Responses at the stand and tree level to ice storm injuries in beech forests in eastern Serbia

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Abstract

The paper presents the study on the condition and structural stability of European beech (*Fagus sylvatica* L.) stands after the 2014 ice storm disturbance. The research was conducted in three pure beech stands on the Rtanj mountain in eastern Serbia. The stand condition after the ice storm was analyzed using changes in taxation elements. The assessment of tree damage was done according to the ICP Forests methodology, while the structural stability of the stands and individual trees was analyzed using the slenderness coefficient. The obtained results indicate very heterogeneous responses of beech stands to the negative impact of the ice storm. Heterogeneity is not only expressed between stands but also within individual stands. The stands after the ice storm are characterized by significantly reduced values of production indicators, but also by satisfactory stability, considering that the trees from the understory suffered the most. Statistically significant differences in the stability of trees of different dimensions expressed through the slenderness coefficient were determined. Consequently, the stands have maintained an appropriate level of stability thanks to the survival and resistance of the dominant trees that are the bearers of functions in these stands (trees with dbh > 40 cm). This indicates the great potential of silvicultural treatments that can increase the stability and resistance of stands in areas with a high risk of such phenomena. In addition, repressive action in the form of salvage logging has a very important role with the aim of ensuring the continuity of stands after damage has occurred.

Keywords

Beech; Ice storm; Injuries; Structural stability; Eastern Serbia

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1 Introduction

Disturbances that occur as consequences of climate change have an increasing impact on the functioning, structural development, and successive changes in forest ecosystems (Seidl et al. 2011; Cohen et al. 2016). The key drivers of the evolutionary strategies of plants are represented by them (Gutschick and Bassirirad 2003). As such phenomena are mostly climate-sensitive (Netherer and Schopf 2010; Turner 2010), their intensification (increase in frequency and intensity) is expected in the coming period and was previously described in the Northern Hemisphere (Little et al. 2009). Damage to forest ecosystems from natural disasters in Serbia is continuously increasing, their share in total forest damage is increasing, and this can be linked to the direct effects of climate change (Ranković et al. 2016).

Ice storms that manifest themselves in the form of ice breaks and falling trees are a phenomenon characteristic of the forests of northern Europe (Šēnhof et al. 2020; Romeiro et al. 2022). The frequent occurrence of these meteorological disasters in the forests of central Europe, as well as in the forests of southeastern Europe, undoubtedly indicates that climate change affects the patterns of their occurrence (Klopčič et al. 2020). The impact of ice storms on forest ecosystems is very complex, considering that they affect both the structural characteristics of forests and the processes that take place in them. The intensity of the damage that can occur under the influence of such extreme climatic events depends on two sets of factors: the first refers to the characteristics of the ice storms; the second refers to the individual parameters of trees and stands (they mostly depend on tree species), as well as to the physical conditions of the location - primarily orographic factors (Bragg et al. 2003).

Ice accumulation is most often the result of freezing rain (also called supercooled rain), whose temperature is below 0°C, and which freezes on contact with solid objects (World Meteorological Organisation, 2023). In Central and Eastern Europe, it is common for one to two such climatic events per year that last for three or more consecutive days (Kämäräinen et al. 2017; Andreiet al. 2019).

At the end of November and beginning of December 2014, eastern Serbia was affected by an ice storm, which was followed by the appearance of a large amount of ice mass on trees, which caused catastrophic damage. In total, the damage was determined on 43,305.78 ha, and 1,874,046 m^3 of dying and damaged trees were recorded, regardless of ownership (Baković et al. 2015). The vertical spread of the ice storm was between 300 and 1000 m asl (Baković et al. 2015; Baković 2016), where the most threatened were forests between 500 and 900 m asl (Krstić et al. 2016; Spasojević et al. 2016). Most of the affected areas are on the northern or northeastern exposures, while the rest are evenly distributed on other exposures (Marković et al. 2019). The slope did not show any significant impact on the occurrence of ice breaks (Marković and Marković 2018).

As the beech proved to be one of the most resistant species to the negative effects of the ice storm in the affected area, the question of the future structural stability of these forests is essential. Previous research has shown that hardwood stands, despite the damaging effects of ice exposure, show surprising resistance to future repeated extreme climate events of this type (Fahey et al. 2020). Consequently, the paper aims to define the state and possibilities for re-establishing the structural stability of beech stands after the occurrence of damage from an ice storm, depending on the degree of damage and conducted salvage logging.

