	13	124.6
2012	26	443.7
2013	59	924.3
2014	59	774.5
2015	67	1021.1
2016	41	884.4
Total	280	4356.1

The progressive increase of the area of drying spruce stands testifies to the need of multicenter investigations of the causes of drying spruce forests and the search of ways to minimize the damage caused.

Spruce stands are not on very dry and dry forest sites according to forest management materials in the Ochersky forest district of the Permsky Kray (Table 2). Fresh hygrotops predominate significantly (86.60%). The area of forest stands decreases with increasing soil moisture.

Relatively rich benign soils predominate (69.84%) in the forest resource of forest district. A relatively large proportion is occupied by relatively poor soils (almost 30%). Extremely poor soils make up only 0.1%.

**Table 2.** Forest stands distribution of the Ochersky forest district on nutrient status and moisture of soils.

Higrotops	Trofotops, ha/ %			
	Extremely poor (A)	Relatively poor (B)	Relatively rich (C)	Total
Fresh (2)	<u>25.1</u>	<u>51970.8</u>	<u>106779.1</u>	<u>158775</u>
	0.02	28.34	58.24	86.60
Moisty (3)	-	<u>1051.3</u>	<u>19623.5</u>	<u>20674.8</u>
		0.57	10.70	11.28
Muddy (4)	<u>80.7</u>	<u>1990.3</u>	<u>1657.2</u>	<u>3728.2</u>
	0.04	1.09	0.90	2.03
Wet (5)	<u>78.3</u>	<u>94.7</u>	-	<u>173</u>
	0.04	0.05		0.09
Total, ha/%	<u>184.1</u>	<u>55107.1</u>	<u>128059.8</u>	<u>183351</u>
	0.10	30.06	69.84	100

The results of the investigations showed that the spruce forests drying were found on soils of different degrees of moisture and fertility. However, about 97 % of drying spruce stands is forest stands of fresh forest site. The absolute majority of drying spruce stands has relatively poor and relatively rich growth conditions. It should be especially noted that the drying spruce stands are not recorded on very dry, dry and wet soils, as well as on extremely poor and richest soils (Table 3).

**Table 3.** Drying spruce stands distribution by nutrient status and moisture of soils.

Higrotops	Soils distribution by trofotops, ha/%		
	Relatively poor (B)	Relatively rich (C)	Total
Fresh (2)	<u>2280.4</u>	<u>1943.3</u>	<u>4223.7</u>
	52.35	44.61	96.96
Moisty (3)	-	<u>117.4</u>	<u>117.4</u>

		2.70	2.70
		<u>15</u>	<u>15</u>
Muddy (4)	-	0.34	0.34
	<u>2280.4</u>	<u>2075.7</u>	<u>4356.1</u>
Total, ha/%	52.35	47.65	100

The share of drying spruce forests on fresh soils, which are least provided with moisture, exceeds considerably the share of those in the forest district (more than 10%). This fact demonstrates that the risk of drying spruce stands increases with a decrease in soil moisture in extreme weather conditions in the conditions of the zone of coniferous-broadleaved (mixed) forests of Permsky Kray. Stability of spruce stands increases with an increase of soil moisture. The absence of drying spruce forest on very dry and dry soils is explained not to the increased stability of spruce under these conditions but to the absence of spruce stands.

The largest share of drying spruce forests (52.35%) is recorded on relatively poor soils. At the same time, the spruce forests share among the drying spruce stands growing on relatively poor soils exceeds by more than 20% the spruce forests share on analogous soils in the forest district as a whole. The share of drying spruce stands is reduced with increasing soil capabilities. The drying spruce stands are not on most rich soils.

It should be noted that analogous results were obtained by other scientists [15].

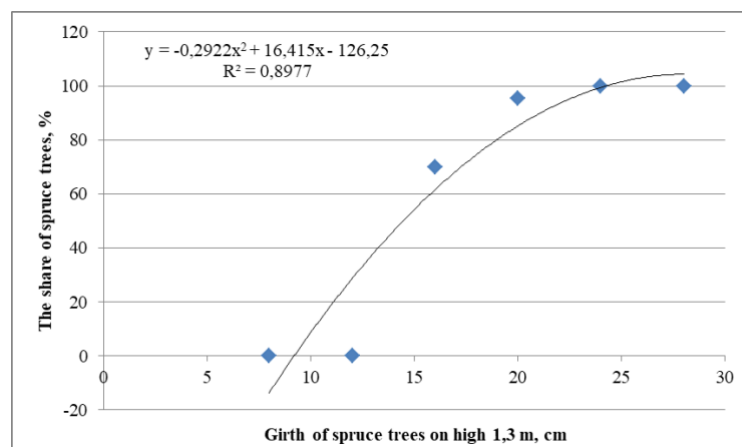
It was established when studying the influence of the bark beetle that the sanitary state of spruce is unsatisfactory generally in stands of all sample plots (Table 4). The stand volume of spruce dead standing trees varies from 38.8 to 61% in green-moss spruce stands.

