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Chapter

Assessment of the State of Forest Plant Communities of Scots Pine (*Pinus sylvestris* L.) in the Conditions of Urban Ecosystems

Elena Runova, Vera Savchenkova,
Ekaterina Demina-Moskovskaya and Anastasia Baranenkova

Abstract

Siberian cities are characterized by one feature: many of them have preserved natural woodlands during construction, which on the one hand give a completely unusual, unique appearance to cities, on the other hand, trees suffer from recreational load, high levels of pollution and other anthropogenic factors. To assess the condition of pine stands, 3 test areas (0.5 ha, 0.1 ha and 1.9 ha) were laid. All considered plantings of natural origin are areas of woodland that were preserved during the construction of the city and are subject to recreational and industrial pollution. The test sites belong to areas with a high anthropogenic load, as they are located along highways and in close proximity to residential and public buildings and are part of parks with a high recreational load. The average age of trees is 70–80 years. The sanitary condition of the massif and its landscape characteristics are also determined. The critical condition of the massif is established, requiring sanitary logging and other forestry measures that could reduce recreational and anthropogenic loads.

Keywords: Scots pine (*Pinus sylvestris* L.), dendrometric characteristics, sanitary condition, damage to the trunk and crown, care

1. Introduction

Place of research: Irkutsk region, Bratsk city, residential district Energetik. On the territory of Bratsk and the Bratsk region, southern taiga and taiga natural complexes of Central Siberia prevail [1, 2]. In the vegetation of the city territory, forests of natural origin and urban plantations stand out. The dominant breed in forests of natural origin is Scots pine (*Pinus sylvestris* L.) - 57% of the total composition of the woodland, hanging birch (*Betula pendula* Roth.) And fluffy birch (*Betula pubescens* Ehrh.) Make up 17%, Siberian larch (*Larix sibirica* Ledeb.) - 6%, aspen (*Populus tremula* L.) - 16%, in much smaller quantities there are ordinary spruce (*Picea abies* L.), Siberian spruce (*Picea obovata* Ledeb.), goat willow (*Salix caprea* L.), shrub alder (*Duschekia fruticosa* Rupr.), common grouse (*Sorbus aucuparia* L.) and Siberian grouse (*Sorbus sibirica* Hedl.).

Inner-city vegetation is artificially created communities that are not self-regulating systems, they need constant care, which in most cases they do not receive. The predominant breed in urban planting is balsamic poplar (*Populus balsamifera* L.), In much smaller quantities are represented hanging birch (*Betula pendula* L.) and fluffy birch (*Betula pubescens* Ehrh.) - 11%, tree-shaped caragana (*Caragana arborescens* Lam.) - 6%, squat elm (*Ulmus pumila* L.) - 4%, Siberian mountain ash (*Sorbus sibirica* Hedl.) - 4%, Siberian larch (*Larix sibirica* Ledeb.) - 3%, apple berry (*Malus baccata* L.) - 3% of the total. The remaining representatives of trees and shrubs make up 2% or less of the total.

The city of Bratsk is located on the banks of the Bratsk and Ust-Ilimsk water reservoirs formed on the Angara River during the construction of hydroelectric power plants and is an agglomeration of dispersed residential areas separated by significantly vast forests and water spaces. Residential areas, various in size and degree of improvement are former villages that arose near industrial enterprises under construction. The area of the city is 428 km^2.

Bratsk is located in the north-west of the Irkutsk region in the central part of the Angara ridge. The city arose in 1955, in connection with the construction of the Bratsk hydroelectric station, north of the old village of Bratsk (Bratsk, Bratskoye), founded as an ostrog in 1631.

Climatic conditions are not favorable for diverse vegetation in urban plantations and forest areas. The climate is sharply continental with long harsh winters (down to - 35-45 ° C) and short hot summers (up to +25–30 ° C). During the year and day, the temperature here can vary within large limits. The cold period lasts an average of six months (from the second decade of October to the third decade of April). The average long-term frost-free period in the central part of the city is 94 days. The first frosts are recorded on September 8, the last - on June 5. About 370 mm of precipitation falls per year. The characteristics of the soils of the region include their fineness due to the large dissection of the relief and the diversity of the lithological composition of the rocks, the low temperature regime due to deep seasonal freezing and slow thawing, insufficient moisture due to the small amount of precipitation and spring waters that roll down the still thawing soils and dirt. Soils are subject to wind and water erosion, which reduces the content of humus and reduces fertility. Soils lack organic and mineral fertilizers and need new agricultural techniques [2].

2. Research methodology and methods

To conduct studies on the state of forest woody vegetation, 3 test areas (0.5 ha, 0.1 ha and 1.9 ha) were laid with a number of trees from 150 to 664 plants. All considered plantations of natural origin are areas of the forest preserved during the construction of the city, subject to recreational effects and industrial pollution. Test areas belong to territories with a high anthropogenic load, as they are located along roads and in close proximity to residential and public buildings and are part of parks with a high recreational load. The average age of trees is 70–80 years.

