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THE EFFECT OF STAND CHARACTERISTICS ON THE OCCURRENCE OF ICE BREAKAGE AND UPROOTED TREES BY ICE IN EASTERN SERBIA

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Abstract: *The subject of this paper is the analysis of the influence of stand characteristics on the damage caused by the cold wave in the winter of 2014/2015 in the area of Eastern Serbia. The research is focused on the areas where, due to the high degree of damage, clear felling was carried out after the ice breakage, and therefore it was not possible to carry out assessment of damage at the level of individual trees. For that reason, the degree of damage was observed indirectly, through the scope of area covered by clear felling as a remedial measure in cases of permanently impaired stand stability. The research was carried out within forest management units in Moravian Forest Area, where the stands with the most severe consequences of the ice breakage were recorded. Key stand forms that affect their sensitivity to extreme weather events were identified through analysis of stand characteristics. The results indicate that mixed and structurally uneven-aged stands are more resistant to ice breakage compared to pure even-aged untended stands, and above all artificially established stands of conifers. The research results can contribute to better understanding of action mechanisms of ice breakage, as well as the improvement of forest management measures in order to increase forest resistance to increasingly frequent extreme climatic events.*

Keywords: ice breakage, uprooted trees by ice, stand characteristics, Eastern Serbia.

UTICAJ SASTOJINSKIH KARAKTERISTIKA NA POJAVU LEDOLOMA I LEDOIZVALA U ISTOČNOJ SRBIJI

Sažetak: *Predmet ovog rada jeste analiza uticaja sastojinskih karakteristika na oštećenja izazvanih ledenim talasom u zimu 2014/2015. godine na području istočne Srbije. Istraživanje je usmereno na površine na kojima je, usled visokog stepena oštećenja, nakon ledoloma sprovedena čista seča, zbog čega nije bilo moguće izvršiti procenu oštećenja na nivou pojedinačnih stabala. Iz tog razloga, stepen oštećenja posmatran je posredno, kroz obim površina obuhvaćenih čistom sečom kao merom sanacije u slučajevima trajno narušene stabilnosti sastojina. Istraživanje je sprovedeno u okviru gazdinskih jedinica u Moravskom*

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šumskom području, gde su evidentirane sastojine sa najtežim posledicama ledoloma. Analizom sastojinskih karakteristika identifikovani su ključni sastojinski oblici koji utiču na njihovu osetljivost na ekstremne vremenske nepogode. Rezultati ukazuju da mešovite i strukturno raznodobne sastojine imaju veću otpornost na ledolome u odnosu na čiste, jednodobne i nenegovane sastojine, a pre svega veštački podignute sastojine četinaru. Rezultati istraživanja mogu doprineti boljem razumevanju mehanizama delovanja ledoloma, kao i unapređenju mera gazdovanja šumama u cilju povećanja njihove otpornosti na sve učestalije ekstremne klimatske događaje.

