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Siberian Spruce stand structures peculiarities in urban plantations

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Abstract. Tree biometrics was measured: stem diameter at breast height (DBH), tree height, as well as crown diameter and length on 15 plots of Siberian spruce urban plantations were in Yekaterinburg-city. The diameter (DBH) distribution of trees was determined based on the statistics and their errors. Variation in stem and crown parameters of the trees and height to diameter ratio was found to be lower in urban plantations than in natural forest stands. DBH variation coefficient is decreased with tree spacing increase. There is a strong relationship between maximum H:D ratio values and tree spacing. It is established that the most favourable conditions in Siberian spruce urban plantations are created if tree spacing is more than 3 m. The relationships between tree parameters in urban plantations where inter-tree competition is lower than in natural forest stands were determined to be linear ones. The accuracy of equations to evaluate tree parameters increases if a second determining factor is included: if tree spacing is included in the tree height and the crown diameter equations, and if tree height is included in the crown volume equation. The study results show that urban plantations can be considered as a unique subject of forest taxation.

1. Introduction

Growing conditions for woody plants in urban environments and in the forests are significantly different. Harmful factors (the presence of dust, soot, toxic gases, changes in the thermal regime, soil compaction, etc.) as some characteristics of cities have a negative impact on the growth and condition of the green planting. Under conditions of the city, full-fledged forest communities are not formed. Urban plantations are characterized by a uniform, more sparse distribution of trees over the area, even age due to a uniform planting material, and experience significant anthropogenic pressures [1]. Therefore, they are morphologically different from both natural and artificial plantings growing in the forest.

Currently, tree stands in urban plantations at the quantitative level are poorly studied both in our country and abroad. This does not allow determining the degree of differences between urban and natural plantations on the main taxation parameters, to identify peculiarities of the formation and growth of the forest stands in urban environments and assess the need to develop a separate regulatory framework for taxation and inventory urban plantations.

As a rule the silvicultural and taxation studies of stands, begin with a study of their structure. The obtained results can serve as a theoretical basis for constructing various normative reference materials,

assessing the environmental and cenotic factors impact on the growth and development of trees and tree stands, determining the size of a sample of trees during valuation works, etc. [2, 3]. In this regard, the study of the stand structures in urban plantations is an urgent task.

The purpose of the work was to study the patterns of the structure of the stands of Siberian spruce trees in single-row urban plantations on the example of the city of Yekaterinburg. To accomplish it, the following tasks were set: assessment of the variability of taxation parameters of trees in urban plantations; the study of the distribution of trees by diameter (DBH); the establishment of relationships between taxation parameters of trees.

2. Materials and Methods

The object of the study was the plantations of Siberian spruce trees in the city landscaping system. The choice of object was because Siberian spruce in Yekaterinburg is one of the most common species among conifers. To solve the problems posed, 15 plots of urban plantations with Siberian spruce, located in different parts of the city along streets, parks and squares, were surveyed. The following measurements were performed in each plot: tree spacing (S), stem diameter at breast height (DBH), tree height (H), as well as crown diameter (Dc) and crown length (Lc). Crown volume was calculated based on crown diameter and crown length measurements using the formula suggested by P.M. Verkhunov and V.L. Chernykh [4]:

$$Vc = \frac{3.14\, Dc\, Lc}{12}. \qquad (1)$$

The total number of measured trees was 358 pcs. The urban plantations under the study are characterized by different ages (from 9 to 70 years) and have a different spacing (from 1.6 to 8.6 m). This allows you to identify structural features of urban plantations associated with age and spacing-(planting density-).

Mathematical-statistical processing of experimental materials was carried out using the program Statistica 10. The following statistical parameters were determined: mean value, standard deviation, coefficient of variation, skewness, kurtosis and their errors.

3. Results

The analysis of diameter and tree height variation is of interest when studying the structure of stands because these parameters are the most important determinants of stand structure in general [5]. The higher the variation of the trait, the greater the imbalance of growth in diameter and height.

The diameter variation coefficient (CVD) was found to vary between 7.5 and 30.9% in different plots. On average, this parameter is 19.8% over the entire data array. The analysis results show that diameter differentiation of Siberian spruce trees is lower in urban plantations than that in natural forests of the Urals. According to S.A. Mamaev et al. [6], the coefficient of variability of the diameter of trees in spruce forests is from 22 to 28% on average. Tree differentiation is known to be based on genetic heredity and it is higher in closed forests due to inter-tree competition. In greening plantations, the second component of tree differentiation (competitive ratios) is less pronounced due to the rarer distribution of trees, especially in single-row plantations.