The purpose of this research work is to study the conditions for the growth and development of Scots pine masses (*Pinus sylvestris* L.). in the center of the village of Energetik in the city of Bratsk with high attendance. The massif was preserved during the construction of the village of Energetik, the age of the trees is approximately the same - 70-80 years. Studies were carried out according to generally accepted methods adopted in forest dendrometry [3, 4] (**Figure 1**).

At the test areas, a continuous inventory of trees was carried out with measuring diameters at the height of the chest with a measuring fork, the height of each tree using a altimeter - an eclimeter, the condition of the crown, the state of the roots

Figure 1.
Test area №1.

and trunk, the curvature of the trunk was determined visually. Kraft classes and a sanitary assessment class were also defined. The class of sanitary assessment is as follows: 1 - healthy (without signs of weakening); 2 - weakened; 3 - severely weakened; 4 - drying; 5 - fresh dry; 5 (a) - fresh wind; 5 (b) - fresh brown; 6 - old dry; 6 (a) - old wind; 6 (b) - old brown; 7 - emergency trees.

Next, the area of the entire project area is defined using the compass and measuring ribbon. For instrumental evaluation, 10 model trees were selected for each trial area. To assess the internal state of the wood, the following were used: Arbotom ® pulsed tomograph and Resistograph ® micro-drilling device of the German company Rinntech. For instrumental evaluation, 10 model trees were selected for each trial area. The principle of operation of Arbotom ® is based on determining the velocity of the pulse through the wood between sensors. Vibration sensors are arranged in series to measure trunk circumference. Measurements were taken at chest height. After the sensors are connected to the power supply unit and the manufacturer's specialized software, a number of shocks are applied to each sensor, after which information about the pulse speed between them is recorded by the computer. The standard deviation limit was set at 10%. The software presents the results in the form of matrix values, linear graphs and plane graphs (tomograms) (**Figure 2**).

The principle of operation of the Resistograph ® device is based on the determination of wood resistance to drilling. The Resistograph ® design uses an ultra-thin drill (1 mm) to reduce damage to the study object. To level the error taking into account the point profile, 2 perpendicular measurements were made on each model tree, the results of which were averaged [5–9].

Processing of the obtained data with isolation of destruction zones is carried out by visual evaluation of the obtained graphs taking into account the averages for the tree in question and for the total sample, as well as the distribution pattern of the

Figure 2.
Arbotom® wood condition measurement.

Figure 3.
Test area №3.

Test Area Number	Breed	Percentage of total trees,%
1	Scots pine (*Pinus sylvestris* L.)	91
	Siberian larch (*Larix sibirica* Ldb.)	5
	Birch fluffy (*Betula pubescens* Ehrh.)	4
2	Scots pine (*Pinus sylvestris* L.)	100
3	Scots pine (*Pinus sylvestris* L.)	100

Table 1.
Breed composition of wood stands on test areas.

relative density of wood. Direct correlation of instrument readings with wood density is not possible due to the absence of fixed graded scales.

An agglomerative hierarchical clustering method was chosen for statistical processing of results. Given the nature of the sampling, the Euclidean distance was adopted as the distance between objects:

$$\rho(x, x') = \sqrt{\sum\nolimits_i^n (x_i - x'_i)^2}, \quad (1)$$

where i are signs; n - number of characteristics.

Clustering was carried out using a complete communication algorithm (far neighbor method), according to which the degree of proximity is estimated by the degree of proximity between distant objects of the clusters (**Figure 3**).

Data is entered in Excel and processed using statistics methods [4]. All test areas are pure or almost pure single-tier pine trees (**Table 1**). In this regard, further evaluation was carried out only on Scots pine (*Pinus sylvestris* L.).

As can be seen from **Table 1**, common pine, as the most flexible in the biological and ecological aspect, tree species predominate in the composition of woodlands.

3. Research result

The results of the studies and treatment of the experimental materials obtained are as follows: Average biometric parameters of wood stands on trial areas are given in **Table 2.**

As can be seen from **Table 2**, the trees in all test areas are severely weakened, there are stunted and drying trees and even old dry. Since the trees are single-age and single-tier, the classification by the degree of growth and dominance by Kraft classes was used. The distribution by Kraft class is shown in **Table 2**. Weakened trees according to the Kraft classification are (IV, Va, Vb) in trial areas of more than 20 percent, which indicates the depressed state of the tree stand, which is also confirmed by sanitary assessment points, which average 2.8 points in trial area No. 1; 3.2 points on trial area No. 2 and 2.5 points on trial area No. 3.

