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The Feasibility of using Annual Rings to Monitor Changes in Boron Concentrations in Air

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Abstract: Boron is one of the most important elements on the agenda in recent years, both because it is a micronutrient for plants and because it is used in more than 250 fields in industry. Due to its intensive use and the continuous expansion of these areas of use, the concentrations of boron, which is produced more and more, are constantly increasing in receiving environments. However, boron, one of the important heavy metals, can cause significant health problems when inhaled from the air and taken into the human body. Therefore, monitoring the changes in boron concentration in the air is of great importance. In this study, the change of boron concentration in *Pinus pinaster, Cupressus arizonica, Picea orientalis, Cedrus atlantica* and *Pseudotsuga menziesii* species growing in Düzce, which is among the 5 most polluted cities in Europe, was examined on the basis of species, organ, direction and period in the last 40 years. The results of the study generally showed that boron concentrations did not change significantly on the basis of direction and year interval. Similarly, boron concentration in wood did not change significantly by species, whereas the change in boron concentration in bark was found to be statistically significant. According to the mean values, the lowest values were obtained in *P. menziesii* and the highest values were obtained in *C. arizonica.*

Keywords: Heavy metal, boron, biomonitor

Öz: Bor, hem bitkiler için mikro besin olması hem de sanayide 250'den fazla alanda kullanılması nedeniyle son yılların gündemdeki en önemli unsurlardan biridir. Yoğun kullanımı ve bu kullanım alanlarının sürekli genişlemesi nedeniyle her geçen gün daha fazla üretilen borun, alıcı ortamlardaki konsantrasyonları sürekli artmaktadır. Ancak önemli ağır metallerden biri olan bor, havadan solunarak insan vücuduna alındığında önemli sağlık sorunlarına yol açabilmektedir. Bu nedenle havadaki bor konsantrasyonundaki değişimlerin izlenmesi büyük önem taşımaktadır. Bu çalışmada Avrupa'nın en kirli 5 şehri arasında yer alan Düzce'de yetişen *Pinus pinaster*, *Cupressus arizonica*, *Picea orientalis*, *Cedrus atlantica* ve *Pseudotsuga menziesii* türlerinde bor konsantrasyonunun değişimi tür, organ, son 40 yılın yönü ve dönemi incelenmiştir. Çalışma sonuçları genel olarak bor konsantrasyonlarının yön ve yıl aralığına göre önemli bir değişim olmadığını göstermiştir. Benzer şekilde odundaki bor konsantrasyonu türlere göre önemli bir değişim göstermezken, ağaç kabuğundaki bor konsantrasyonunun değişimi istatistiksel olarak anlamlı bulunmuştur. Ortalama değerlere göre en düşük değerler *P. menziesii*'de, en yüksek değerler ise *C. arizonica*'da elde edilmiştir.

Anahtar Kelimeler: Ağır metal, Bor, Biyomonitör

1. Introduction

Plants are the most important living groups that form the basis of life on earth due to their ability to photosynthesize [1-3]. Plant growth is largely dependent on climatic and edaphic factors [4-6]. One of the most important factors shaping plant growth is nutrients. Nutrients are classified as macro and micronutrients and are absolutely essential for plant growth [7-9].

Boron (B) is the only nonmetal element among microelements. Boron enables the formation of cell walls and tissue regeneration in plants, activates some dehydrogenase enzymes, and plays a role in carbohydrate biosynthesis. It is effective on nucleic acid and protein metabolism. It plays a role in the replacement of sugars within the plant [10]. However, B is also a heavy metal [11]. Its high concentration in soil and water has a toxic effect on plants. In old leaves, leaf tips turn yellow and necrosis occurs. Symptoms then spread to the leaf margins and midrib. Leaves take a burnt appearance and fall off early [10]. Boron is used in more than 250 areas of industry, including construction, health, ceramics, ceramics, glass, cleaning, metallurgy, metallurgy, aerospace and aeronautics, as it increases the physical, chemical and technological properties of the materials it is a component of due to its ability to compound with organic and inorganic materials [12]. Therefore, the concentration of boron in receiving environments such as air, water and soil is constantly increasing.

