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Preliminary communication

ASSESSMENT OF THE POTENTIAL OF ALBINO BEECH COMPARED TO PIGMENTED BEECH AS A BIOINDICATOR OF ENVIRONMENTAL CONDITIONS

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Abstract: *The common beech (Fagus sylvatica L.) can be used in forest ecosystem monitoring as a model for assessing environmental changes. Its long lifespan and wide distribution make it a suitable bioindicator of atmospheric deposition, soil acidification, and stress related to climate changes. Numerous studies have shown that foliar analysis of beech reflects both regional trends in acidic depositions and heavy metal input, as well as local pollution gradients. Crown defoliation and vitality parameters further complement this chemical signal by integrating complex stress factors such as drought and temperature-related ecosystems. In addition, recent years have seen growing interest in rare albino individuals of woody species, including albino beech. Due to the absence of chlorophyll and altered relationships between the phloem and xylem, albino shoots may act as "traps for mineral nutrients." Studies on albino sequoias have confirmed elevated concentrations of Cd, Cr, and Ni in albino leaves compared to pigmented ones, indicating potentially high sensitivity to environmental pollution and possible applications in phytoremediation. A similar pattern of heavy metal accumulation can also be observed in albino beech, which can accumulate higher concentrations of heavy metals such as Ni and Cd compared to pigmented individuals. This paper summarizes the current knowledge on the use of beech as a bioindicator of environmental conditions and compares it with available data for albino woody species, with special emphasis on albino beech. It is concluded that the greatest potential lies in combining standardized regional monitoring of common beech with targeted research of albino individuals as extreme models for studying element cycling and heavy metal accumulation.*

Keywords: common beech, albino beech, bioindicators, heavy metals.

ISPITIVANJE POTENCIJALA ALBINO BUKVE U ODNOSU NA BUKVU SA PIGMENTOM, KAO BIOINDIKATORA STANJA ŽIVOTNE SREDINE

Sažetak: *Obična bukva (Fagus sylvatica L.) može se koristiti u monitoringu šumskih ekosistema kao model za procenu promena u životnoj sredini. Njen dug životni vek i široka rasprostranjenost čine je pogodnim bioindikatorom atmosferskog deponovanja,*

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zakišeljavanja zemljišta i stresa povezanog sa klimatskim promenama. Brojna istraživanja pokazala su da folijarna analiza bukve odražava i regionalne trendove u kiselim depozicijama i unosu teških metala, kao i lokalnim gradijentima zagađenja. Parametri defolijacije krošanja i vitalnosti dodatno dopunjuju ovaj hemijski signal integrišući kompleksne stresove, kao što su suša i temperaturni ekosistemi. Paralelno sa tim, u poslednje vreme raste interesovanje za retke albino jedinke drvenastih vrsta, uključujući i albino bukvu. Zbog odsustva hlorofila i izmenjenih odnosa između floema i ksilema, albino izdanci mogu delovati kao „zamke za mineralne hranljive materije". Studije na albino sekvojama potvrdile su povišene koncentracije Cd, Cr i Ni u albino listovima u poređenju sa pigmentisanim, što ukazuje na potencijalno visoku osetljivost na zagađenje životne sredine i moguće primene u fitoremedijaciji. Slična dinamika akumulacije teških metala može se posmatrati i kod albino bukve, koja može akumulirati veće koncentracije teških metala kao što su Ni i Cd u poređenju sa pigmentisanim jedinkama. U ovom radu sumirana su postojeća saznanja o upotrebi bukve kao bioindikatora uslova životne sredine i upoređena sa raspoloživim podacima za albino drvenaste vrste, sa posebnim osvrtom na albino bukvu. Zaključuje se da najveći potencijal leži u kombinovanju standardizovanog regionalnog monitoringa na običnoj bukvi, sa ciljanim istraživanjima albino jedinki kao ekstremnih modela za proučavanje kruženja elemenata i akumulacije teških metala.

Ključne reči: obična bukva, albino bukva, bioindikatori, teški metali

1. INTRODUCTION

Living organisms are widely used as bioindicators of environmental conditions because they integrate the effects of various stressors over an extended period of time, unlike chemical analyses which provide only a snapshot of the current situation (Božović *et al*., 2024). Woody species are particularly suitable as bioindicators, as they are long-lived, permanently attached to their habitat, and accumulate signals of pollution and changes in nutrient status in their organs (leaves, roots, wood) (Božović *et al*., 2025).

The common beech (*Fagus sylvatica* L.), or its Balkan taxon Fagus moesiaca, is one of the key forest species in Europe and southeastern Europe. Due to its wide distribution and its role as a dominant species in many stands, beech is a focus of international monitoring programs (ICP Forest) and is often used as a model species for tracking acidification, atmospheric deposition, and climate change (Berger *et al*., 2016; Ognjenović *et al*., 2023).

In parallel with this, interest has been steadily increasing in rare albino forms of woody species, including albino beech (*Fagus sylvatica* subsp. *moesiaca* f. *albina*). Previous studies on albino shoots and albino sequoias indicate that such organs can accumulate more nutrients and heavy metals than pigmented tissues (Lo Gullo *et al*., 2012; Pittermann *et al*., 2018). The accumulation of higher concentrations of heavy metals, especially nickel (Ni), in albino beech compared to common beech growing under the same conditions is particularly important for understanding local contamination (Božović *et al*. 2025).