The hypotheses are as follows: (a) the remaining trees in the stand after the ice storm have satisfactory stability and can ensure the regeneration of the stand; (b) trees of different dimensions show significant differences in stability, observed through the slenderness coefficient.

2 Material and methods

The research was conducted in three pure beech stands in the management unit "Rtanj", within the State Enterprise "Srbijašume", Belgrade. The locations of the experimental fields were chosen to show the structural characteristics of stands affected by an ice storm in the most representative way. The experimental fields are square, 0.25 ha in size.

Figure 1. Beech forests damaged by an ice storm in the researched area.

Experimental field 1 was set up in a coppice beech stand (department 83a), which was described as a preserved stand, with a complete canopy, in good health condition before the ice storm occurred. It is located at an altitude of 470-740 m, on a uniform slope of 16-20° and northeast exposure. The soil is acidic brown, 41-80 cm deep, skeletal (11 to 30%) with a favorable humification process, while the geological base consists of crystalline schists. Salvage logging was not performed in this stand due to the low level of damage.

Experimental field 2 was set up in a high beech stand (department 78a). Before the ice storm, this stand had a full canopy, was preserved, and was in moderately poor health. It is located at an altitude of 500-820 m, a uniform slope of 16-20°, and western to northwestern exposure. The soil is acidic brown, 41-80 cm deep, slightly skeletal (up to 10%) with a favorable humification process. The geological base consists of crystalline schists. The experimental field was set up in a part of the stand where only heavily damaged trees were removed by salvage logging.

Experimental field 3 was placed in a coppice beech stand (department 30b). Before the ice storm, this stand had a full canopy, was preserved, and was in moderately poor health. It is located at an altitude of 630-750 m, on a uniform slope of 16-20° and northeast exposure. The soil is rendzina, 16-40 cm deep, slightly skeletal (up to 10%) with a favorable humification process. The geological base consists of organic limestone in decay. Salvage logging was not performed in this stand due to the low level of damage.

Data on the state of studied stands before the ice storm were taken from the forest management plan for management unit ”Rtanj”. At the same time, data about the state of the studied stands after the ice storm were collected on experimental fields. Diameter at breast height and total height were measured for all trees above the taxation limit of 10.0 cm in high and 5.0 cm in coppice forests. Assessment of damage to tree crowns and changes in leaf color was performed by visual assessment based on the ICP Forests monitoring method (Eichhorn et al. 2016). Crown damage was determined as the percentage of crowns missing from the trees, based on a comparison with a reference undamaged tree in the experimental field or the immediate vicinity. The health condition of the trunk was analyzed, and the presence of a secondary crown was also noted.

A comparative analysis of the structural characteristics of stands before and after the damage caused by the ice storm was performed using descriptive statistical analysis. For the analysis of the structural stability of the studied stands after the occurrence of damage from the ice storm, the slenderness coefficient was used, which was analyzed at the level of trees and stands (Stojanović and Krstić 2000):

$$SC = \frac{H_{tot}}{DBH}$$

Where: SC - slenderness coefficient of the tree; H_{tot} - total height of the tree (m); DBH - corresponding tree diameter at breast height (m).

Trees are categorized into three groups based on their slenderness coefficient (Stojanović and Krstić 2000), (Table 1).

Table 1. Slenderness coefficient classes.

Slenderness coefficient	Stand stability	Endangerment of the stand
< 80	Satisfactory stability	Doesn`t exist
80 – 100	Insufficient stability	There is a risk of windbreaks or falling trees
> 100	Low stability	High possibility of windbreaks or falling trees

To define the potential statistical differences when it comes to the stability of the remaining trees in the stands after the damage caused by the ice storm, analysis of variance (ANOVA) and LSD Post Hoc test at the level of significance 0.05 were used. The values of the slenderness coefficient of the trees were analyzed, whereby the trees were classified into three groups according to their dimensions (dbh): trees with dbh<20 cm (Group I), trees with dbh 20-40 cm (Group II), and trees with dbh>40 cm (Group III). The normality of the dependent variable was checked using the Kolmogorov-Smirnoff and Shapiro-Wilk tests.

3 Results and discussion

3.1 The state of stands after the ice storm

In the stand on experimental field 1, the number of trees before the ice storm was 794 per ha, while it was reduced to 336 trees after it, which represents a decrease of 58.7% (Figure 2). The biggest differences were recorded in diameter classes of 17.5 and 22.5 cm, while the floor of the dominant trees suffered very little damage. Most of the remaining trees have reduced crowns, the average crown damage is 53.0%, while leaf discoloration is 3.8%. In this experimental field, 11.9% of dead-standing trees were recorded. Cracks in the bark were recorded on 23.8% of the trees, and rot in the part of the trunk near the surface on 9.5%. The secondary crown was formed by 23.8% of the trees.