Dynamics of average height of trees by thickness stages is shown in **Figures 4–6.**

As can be seen from **Table 2** and **Figures 4–6**, all woodlands have a clearly underdeveloped height and at the age of 70–80 years belong to the woodlands of 4–5 bonitet classes (on the scale of Professor Orlov), which indicates low productivity of woodlands and very unfavorable growing conditions. Productivity (Orlov bonitet classes are determined by the ratio of height and diameter at a certain age). The low bonitet class indicates poor growing conditions (soil or climatic). If we compare the average height of trees of the same age of class III bonitet (through which most forests of the Angara region grow), then the studied trees lack by 3–9

Test Area Number	Average age, years	Average diameter, cm	Average height, m	Vearage height of crown base, m	Root condition	Sanitary grade,%	Kraft grade, %
1	70–80	30.21 ± 1.2	17.2 ± 0.9	7.2 ± 0.3	Not visible	1–14 2–11 3–55 4–17 5–3	I – 18 II – 12 III – 42 IV – 26 V – 2
2	70–80	26.24 ± 0.8	16.4 ± 0.7	7.0 ± 0.2	Not visible	1–3 2–17 3–58 4–7 5–14 6–1	I – 15 II – 28 III – 36 IV – 10 Va – 10 Vб – 1
3	70–80	21.6 ± 1.1	10.1 ± 0.6	5.3 ± 0.5	Visible – 87 Not visible – 575	1–0 2–82 3–1 4–10 5–0 6–7	I – 12 II – 8 III – 39 IV – 21 Va – 19 Vб – 1

Table 2.
*Biometric indicators of the studied Scots pine tree (*Pinus sylvestris *L.).*

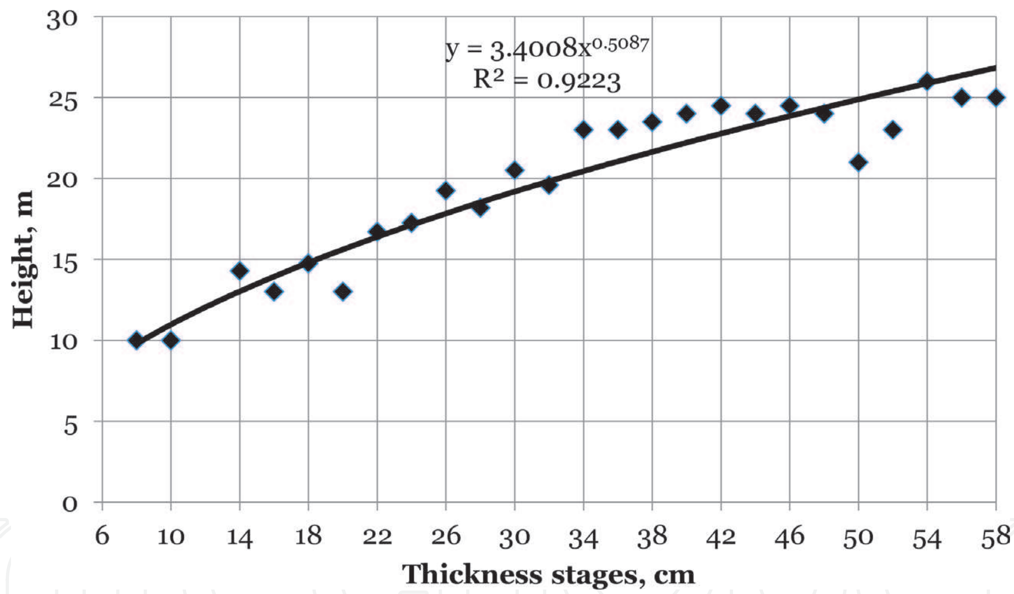


Figure 4.
Height distribution by thickness stages for site No. 1. The figure shows the relationship between the thickness of trees determined at a height of 1.3 meters (abscissa axis) and the height of trees in meters (axis of ordinates) on the first test area.

meters in height, which is very significant, especially on test area No. 3, where the lowest height and the highest recreational load.

When analyzing the condition of tree crowns, it is worth noting that deviations in crown shapes from the norm (flag-shaped, compressed or cut crown) are found in 50% of trees on site No. 1, 35% on site No. 2 and 53% on site No. 3. The percentage of crown condition is shown in **Figures 7–9**.

During measurements, the presence of trunk defects was noted in 95% of cases at site No. 1; 99% - at site No. 2; 96% - at site No. 3. At the same time, it should be noted that in most cases there were 2 or more types of external wood defects on the trunk (**Figures 9** and **10**; **Table 3**).

