

ASSESSMENT OF THE CONDITION OF BALSAM POPLAR TREES (*Populus balsamifera* L.) IN A RESIDENTIAL AREA OF BRATSK

OCENA STANJA BALZAMASTIH TOPOLOV (*Populus balsamifera* L.) V STANOVANJSKIH DELIH BRATSKA

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ABSTRACT

In this study, we investigated the health status of balsam poplar (*Populus balsamifera* L.) trees in a residential area of the city of Bratsk (Irkutsk Oblast, Russia). Visual and instrumental assessment of the health status of pruned and unpruned trees was performed. The identified internal defects in the tree were analyzed with a Resistograph device, which enabled the extent of decayed wood to be determined. Visual analysis revealed various types of damage: dried branches, brittle crowns, frost cracks, mechanical damage, curvature of trunks, decay and inclusions of foreign bodies. We compared trees with and without canopy pruning. We found that pruned trees were significantly more damaged than non-pruned trees. Decomposing wood at different stages of development was found in all the trees studied. A tree passport combining the visual and instrumental assessment data was compiled for each tree. The results of the research were used to formulate conclusions and recommendations for improving the management of urban trees in order to restore their ecological and aesthetic functions.

Ključne besede: *Populus balsamifera* L., visual analysis, Resistograph, urban area, wood, decay

IZVLEČEK

V tej študiji smo raziskovali zdravstveno stanje balzamastih topolov (*Populus balsamifera* L.) v enem izmed stanovanjskih območij Bratska (Irkutsk Oblast, Rusija). Opravljena je bila vizualna in instrumentalna ocena zdravstvenega stanja obrezanih in neobrezanih dreves. Ugotovljene notranje napake v drevesu smo analizirali z napravo Resistograph, s katerim je mogoče ugotoviti obseg razkrojenega lesa. Vizualna analiza drevesa je pokazala različne vrste poškodb: posušene veje, lomljive krošnje, mrazne razpoke, mehanske poškodbe, ukrivljenost debel, razkroj in vključke tujkov. Primerjali smo med drevesi z in brez obrezovanja krošenj. Ugotovili smo, da so bila obžagana drevesa bistveno bolj poškodovana kot neobžagana. Razkrajajoči se les je bil ugotovljen pri vseh preučevanih drevesih, vendar v različnih razvojnih fazah. Za vsako drevo je bil izdelan drevesni potni list, ki združuje podatke vizualne in instrumentalne ocene drevesa. Rezultati raziskave so bili uporabljeni za oblikovanje zaključkov in priporočil za izboljšanje gospodarjenja z mestnim drevjem zato, da se je lahko obnovila njihova ekološka in estetska funkcija.

Key words: *Populus balsamifera* L., vizualna analiza, rezistograf, urbano področje, les, razkroj

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1 INTRODUCTION

1 UVOD

In recent decades, environmental degradation at the global, regional and local levels has become an increasingly urgent problem. Increased consumption of the natural resources of Siberia caused by intensive development and industrial production has led to a serious deterioration of the natural environment in a region that had previously been nearly free of anthropogenic impacts (Plyusnin, 2014).

Today, the ecosystem of Siberia is exposed to the impacts of various anthropogenic factors, such as in-

dustrial logging, forest fires and air pollution caused by industrial enterprises (Plyusnin, 2014). As a result, an immense quantity of harmful chemicals and suspended particles are released into the atmosphere of the region every day. Several studies of the physicochemical properties of such aerosols carried out in recent years in the Baikal region have confirmed their significant role in the pollution of the atmosphere of the ecosystem of Lake Baikal (Popovicheva et al., 2021) and, as a consequence, of the entire Siberian region. These factors are causing the decline of trees and forests in Siberia and the Russian Far East (Takahashi et al., 2020).

Green areas (plantations of trees and shrubs) in cities are most susceptible to destructive urbanization.

