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Original article

THE INFLUENCE OF THE TYPE OF FOREST AND THE TYPE OF FOREST GROWING CONDITIONS ON THE STABILITY OF SPRUCE STANDS IN THE ZONE OF CONIFEROUS-DECIDUOUS FORESTS OF THE PERM KRAI

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There has been a massive drying out of spruce plantations in recent years. Many versions about the cause of this phenomenon have been put forward by scientists. Despite the active study of the problem of drying out of spruce plantations around the world, a forest management system aimed at reducing the damage from drying out has not been developed yet. Important silvicultural indicators of plantations that can affect their stability are the type of forest growing conditions and the type of forest. The purpose of the study was to establish the influence of the type of forest and the type of forest growing conditions on the resistance to drying out of spruce forests growing in the zone of coniferous-deciduous forests of the Perm Krai. The spruce forests of this territory were the objects of study. The sanitary condition of spruce forests growing in common types of forest growing conditions (B2, C2, C3) and forest types (green moss spruce and pine forest, wood sorrel spruce and pine forest, linden spruce and pine forest, grass spruce and pine forest) of the Perm Krai was determined. The weighted average scores values of the sanitary condition of the spruce forest of the surveyed forest plantations were distributed by forest types and types of forest growing conditions. Statistical indicators of the average weighted scores of the sanitary condition of spruce in different types of forests were obtained. A one-factor analysis of variance was carried out to compare the mean values. It was established that the type of forest and the type of forest growing conditions have an impact on the sanitary condition of spruce stands. The better the forest growing conditions, the more resistant the spruce trees are to drying out, on average. At the same time, soil moisture is more important than soil nutrient status.

Keywords: type of forest; type of forest growing conditions; sanitary condition; weighted average scores of the sanitary condition; drying out of spruce forests; Perm Krai; zone of coniferous-deciduous forests; soil moisture; soil nutrient

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Научная статья

ВЛИЯНИЕ ТИПА ЛЕСА И ТИПА ЛЕСОРАСТИТЕЛЬНЫХ УСЛОВИЙ НА УСТОЙЧИВОСТЬ ЕЛОВЫХ ДРЕВОСТОЕВ ЗОНЫ ХВОЙНО-ШИРОКОЛИСТВЕННЫХ ЛЕСОВ ПЕРМСКОГО КРАЯ

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В последние годы наблюдается массовое усыхание еловых насаждений. Учеными выдвинуто множество версий о том, что же является причиной этого явления. Несмотря на активное изучение проблемы усыхания еловых насаждений во всем мире, система управления лесным хозяйством, направленная на снижение ущерба от усыхания, до сих пор не выработана. Важными лесоводственными показателями насаждений, которые могут влиять на их устойчивость, являются тип лесорастительных условий и тип леса. Цель исследования – установление влияния типа леса и типа лесорастительных условий на устойчивость к усыханию ельников, произрастающих в зоне хвойно-широколиственных лесов Пермского края. Объектами исследования послужили ельники, произрастающие в зоне хвойно-широколиственных лесов Пермского края. Определено санитарное состояние еловых лесов, произрастающих в распространенных типах лесорастительных условий (В2, С2, С3) и типах леса (ельник и сосняк зеленомошные, ельник и сосняк кисличные, ельник и сосняк липняковые, ельник и сосняк травяные) Перм-

ского края. Значения средневзвешенных баллов санитарного состояния ели обследованных лесных насаждений распределены по типам леса и типам лесорастительных условий. Получены статистические показатели средневзвешенных баллов санитарного состояния ели в различных типах леса. Для сравнения средних значений выполнен однофакторный дисперсионный анализ. Установлено, что тип леса и тип лесорастительных условий оказывают влияние на санитарное состояние еловых древостоев. Чем лучше лесорастительные условия, тем в среднем деревья ели более устойчивы к усыханию. При этом, более важное значение имеет влажность почвы, чем трофность почвы.