Diameter variation depends on tree age and spacing (Table 1). The average values of the variation coefficient by age classes are in class 1 − 13.9%, in 2 − 21.0%, in 3 − 23.6 and in 4 − 25.5%. Thus, there is a tendency to increase the studied parameter with the increasing age of planting trees. The coefficient of variation of tree diameters is known to be decreased with increasing of the age of plantations.

The coefficient of variation of the diameter of trees decreases as tree spacing increases at a fixed age of plantations. Thus, in the plantations aged between 41 and 60 years old, mean diameter variation coefficient is 30.9% with a tree spacing of 3.0 m, and with a tree spacing of 6.1 m, mean diameter variation coefficient is 16.3%. Similar tendency is observed in young urban plantations (20 years old and younger) as well.

Height tree differentiation is much lower than diameter differentiation both in urban plantations and natural forest stands. Height variation coefficient in individual plots ranges between 3.2% and 21.9%. Mean values for this parameter are the following: 11.8% (age class 1), 15.1% (age class 2), 10.8% (age class 3), and 3.2% (age class 4) (Table 1.).

Coefficient of variation of the spruce trees height in urban plantations is significantly lower than in natural stands is. According to S.A. Mamaev et al. [4], this parameter varies between 10.2% and 18.7% in spruce forests in the middle Urals.

Table 1. Mean values of the taxation indicators variation coefficients of spruce trees, depending on age class and tree spacing.

Age class years	Variation coefficients in relation to tree spacing, m, %			
	≤ 3.0	3.1–6.0	≥ 6.1	Mean value
Stem diameter at breast height				
1	18.6	9.2	-	13.9
2	-	20.8	21.8	21,0
3	30.9	-	16.3	23.6
4	25.5	-	-	25.5
Tree height				
1	15.2	5.8	-	11.8
2	-	14.7	18.0	15.1
3	10.4	-	11.2	10.8
4	3.2	-	-	3.2
Crown diameter				
1	21.9	8.8	-	15.4
2	-	20.1	13.0	19.2
3	34.8	-	21.8	28.3
4	14.7	-	-	14.7
Crown length				
1	24.0	7.8	-	15.9
2	-	16.8	32.7	18.8
3	17.0	-	25.5	21.2
4	13.7	-	-	13.7

When analyzing approximately even-aged stands, there is a tendency to reduce the variability of tree height with increasing tree spacing. Thus, in stands aged 31–40 years old, variability coefficients for this parameter are the following: 15.3% for 3.4 m spacing, 16.7% for 3.8 m spacing, 14.6% for 4.1 m spacing, 12.3% for 5.0 m spacing.

Crown development is of prime importance in urban plantations. This is because the preservation of a favorable environmental situation in the city is primarily determined by the size of the photosynthesizing mass of trees.

Siberian spruce crown diameter varies from 1.05 m in 9 year-old trees to 7.31 m in 60 year-old trees. The variation of crown diameters is approximately at the level of variability of stem diameters at breast height. A clear dependence of the studied parameter on the age of green planting is not detected. Mean values variation coefficients of crown diameters in relation to age classes are the following: 15.4% (age class 1), 19.2% (age class 2), 28.3% (age class 3), and 14.7% (age class 4) (Table 1).

In even-aged stands, the variability of the diameter of the crowns naturally decreases with increasing a tree spacing.

Crown length in the urban Siberian spruce plantations under investigation varies between 1.07 m and 18.91 m, and variation coefficients for this parameter range from 3.7 % to 32.7 %, which is lower

than those for crown diameter (Table 1). Experimental data analysis did not reveal any impact of stand age and tree spacing on variation coefficient values.

Having compared the experimental variation coefficients of tree parameters for urban plantations Siberian spruce with the data of the scale of variability of plant quantitative characteristics S.A. Mamaev [7], we can point out the following: In uneven-aged plantations, the variation of DBH and crown diameters is estimated as medium and high, of tree height as very lower, low, and medium, and of crown length as medium. Stand heterogeneity in terms of tree parameters is known to be an indicator of their stability and sustainability [8]. These quality parameters increase with increasing variability of trees. According to this statement, one can speak of a relatively low stability of the studied plantations.

When studying stand structure, it is essential to analyze tree diameter distribution series because stem diameter at breast height is a key parameter that is in close relationship with the other tree and stand parameters.

The shape of the diameter distribution curve is known to be characterized best by such coefficients as skewness and kurtosis. The variation range of skewness in the plantations under investigation is rather wide: from –0.65 to 0.82. Its connection with the age and tree spacing is not clear. Mean skewness for trees in all the plots is 0.07.

The kurtosis for the series under study varies from –2.25 to 1.92. The relationship of this statistic with the age and tree spacing, as in the case with the skewness, is not expressed.