The main component of the ecological infrastructure of cities is the system of green common areas: urban gardens, parks, squares and boulevards (Ekinici and Sağlam, 2016; Egerer et al., 2019). A significant part of a city's vegetation is made up of trees and bushes located along roads, highways and footpaths. They play the role of an ecological barrier protecting residential areas from the adverse effects of industrial enterprises and vehicles, and therefore they are significantly affected by adverse natural and anthropogenic factors: high air temperatures in summer, low air temperatures in winter, wind, dust, exhaust gases, anti-ice agents and recreational load. Artificial street lighting violates the light regime, and the use of storm sewers to remove surface water leads to a lack of moisture. As a result, the tree and shrub vegetation of cities is exposed to various types of damage and diseases, inevitably leading to a reduction in life span and increased mortality.

Balsam poplar (*Populus balsamifera* L.) is the most widespread tree species on the streets of Siberian cities experiencing a harsh continental climate. It is resistant to dust and gases, including those from vehicles, and it traps dust well (Lavoie et al., 2013). It is undemanding with respect to soil composition and moisture requirements, and it is resistant to cold (Possen et al., 2011; Lehvavirta et al., 2014; Garcia-Garcia et al., 2016; Yalaltinova et al., 2018). Another advantage of poplar is its rapid growth (FAO, 2016). It quickly gains the green mass necessary to ensure the protection of residential areas from adverse environmental influences.

In the harsh climate of the Siberian region and unfavorable environmental conditions in the city of Bratsk, balsam poplar (*Populus balsamifera* L.) also dominates among the trees. The poplar stands are currently 40–50 years old. Under natural conditions, the average life expectancy of poplar is 80–90 years. However, due to the enormous environmental load in urban conditions and due to the detrimental effect of urbanization, the critical age of vegetation is reached much more quickly (Lüttge and Buckeridge, 2020), and poplar is no exception. Therefore, it is necessary to study poplars of a certain age to assess their health status and replace plantings on city streets.

Researching the health of trees in cities is important because they pose a danger to people (pedestrians) and urban infrastructure in the event of a collapse. This can happen when the stability of the tree is compromised due to many factors: improper crown formation, a severe lean of the trunk, internal defects

in the wood (voids, decay), wind and snow loads, etc. The most dangerous factors are internal defects, since they greatly undermine the health of the tree and lead to fragility, instability and death. Such defects may not be visually noticeable or may appear insignificant. Therefore, only detailed diagnostics make it possible to draw conclusions about the health of a tree and the risk of its collapse.

Various methods of analysis are used to study the health of trees: instrumental and visual; quantitative and qualitative; and non-destructive (non-invasive), low-destructive (minimal damage) and destructive (invasive) (Wassenaer et al., 2009; Arciniegas et al., 2014).

Considering the value of urban tree plantations, the difficulty of replacing them and the increased external load on them, it would be desirable to develop and introduce non-invasive methods or those causing minimal damage for assessing the quality of wood.

The least destructive method is visual analysis. Therefore, it should be used in conjunction with other methods, especially quantitative or instrumental methods. A traditional method for assessing the condition of trees involves measuring the resistance to drilling. The principle is to probe the wood under study and measure the thickness of sound wood around voids or decay using some form of drilling or coring. The Resistograph is considered to be a more sensitive drilling method compared to incremental drills or large drills. It enables the accurate measurement of the thickness of sound wood and provides informative results (Wassenaer et al., 2009). In addition, the quality and reliability of Resistograph® readings is confirmed by its high correlation coefficient. It has the highest correlation coefficient in comparison with similar devices ($r^2 = 0.9$).

The following other methods are also used: acoustic (measuring the speed of propagation of a sound wave along the radial direction of the tree trunk), electromagnetic (based on electromagnetic waves), acoustic tomography (using elastic waves in the low frequency range) and ultrasound tomography (using elastic waves in the high frequency range). The listed methods of wood decay testing offer a good balance between accuracy, invasiveness and ease of use in the field (Bucur, 2003; Johnstone et al., 2010). However, there are problems with in-depth assessment of the used measurement systems and signal processing (Arciniegas et al., 2014). For example, the accuracy of determining the position of structural elements in wood using drilling methods is higher than when using acoustic tomography methods.

Thus, each of the considered methods for assessing the health of trees has advantages and disadvantages and can be applied to study the health of urban plantings. To reduce the disadvantages of existing methods and increase the accuracy of the data obtained, it is necessary to use them simultaneously, combining several diagnostic methods for the same object of research. This makes it possible to conduct a comprehensive and reliable assessment of the health of trees.