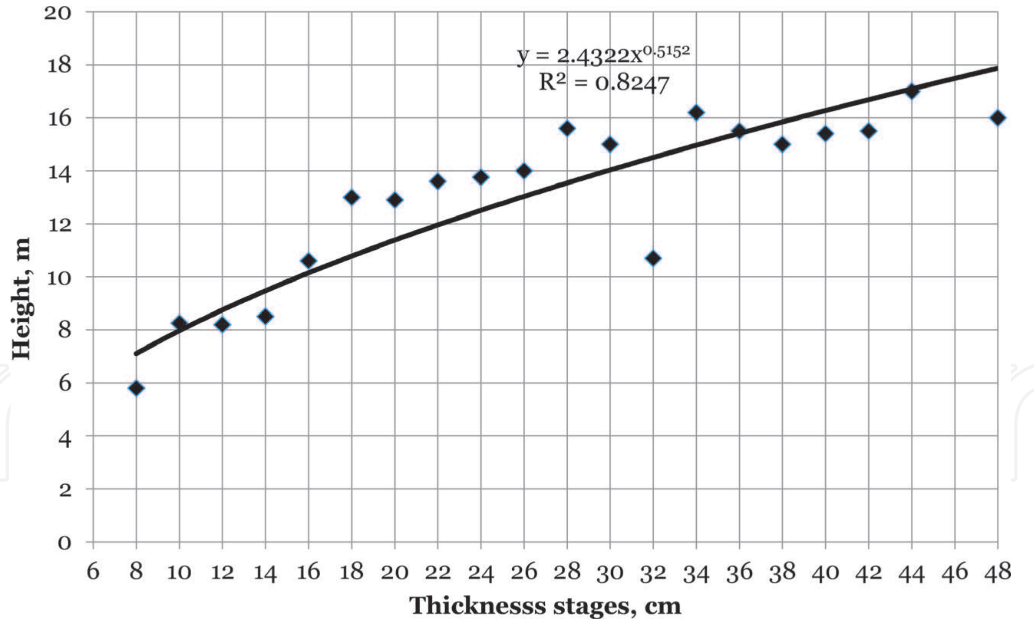


Figure 5.
Height distribution by thickness stages for site No. 2. The figure shows the relationship between the thickness of trees determined at a height of 1.3 meters (abscissa axis) and the height of trees in meters (axis of ordinates) on the second test area.

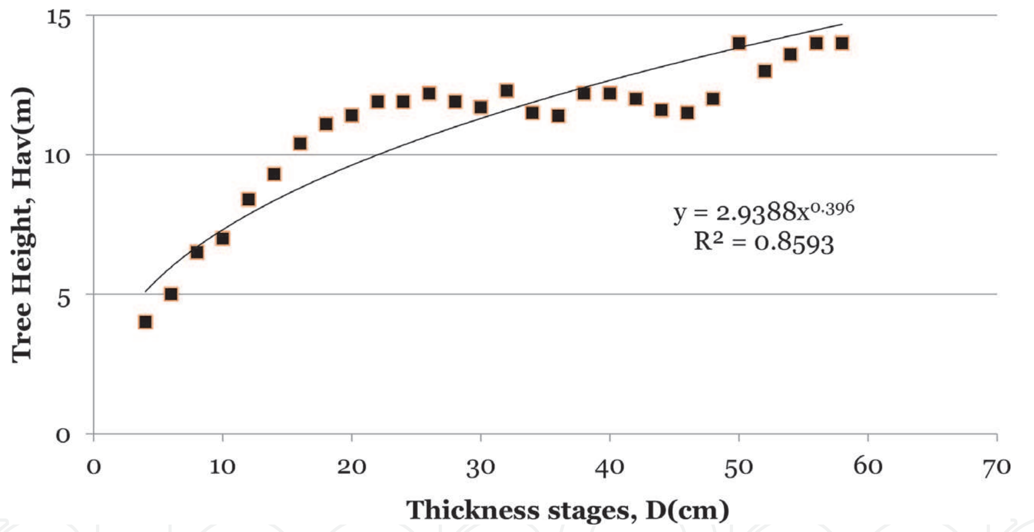


Figure 6.
The distribution of heights by thickness stages for site No. 3. The figures show the correlation between the thickness of trees determined at a height of 1.3 meters (abscissa axis) and the height of trees in meters (ordinate axis) on the third test area.

All model trees studied are ripe and restless. Most trees have a slope or curvature of the trunk and crown asymmetry. Visible wood defects are often observed - dryness, mechanical damage. The trunk height is from 12 to 19 meters, the trunk diameter is from 30 to 70 cm. **Table 4** shows the taxation indicators of the three trees most characteristic of the study object.

The nature of the tomograms obtained indicates a heterogeneous distribution of the wood density of the studied model trees. The speed varies from 912 m/s to 2018 m/s. The maximum frequency of occurrence falls in the range of 1003–1349 m/s. The degraded wood content ranges from 12 to 79% (average content is 30%). According to Resistograph ®, the average drilling resistance of the sample model trees was 121. The degraded wood content ranges from 26% to 85% (average content is 50%). In the vast majority of cases (96% of the sample), resistogram

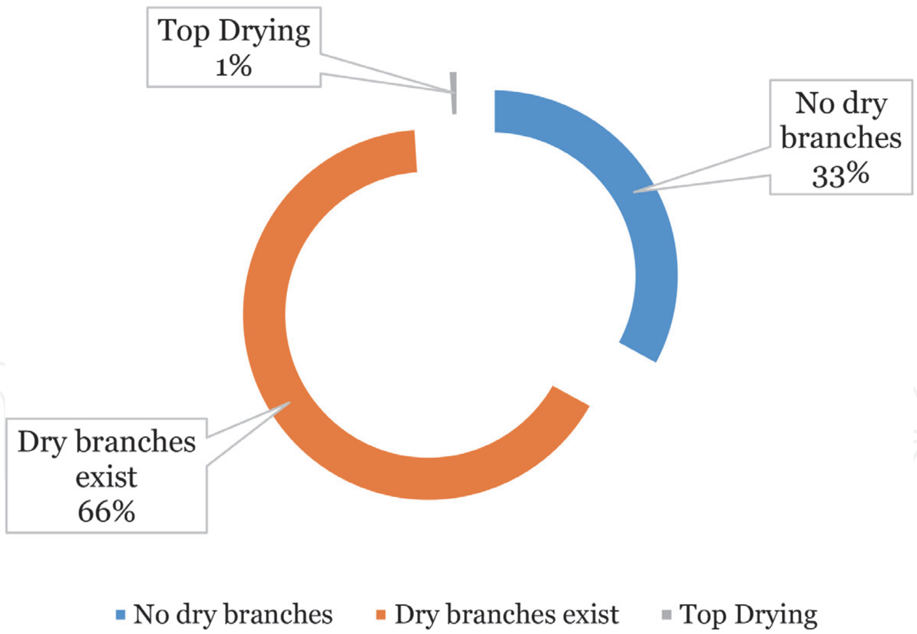


Figure 7.
Presence of signs of drying of the crown of trees of site No. 1, % of the sample.