Ключевые слова: *тип леса; тип лесорастительных условий; санитарное состояние; средневзвешенный балл санитарного состояния; усыхание еловых насаждений; Пермский край; зона хвойно-широколиственных лесов; влажность почвы; трофность почвы*

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Introduction

In the last few years, the problem of mass drying out of spruce plantations has been actively discussed in the scientific literature [9, 14, 18-22]. Many versions about the cause of this phenomenon have been put forward by scientists. Most scientists believe that droughts and high air temperatures, as well as the accompanying mass reproduction of xylophages, lead to the drying out of spruce forests [18-20]. Other scientists [14] believe that the causes of the drying out of spruce forests are pathological processes that cause by pests and diseases, as well as the impact of adverse climatic factors and economic activity. At the same time, A.M. Mezhibovsky [9], refuting all the assumptions of scientists, connects the mass drying out with soil contamination with root fungus (*Heterobasidion annosum* (Fr.) Bref.).

Despite the fact that the active study of the problem of drying out of spruce plantations around the world, a forest management system aimed at reducing the damage from drying out has not been developed yet.

The spruce forests of the Perm Krai, growing in the zone of coniferous-deciduous forests, are also subject to large-scale desiccation (Fig. 1) [4].

Figure 1. Declining spruce plantation in Oktyabrsky urban district of Perm Krai, 2018 (Ivanchina L.A. is the author of the photo)

Important silvicultural indicators of plantations that can affect their stability are the type of forest growing conditions and the type of forest.

The type of forest growing conditions is the whole of uniform forest growing conditions in forest areas, including a complex of edaphic, hydrological and climatic factors. The complex of these factors determines the conditions for the growth and development of the forest. Forest areas with a common type of forest growing conditions, with the same composition of stands and with a number of other common features are combined into forest types [17].

The purpose of the study was to establish the influence of the type of forest and the type of forest growing conditions on the resistance to drying out of spruce forests growing in the zone of coniferous-deciduous forests of the Perm Krai.

Scientific novelty

In the process of this study, for the first time, the issue of increasing the variability of the weighted average score of the sanitary condition of spruce stands with the improvement of the conditions of the place of growth was considered.

Materials and methods

The objects of study were spruce plantations growing in the Kishertsky, Kuedinsky, Oktyabrsky, Osinsky, Ochersky and Chaikovsky forestries of the Perm Krai. These forestries are located in the zone of coniferous-deciduous forests of the Perm Krai [10].

The investigated area is shown in Figure 2. Its territory is located on the eastern edge of the Russian Plain. The relief is hilly, intersected by a network of valleys and dens [1]. Mixed forests with the European spruce (Picea abies (L.) H.Karst.) as part of stands grow within the boundaries of the research area [11].

The spruce stands growing in the most common types of forest growing conditions and types of forest in the studied territory were examined.

A description of the types of forest growing conditions is given according to Pogrebnyak P.S. [13].

B_2 (relatively poor fresh). Plantations growing in these forest growing conditions occupy weighed average positions with a slightly wavy relief. Sandy loamy low-podzolic soils. The understory is rare and consists of red elderberry (*Sambucus racemosa* (L.)), rough spindle tree (*Euonymus verrucosus* (Scop.)), alder buckthorn (*Frangula alnus* (Mill.)), and rowan (*Sorbus aucuparia* (L.)). Oligotrophs and mesotrophs grow in the ground cover: Schreber's pleurocium (*Pleurozium Schreberi* ((Brid.) Mitt.)), wild strawberry (*Fragaria vesca* (L.)), lady's bedstraw (*Galium verum* (L.)), reed grass (*Calamagrostis arundinacea* ((L.) Roth.)), etc.

C_2 (relatively rich fresh). These conditions of the place of growth occupy more or less elevated, flat, well-drained locations. Hawthorn (*Crataegus laevigata* ((Poir.) DC.)), common hazel (*Corylus avellana* ((L.) H.Karst.)), rough spindle tree (*Euonymus verrucosus* (Scop.)) grow in the understory. Oligotrophs (for example, red whortleberry (*Vaccinium vitis-idaea* (L.)), mesotrophs (for example, stone bramble (*Rubus saxatilis* (L.))) and megatrophs (for example, European hazelwort (*Asarum europaeum* (L.))) grow in the ground cover. Spruce plantations grow with the participation of linden or broad-leaved species in relatively rich fresh forest growing conditions in the south of the Perm Krai.