**Table 4.** Stand volume of spruce trees distribution on sanitary state categories, m<sup>3</sup>/ha/%.

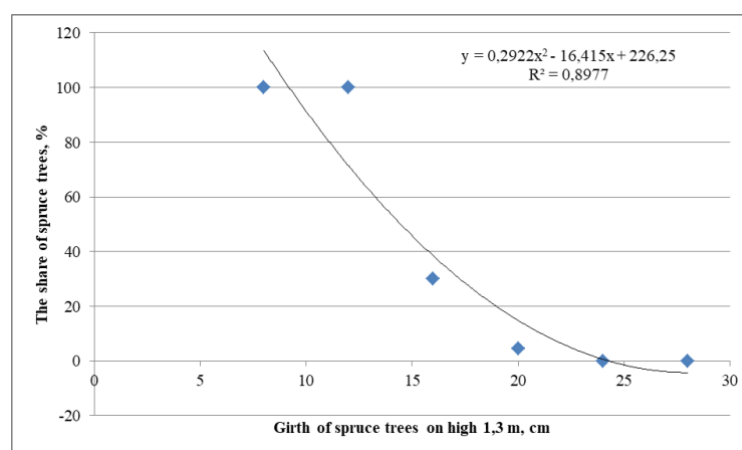
№ SP	Stand volume on sanitary state categories						Total
	Healthy	Weakened	Strongly weakened	Drying off	Fresh dead standing trees	Old dead standing trees	
11	<u>155</u> 51.7	<u>12</u> 3.8	<u>17</u> 5.7			<u>116</u> 38.8	<u>300</u> 100
12	<u>134</u> 22.5	<u>52</u> 8.8	<u>7</u> 1.1	<u>39</u> 6.6	<u>169</u> 28.3	<u>194</u> 32.7	<u>595</u> 100
15	<u>97</u> 49.8	<u>10</u> 5.3	<u>9</u> 4.6		<u>1</u> 0.4	<u>77</u> 39.9	<u>194</u> 100

However a significant share of fresh dead standing trees, as well as the presence of drying off trees on the sample plots 12, testifies that the drying of spruce forests continues in the coniferous-broadleaved forests of the Permsky Kray.

Data on the influence of the bark beetle on the drying of spruce trees in stands of a green-moss spruce forest are shown in Figure 2-3.



**Figure 2.** Share of drying spruce trees with bark beetle gallery in green-moss spruce stands.



**Figure 3.** Share of drying spruce trees without bark beetle gallery in green-moss spruce stands.

The results testify that the bark beetle attacks partially the spruce trees 16 and 20 cm diameter class, as well as all the trees of subsequent diameter class (Figure 4). The beetle never attacks spruce trees up to 14 cm in diameter (Figure 5). In our opinion this is explained to the fact that these trees have a thin bark, and the beetle does not have bark thickness for laying inside the mother gallery, and grub for subsequent feeding.

Number of trees, eaten by the bark beetle, increases with an increase of the girth trees. This dependence is described by formula

$$y = -0,2922x^2 + 16,415x - 126,25, \quad (1)$$

where  $x$  is the girth of the tree on high 1.3 m, cm;  $y$  is the share of trees stricken by the bark beetle, %. At the same time, the high value of the determination coefficient ( $R_2 = 0.889$ ) testifies a very strong correlation of the investigated indicators. The formula is just in the range of tree diameters on high 1.3 m from 6 to 26 cm.

Inverse relationship is observed by spruce trees without mines of bark beetle:

$$y = 0,2922x^2 - 16,415x + 226,25 \quad (2)$$

The formula is just with a determination coefficient  $R_2 = 0.889$  and the range of tree diameters on high 1.3 m from 6 to 26 cm.

All facts demonstrate that the bark beetle is not the primary reason of the drying spruce forests in the Permsky Kray.



**Figure 4.** Spruce old dead standing trees with the presence of bark beetle mines.



**Figure 5.** Spruce old dead standing trees without the mines of bark beetle.

Thus, the results obtained by us disprove the opinion of the majority of scientists about the impact of the bark beetle on the drying spruce forests. It is necessary to conduct complex investigations to determine the reasons of the drying spruce stands. It is necessary to attract various specialists, it is necessary appropriate financing.

### Conclusions

Progressive annual increase of drying spruce stands was noted in the coniferous-broadleaved (mixed) forests of the Permsky Kray. The forest site type impact was established on the drying of spruce trees. The stability of spruce trees increases to drying with increasing soil capabilities and moisture content of soil. The opinion of the majority of scientists has been refuted about the bark beetle impact on the drying spruce forests. The obtained data testify that the bark beetle is not the main reason of spruce

stands drying of the Permsky Kray. Complex investigations are needed to establish the reasons of drying spruce forests and to minimize the damage caused. It is necessary to attract various specialists, it is necessary appropriate financing.

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