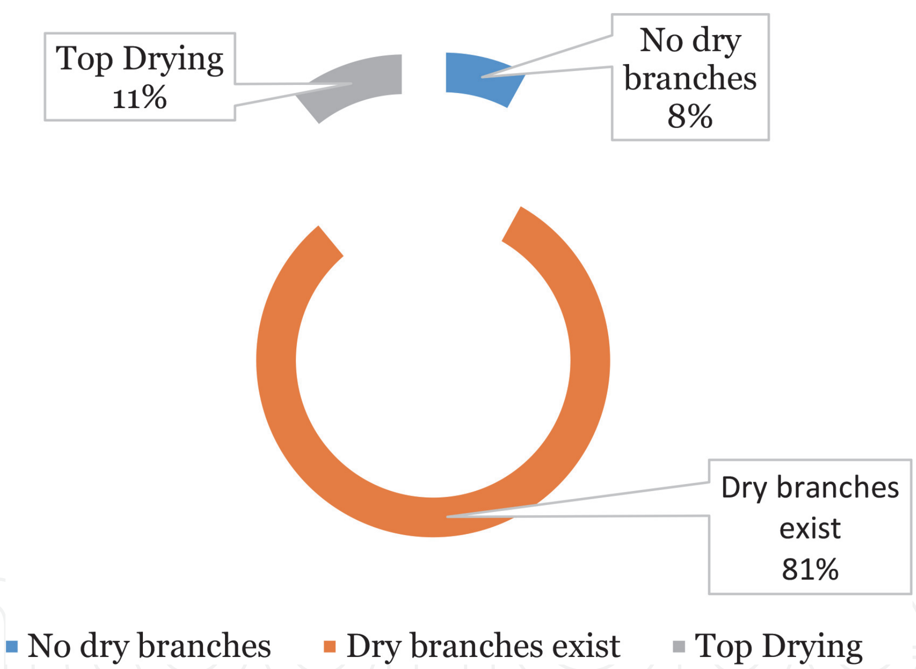


Figure 8.
Presence of signs of drying of the crown of trees of site No. 2, % of the sample.

readings reflect a significantly higher percentage of trunk destruction. This is a consequence of incomplete accounting of the area of peripheral areas of sickness during profile analysis by drilling.

Particularly strong oppression of trees can be traced on test area No. 3. Therefore, its characteristics should be discussed separately.

As can be seen from **Table 5**, the trees on this test area develop accordingly to the dwarf type, the bonitet class (woodland productivity) is only V, that is, the lowest at a given diameter. The average class of sanitary assessment is 3.6, which indicates almost the decay of the tree. **Table 5** shows the main forms of tree crowns and their number in pieces and percentages. It should be noted that on the 1.9 hectare site there are quite a large number of trees, namely 662 plants, in some areas the fullness of the tree stand significantly exceeds the maximum equal to 1.0.

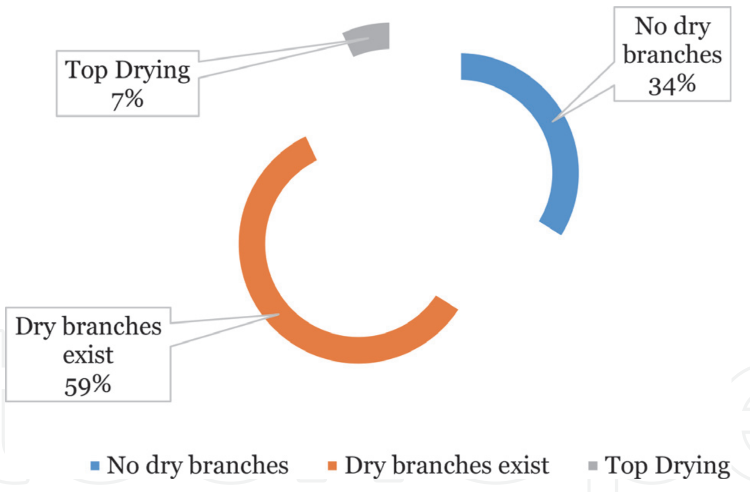


Figure 9.
Presence of signs of drying of the crown of trees of site No. 3, % of the sample.

Figure 10.
Mechanical damage to tree trunks.

Test Area Number	Number of kinds of trunk defects	Share in sample,%
1	No defects	5
	1 kind of defect	14
	2 or more kinds of defects	81
2	No defects	1
	1 kind of defect	26
	2 or more kinds of defects	73
3	No defects	4
	1 kind of defect	30
	2 or more kinds of defects	66

Table 3.
Number of trunk defects in test areas.