This study investigates the health status of trees (balsam poplar) in the city of Bratsk using the following diagnostic methods: visual assessment of their condition (determination of the presence and type of damage, measurement of the lean of the trunk) and instrumental diagnostics of the internal state of the tree using a Resistograph.

2 MATERIALS AND METHODS

2 MATERIAL IN METODE

The study was carried out in the city of Bratsk (56°07'00.0"N 101°36'00.0"E), which is in Eastern Siberia, in the northwest of the Irkutsk region. The distance from the city of Bratsk to the regional center (the city of Irkutsk) is 460 km in a straight line. Bratsk is located on the banks of the Bratsk and Ust-Ilimsk reservoirs, formed on the Angara River, which flows from the freshwater Lake Baikal.

The residential area of the city is an agglomeration of dispersed residential areas located at a considerable distance from each other (about 30 km) and separated by significant forested areas and waterbodies (recreational zones).

The level of air pollution in the city has been assessed as very high for many years. The main polluting enterprises are the branch of the OJSC Ilim Group in the city of Bratsk, which specializes in the production of bleached sulphate pulp, and OJSC RUSAL Bratsk, the world's largest aluminum producer.

The city's greening system (recreational zones) is mostly represented by trees and shrubs. In urban areas, they are mainly planted in single-row plantings. The most common among them are *Populus balsamifera* L., *Betula pendula* Roth, *Acer negundo* L., *Ulmus pumila* L., *Malus baccata* L. Shrubs, mainly *Saragana arborescens* Lam., are located mainly along sidewalks (footpaths).

The study was conducted in one of the residential areas (microdistricts) of the city of Bratsk from May to October. The object of the study was balsam poplar (*Populus balsamifera* L.) located along roadways. The trees were planted during the construction of the city (in the 1960s and 70s). Their age is 40–50 years. The number of trees surveyed was 653. The trees were numbered and examined for external (visual) and internal health. To assess the external state of the tree, VTA (visual tree inspection) was used, including an assessment of the condition of the tree, the position of damage (wound scars, fungi), measurement of the lean of the tree trunk, and measurement of the distance of the tree from the edge of the road. In addition, an instrumental assessment of the trees was carried out in order to detect possible internal damage. The distance from the edge of the road to each tree was measured. The number of such trees was 102.



Fig. 1: External view of the Resistograph®

Slika 1: Zunanji videz Resistographa®

Instrumental diagnostics of the internal state of trees was carried out using the Resistograph® device from the German company RINNTECH (Fig. 1). The principle of operation of the device is based on the determination of the resistance of the wood to drilling. The measurement was carried out at a height of 1.2–1.4 meters. The depth of the drilling was 35–40 cm (depending on the diameter of the tree trunk). In the process of measuring with the Resistograph® in real time, graphs of the change in resistance (resistograms) were obtained at a scale of 1:1. The obtained resistograms were used to determine the percentage of wood decay (the degree of wood decay). The results of all measurements were saved in the device memory and then transferred to a computer. With the help of the DECOM computer program, these data were processed by a specialist: areas with healthy wood were marked in green, areas with decay at an early stage of development in yellow, and areas with highly developed stem decay in red. The proportion of different wood areas (in percent) was calculated automatically. This indicator made it possible to determine the density of the wood, the presence of a cavity, and to differentiate between undecayed/sound and decayed wood based on the density. To reduce damage to the test object (wood), an ultra-thin drill (drill needle) was used in the construction of the Resistograph®. For each tree, a description was compiled which presents the data from the visual and instrumental assessment of the tree.

3 RESULTS AND DISCUSSION

3 REZULTATI IN RAZPRAVA

Most poplars on city streets undergo radical pruning to reduce the formation of fluff in the summer. In this case, the most traumatic and unaesthetic method of heading is applied. It involves the complete removal

of the crown from the top of the tree trunk (Fig. 2). This type of pruning of the crown of mature trees is extremely damaging, leading to premature aging and death (Hevia et al., 2016). A large-diameter cut is formed, which leads to the development of various diseases as various microorganisms and spores of fungi that cause decay can enter the wound.