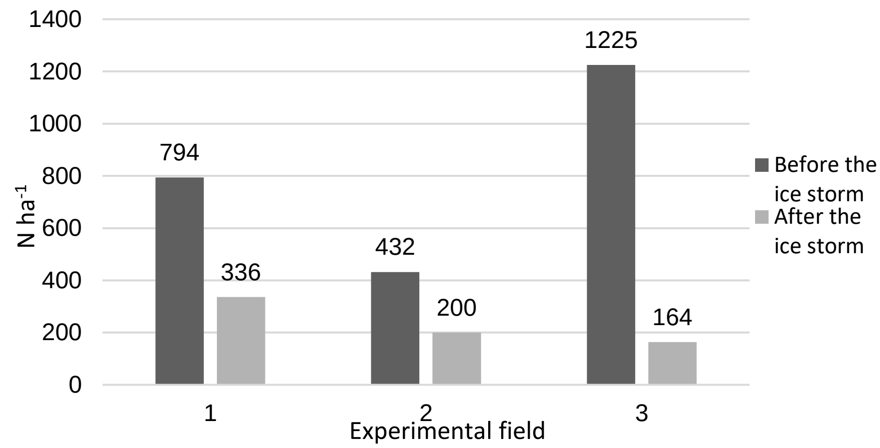

Figure 2. Number of trees per hectare before and after the ice storm.

Before the ice storm in the stand on experimental field 2, the number of trees was 432, while it was reduced by 53.7% after it, i.e. to 200 trees per ha (Figure 2). The biggest differences were recorded in diameter classes 17.5 and 27.5 cm. Dominant trees also suffered significant damage and were removed as part of salvage logging. Consequently, no remaining dead-standing trees were recorded in this experimental field. The remaining trees of the parent stand have significantly reduced crowns, with the average crown damage amounting to 53.2%, while the change in leaf color amounts to 4.0%. Cracks in the bark were recorded on 42% of the trees, and rot in the part of the trunk near the surface on 34%. The secondary crown was formed by 40% of the trees.

The biggest differences were recorded in the stand on experimental field 3, where the number of trees before the ice storm was 1225. After the ice storm, it was reduced to 164 trees per hectare, which represents a decrease of 86.6% (Figure 2). In this experimental field, the largest number of trees was reduced in the diameter classes of 12.5 and 17.5 cm. Despite the extensive damage in the understory, the dominant trees suffered very little damage. Most of the trees have reduced crowns, with the average crown damage amounting to 61.6%, while leaf discoloration amounts to 3.9%. In this experimental field, 7.3% of dead-standing trees were recorded. Cracks in the bark were recorded on 39% of the trees, and rot in the part of the trunk near the surface on 4.9%. A secondary crown was formed by 26.8% of the trees formed.

Considering that the dominant trees suffered the least damage in the studied stands, significantly better insight into the state of the stands after the ice storm is provided by the indicators of stand productivity, basal area, and volume.

The biggest differences were recorded in experimental field 3, where the basal area after damage from the ice storm was reduced by 57.2%, and the volume by 55.5% (Figures 3 and 4). Even though the mentioned parameters were significantly reduced, the dominant trees suffered very little damage, and the stand retained a high level of structural stability after the ice storm. In the stand on experimental field 1, the basal area and volume reduction are the least and amount to 31.5% and 21.2%, respectively (Figures 3 and 4), which indicates the high structural stability of the stand both before and after the ice storm. The stand on experimental field 2 suffered the greatest damage in the floor of the dominant trees, so despite having the least number of damaged trees, the basal area and volume were reduced by 45.4% and 59.8%, respectively (Figures 3 and 4). Considering this state of the stand, and the potential further deterioration of the volume, salvage logging was carried out in this stand, which removed the entire damaged volume. This is very important because the condition of the stands after the ice storm largely depends on whether timely salvage logging has been carried out (Irland 2000; Zhu et al. 2022).