C_3 (relatively rich wet). These conditions are typical for locations with good drainage. Soils are podzolic, among them loamy or clay. Spruce forests have the highest productivity in these conditions. There are common hazel (*Corylus avellana* ((L.) H.Karst.)), rough spindle tree (*Euonymus verrucosus* (Scop.)) in the understory. It is possible to meet in the ground cover the following: whortleberry (*Vaccinium myrtillus* (L.)), male or lady fern (*Dryopteris filix-mas* ((L.) Schott) and *Athyrium filix-femina* ((L.) Roth ex Mert.), respectively), common wood-sorrel (*Oxalis acetosella* (L.)).

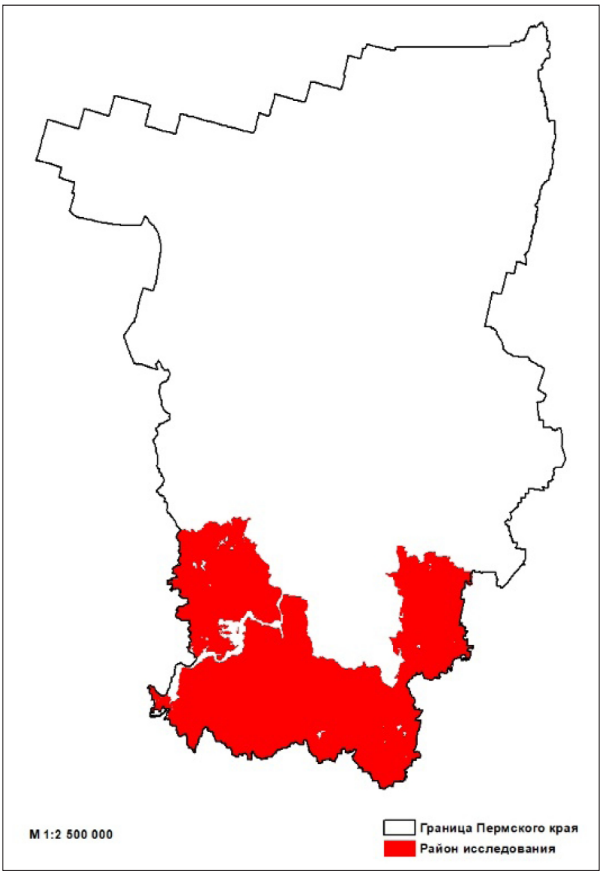

Figure 2. Map-scheme of the research area within the boundaries of the Perm Krai

The forest management has developed its own classification by forest types for the Perm Krai [12]. In accordance with the classification of V.N. Sukachev [2], the following types of forest are included in the group of forest types of green moss spruce forests: wood sorrel spruce, bilberry spruce, cowberry spruce. The green moss spruce forest stands out as a separate type of forest in the classification scheme modified for the Perm Krai. The grass spruce is also allocated as a separate type of forest. The situation is similar with the green moss and grass pine forests. The description of the forest types that served as the objects of study is given below [12].

Green moss spruce forest (G-m. sp.). The soils are deep-podzolic, low-humic and loamy under green moss spruce stands. Spruce and fir predominate in the composition of forest stands, pine, birch, and aspen are singly involved. The average quality class is III (II). The understory is rare and consists of may rose (*Rosa majalis* (Herrm.)) and rowan (*Sorbus aucuparia* (L.)). Schreber's pleurocium (*Pleurozium Schreberi* ((Brid.) Mitt.)) and may lily (*Maianthemum bifolium* (L.) F.W.Schmidt)) grow in the ground cover.

Wood sorrel spruce forest (W-s. sp.). This type of forest is formed on shallow-podzolic medium-humic loamy soils. Spruce, fir, and birch are the main species that make up the forest stand, aspen, and linden are less common. The average quality class is II (III). The understory with medium density and it is formed by rowan (*Sorbus aucuparia* (L.)) and fly honeysuckle (*Lonicera xylosteum* (L.)). The ground cover consists of common wood-sorrel (*Oxalis acetosella* (L.)), common lungwort (*Pulmonaria officinalis* (L.)), ground elder (*Aegopodium podagraria* (L.)).

Linden spruce forest (L. sp.). The soils of the linden spruce forest are sod-podzolic, medium-humic loamy. Spruce, fir, linden, and birch participate in the composition of forest stands. The average quality class is II (III). The dense understory mainly contains small-leaved lime (*Tilia cordata* (Mill.)). The ground cover is made up of European hazelwort (*Asarum europaeum* (L.)), greater starwort (*Stellaria holostea* (L.)).