Of the examined trees, 45 % were pruned. Visual inspection of the trees revealed that most of the trees had various types of damage and injuries: dried tree branches, brittle crowns, bark injuries exposing the wood, wood cracks from frost, mechanical damage, curvature of the trunk, and the presence of wood decay.

A comparison of trees that had undergone pruning of the tree crown (pruned trees) and those whose crown had not been pruned (unpruned trees) was done. It showed that in pruned trees, thinning of crowns and the formation of rounded growth (thickening of the trunk of the tree and rounded shape) occurs twice as often. This indicates that the tree is weakened. It was also found that damage in the form of outgrowths on the trunks is present in 41 % of the surveyed pruned trees, whereas it is present in only 18 % of unpruned trees. Deformation of the trunk was found in 20 % of the surveyed pruned trees and in 9 % of unpruned poplars.

The development of decay in wood, which is caused mainly by xylotrophic fungi, leads to a weakening of the mechanical strength of the wood. As a result, the tree (or a separate part of it - for example, a skeletal branch) may fall. The presence of decay in the trunk of a tree can be indicated by certain visual diagnostic signs known to specialists (hollows, voids, swelling of the trunk, fruit bodies of wood decaying fungi, resinification, tree growth retardation, and others). The most dangerous for the stability of the tree is the development of decay and the formation of hollows in the root



Fig. 2: Balsam poplars which have undergone pruning (heading)

Slika 2: Videz obglavljenih balzamastih topolov

Table 1: The degree of decay in wood of stems observed in balsam poplar

<i>Populus balsamifera</i> L.	Degree of decay (%)								
	Decay in the initial stage of development			Strong decay			Presence of a cavity		
	min	max	average	min	max	average	min	max	average
Pruned trees	5.3	89.9	47.5	2.5	48.5	25.5	18.4	28.3	23.4
Unpruned trees	23.9	47.2	35.5	3.1	12.6	7.8	-*	-	-

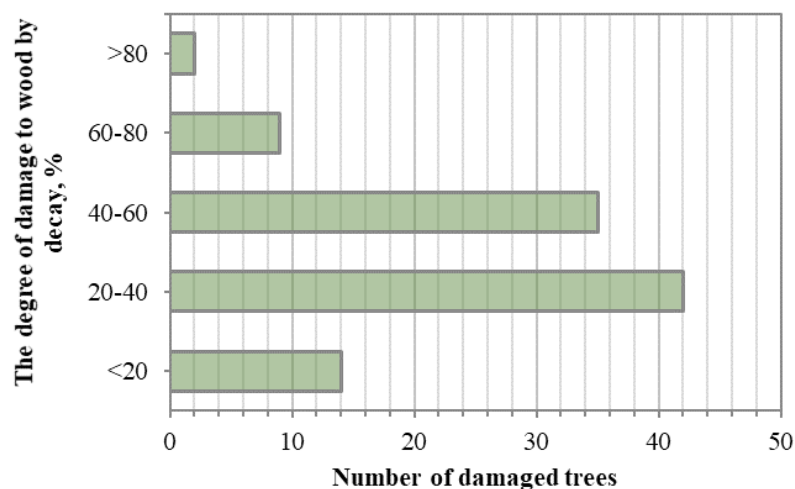
*“-” Not found

of the tree, which could lead to the whole tree falling. Visual diagnostic methods do not always allow us to establish the size and nature of the spread of decay in the trunk and roots of a tree. Therefore, in most cases, it is not possible to draw a conclusion about the degree of hazard posed by a tree based solely on external diagnostic signs. Sometimes these signs are present, but there is no decay. The opposite also occurs: decay is present in the trunk, but outwardly it is not noticeable in any way. In addition, decay in the trunk does not appear immediately and has several stages of development. In the first stage, there is the possible appearance of decay. This is facilitated by the presence of a cavity, embryos of decay, cavities, a defect inside the tree trunk in the form of a cavity, empty space or a hollow, around which decay can initiate. In the second stage, there is decay at the initial stage of development. The final stage is characterized by highly developed decay. Only a modern scientifically grounded approach to solving this problem can determine the thickness of healthy wood, the size and extent of decay, as well as a number of other indicators. It consists of conducting a comprehensive assessment of the internal state of trees, including visual (qualitative) and instrumental (quantitative) diagnostics.