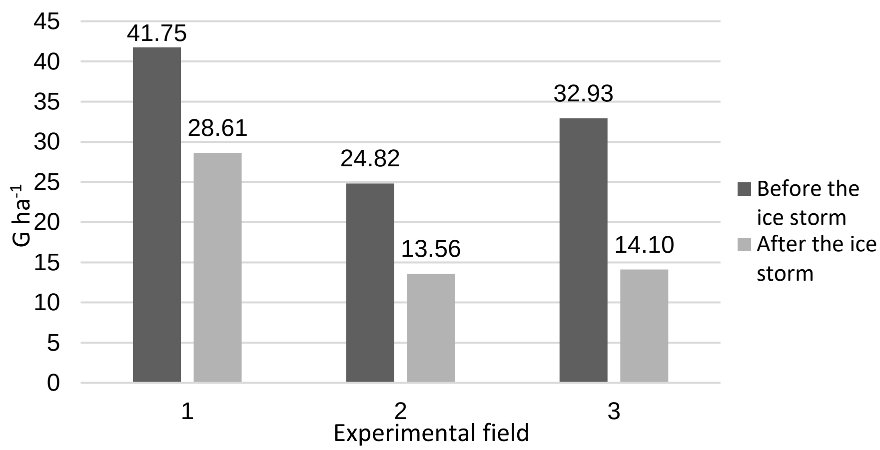

Figure 3. Basal area in experimental fields before and after the ice storm.

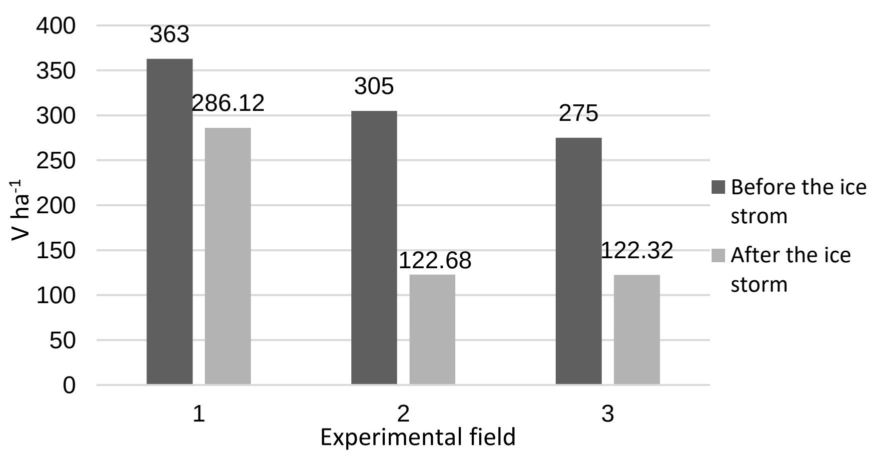

Figure 4. Total volume in experimental fields before and after the ice storm.

The canopy of the stand on experimental field 1 was 0.7 before the ice storm, while after the ice storm, it was still 0.7 on part of the surface, and 0.5-0.6 on part of the surface. In the stand on experimental field 2, there were major changes, before the occurrence of the ice storm the canopy was 0.5-0.6, while after the ice storm on one part of the surface, it kept this value, and on the parts of the surface where the trees from the dominant floor died it was 0.3-0.4. In the stand on experimental field 3, the canopy before the damage caused by the ice storm was 0.8, while after the ice storm, it was 0.7 on a larger part of the surface, and 0.5-0.6 on smaller parts of the surface. Excessive reduction of the stand canopy can be a huge problem because, in this way, space is opened for the intensive development of tree species with pronounced biological strength, which previously did not have a dominant role in these stands (Holzmueller et al. 2012; Covey et al. 2015). The consequences of a reduced canopy can be unsatisfactory natural regeneration, reduction of biodiversity, as well as intensive weeding of stands, especially in stands where beech is the dominant tree species (Boerner et al. 1988; Zhu et al. 2022).

3.2 Stability of the studied stands

After the ice storm, the stands seem to be stable enough despite the damage. However, the trees in the understory were the ones that suffered the most damage. There were some exceptions, like in experimental field 2 where heavily damaged dominant floor trees were removed during salvage logging.

The average value of the slenderness coefficient in the stand in experimental field 1 is 72.7, in experimental field 2 63.9, and in experimental field 3 63.8 (Table 2). These slenderness coefficient values also indicate satisfactory stand stability after the ice storm, which confirms the first hypothesis in this paper. In addition, a significant number of trees that remained in the stands formed a secondary crown. Consequently, there was a gradual increase in the canopy of the stand compared to the state immediately after the damage from the ice storm. Occurrences of ice storms are occasional, mostly related to isolated areas, and short-term (Šēnhofa et al. 2020). Therefore, such phenomena cannot be prevented, however, the resistance and flexibility of the stands can be increased if the critical conditions are understood and specific measures are taken with the aim of their further survival and development (Valinger and Fridman, 2011; Wallentin and Nilsson, 2014; Šēnhofa et al. 2020).