A number of researchers [2, 3] consider relative height, the ratio of the height of the woody plant to its diameter (H:D), to be the most informative indicator of the assessment of tree differentiation and the intensity of competitive relationships between them.

In order to assess the applicability of this parameter in the studying of tree differentiation and stability in urban plantations, we calculated H:D ratio for each Siberian spruce sample tree. The results of the comparison between our experimental data and the data obtained by other researchers [2, 3] show that H:D ratios for trees are lower in the urban plantations than in natural forest stands. Moreover, there is a strong relationship between maximum H:D ratio values in relation to tree spacing that can be properly described by an equation presented in Figure 1.
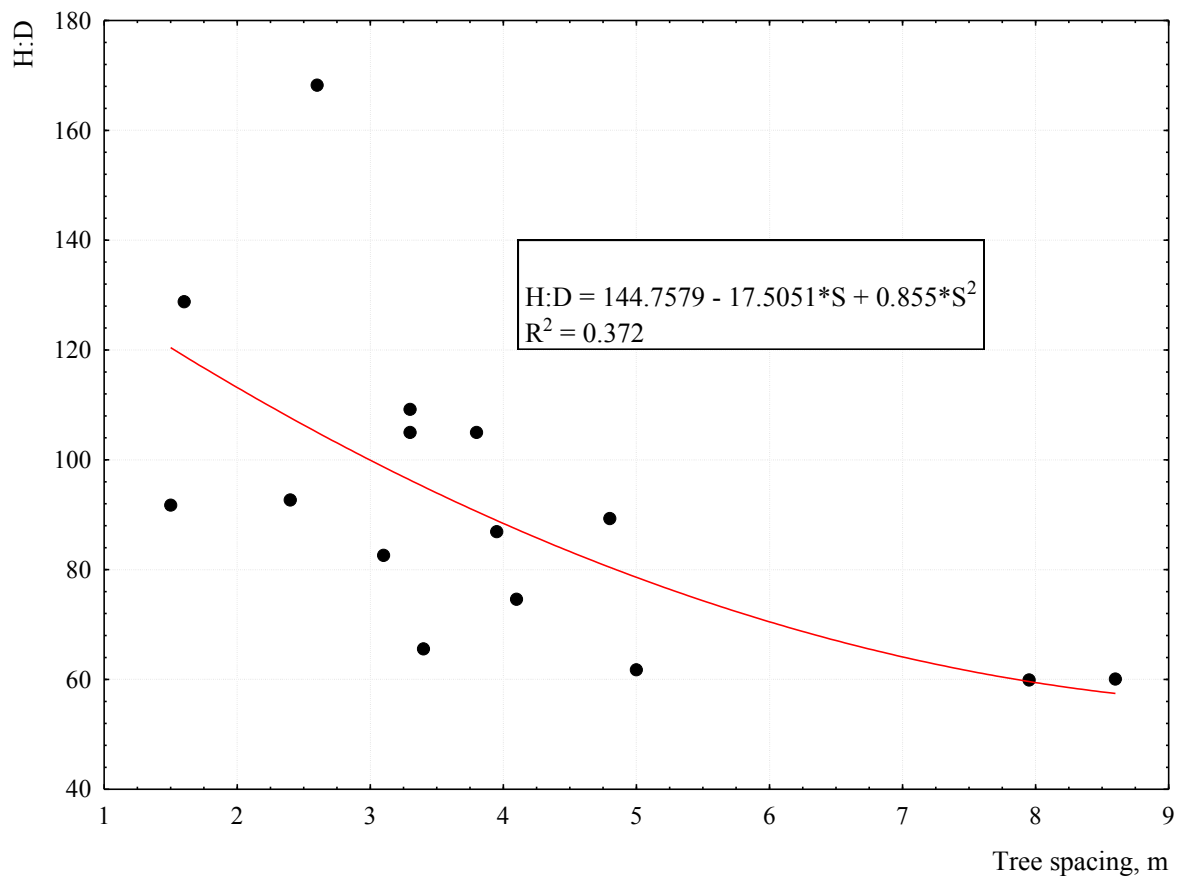
Figure1. The relationship between maximum H:D ratio values and tree spacing in urban plantations.

The H:D ratio values in relation to tree spacing obtained using the equation are shown in Table 2. Stress while growing and the degree of inter-tree competition are known to become critical to the survival of the trees and stands when H:D ratio exceeds 100% [3]. Trees maintain their vitality as long as the proportions of its organs do not extend beyond the boundaries of the tree species [9]. Data shown in Table 2 suggest that conditions critical for Siberian spruce can be created if tree spacing is less than 2–2.5 m. Therefore, when planting Siberian spruce in urban setting, tree spacing is recommended to be no less than 3 m. Increasing the distance between the trees eliminates the need for early withdrawals (thinning), so the planting step can be increased up to 4 meters or more.