Preglednica 1: Stopnja razkrojenosti lesa v deblih balzamas-tih topolov

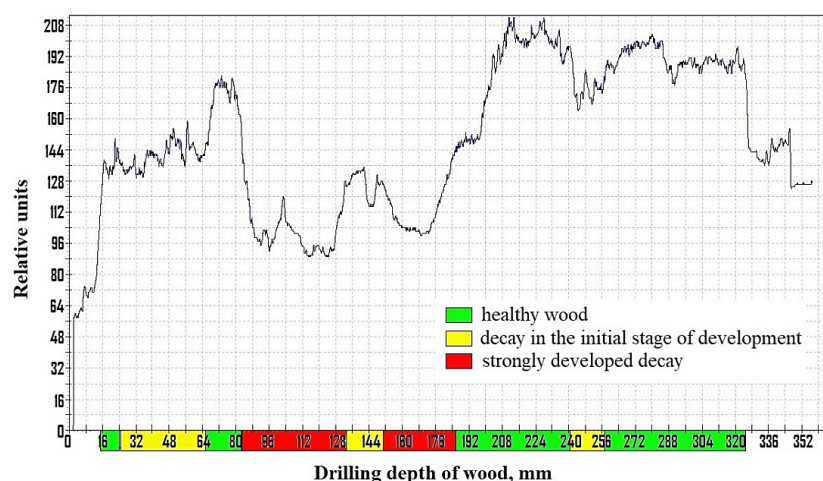
When diagnosing balsam poplars using a Resistograph, it was possible to establish a quantitative indicator of the degree of tree decay (in %) and the stage of development of this decay in all trees. According to the data obtained, decay at the initial stage of development was found in absolutely all 102 studied samples. It affects from 5 to 90 % of the wood of the studied poplars (Table 1). Strongly developed decay is found in 27 % of the surveyed trees. It should be noted that the possible appearance of decay (the presence of a cavity, embryos of decay, cavities) was found only in pruned trees, and the total amount of decay present in them is much higher than that of unpruned trees (Table 1).

It was found that the degree of the decay of wood of the studied trees is different and varies over a wide range (Fig. 3). Almost 35 % of poplars have a significant degree of wood decay (from 20 to 40 %). More than 40 % of trees have a high degree of wood decay (up to 60 %). More than 10 % of trees have a very high and extremely high degree of wood decay (60 % and more), and only 14 % of poplars are less affected by decay (up to 20 %) (Fig. 3). The data obtained confirm the presence of a significant negative impact of the urban environment on the health of trees, and balsam poplars in particular. Their health deteriorates and their life expectancy is reduced.

**Fig. 3:** Degree of decay in the wood of balsam poplar (*Populus balsamifera* L.)**Slika 3:** Stopnja razkroja v lesu balzamas-tih topolov (*Populus balsamifera* L.)



a



b

Fig. 4: Visual (a) and instrumental (b) assessment of the state of the tree No. 22

The visual diagnostic method is not a reliable way of assessing the health of trees, especially in express diagnosis (Fig. 4a). For example, the use of the Resistograph to more closely examine a poplar (Sample No. 22, Fig. 4b) revealed the presence of decay along the lower part of the tree, which at first glance was not obvious. As this sample shows, a tree that is very severely decayed (81 % of the wood is decayed) may not necessarily appear to have significant external damage. Such a tree is susceptible to collapse and poses a threat to urban infrastructure and people. Trees of this nature are subject to compulsory removal.

Trees that have a leaning trunk represent the greatest danger. If the lean angle of the tree trunk is equal to or greater than 45° , then it must be cut down and removed. No trees with such a trunk defect were found. However, trees were found with a trunk lean angle of $30\text{--}40^\circ$, with bifurcation of the trunk and crown asymmetry. They are also dangerous since collapse is pos-

Slika 4: Vizualna (a) in instrumentalna (b) ocena stanja drevesa št. 22

sible under dynamic loads from strong winds.

It was found that of all the trees under study, half of the poplars (50 %) had a trunk lean of 10 to 20° , 12 % had a trunk lean of between 20 and 30° , and 2 % had a trunk lean of more than 30° .