Grass spruce forest (G. sp.). Sod-podzolic gleyic loamy or clay soils with a high content of humus are formed under the conditions of the grassy spruce forest. Spruce, fir, birch, aspen, linden, and pine participate in the composition of forest stands. The average quality class is II (III). There are may rose (*Rosa majalis* (Herrm.)) and bird cherry (*Prunus padus* (L.)) in the understory of medium density. The ground cover includes meadow-sweet (*Filipendula ulmaria* (L.) Maxim.), wood horsetail (*Equisetum sylvaticum* (L.)), northern wolfsbane (*Aconitum septentrionale* (Koelle)).

Green moss pine forest (G-m. p.). Plantations of green moss pine forest are formed on loose sandy soils with a low content of humus. Pine is the predominant species. Spruce, fir, and birch can also be found in the forest stand. The average quality class is II (III). The understory is rare and consists of rowan (*Sorbus aucuparia* (L.)), common juniper (*Juniperus communis* (L.)). Schreber's pleurocium (*Pleurozium Schreberi* ((Brid.) Mitt.)), red whortleberry (*Vaccinium vitis-idaea* (L.)) grow in the ground cover.

Wood sorrel pine forest (W-s. p.). Plantations of this type of forest grow on sod-low-podzolic loamy soils. The tree stand consists of pine, spruce, birch, and aspen. The average quality class is II (I). Sparse understory is formed by row-

an (*Sorbus aucuparia* (L.)), common juniper (*Juniperus communis* (L.)), may rose (*Rosa majalis* (Herrm.)). European hazelwort (*Asarum europaeum* (L.)), common wood-sorrel (*Oxalis acetosella* (L.)) participate in the grass cover.

Linden pine forest (L. p.). The soils of the linden pine forest are sod-podzolic (medium or low), medium-humic sandy loamy. The average quality class is II. The forest stands include pine, spruce, birch, and linden. The main component of the dense understory is small-leaved linden (*Tilia cordata* (Mill.)). The ground cover is also dense, there are ground elder (*Aegopodium podagraria* (L.)), stone bramble (*Rubus saxatilis* (L.)) among its plants.

Grass pine forest (G. p.). Soils are formed fresh, medium-humic, sod-podzolic loamy. The average quality class is II (III). The forest stands include pine, spruce, birch, fir, and aspen. There are rowan (*Sorbus aucuparia* (L.)) and may rose (*Rosa majalis* (Herrm.)) in the understory. Whortleberry (*Vaccinium myrtillus* (L.)), stone bramble (*Rubus saxatilis* (L.)) are involved in the dense ground cover.

Methodology

The materials of acts of forest pathological surveys conducted in the period from 2012 to 2020 were analyzed. These acts contain information on the taxation stand characteristics and on the distribution of timber stock by categories of sanitary condition, as well as the information on the weighted average scores of sanitary conditions for each species. In order to exclude the influence of other taxation parameters, stands of the 4th class of age and average density were selected. Stands of this age class, in compliance with previous studies, are most susceptible to drying out [5]. Medium-stocked stands are stands with a relative density of 0.6-0.7 [2].

The values of the weighted average scores of the sanitary condition of spruce in the selected forest areas are distributed by forest types and types of forest growing conditions.

Statistical processing of the obtained samples was carried out in the Microsoft Excel 2019 program. A map-scheme of the study area was prepared in the ArcGIS ArcMap 10.8 program.

Results

Table 1 shows the statistical indicators of samples of weighted average scores values of the sanitary condition of spruce forest stands, distributed by forest types and types of forest growing conditions.

A large number of surveyed plantations of green moss spruce and pine forests, wood sorrel spruce forests and linden spruce forests are explained by the

significant prevalence of these types of forests over the territory of the study area. Other forest types (linden, wood sorrel and grass pine forest, grass spruce forest) are not widely distributed.

Table 1.