Ključne reči: ledolomi, ledoizvale, sastojinske karakteristike, istočna Srbija

1. INTRODUCTION

Despite numerous studies dealing with the impact of abiotic disorders on forest ecosystems, there is still insufficient knowledge about the connection between the structural characteristics of stands and the intensity of damage in conditions of extreme ice breakage, especially in the region of Southeast Europe. In recent decades, under the conditions of climate change, an increase in the frequency of extreme weather events has been observed (Seidl et al., 2017). Forest ecosystems are continuously exposed to the effect of natural disorders, whereby abiotic factors such as ice breakages, snow breakages and wind breakages have especially significant role. Given their increasing frequency, ice breakages stand out as one of the most significant forms of abiotic disorders in forest ecosystems, especially in mountainous areas. Forest ecosystems depend on their capacity to withstand and recover from natural and anthropogenic perturbations (Forzieri, G. et al., 2022). Estimates indicate that in European forests, snow breakages annually damage around 4 million m³ of wood volume, whereby the damages are most often manifested in the form of tree breaks, but also bending and fallen timber (Nykänen et al., 1997). The mechanism of damage formation is connected to the accumulation of ice in crowns, which leads to the load increase and consequent breaking of branches and trees, and in extreme cases also whole stands. The studies show that the combination of unfavorable habitat conditions and unfavorable stand structure significantly increases the probability of occurrence of such disorders (Brang et al., 2001). Long-term trends indicate the increase in frequency of natural disorders in European forests, which is related not only to climate changes, but also to changes in the structure and method of forest management. The increase in the age of stands, wood volume and total forest area contributes to their greater sensitivity to the action of abiotic factors (Schelhaas et al., 2003). According to the results of a research (Peltola et al., 1999), even-aged and dense stands of conifers, especially in the exposed and wet habitats, show increased damage risk, while the structure and the level of stand maintenance have a key role in their resistance. On the other hand, the increase in biological and structural diversity can contribute to the decrease of risk from great damages, because different species and structures react differently to disorders (Jactel et al., 2009). Ice breakages do not affect only individual trees, but also the long-term processes in forest ecosystems, including succession, changes in the composition of species and an increase in the amount of dead wood, as well as changes in microclimatic conditions. Although these processes can have positive effect on

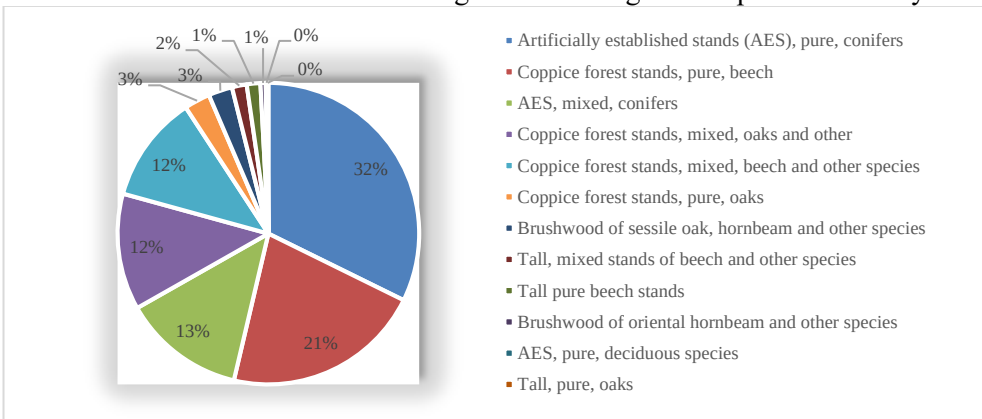
biodiversity, at the same time they increase the risk from secondary harmful factors, such as insects and pathogens. The resistance of beech stands to ice breakages depends on the combination of habitat conditions and structural characteristics, which indicates the need for adaptive forest management in the conditions of increasingly frequent extreme climatic events (Kanjevac et al., 2023). In Moravian and Timok forest areas, which were affected by ice breakages in the winter of 2014 Pavlović et al. (2022, 2023) state that the greatest damages were recorded in the stands with an unfavorable structure, above all in older and more mature stands, dense, insufficiently tended and stands with pronounced dominance of one species. Also, it was established that the intensity of the damage was largely conditioned by the combination of habitat factors (relief, exposure, altitude). Similar patterns were also recorded in other parts of Europe (Slovenia), where, for example, stands of spruce (*Picea abies*) showed increased sensitivity due to their morphological characteristics (Saje, 2014). The main meteorological conditions that lead to the occurrence of ice breakages include the occurrence of freezing rain, temperature inversions, high humidity and wind, which further increases the load on tree crowns. Bearing in mind the above, the area of Eastern Serbia, including the forests managed by Forest Estate Niš, represents an area of increased risk of these disorders, which indicates the importance of further research and the application of the adaptive approach to forest management.