The aim of this paper is to present previous research on the potential of beech as a bioindicator of environmental conditions and to compare it with results obtained for albino woody species, with special emphasis on albino beech.

2. OVERVIEW OF PREVIOUS RESEARCH

2.1. Common beech as a bioindicator of environmental conditions

Foliar analysis of beech (the content of macro- and microelements in leaves) forms the basis of numerous studies and represents an integral part of European forest monitoring networks. In the Vienna forest region, the process of recovery from acid rain has been monitored over several decades. Berger *et al*. (2016) analyzed 97 beech stands and found that soil pH and sulfur deposition were gradually improving, but that the macronutrient status of beech (especially Ca, Mg, and P) had not improved at the same rate, indicating a slow recovery of forest ecosystems.

In the same areas, Türtscher *et al*. (2017) showed that the decline in atmospheric deposition of heavy metals (Pb, Ni, etc.) over three decades was clearly reflected in the metal content of both the soil and beech leaves. The Pb content in the surface soil horizon, as well as foliar concentrations of Pb, Cu, Zn, and Ni, decreased significantly compared to the 1980s, confirming that beech leaves can serve as an archive of pollution history.

In addition to regional studies, foliar metal concentrations in beech leaves have also been used in urban and industrial environments, where higher levels of Pb, Zn, Cu, and Cd were found in the leaves of trees located closer to roads and emission sources (e.g., studies on urban forests in Central Europe). These findings confirm that beech responds to local pollution gradients.

Ognjenović *et al*. (2023) showed that the nutritional status of beech leaves (N, P, K, Ca, Mg, and microelements) and crown defoliation depend on the combined effects of climate, altitude, and other environmental factors. Defoliation is thus used as a complementary indicator of complex stress (such as drought, extreme temperatures, pollution) together with foliar analysis.

2.2. Albino woody species as nutrient traps

Albino shoots on woody species most likely arise due to different mutations. Lo Gullo *et al*. (2012) compared albino shoots of Citrus sinensis and Nerium oleander with the hemiparasitic mistletoe Scurrula elata. It was determined that albino leaves contain significantly higher concentrations of K, S and Zn compared to the green leaves of the host, and the authors introduced the concept of a "mineral nutrient trap" – albino shoots function as traps for nutrients, since due to the absence of photosynthesis and altered phloem–xylem dynamics, they do not participate in the usual recycling of elements.

Albino redwoods (*Sequoia sempervirens*) further illustrate the extremity of this physiological condition. Pittermann *et al*. (2018) showed that albino shoots have a different water regime, higher stomatal conductivity, and greater susceptibility to cavitation compared to green shoots. Reviews of previous research also indicate that albino redwoods accumulate heavy metals (Ni, Cu, Cd) in higher concentrations than healthy needles, which has led to the hypothesis that these individuals may function as the "kidneys" of the forest ecosystem.

Marković *et al*. (2024) described an adult albino *Fagus sylvatica* subsp. *moesiaca* tree (picture 1) in central Serbia. Its leaves are smaller, the growth habit is

dwarf and bush-like, and the authors point out the possible parasitic nature of the individual and the potential importance of the underground mycorrhizal network.

Picture 1. *Albino beech from the studied site*

These studies together suggest that the albino parts of trees physiologically and pathologically amplify the signal of element cycling and potential contamination.

3. DISCUSSION

Previous research shows that common beech and albino woody species lie at the opposite ends of the same bioindication spectrum. Common beech is an ecologically relevant and practical bioindicator. Its wide distribution, standardized sampling protocols (ICP Forest), and the availability of reference ranges for foliar nutrient and metal concentrations enable regional comparative analyses. Foliar analysis of the chemical composition of beech reliably reflects spatial and temporal trends of acidification and heavy metal pollution, while defoliation and tree vitality complement the picture of complex stress (Berger *et al*., 2016; Türtscher *et al*., 2017; Ognjenović *et al*., 2023).

Marković *et al*. (2024) present the morphological characteristics of albino beech, noting that in comparison with common beech there are clear differences in leaf size among trees from the same site.

On the other hand, albino woody individuals, including albino beech, are very rare and locally restricted. The "nutrient trap" concept (Lo Gullo *et al*., 2012) and results obtained from albino redwoods (Pittermann *et al*., 2018) indicate that albino leaves may reach significantly higher concentrations of certain elements, including Cd, Cr, and Ni. The accumulation of higher concentrations of heavy metals in albino species further increases their importance as a local bioindicator.

In that sense, common beech is most suitable for:

- long-term, regional monitoring of forest biochemistry and atmospheric deposition,
- comparisons between different regions, altitudes, and types of habitats,

- detection of trends related to climate changes and declining emissions.

Albino beech and other albino woody species may, in contrast, be useful for:

- identifying local hotspots of heavy metal contamination,
- understanding the flow of elements within shared root and mycorrhizal systems,
- investigating the potential for hyperaccumulation of pollutants and possible phytoremediation.