Table 2. The slenderness coefficient of the trees in the experimental fields.

Slenderness coefficient							
Experim. field	Min	Max	Mean	St. dev.	Median	Group slenderness coefficient	%
1	47.9	103.4	72.7	13.3	69.6	<80	75.7
						80-100	20
						>100	4.3
2	29.3	116.8	63.9	16.2	61.2	<80	87.8
						80-100	4.3
						>100	4.9
3	26.5	103.8	63.8	16.0	63.0	<80	91.4
						80-100	5.7
						>100	2.9

3.3 Stability of individual trees

Ice storm damage, viewed at the individual tree level, is the result of complex interactions between disturbance intensity, biological factors associated with the tree, stand characteristics, habitat characteristics, and other external factors (Kenderes et al. 2007; Klopčić et al. 2020). Accordingly, a preventive tool that can achieve significant effects in this regard is appropriate silvicultural measures, while repressive measures are mainly related to salvage logging, which is also of great importance.

The presence of trees in the studied stands with a slenderness coefficient value that indicates satisfactory stability is 75.7% in the stand on experimental field 1, 87.8% in the stand on experimental field 2, and 91.4% in the stand on experimental field 3 (Table 2).

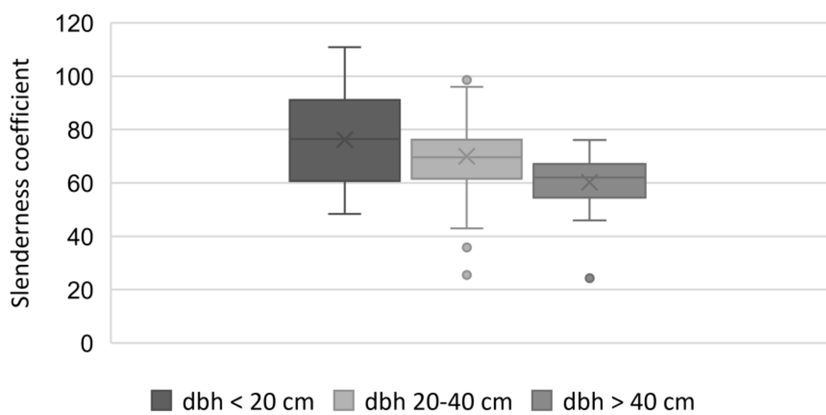

Figure 5. Slenderness coefficient of trees of different dimensions.

The average value of the slenderness coefficient of trees of group I is 76.26±3.79 SE, for trees of group II 69.99±1.31 SE, and for trees of group III 60.29±1.87 SE (Figure 5).

Analysis of variance (ANOVA) revealed statistically significant differences between the slenderness coefficients of trees of different dimensions, classified into 3 groups ($F=9.914$, $p=0.05$): trees with dbh<20 cm (Group I), trees with dbh 20-40 cm (Group II), and trees with dbh>40 cm (Group III). Using the LSD Post Hoc test, statistically significant differences were defined between the slenderness coefficients of trees of groups I and III (Mean diff. 15.97±3.75 SE, $p=0.001$), between trees of groups II and III (Mean diff. 9.69±2.78 SE, $p=0.001$), while a statistically significant difference with a lower level of confidence was defined between trees of groups I and II (Mean diff. 6.27±3.15 SE, $p=0.048$). This confirms the second hypothesis in the paper.

4 Conclusions

The obtained results indicate very heterogeneous responses of different beech stands to the negative impacts of the ice storm. Heterogeneity is not only pronounced between stands but also within individual stands, indicating that responses should be studied both at the stand level and at the tree level.

As the beech stands in the analyzed area are structurally heterogeneous, often with a distinct understory, the different responses of the stands and trees are clearly expressed, which can be seen through the intensity of the damage that occurred in these stands. The results in the paper indicate that the stands have maintained an appropriate level of stability thanks to the survival of the dominant trees that are the bearers of functions in these stands (trees with dbh>40 cm). These trees were at the same time the least damaged, in many cases they form a secondary crown, which indicates that they have the capacity for a full recovery. In addition, the results in the paper indicate that these trees have satisfactory stability.

There are two possible courses of action in situations where there is a high risk of the occurrence of such extreme climatic phenomena: preventive action in the form of appropriate silviculture treatments aimed at increasing the stability and resistance of the stand and repressive action in the form of adequate and timely salvage logging with the primary goal of maintaining the part of the stand that is not severely damaged. Consequently, there is great scope for future research to develop potential solutions for forests located in areas at high risk of future negative extreme climate events.

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