№ of the tree	6	7	8
D_{main} cm	38	44	52
$D_{1,3}$ cm	32	38	44
H_{tr}, m	12.5	18.8	19.0
Tree age	68	72	78
Visible defects of the trunk	Drywall, trunk slope	Drywall, trunk slope	Drywall, trunk slope
Average pulse speed, m/s	936	966	1011
Average drilling resistance, relative units.	137	134	142
Disturbed wood content according to Arbotom ®,%	78	52	15
Disturbed wood content according to Resistograph ®,%	50	57	69

Table 4.
Taxation characteristics of model trees.

Type	Quantity	%
Flag-shaped	326	49.10
Oval	311	46.84
Round shaped	3	0.45
No crown or dried up	24	3.61
Total	664	100

Table 5.
Distribution of the number of trees by crown forms in test area No. 3.

As the table shows, almost all crowns, namely 95.94% of the total number of trees, have either a flag-shaped crown or a strongly compressed oval crown. **Figure 11** shows in more detail the distribution of crowns in form.

Table 6 and its results indicate extreme soil compaction as a result of long-term recreational load, there is no living soil cover characteristic of the forest, so it is impossible to determine the type of forest and type of forest conditions. More than 13% of trees have a highly bare root system, which has mechanical damage and does

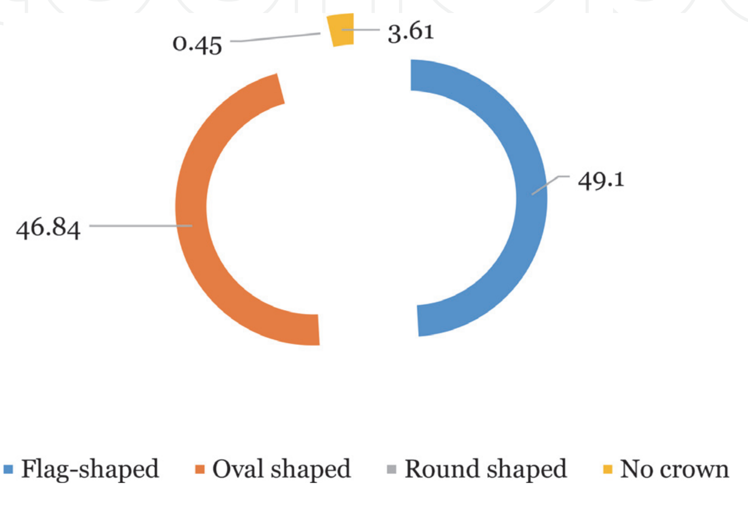


Figure 11.
Crown form distribution chart, %.

Type	Quantity	%
Bare rooted	88	13,11
Not visible	576	86,59

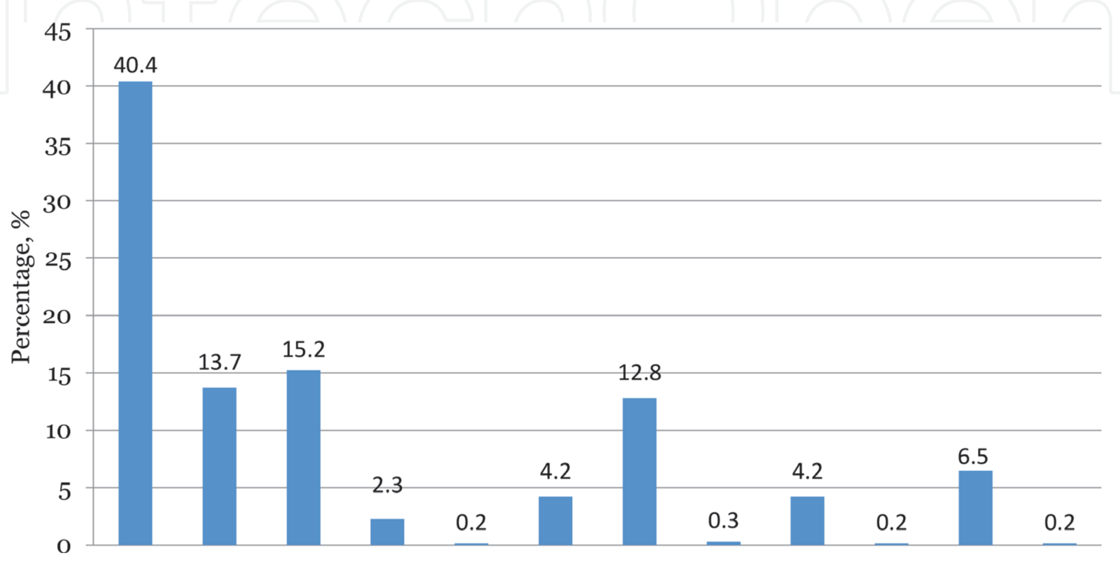
Table 6.
Conditions of tree roots on test area No. 3.