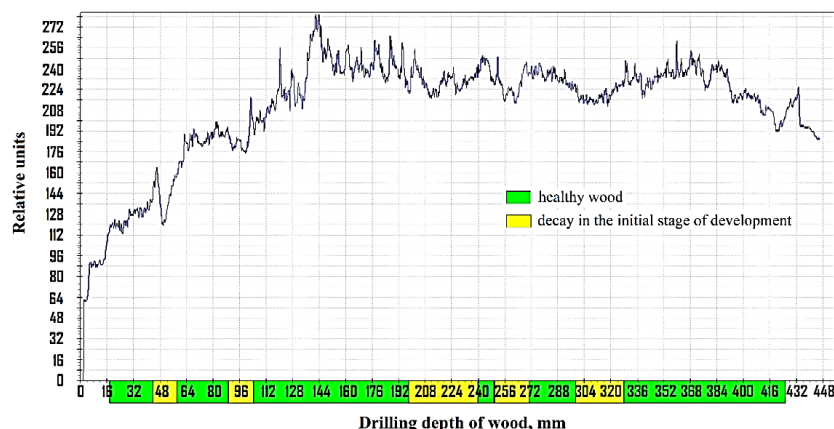
The architecture of the crown plays an important role. Many of the poplars have an asymmetrical crown. Some have large branches that have formed due to improper pruning of the crown. These factors also increase the likelihood of tree collapse.

Figure 5 shows a photograph of a poplar (Sample No. 35) with a resistogram. The instrument method revealed that 30% of the wood is affected by decay in the initial stage of development. This is not imply high risk, but due to the asymmetric arrangement of the branches and the absence of bark on the trunk, the tree must be removed for safety reasons.

Diagnostics of the presence of cavities in the tree trunk is of great importance for assessing the hazard



a



b

Fig. 5: Visual (a) and instrumental (b) assessment of the state of tree no. 35

Slika 5: Vizualna (a) in instrumentalna (b) ocena stanja drevesa št. 35

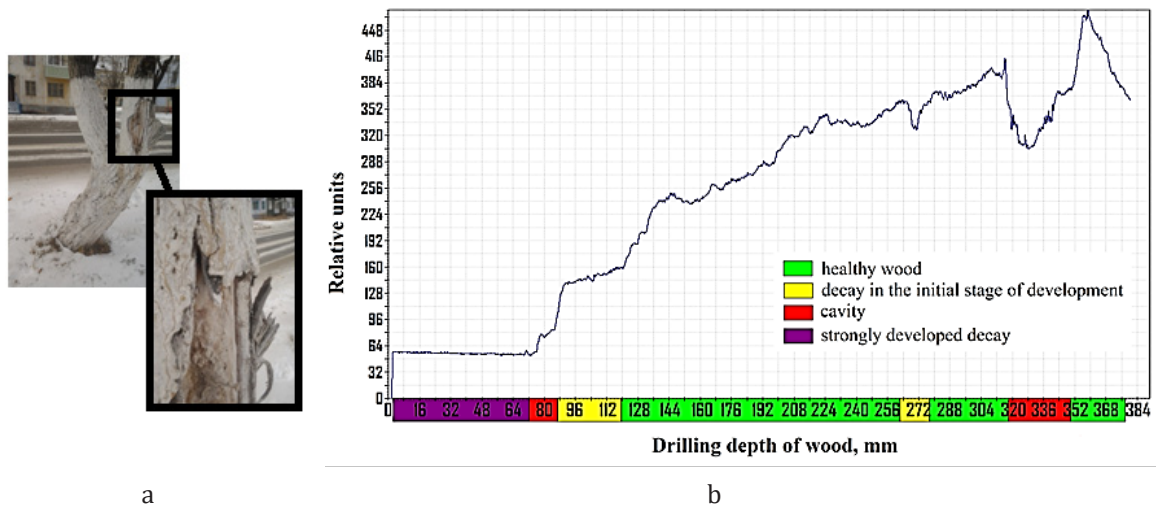


Fig. 6: Visual (a) and instrumental (b) assessment of the state of the tree no. 26

status of poplars. If a cavity is found, and it is located behind a section of healthy wood, then the level of danger is low. This means that the tree was able to create a protective barrier on its own, preventing the advance of decay into healthy wood. However, if a piece of wood affected by decay is found behind the cavity, then there are no obstacles to further decay, and it will spread freely further into the trunk, which over time will lead to the death of the tree. Another important risk factor is the thickness of sound wood surrounding the cavity (Brudi and van Wassenauer, 2001; Niklas and Spatz, 2004; Mattheck, 2007). If there is not enough wood surrounding the cavity, the tree is likely to collapse.