2. MATERIAL AND METHODS

The research was carried out in the territory of Eastern Serbia, which was affected by intensive ice breakages during the winter of 2014. Within Morava Forest Area, the stands within Forest Management Units (FMUs) Obla glava, Kamenički vis I, Kamenički vis II, Bukovik-Mratinja, Devica, Svrlijško-Gulijanske planine and Rtanj were analyzed, where some of the stands suffered damages of such intensity that it was necessary to carry out their remediation using clear felling. The researched area is characterized by pronounced mountainous relief, frequent occurrence of temperature inversions, as well as increased frequency of freezing rain, which represents significant predisposing factor for the occurrence of ice breakages. The data on the areas on which clear felling was carried out was collected from the planning and record documentation of the forest management units. Basic structural parameters were recorded for each analyzed stand, including area, dominant tree species, origin (naturally or artificially established stands), structural form, developmental stage (age), preservation status, degree of mixedness and tendance. The data were obtained from the Forest management plans for the aforementioned Forest management units. The damage intensity was not assessed at the level of individual trees, but indirectly, based on the areas included in clear felling as a remediation measure in the stands with permanently impaired stability. Within the Morava Forest Area, clear felling was carried out on a total area of 647.85 ha. Of this, 131.29 ha were clear-felled in FMU “Bukovik–Mratinja,” 127.65 ha in “Obla glava,” 121.64 ha in “Kamenički vis I,” 101.21 ha in “Svrlijško-Gulijanske planine,” 76.19 ha in “Rtanj,” 71.43 ha in “Kamenički vis II,” and 18.44 ha in “Devica.” By reviewing the stand condition before the natural disaster, it was determined which stand forms are the most sensitive to extreme climatic influences.

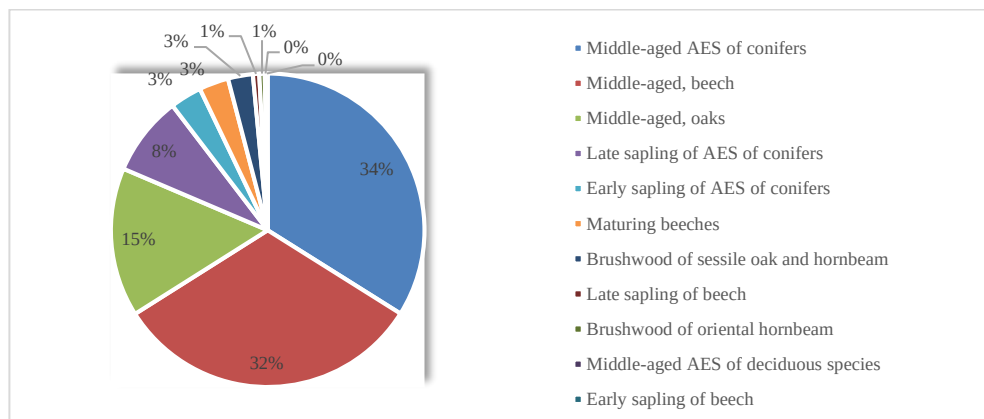
3. RESULTS AND DISCUSSION

By analyzing the collected data, it was determined that the intensity of stand damage caused by the ice breakage varies significantly depending on structural characteristics of the stands. The first thing to note is that all the stands that are affected by a natural disaster are even-aged or structurally even-aged, which means that the structure of the mensurational parameters corresponds to even-aged structure, even though they are sometimes uneven-aged. In any case, a simple even-aged structure represents a very risky and unstable stand form in relation to unfavorable abiotic influences resulting in ice breakages and uprooted trees by ice.