Studies have shown that heavy metals, even those necessary as nutrients for living organisms, are harmful to health at high concentrations [13-15]. Especially heavy metals inhaled from the air can cause many health problems and even death in humans [16-20]. Studies reveal that approximately 7 million human deaths and more than 4 million premature births are associated with air pollution every year worldwide [17]. According to data from the European Environment Agency, air pollution is the single biggest environmental problem in Europe [21]. Worldwide, environmental pollution is shown as the most important global problem along with global warming [22-24] and urbanization [25-26]. Heavy metals are the most dangerous and harmful components of air pollution [27]. Therefore, it is of great importance to monitor the changes in heavy metal concentrations in the air and reduce the concentrations in polluted areas [28]. It is known that plants are the most effective tool for monitoring and reducing heavy metal pollution [29-30]. Previous studies have shown that tree annual rings can be used effectively in monitoring heavy metal pollution in air [31-32]. However, it is emphasized that the plant species that can be used in monitoring the change of each heavy metal pollution and reducing pollution should be determined separately [33]. In this study, it was aimed to determine the most suitable tree species for monitoring and reducing the change of Boron pollution in the air over the years.

2. Material and Method

The study was conducted on *Pinus pinaster* (Pp), *Cupressus arizonica* (Cpa), *Picea orientalis* (Po), *Cedrus atlantica* (Cda) and *Pseudotsuga menziesii* (Pm) species growing in Düzce city center. The species subject to the study are frequently used in landscape studies, especially in Europe. Düzce, where the study was conducted, is among the 5 most polluted cities in Europe according to the 2021 World Air Pollution report [34]. Previously, the changes of Cr [28], Bi [35] and Tl [36] elements in the city center of Düzce province were determined using these tree species. Within the scope of the study, the materials and methods used in these studies were used. At the end of the vegetation season in 2022, the main trunks of the trees subject to the study were cut at a height of about 50 cm from the ground by marking the north direction and trunk stump samples with a thickness of about ten cm were taken and Boron concentrations were determined using ICP-OES after pre-treatment. This method is one of the most frequently used methods in recent years to determine heavy metal concentrations in plant organs such as soil [37-40], leaves [41-42] and wood [43]. The values obtained as a result of the study were evaluated with the help of SPSS package program, analysis of variance and Duncan test were applied to the data. Thus, the variation of boron concentration (ppb) on the basis of species, organ, direction and year range was determined.

3. Result

The variation of B concentration by species and direction is given in Table 1.

Table 1. Variation of B concentration by species and direction

Species	North	East	South	West	Average
Pp	4204.9^{a}	7329.7^{b}	5988.8	2953.3^{a}	5119.1^{ab}
Cpa	12246.0^{c}	9395.7^{c}	5179.3	5708.4^{a}	8132.3^{c}
Po	4053.6^{a}	6142.2^{ab}	3877.7	14808.4^{b}	7277.2^{bc}
Cda	4035.9^{b}	4864.6^{a}	6014.1	5949.4^{a}	6716.0^{abc}
Pm	4794.0^{a}	4091.5^{a}	2893.3	6878.7^{a}	4694.5^{a}
F Value	25.1***	8.8***	2.0 ns	2.8*	3.3*

According to results of Duncan's test, values followed by the different letters (a and b) refer significant differences among species within each direction. ns = not significant; * = p≤0.05; *** = p≤0.001.

When the values in the table are examined, it was determined that the change in B concentration on species basis was statistically significant in all directions except south. In the north direction, the highest value was obtained in Cpa, while the lowest values were obtained in Pp, Po and Pm species. In the east direction, the highest value was observed in Cpa while the lowest values were observed in Cda and Pm. In the west direction, the highest value was found in Po species. According to the average values, the lowest value was obtained in Pm species. The variation of B concentration by species and organ is given in Table 2.

