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Monitoring Changes in Airborne Sodium Pollution and the Feasibility of Using *Pseudotsuga menziesii* for Pollution Reduction

Soner Yeşil [1], Erol Kırdar [2] and Halil Barış Özel [2,*]

[1] *Department of Forest Engineering, Graduate School, Bartın University, Türkiye.*

[2] *Department of Forest Engineering, Faculty of Forestry, Bartın University, Türkiye.*

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Abstract

Sodium (Na) is the seventh most abundant element in the Earth's crust. It is one of the essential elements for living organisms and is a widely occurring metal. Therefore, determining Na accumulation in wood, the largest organ of trees with long lifespans and large biomass, is important. In this study, the variation of Na in the trunk organs of Douglas fir (*Pseudotsuga menziesii*), commonly used in landscaping, was evaluated based on organ, direction, and season. The samples used in the study were obtained from Düzce, one of the provinces with the most polluted air in Europe. The results of the study determined that Na concentrations in the outer bark were higher than those in the inner bark and wood. The highest values in all organs were obtained in the western direction, where agricultural areas are concentrated. Furthermore, it was found that Na concentrations in wood generally varied within a narrow range. These results suggest that atmospheric Na pollution is likely caused by agricultural activities and that *Pseudotsuga menziesii*, the subject of this study, is not a suitable biomonitor for tracking changes in atmospheric Na pollution.

Keywords: Douglas fir; Heavy metal; Biomonitor; Sodium

1. Introduction

Plants use sunlight to perform photosynthesis, thereby synthesizing organic compounds and producing the essential nutrients required by all other living organisms. Thus, plants form the basis of life on Earth (Sevik et al., 2016; Özdikmenli et al., 2024; Erdem et al., 2024). In addition, green plants perform many other functions during photosynthesis. For example, plants reduce air pollution in their environment, positively affect people psychologically, regulate the water regime, prevent erosion, and provide shelter as well as food for many living things (Ozkazanc et al., 2019; Çobanoglu et al., 2023; Koc et al., 2024; Özel et al., 2025). In addition to all this, they are among the most important raw material sources for many sectors and are therefore of economic importance (Özel et al., 2024).

The ability of plants to perform all the functions they provide depends primarily on their ability to develop healthily. The development of living organisms is shaped by the interaction between their genetic structure (Hrivnak et al., 2024) and environmental factors (Sevik et al., 2019a; Dogan et al., 2023; Tandogan et al., 2023; Gur et al., 2024). The most important environmental factors in plant development are climatic factors such as temperature and precipitation (Yigit et al., 2021; Zeren Cetin et al., 2025a,b) and edaphic factors such as nutrient status, soil depth, and pH (Erdem et al., 2024; Kravkaz Kuscu et al., 2018). Among these factors, nutrient elements are substances that are limited in the soil and whose concentration decreases as they are used by plants. During their development, plants absorb nutrients from the soil through their roots and use them during their metabolic activities. The nutrients accumulated by plants in organs such as leaves, flowers, and fruits are retained in the plant body for only a short period, typically a few years, before being released back into the soil, where they dissolve and continue to participate in the nutrient cycle. However,

* Corresponding author: Halil Barış Özel

nutrients stored in the woody parts, especially the main trunk, remain outside the nutrient cycle for decades or even centuries, depending on the tree species (Koc et al., 2024). Therefore, determining the nutrient elements stored in the main trunk is important.

Within the scope of this study, the aim was to determine sodium (Na) concentrations in the wood and bark of the main trunk of Douglas fir (*Pseudotsuga menziesii*) based on organ, direction, and period. Na is an element that is widely found in certain proportions in the structure of most plants but is not essential for plant growth and development. It is abundant in natural compounds (especially NaCl). It is highly reactive, burns with a yellow flame, reacts violently with water, and oxidizes rapidly in air (Kravkaz Kuşçu, 2025). However, it is an important and common metal, and studies have shown that even essential metals can be harmful to living organisms in high amounts (Koc et al., 2024; Ozturk Pulatoglu et al., 2025). It is emphasized that heavy metals are extremely harmful to living organisms, especially humans, when inhaled from the air (Ghoma et al., 2023; Sevik et al., 2024). Therefore, the aim of this study is to investigate the change in Na concentration in individuals of toothwort, which is widely used in landscaping not only in our country but also in many regions of the world, growing in areas with high levels of heavy metal pollution.

2. Material and methods

Since the study results were also expected to provide information on heavy metal accumulation and transfer within Douglas fir trees, it was deemed appropriate to select trees grown in areas with high heavy metal pollution for the study. For this reason, materials obtained from trees grown in the city center of Düzce were used in the study. According to the World Air Pollution Report 2021, Düzce is one of the five cities with the most polluted air in Europe (Koc et al., 2024), and numerous studies conducted in the region have determined that heavy metal accumulation in trees growing in this region is at very high levels (Koç et al., 2025a, b; Isinkaralar et al., 2025a, b; Yaşar Ismail et al., 2025).