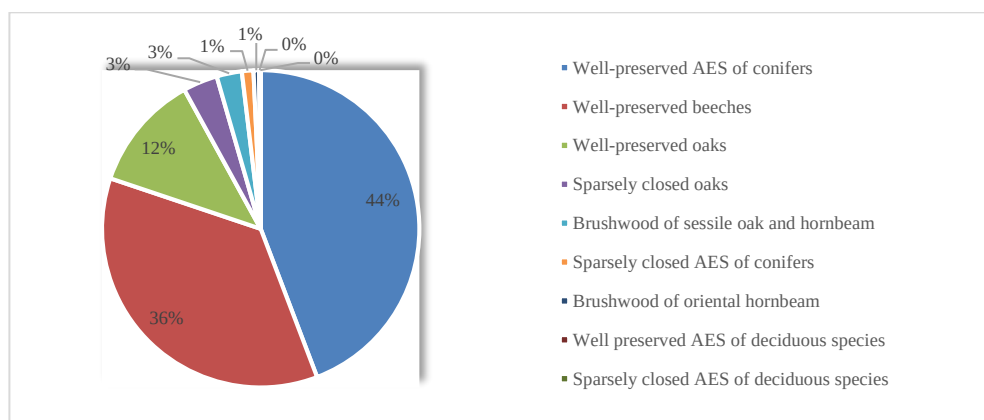
Graph 1. *The structure of damaged stands by origin*

From the Graph 1 it can be seen that pure artificially established stands of conifers on alien habitat according to area represent 1/3 of the total damaged stands. Mixed artificially established stands of conifers are somewhat more stable, but certainly with an increased risk. It can also be seen that by origin pure coppice forest stands are more endangered than mixed tall stands and that as a species beech is more endangered than oaks. Certainly, natural tall stands (especially mixed oak stands) proved to be the most resistant. Schelhaas et al., (2003) highlight that conifers, due to their dense and compact crown, are more exposed to damage than deciduous species. The lower sensitivity of mixed stands compared to monocultures confirms the hypothesis of greater stability of structurally diverse systems. Jactel et al., (2009) point out that increased biological and structural diversity reduces the risk of major damage, because different species react differently to the same stress factors, thus mitigating the overall effect of the disorder. Greater susceptibility of artificially established stands to damage can be linked to their homogeneous structure and often insufficient adaptability to local habitat conditions, which is also in accordance with the findings of other authors which indicate greater stability of natural stands (Seidl et al., 2017).



Graph 2. *The structure of damaged stands by developmental stages*

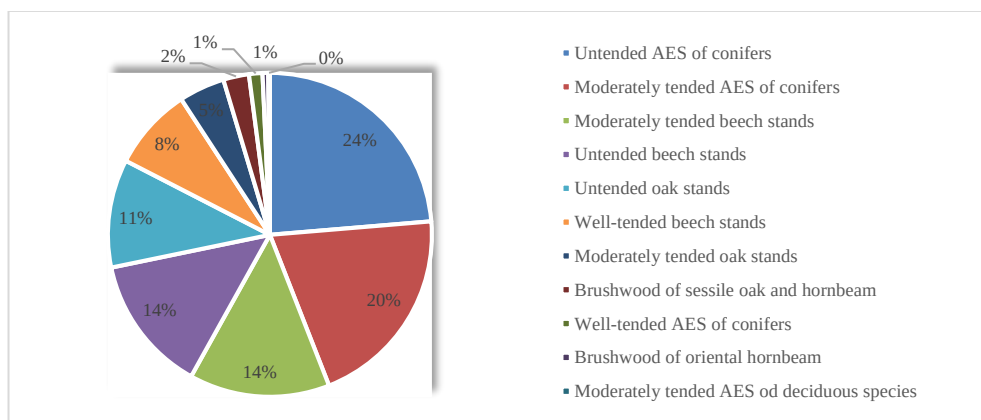
From Graph 2, it can be seen that the most endangered are middle-aged stands, and among them artificially established stands of conifers suffered the most (34%) on alien habitat, then beech (32%) and oak (15%) stands. This exception in the researched stands can be explained also by the influence of other factors on the degree of damage (position of the stand in relation to the cold wave and other environmental factors). It should also be taken into account that in terms of area the researched forest area is dominated by middle-aged stands. According to other sources (Schelhaas *et al.*, 2003), the most endangered are older stands characterized by larger tree dimensions which leads to increased load under the influence of accumulated ice. Similarly, Peltola *et al.*, (1999) indicate that the trees of larger dimensions suffer greater mechanical load under the influence of wind, snow and ice, which increases the probability of their breaking. The increased height of trees and unfavorable ratio of height and diameter (form quotient) decrease mechanical stability of trees and increase their sensitivity to ice load (Kanjavec *et al.*, 2023).