However, their application is limited by their rarity and physiological instability. It is therefore realistic to view them as specialized research models that complement, but do not replace, classical monitoring on common beech.

4. CONCLUSION

1. Common beech (*Fagus sylvatica* / *Fagus moesiaca*) is a confirmed bioindicator of forest ecosystem status, particularly regarding acidification, atmospheric deposition, and heavy metal contamination.
2. Foliar analysis of beech and the vitality parameters (defoliation, growth) reliably reflect long-term changes in pollution and climatic stress at the regional scale.
3. The greatest potential lies in a combined approach: standardized monitoring of common beech for regional analyses, with targeted inclusion of albino individuals as special models for studying element cycling and the hyperaccumulation of heavy metals.
4. Future research should focus on the upper limit of the adsorptive capacity of albino beech and potential applications of albino individuals in sites with elevated concentrations of macro- and microelements.

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Summary

Common beech (*Fagus sylvatica* L.) occupies a central position in forest monitoring programs in Serbia. Due to its wide distribution, longevity, and importance in the structure of forest ecosystems, it can be used as a model species for the assessment of environmental conditions. Long-term studies in beech stands of the Vienna Forest region have shown that the decline in atmospheric deposition of sulfur and heavy metals follows the reduction in their content in soil and leaves, but that nutritional imbalances (e.g., deficiency of base cations) persist longer, indicating a slow ecosystem recovery. In urban and industrial areas, foliar concentrations of Pb, Zn, Cu, and Cd clearly reflect spatial gradients of pollution. At the same time, vitality parameters such as defoliation and crown damage complement the chemical composition, integrating stresses arising from climate, pollution, and habitat conditions.

At the same time, over the past decade there has been a growing interest in rare albino individuals of woody species. In albino shoots and albino trees, we assume that there is a complete absence of chlorophyll synthesis and altered phloem–xylem dynamics. Experimental studies have shown that albino shoots can accumulate significantly higher

amounts of nutrients (K, S, Zn) compared to green leaves, which led to the formulation of the "mineral nutrient trap" concept. Research on albino redwoods indicates increased accumulation of heavy metals (Ni, Cu, Cd) in albino needles. These findings suggest that albino beech may act as a highly sensitive local bioindicator of heavy metal contamination, with potential application in the phytoremediation of degraded habitats.

Based on the literature review, it can be concluded that common beech remains a key, "standard" bioindicator for regional monitoring of forest ecosystem status, while albino woody individuals represent specialized models that allow a deeper understanding of nutrient flows and hyperaccumulation of metals. The greatest potential lies in a combined approach, where standardized monitoring of common beech is complemented by targeted studies of albino individuals at sites of particular interest.

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Rezime

Obična bukva (*Fagus sylvatica* L.) zauzima centralno mesto u programima monitoringa šuma u Srbiji. Zbog široke rasprostranjenosti, dugovečnosti i važnosti u strukturi šumskih ekosistema, ona se može koristiti kao model vrste za procenu stanja životne sredine. Dugoročna istraživanja u bukovim sastojinama Bečkog šumskog područja pokazale su da opadanje atmosferske depozicije sumpora i teških metala prati smanjenje njihovog sadržaja u zemljištu i lišću, ali da se nutritivni disbalansi (na pr. nedostatak bazičnih katjona) zadržavaju duže, što ukazuje na spor oporavak ekosistema. U urbanim i industrijskim sredinama folijarne koncentracije Pb, Zn, Cu i Cd jasno prate prostorne gradijente zagađenja. Istovremeno, parametri vitalnosti kao što su defolijacija i oštećenost krošanja dopunjuju hemijski sastav, integrišući stresove koji potiču od klime, zagađenja i uslova staništa.

Uporedo sa time, u poslednjoj deceniji raste interesovanje za retke albino jedinke drvenastih vrsta. Kod albino izdanaka i albino stabala pretpostavljamo da dolazi do potpunog izostanka sinteze hlorofila, promenjene floem–ksilem dinamike. Eksperimentalne studije su pokazale da albino izdanci mogu da akumuliraju znatno više hranljivih elemenata (K, S, Zn) u odnosu na zelene listove, što je dovelo do formulisanja koncepta „mineral nutrient trap". Istraživanja na albino sekvojama ukazuju na povećanu akumulaciju teških metala (Ni, Cu, Cd) u albino iglicama. Ovi nalazi navode na zaključak da albino bukva može delovati kao lokalno vrlo osetljiv bioindikator kontaminacije teškim metalima, uz potencijalnu primenu u fitoremedijaciji degradiranih staništa.

Na osnovu pregleda literature može se zaključiti da obična bukva ostaje ključni, „standardni" bioindikator za regionalno praćenje stanja šumskih ekosistema, dok albino drvenaste jedinke, predstavljaju specijalizovane modele koji omogućavaju dublje razumevanje tokova elemenata i hiperakumulacije metala. Najveći potencijal leži u kombinovanom pristupu, u kojem se standardizovani monitoring na običnoj bukvi dopunjuje ciljanim istraživanjima albino jedinki na lokalitetima od posebnog interesa.