Statistical indicators of the weighted average scores of the sanitary condition of spruce forest stands in various forest types and types of forest growing conditions (TFGC)

Statistical indicator	Values by forest type/types of forest growing conditions (TFGC)										
	B_2 (relatively poor fresh)				C_2 (relatively rich fresh)				C_3 (relatively rich wet)		
	G-m. sp.	G-m. p.	L. p.	**Sub-total, TGFC**	W-s. sp.	L. sp.	W-s. p.	**Sub-total, TGFC**	G. sp.	G. p.	**Sub-total, TGFC**
Medium-stocked stands of 4 age classes											
Forest allotment sample size, pcs.	162	72	8	**242**	214	115	28	**357**	45	4	**49**
Average	3,62	3,78	3,73	**3,67**	3,56	3,52	3,97	**3,58**	3,36	3,45	**3,36**
Standard error	0,06	0,08	0,3	**0,05**	0,05	0,06	0,13	**0,04**	0,1	0,77	**0,11**
Standard deviation	0,71	0,68	0,84	**0,71**	0,72	0,70	0,68	**0,72**	0,66	1,54	**0,74**
Dispersion	0,51	0,47	0,71	**0,50**	0,52	0,49	0,47	**0,52**	0,44	2,38	**0,55**
Maximum	5,0	5,0	4,92	**5,0**	5,27	4,8	5,22	**5,27**	4,8	5,0	**5,0**
Minimum	2,21	2,1	2,74	**2,1**	2,3	2,28	2,8	**2,28**	2,1	1,8	**1,8**
Interval	2,79	2,9	2,18	**2,9**	2,97	2,52	2,42	**2,99**	2,7	3,2	**3,2**
Median	3,74	3,86	3,72	**3,76**	3,51	3,43	3,97	**3,51**	3,3	3,51	**3,3**
Mode	3,8	4,3	-	**4,6**	2,7	2,7	3,3	**2,7**	4,0	-	**4,0**
Excess	-1,2	-0,87	-1,42	**-1,14**	-1,09	-1,24	-1,12	**-1,12**	-0,27	-4,54	**-0,32**
Asymmetry	-0,002	-0,296	0,25	**-0,078**	0,2	0,16	-0,03	**0,163**	0,198	-0,09	**0,178**
Coefficient of variation	19,61	17,99	22,52	**19,35**	20,22	19,89	17,13	**20,11**	19,64	44,64	**22,02**

Among plantations of spruce forest types, spruce trees growing in the conditions of the green moss spruce forest are characterized by the worst sanitary condition (weighted average score of sanitary condition is 3.62). Spruce trees growing in the conditions of wood sorrel and linden spruce forests feel a little better (3.56 and 3.52, respectively). Spruce trees growing in the conditions of the grass spruce stands are characterized by the best sanitary condition (weighted average score of sanitary condition is 3.36).

Spruce dries in pine forests. In wood sorrel pine forests, the average value of the weighted average score of the sanitary condition of spruce trees is 3.97, in green moss pine forests - 3.78, in linden pine forests - 3.73. Spruce trees grow-

ing in the conditions of grass pine forest are distinguished by the best sanitary condition (weighted average score of the sanitary condition is 3.45).

A one-way analysis of variance was performed in order to compare the mean values. The results of the analysis when comparing mean values by forest types are presented in Table 2.

Table 2.

The results of one-way analysis of variance when comparing the mean values of the average weighted scores of the sanitary condition of spruce forest stands by forest types

Source of variation	SS	df	MS	F	P-Value	F critical value
Between groups	10,04612215	7	1,435160307	2,817706031	0,006752763	2,02387048
Within groups	325,9753098	640	0,509336422			
Subtotal	336,0214319	647				

The actual value of the Fisher ratio (2.82) is greater than the critical value (2.02), respectively, we reject the null hypothesis about the equality of the average values. The results of one-way analysis of variance indicate that the type of forest affects the sanitary condition of spruce stands.

The maximum values of the weighted average score of the sanitary condition of spruce stands are found among plantations of the wood sorrel forest type (5.27 in the wood sorrel spruce forest and 5.22 in the wood sorrel pine forest). And the minimum values are among plantations of grass forest type (2.1 in grass spruce forest and 1.8 in grass pine forest) and in plantations of green moss pine forest (2.1).

The highest level of variability is characterized by the values of the weighted average score of the sanitary condition of stands growing in plantations of grass pine forest (44.64%), and the lowest – in plantations of wood sorrel pine forest (17.13%).