Graph 3. *The structure of damaged stands according to preservation status*

Well-preserved stands according to Graph 3 represent the highest degree of risk. This can be explained by their greater density and, therefore, higher tree form quotient, especially in artificially established stands of conifers. On the other hand,

denser stands represent a greater barrier to air currents which have significantly affected breakages and fallen timber originating from trees that were burdened by larger deposits of ice. Sparsely closed stands represent less resistance to air currents. Here too, oak proved to be more resistant than beech. Preservation status and tendance are closely related stand characteristics. Untended stands should not be considered preserved, because they often have too many trees per unit area, which makes them unstable. Preserved stands should have optimal number of trees representing a stable forest ecosystem. However, in practice, stands with a larger number of trees than optimal are often declared to be preserved stands.



Graph 4. *The structure of damaged stands by tendance*

From the Graph 4 it can be seen that untended (24%) and moderately tended (20%) artificially established conifer stands are the most endangered and that together they form 44% of stands with total damage on which clear felling had to be done. The second in terms of the damage level are untended and moderately tended beech stands, which by area make up 28% of the stands with total damage from ice breakages and uprooted trees by ice. The oak stands proved to be somewhat more resistant although tendance measures influenced also the increase of their stability. Increased sensitivity of dense and insufficiently tended stands can be explained by decreased stability of individual trees, as well as by pronounced mutual influence in the conditions of a large canopy, which leads to the occurrence of chain of damage. Such results confirm findings of Brang *et al.* (2001), which emphasize the importance of stand structure in determining its response to extreme disorders.

Compared to the research conducted in Central Europe (Gardiner *et al.*, 2014), it can be concluded that there are similar sensitivity patterns, but forests of Serbia show greater spatial variability. The reason for this lies in the heterogeneity of relief, exposure, and habitat conditions. The specificity of the researched area is reflected in the combination of continental and mountain climate, as well as in frequent temperature inversions. These conditions additionally increase the risk of freezing rain and intensity of damage. From the perspective of sustainable management, the results clearly indicate the importance of increasing the structural diversity of stands. Mixed and uneven-aged stands show greater resistance thanks to better load distribution and greater stability (UNECE, FAO/2015). Also, timely

application of silvicultural measures plays a significant role, above all thinning, by which canopy density is decreased and stability of trees is increased. These findings are consistent with the recommendations (UNECE, FAO/2015), which emphasize the need for adaptive approach to forest management in the conditions of climate change.

4. CONCLUSION

Based on the conducted research, it can be concluded that the highest degree of damage to forest stands due to ice breakages in the area of eastern Serbia is not accidental, but it is conditioned to a significant extent by the structural characteristics of t stands.

- Almost all totally damaged stands were even-aged or structurally even-aged;
- The most endangered are artificially established stands of conifers on alien habitat, then coppice forest stands of beech, followed by coppice forest stands of oaks. Tall natural stands showed the greatest resilience (especially oak stands);
- Pure stands are more endangered than mixed (especially artificially established stands of conifers);
- Due to smaller share of mature and maturing stands in the forest growing stock of the researched area, middle-aged stands were the most endangered, especially middle-aged artificially established stands of conifers. They were followed by middle-aged beeches, while middle-aged oak stands were less endangered;
- The stands which were declared preserved in the planning documents, nevertheless had a larger number of trees per unit area than optimal and became unstable;
- Untended artificially established stands of conifers on alien habitat proved to be the most unstable stands, and they are followed by untended coppice stands of beech.