Type	Quantity	%
partial drywall, rot	268	40,36
partial drywall	91	13,70
partial drywall, mechanical defects	101	15,21
partial drywall, mechanical defects, rot	15	2,26
partial drywall, rot, cancerous object	1	0,15
healthy	28	4,22
rot	85	12,80
rot, cancerous object	2	0,30
mechanical defects	28	4,226
mechanical defects, cancerous object	1	0,15
mechanical defects, rot	43	6,48
cancerous object	1	0,15
Total	664	100

Table 7.
Identification of the quality status of the tree trunk in test area No. 3.

not allow plants to develop fully. The state of trees in terms of the quality of trunk wood is especially manifested, absolutely all trees have numerous mechanical and mushroom damages (**Table 7**).

The trunks have a drywall to a greater extent, which was formed from mechanical action on the trunks, drywall with open damaged wood led to the presence of mushroom lesions and rotting, up to the hollow. **Figure 12** shows the distribution of the number of trees by type of stem injury.



Figures 12.
Diagram of stem damage distribution by number of trees, %.

In addition to damage to the trunk wood, the trees under study had a different degree of crown damage, which was expressed by the presence of a large number of dry branches (**Table 8**).

Figure 13 shows the percentage distribution of trees by crown condition. On the axis of ordinates are represented percentages, on the axis of abscissa - categories of trees as per crown.

Type	Quantity	%
No dry branches	223	33.58
Dry branches exist	394	59.34
Half dried tree, top drying	1	0.15
Dry tree	41	6.17
Top drying	3	0.45
Half dried tree	2	0.30
Total	664	100

Table 8.
Presence of dry branches of investigated trees on test area No. 3.

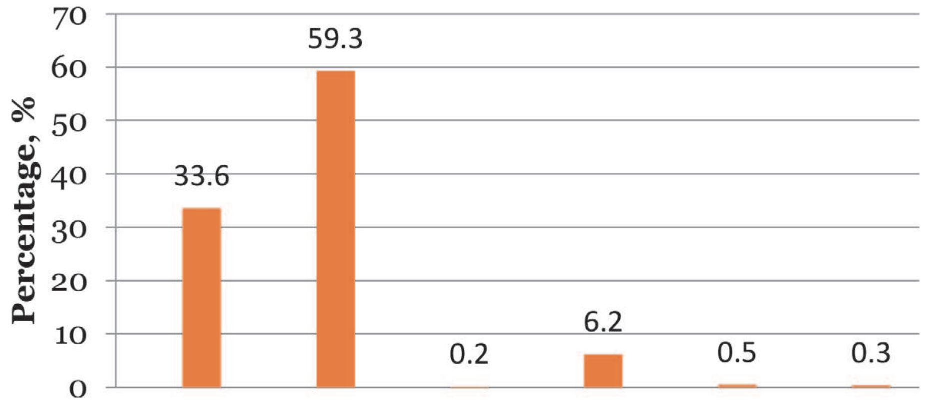


Figure 13.
Distribution of the number of trees by the degree of damage to the crown (presence of dry branches), % on test area No. 3.

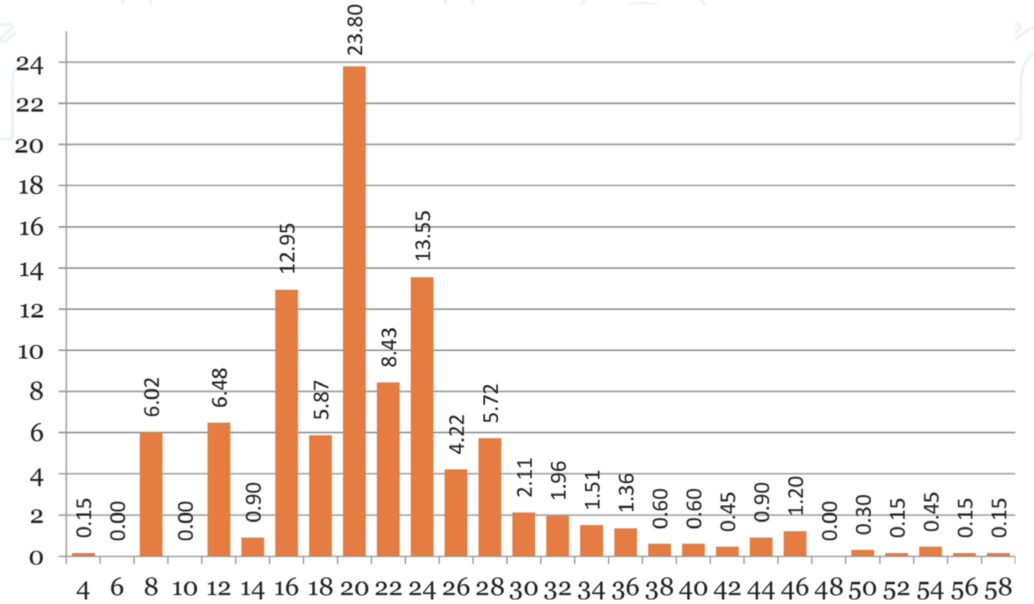


Figure 14.
Distribution of number of trees in% by diameters in test area No. 3.