Samples were taken in 2022 at the end of the vegetation season by cutting approximately 50 cm above the ground from the main trunk, with the north direction determined. They were brought to the laboratory, cleaned, and grouped into five-year increments from the oldest to the newest. Since it is generally not possible to analyze annual rings individually in studies, grouping is performed. Samples are taken based on criteria such as the study objective, the number of annual rings in the tree, and the width of the annual rings, with groupings of 3, 5, or 10 years (Key et al., 2023; Isinkaralar et al., 2024; Ozturk Pulatoglu et al., 2025). Samples were taken from each group of wood, inner bark, and outer bark from four directions using a steel drill. The samples were left to dry at room temperature for two weeks and then placed in glass Petri dishes and dried in an oven at 45 °C for two weeks. After drying, a pre-combustion process was applied in a specially designed microwave oven, and Na analyses were performed using an ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy) device. The method used in this study has been widely used in related studies in recent years (Sevik et al., 2024; Erdem et al., 2024). Variance analysis and Duncan's test were applied to the obtained data using the SPSS 22.0 software package.

3. Findings

The change in Na concentration in Douglas fir based on organ and direction, the calculated average values, the F value calculated as a result of the variance analysis, and the lettering indicating the Duncan test groups are given in Table 1.

Table 1 Change in Na concentration in *Pseudotsuga menziesii* based on organ and direction

Organ	North	East	South	West	F Value	Average
OB	162.4 cC	122.1 cB	96.6 bA	169.6 cD	8626.8***	137.7 C
IB	79.0 bB	78.2 bA	93.8 bC	117.9 bD	8657.9***	92.2 B
Wood	48.6 aBC	45.7 aAB	42.8 aA	52.9 aC	7.6***	47.5 A
F Value	339.3***	111.8***	127.2***	191.0***		312.6***
Average	58.9	53.5	50.3	65.8	2.4 ns	

When examining the values in the table, it is seen that the change in Na concentration in Douglas fir is significant at a 99% confidence level in all directions on an organ basis and in all organs on a direction basis. According to the Duncan test results, two groups were formed in the south direction, with wood in the first group and inner and outer bark in the second group. Three groups were formed in other directions, and each organ was in a separate group. In terms of direction, the lowest values were obtained in the wood and outer bark in the south and in the inner bark in the east. The highest values were obtained in all organs in the west. The change in Na concentration in Douglas fir based on period and direction is given in Table 2.

Table 2 Change in Na concentration in *Pseudotsuga menziesii* based on period and direction

Period	North	East	South	West	F Value	Average
2018-2022	57.3 iC	32.6 aA	39.9 eB	58.6 hD	4344.2***	47.1 ab
2013-2017	39.1 aA	57.4 jC	42.1 fB	63.7 jD	3216.7***	50.6 b
2008-2012	55.2 hC	47.6 hB	46.9 hB	41.2 bA	536.2***	47.7 ab
2003-2007	64.4 jC	57.0 jA	62.4 jB	78.3 kD	1653.6***	65.5 c
1998-2002	51.2 gB	51.5 iB	43.0 gA	57.5 gC	744.4***	50.8 b
1993-1997	43.4 dB	62.6 kD	34.2 aA	47.1 dC	5206.8***	46.8 ab
1988-1992	47.2 fB	38.4 dA	38.3 dA	62.7 iC	3778.3***	46.6 ab
1983-1987	46.5 eC	43.1 fB	42.6 fgA	42.1 cA	149.2***	43.6 ab
1978-1982	39.9 bB	45.3 gC	37.1 cA	50.9 eD	570.5***	43.3 ab
1973-1977	43.0 dC	42.4 eC	38.7 dB	36.7 aA	173.5***	40.2 a
1968-1972	55.2 hD	33.4 bA	35.2 bB	53.3 fC	2322.9***	44.3 ab
1963-1967	40.9 cB	37.2 cA	53.2 iD	42.4 cC	1672.1***	43.4 ab
F Value	1347.2***	2122.2***	1188.6***	4757.9***		7.6***

As can be seen in Table 2, according to the results of the variance analysis, it was determined that the change in Na concentration in wood was statistically significant at a 99.9% confidence level in all periods based on direction and in all directions based on period. The most important point to note is that the difference between the lowest and highest values is quite small. The difference between the lowest value (32.6 ppm obtained in the east direction in the 2018-2022 period) and the highest value (78.3 ppm obtained in the west direction in the 2003-2007 period) was calculated to be approximately 2.4 times.