Table 2. Maximum H:D ratio values in relation to tree spacing

Tree spacing, m	H:D ratio, %
1	130
2	110
3	82
4	70
5	65

Establishing relationships between tree parameters is of utmost theoretical and practical importance. It is known that their character is largely determined by the level of competition in the stands. In particular, growth isometrically observed in some single growing trees [2]. Therefore, the nature of these relationships in urban plantations, which differ from natural tree stands by weaker

competition between trees, can be specific. Table 3 shows the equations of relations between the various taxation parameters of trees, confirming that above mentioned.

Extensive graph analysis of the relationships under investigation was carried out prior to developing the equations.

Table 3. Mathematical models of Siberian spruce parameters in urban plantations

Equation type and its parameters	Determination coefficient	Standard error	The number of equations
H = 1.6933 + 0.5139 DBH	0.771	2.94	2
H = 4.0781 + 0.6280 DBH −1.2432 S	0.905	1.96	3
Lc = 0.0431 + 0.8809 H	0.996	0.30	4
Dc =1.0194 + 0.1742 DBH	0.956	0.41	5
Dc = 0.8303 + 0.1651 DBH + 0.0988 S	0.958	0.39	6
Vc = -2.4980 + 0.8652*DBH	0.884	3.31	7
Vc = -3.6644 + 0.5111*DBH + 0.6888 H	0.920	2.85	8

The data from Table 3 and graph analysis results show that the relationship between tree height and stem diameter at breast height in all plots of Siberian spruce urban plantations can be expressed as a straight line. This is due to the fact that there is either low or no inter-tree competition because of comparatively large distances between them. The accuracy of tree height calculation increases substantially if, apart from DBH, tree spacing is included in the equation. Moreover, in trees of the same diameter, the height decreases with an increase in the last parameter.

Linear relationships were observed between crown length and tree height, crown diameter and stem diameter at breast height, as well as crown volume and stem diameter at breast height. The accuracy increases if tree spacing is included as a second determining factor in the crown diameter equation, and tree height is included in the crown volume equation. The results show that for trees of the same diameter, the diameter of the crown increases with an increase in the step of planting, and the volume of the crown increases with an increase in the height of the stem.

On the whole, determination coefficients given in Table 3 suggest that the equations developed are adequate and correct, and they correspond to the experimental data. They can successfully be used in assessment work in urban plantations of the city.

4. Conclusions

The results of the study show that for tree differentiation by tree parameters is lower in urban plantations of Siberian spruce than in natural forest stands. This is an indirect sign of relatively low stability and sustainability.

H:D ratio is lower in urban plantations that in natural forest stands. There is a relationship between maximum H:D ratio values and tree spacing. H:D ratio values show that the most favourable conditions in urban plantations are created if tree spacing is more than 3 m.

The relationships between tree parameters in urban plantations, where inter-tree competition is lower than in natural forest stands, are linear.

Calculation accuracy of tree heights and crown diameters increases substantially, if, apart from DBH, tree spacing is included as a second determining factor in the equations, and tree height is included in the crown volume equation.

In general, the study results show that urban plantations can be considered as a specific taxation object.

References

[1]   Sobchak R O, Degtyareva O N and Astafurova T P 2014 Comprehensive assessment of the condition of Siberian fir Abies sibirica Ledeb. in an urban environment *Conifers of the*

boreal area **2** 100–108

[2]   Tretyakova V A 2006 Differentiation of trees and growth of plantations of the main forest-forming species of Siberia. synopsis dis. ... cand. biological sciences Krasnoyarsk p 21

[3]   Kuzmichev V V 2013 *Regularities of Stands Dynamics: Principles and Models* (Novosibirsk: Nauka) 208

[4]   Verkhunov P M and Chernykh V L 2007 *Forest Inventory* (Yoshkar-Ola) 398

[5]   Balakir M V 2012 Distribution of the trees diameters in spruce stands of artificial origin *Proceedings of BSTU* Forestry Minsk BSTU **1** 30-32

[6]   Mamaev S A and Popov P P 1989 *Siberian Spruce in the Ural* (*Intraspecific variability and structure of populations*) (Moscow Nauka) 104

[7]   Mamaev S A 1972 *Forms of Intraspecific Variability of Woody Plants (based on Pinaceae family at the Ural)* (Moscow: Nauka) 283

[8]   Drobyshev Yu I, Korotkov S A and Rumyantsev D E 2003 The stability of the stands: structural aspects *Forestry Information* **7** 2-11

[9]   Demakov Yu P 2000 *Diagnostics of sustainability of forest ecosystems (methodological and methodical aspects)* (Yoshkar-Ola) 416