Another evidence of the extreme oppression of trees in the pine massif is the nature of the distribution of trees along the thickness stages. In normal, healthy wood, this distribution is close to the normal distribution curve. Let us look at **Figure 14**, which shows a diagram of the distribution of trees by diameter at a height of 1.3 meters.

The **Figure 12** shows the percentage of trees by diameter on test area No. 3. Percentages are represented along the ordinate axis, along the abscissa axis - the thickness of trees at a height of 1.3 meters. It can be seen what a large range of diameters in the woodland is from 4 centimeters to 58 at a uniform age, which indicates strong intraspecific competition of trees.

4. Discussion of the results

Based on the conducted studies, it can be concluded that the results of studies of the Arbotom ® and Resistograph ® devices of the German company Rinntech [7–17] are quite often found in scientific publications. However, in most studies, the assessment of the state of the stem wood using appropriate instruments is performed separately [5, 7, 8, 11, 14]. The data are comparable with the data of well-known scientists in terms of quantitative indicators [7, 8, 10, 12–14], which confirms the reliability of our studies. We tried to compare the data of the readings of the two devices and compare them in our work. Cluster analysis methods were also used to simultaneously compare the readings in order to more accurately quantify the condition of trees and predict the appearance of emergency trees that are dangerous to human life in the city under wind loads. Most often, urban plantings were described using visual or dendrometric characteristics [16–18], but only visual assessment did not determine how long a particular tree or plant species could exist in an urban environment without loss of viability and signs of accidents. That is, the visual assessment method cannot determine the degree of damage to the tree by internal rot and the degree of development of rot, up to the formation of a hollow [16–18]. In this work, visual and measurement methods for assessing the state of forest areas included in the urban environment were also carried out, which is unique, since it is typical only for the northern regions of Russia, where cities are relatively poorly built (50–70 years). A fairly high correlation was found between dendrometric parameters, the state of the roots and tops of trees, and the presence of internal trunk defects. The reduction in the life expectancy of trees in urban conditions under recreational loads and high levels of atmospheric pollution has been proven.

5. Chapter conclusions

Based on the studies carried out, the following conclusions can be drawn:

1. Natural forests preserved 60–65 years ago during the development of the city of Bratsk certainly perform esthetic and sanitary protective functions. But at the same time they themselves are subjected to strong anthropogenic effects. Typically, there are no forest plants of living soil cover, in some cases the trees are dead cover due to the high degree of trampling. Plants grow in 4–5 bonitet class, have a height of almost twice as high as trees of the same age of 1 bonitet class.

2. Trees have a large percentage of shape of the trunk defects, primarily drywalls and prophecy, which is associated with mechanical effects on tree trunks.

3. Tree crowns are cut, often have a flag-shaped crown, a large number of dry branches.

4. Studies have proved the presence of internal defects in all studied model trees. It is possible to conclude the general oppression of woody vegetation of the test areas under consideration.

5. Among the studied model trees, trial area No. 2 is noticeably distinguished in terms of wood hardness. However, in the general picture of the distribution of internal defects, significant selectivity between sites is not observed. Thus, one can conclude that the conditions for the growth of the woodland are relatively equal and the green spaces of various areas of the urban ecosystem of the city are evenly oppressed.

6. Under conditions of industrial pollution and increased recreational loads, processes of earlier aging of trees occur up to their natural death. In the forest environment, the life expectancy of common pine is from 350 to 600 years in Russia [10], and in the urban environment without proper care and with a high level of anthropogenic load, already at the age of 70–80 years there are pronounced signs of tree aging, which are manifested in the presence of dry branches, dry trees, the presence of internal rots, stem pests.

7. When compiling an assessment of the state of the plantation as a whole, it is advisable to recommend comparing the data of the two devices both according to the parameters of the expert assessment (proportion of disturbed wood) and according to the parameters of automated measurements (instrument data) to compile the most complete picture of the state of dendrocenosis.

8. The work performed is of great practical importance, as it allows to identify emergency trees that can be exposed to wind and windbreak under heavy wind loads, and to carry out timely replacement with younger and healthier trees.

9. All these signs indicate the need for additional studies of the internal condition of the wood of model trees of the sites considered by instrumental methods. In view of the high value of urban forests, non-destructive testing methods are recommended. Woodlands require a whole range of forestry measures to preserve these unique objects of the urban environment - such as sanitary cutting of dead trees, cutting off dry branches, introducing a fertile layer of land, and treating mechanical damage to the trunk.

10. The developed proposals should be used in the care of green spaces in urban urban ecosystems, especially in the care of areas of natural forests that are located inside urban development. Regular monitoring of the condition of such plantings is planned to be carried out not only for Pinus sylvestris L., but also for other tree and shrub species growing under anthropogenic loads.

6. Grainude

I express my gratitude to my colleagues in the work who took part in the collection of experimental material I.A. Garus, A.N. Mukhacheva.

Author details

Elena Runova[1]*, Vera Savchenkova[2], Ekaterina Demina-Moskovskaya[2] and Anastasia Baranenkova[2]

1 Bratsk State University, Bratsk, Russian Federation

2 Mytischi Branch of Bauman Moscow State Technical University, Moscow, Russian Federation

*Address all correspondence to: runova0710@mail.ru

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