4. Result and Discussion

The study found that the highest values were obtained in the outer bark. This result has been obtained in numerous studies on the subject (Sevik et al., 2019b; Key et al., 2023; Canturk et al., 2024). This situation is largely due to external sources. As is known, heavy metals can enter the plant body directly from the soil through the roots, from the air through the leaves, and through the stem sections (Kulac et al., 2025). In areas with high levels of airborne heavy metal pollution, particulate matter becomes contaminated with heavy metals and acts as a trap, easily adhering to the rough outer bark surface and significantly increasing the heavy metal concentration in the bark (Ozturk Pulatoglu et al., 2025). In some species, heavy metals in the bark enter the inner bark and wood through this pathway, significantly increasing the heavy metal concentration in the inner bark first, followed by the wood. However, in this study, it was determined that the Na concentrations in the inner bark and wood were lower than those in the outer bark, and the Duncan test also showed that the values obtained in the inner bark and wood were in the same group. In this case, it can be said that the entry of Na from the outer bark into the plant body is limited.

The study found that the lowest values were obtained in the south and east, while the highest values were obtained in the west. Studies have shown that heavy metals are largely associated with mining (Kuzmina et al., 2023), industry (Isinkaralar et al., 2025b; Ozturk Pulatoglu et al., 2025), traffic (Koç et al., 2025a,b), urban areas (Gültekin et al., 2025), and agricultural activities (Ozturk Pulatoglu et al., 2025). The study area is surrounded by urban areas and highways to the north and west, while the south and east are largely surrounded by agricultural areas. The study found that the highest values in all organs were obtained in the western direction. This situation can be interpreted as indicating that agricultural activities are the most important source of Na pollution in the air. Studies show that agricultural activities, like traffic and urban areas, are also sources of numerous heavy metals (Sevik et al., 2025; Kulac et al., 2025).

The study found that Na concentrations in wood tissues generally varied within a narrow range, and that the Na concentrations determined in adjacent wood tissues were quite close to each other. The study determined that there was approximately a 2.4-fold difference between the lowest and highest values determined in the wood. However, numerous studies on heavy metals have determined that there can be a difference of tens of times between heavy metal concentrations in neighboring wood tissues (Koç et al., 2025a,b). This situation is related to the transfer of heavy metals between wood tissues. The results of the study can be interpreted as Na being transferable between wood tissues. Studies conducted to date have determined that many elements can be transferred between the wood tissues of different tree species. For example, it has been determined that Pb and Zn can be transferred in *Cedrus deodora*, As, Sr, Pd, V, Ag, Se, Sb, and Tl in *Pinus nigra*, Na in *Robinia pseudoacacia* (Kravkaz Kuşçu, 2025), Co in *Cedrus atlantica*, and Bi, Li, and Cr in *Cupressus arizonica* wood. In contrast, it has been noted that the transfer of Cu in *Cedrus deodora*, Tl in *Picea orientalis*, Ni, Cr, and Mn in *Cedrus atlantica*, Cd, Ni, Cr, Tl, Fe, and Zn in *Cupressus arizonica*, and Cd, Ni, Zn, Co, Pb, Cr, Mn, and Zn in *Corylus colurna* is more limited in wood tissues (Key et al., 2023; Koç, 2025; Şevik et al., 2024).

Heavy metal accumulation can vary significantly depending on the species and organs within the same species (Isinkaralar et al., 2024). This is because many factors simultaneously play a role in the uptake and accumulation of heavy metals in plants. The entry and movement of heavy metals into the plant body are influenced by various factors, including plant species, organ structure, surface area, interactions between heavy metals and plants, and weather conditions (Yaşar İsmail et al., 2024). Furthermore, plant habitus and development also significantly affect heavy metal uptake and accumulation (Erdem et al., 2023). Therefore, all factors affecting plant habitus also affect the uptake and accumulation of heavy metals in these plants. Plant habitus is influenced by genetic structure (Kurz et al., 2023; Sevik et al., 2012) as well as edaphic (Yucedag et al., 2019) and climatic (Yigit et al., 2019; Aricak et al., 2024; Cantürk et al., 2024; Ertürk et al., 2024) environmental factors, as well as stress factors (Sevik and Topacoglu, 2015), maintenance, pruning, and hormone applications (Guney et al., 2016; Özel et al., 2022; Kalayci et al., 2025), among many other factors. Therefore, many of these factors directly and indirectly affect each other and, consequently, the heavy metal accumulation potential of plants, and knowledge about this complex mechanism is still limited (Kravkaz Kuşçu, 2025).

5. Conclusion

The results of the study revealed that Na concentrations in Douglas fir bark were higher than those in the inner bark and wood. However, it was determined that Na concentrations in the wood generally varied within a narrow range. The limited range of variation in the wood was interpreted as indicating that Na could be transferred between wood tissues. This situation indicates that the species studied is not a suitable biomonitor for monitoring changes in Na pollution.

The study found that Na concentrations in the outer bark were higher. The highest values in the outer bark were obtained in the west, i.e., in the direction of intensive agricultural areas. This situation can be interpreted as indicating that agricultural areas are the main source of Na pollution in the air. Agricultural fertilizers are thought to be a significant source of Na. It is recommended that studies on this subject be diversified and continued, that other heavy metals also be included in the studies, and that necessary measures be taken to reduce pollution.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they no conflict of interest.

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