Figure 6 shows a photograph of a studied poplar (Sample No. 26) and a resistogram. Decay at the initial stage of development affected 13 % of the wood, and highly developed decay affected 12 % of the wood. A cavity accounts for 28 % of the wood, with a section of wood with highly developed decay immediately adjacent the cavity. In addition, the trunk of the poplar is quite curved. Based on the set of established data on the health of this poplar and predicted deterioration, it can be concluded that the tree should be removed.

It was found that a significant proportion of the trees were planted in violation of the planting rules. According to sanitary rules (SNiP 2.07.01-89), the distance from the edge of the road to the tree must be at least 2 meters. Only 49 % of the poplars are located according to this rule. The rest were in significant violation of the established standard, at a distance of 0.2 to 0.8 m from the edge of the road.

Thus, according to the results of a comprehensive assessment (visual and instrumental) of the health of balsam poplar in row plantings located along two streets of the city, it was found that 17 trees were sub-

Slika 6: Vizualna (a) in instrumentalna (b) ocena stanja drevesa št. 26

ject to removal. Six of them had clear visual signs of damage: root decay, a significant area of bare trunk (without bark), dried tree branches and trunk. An instrumental assessment of the health status of poplars made it possible to detect significant internal injuries in 11 trees that externally did not have significant superficial injuries. As a result, they were also recommended for cutting and replacement.

4 SUMMARY

The condition of trees growing in urban areas requires close attention since they are subject to various anthropogenic factors. We carried out a comprehensive assessment of the health status of balsam poplar (*Populus balsamifera* L.) trees in a residential area of the city of Bratsk. Visual and instrumental analysis of tree health revealed the rapid deterioration of tree health irrespective of tree age. Visual analysis showed various types of damage: dried branches, brittle crowns, frost cracks, mechanical damage, curvature of the trunk, decay and inclusions of foreign bodies. Trees subjected to “rejuvenation” pruning of the crown (pruned trees) had more damage than trees without such treatment (non-pruned trees). Trees with suspected internal wood defects were examined using a Resistograph, which enabled the accurate determination of the degree of damage to the wood caused by decay and the stage of development of the decay. Decay was found in all trees, but at different stages of development. Several trees did not appear to have serious damage upon visual inspection, but the instrumental assessment of their health showed significant internal damage to the wood. Such trees were therefore recommended for removal and replacement.

5 POVZETEK

Stanje dreves, ki rastejo v urbanih okoljih, je treba skrbno spremljati, saj so podvržena različnim antropogenim dejavnikom. Izvedli smo celovito oceno zdravstvenega stanja balzamastih topolov (*Populus balsamifera* L.) v stanovanjskem naselju mesta Bratsk. Vizualna in instrumentalna ocena je razkrila hitro slabšanje zdravstvenega stanja, ne glede na starost dreves. Vizualna analiza je pokazala različne vrste poškodb: posušene veje, lomljive krošnje, mrazne razpoke, mehanske poškodbe, ukrivljenost debel, razkroj in vključke tujkov. Drevesa, ki so bila "pomlajena" z obžagovanjem (obžagana drevesa) so imela več poškodb kot drevesa, ki niso bila deležna pomlajevanja (neobžagana drevesa). Drevesa, pri katerih je obstajal sum na notranje napake, smo analizirali z napravo Resistograph, ki omogoča natančno oceno obsega razkrojene-ga lesa ter razvojno fazo razkroja. Razkrajajoči se les je bil ugotovljen pri vseh drevesih, vendar v različnih razvojnih fazah. Nekaj dreves po vizualni oceni ni bilo hudo poškodovanih, vendar pa je instrumentalna ocena njihovega zdravstvenega stanja pokazala precejšnjo notranjo poškodovanost lesa. Za takšna drevesa smo zato predlagali odstranitev in nadomestitev z novimi.

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