The results of the research have a significant practical application in planning of forest management, especially in the context of climate change and increased frequency of extreme weather events. The identification of the stands with increased risk of ice breakage enables timely conducting of preventive measures, such as increase of structural diversity, adequate silvicultural interventions and selection of more resistant tree species.

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Summary

Based on the conducted research it can be concluded that the stand damage intensity caused by ice breakage largely depends on their structural characteristics. Given that the analysis is based on the areas where clear felling was carried out, as a final measure of remediation, the determined damage patterns indicate factors that contribute to the reduction of stand stability in conditions of extreme weather events. The research results showed that almost all totally damaged stands were even-aged or structurally even-aged. The most endangered are artificially established stands of conifers, then coppice stands of beech, and finally coppice stands of oaks. Tall natural stands showed the greatest resilience, and especially oak stands. Pure stands are more endangered than mixed stands (especially artificially established stands of conifers). Due to smaller share of mature and maturing stands, middle-aged stands were the most endangered, especially middle-aged artificially established stands of conifers. They are followed by middle-aged beeches, while middle-aged oak stands are less endangered. The stands which were declared preserved in the planning documents, had a higher number of trees per unit of area than the optimal, so they also became unstable. Untended artificially established stands of conifers on alien habitat proved to be the most unstable, followed by untended coppice forest stands of beech. The obtained results confirm that the stand structure is one of the key factors in their resistance to abiotic disorders, and indicate the need to apply appropriate forest management measures. In this sense, the timely care of stands, the increase of their structural and biological diversity, as well as the adaptation of the composition of species to habitat conditions, are of particular importance. Considering the expected increase in the frequency of extreme climate events in the future, the results of this research can contribute to improvement of forest management practice, in order to increase their stability and resistance to ice breakages and other abiotic disorders.

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Rezime

Na osnovu sprovedenog istraživanja može se zaključiti da intenzitet oštećenja sastojina izazvanih ledolomom u velikoj meri zavisi od njihovih strukturnih karakteristika. S obzirom na to da je analiza zasnovana na površinama na kojima je sprovedena čista seča, kao krajnja mera sanacije, utvrđeni obrasci oštećenja ukazuju na faktore koji doprinose smanjenju stabilnosti sastojina u uslovima ekstremnih vremenskih događaja. Rezultati istraživanja pokazali su da su gotovo sve totalno oštećene sastojine bile jednodobne ili strukturno

jednodobne. Najugroženije su veštački podignute sastojine četinar, potom izdanačke bukve pa izdanačke hrastova. Visoke prirodne sastojne su pokazale najveću otpornost, a naročito sastojine hrastova. Čiste sastojine su ugroženije od mešoviti (naročito veštački podignute sastojine četinar). Usled manjeg učešća zrelih i dozrevajućih sastojina, srednjedobne sastojine su bile najugroženije, naročito srednjedobne veštački podignute sastojine četinar. Zatim slede srednjedobne bukve, dok su srednjedobne sastojne hrastova manje ugrožene. Sastojine koje su u planskim dokumentima proglašene očuvanim, imale su veći broj stabala po jedinici površine od optimalnog te su i one postale nestabilne. Kao najnestabilnije su se pokazale nenegovane veštački podignute sastojine četinar na tuđem staništu, a nakon njih nenegovane izdanačke sastojine bukve. Dobijeni rezultati potvrđuju da struktura sastojine predstavlja jedan od ključnih faktora njihove otpornosti na abiotičke poremećaje, te ukazuju na potrebu primene odgovarajućih mera gazdovanja šumama. U tom smislu, poseban značaj imaju pravovremena nega sastojina, povećanje njihove strukturne i biološke raznovrsnosti, kao i prilagođavanje sastava vrsta stanišnim uslovima. Imajući u vidu očekivani porast učestalosti ekstremnih klimatskih događaja u budućnosti, rezultati ovog istraživanja mogu doprineti unapređenju prakse gazdovanja šumama u cilju povećanja njihove stabilnosti i otpornosti na ledolome i druge abiotičke poremećaje.