Relatively rich fresh (C_2) conditions of the place of growth dominate in the research area (357 forest plots were surveyed). Relatively rich wet forest growing conditions are much less common (49 forest plots were surveyed).

The obtained average values of the average weighted scores of the sanitary condition of spruce forest stands by types of forest growing conditions indicate that the better the conditions of the place of growth, the more resistant the spruce trees are to drying out, on average. At the same time, soil moisture is more important than soil nutrient status (the sanitary condition of spruce stands

growing on fresh, relatively rich soils is, on average, 0.09 better than on fresh, relatively poor soils; the sanitary condition of spruce stands growing on fresh, relatively rich soils, on average 0.22 better than on wet, relatively rich soils).

Table 3 presents the results of a one-way analysis of variance when comparing average values by types of forest growing conditions.

Table 3.

The results of one-way analysis of variance when comparing the average values of the average weighted scores of the sanitary condition of spruce forest stands by types of forest growing conditions

Source of variation	SS	df	MS	F	P-Value	F critical value
Between groups	4,101394618	2	2,050697309	3,984995226	0,019052142	3,009689273
Within groups	331,9200373	645	0,514604709			
Subtotal	336,0214319	647				

The actual value of the Fisher ratio (3.98) is greater than the critical value (3.01), therefore, the null hypothesis about the equality of the mean values is rejected. It indicates that the sanitary condition of spruce stands depends on the type of forest growing conditions.

The degree of variability of the studied trait increases with the improvement of the conditions of the place of growth (the coefficient of variation of the weighted average score of the sanitary condition of spruce stands in relatively poor fresh forest growing conditions is 19.35%, in relatively rich fresh – 20.11%, in relatively rich wet – 22.02%). This is explained by the fact that with the improvement of forest growing conditions, competition increases, which leads to an increase in the stratification of the population into coenotically heterogeneous groups [15]. The research results indicate that this regularity extends to the sanitary condition of forest stands.

Discussion

Similar results have been previously obtained by us on the example of plantations of the Ochersky forestry of the Perm Krai [3]. Far Eastern scientists noted a high connection between drying out and forest types [8].

In the Moscow region, the proportion of affected spruce forests in relatively low-trophic conditions of the place of growth is significantly higher than the proportion of the corresponding plantations in general. And in relatively higher trophic conditions, it is much lower [6].

Plantations of bilberry, ferny, green moss, riparian-grass, ground elder, wood sorrel and nettle forest types are subject to drying out in Belarus [16]. At the same time, wood sorrel spruce forests dry out to the greatest extent [7].

The obtained results of studies based on a large amount of material made it possible to establish that forest growing conditions affect the resistance of spruce forests to drying out, while soil moisture is more important.

From our point of view, the influence of forest growing conditions on the resistance of spruce forests to drying out is as follows. Under more favorable conditions, woody plants are more provided with soil moisture and nutrients, respectively, are more able to resist unfavorable factors leading to drying out.

It is necessary to investigate in detail the effect of soil moisture on the drying out of spruce stands with experiments in the field conditions and with the use of equipment in the future. Moreover, it is necessary to study the effect of the groundwater level on the drying out of spruce forests. These studies will allow us to determine whether soil moisture is one of the causes of drying out of spruce forests or only affects their stability.

Conclusion

The type of forest and the type of forest growing conditions affect the sanitary condition of spruce stands. A high connection between drying out and forest types is also noted by other scientists. In plantations of spruce forest types, the worst sanitary condition is characterized by spruce trees growing in the conditions of the green moss spruce forest, and the best – in the conditions of the grass spruce forest. In plantations of pine forest types, the worst sanitary condition of spruce stands is observed in wood sorrel pine forests, and the best – in grass pine forests.

Additionally, the minimum values of the weighted average score of the sanitary condition of spruce stands were noted in the plantations of grass forest types. The better the forest growing conditions, the more resistant the spruce trees are to drying out, on average. At the same time, soil moisture is more important than soil nutrient status.

With the improvement of the conditions of the place of growth due to increased competition, the variability of the values of the weighted average score of the sanitary condition of spruce forest stands increases.

Conflict of interest information. The authors declare that there is no conflict of interest.

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