According to the results of analysis of variance, it was determined that the change in B concentration was statistically significant only in the barks on species basis. In the outer bark, the highest value was observed in Cpa, while the lowest value was observed in Pp and Po. In the inner bark, the highest value was obtained in Cpa while the lowest value was obtained in Pm. According to the average values, the lowest value was observed in the inner bark and wood, while the highest value was obtained in the outer bark. The variation of B concentration by period and direction is given in Table 3.

Table 2. Variation of B concentration by species and organ

Species	Outer bark	Inner bark	Wood	Average
Pp	7508.1^{a}	7191.3^{b}	4561.5	4561.5
Cpa	18523.3^{c}	10432.6^{c}	56545.9	6545.9
Po	7056.5^{a}	7668.9^{bc}	7254.4	7254.4
Cda	13612.4^{b}	7682.5^{bc}	5733.1	5733.1
Pm	11499.6b	2964.2a	4017.9	4017.9
F Value	24.1***	8.3***	1.9 ns	1.9 ns
Average	11640.0^{B}	7187.9^{A}	5622.2^{A}	

According to results of Duncan's test, values followed by the different letters (a and b) refer significant differences among species within each direction. ns = not significant; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

Table 3. Variation of B concentration by period and direction

AGE	North	East	South	West	F Value	Average
2018-2022	6775.8^{a}	4470.5^{ab}	3380.7^{ab}	4653.0^{a}	1.8ns	4858.8^{a}
2013-2017	4526.3^{a}	3825.1^{a}	2997.0^{ab}	3999.2^{a}	1.0ns	3837.6^{a}
2008-2012	5231.1^{a}	6392.2^{abc}	8601.8^{c}	4622.5^{a}	1.1ns	6211.9^{ab}
2003-2007	5053.9^{Ba}	4868.9^{Bab}	2466.0^{Aab}	2768.9^{Aa}	4.7**	3789.4^{a}
1998-2002	8663.1^{Ba}	7394.1^{Bbc}	1954.7^{Aa}	3590.9^{Aa}	8.6***	5400.7^{a}
1993-1997	4705.6^{Aa}	4891.6^{Aab}	3543.7^{Aab}	24183.4^{Ab}	3.7*	9331.1^{b}
1988-1992	7685.8^{a}	8010.8^{c}	6253.3^{bc}	3782.2^{a}	1.9ns	6433.0^{ab}
1983-1987	5819.5^{Ba}	6059.3^{Babc}	2672.3^{Aab}	5335.2^{Ba}	3.5*	4914.3^{a}
F Value	1.3 ns	2.6*	3.3**	3.2**		2.2*

According to results of Duncan's test, values followed by the different letters (a and b) refer significant differences among species within each direction. ns = not significant; * = p≤0.05; ** = p≤0.01; *** = p≤0.001.

Considering the above values, the change in B concentration is statistically significant in all periods except 1988-1992, 2008-2012, 2013-2017 and 2018-2022. In all directions except the north, the change in B concentration on a period basis is statistically significant. The highest value in the eastern direction was observed in the period 1988-1992, the highest value in the southern direction in the period 2008-2012 and the highest value in the western direction in the period 1993-1997. According to the mean values, the highest value was obtained in the period 1993-1997. Changes in B concentration by organ and direction are given in Table 4.

Table 4. Variation of B concentration by organ and direction

ORGAN	North	East	South	West	F Value
Outer bark	13094.3^{c}	11162.7^{b}	10415.9^{b}	11887.1^{a}	0.6 ns
Inner bark	9113.2^{b}	6243.5^{a}	5620.9^{a}	7773.9^{a}	2.5 ns
Wood	6057.6^{a}	5853.8^{a}	3983.7^{a}	6616.9^{a}	1.8 ns
F Value	15.2***	12.7***	11.5***	0.8 ns	
Average	7066.9	6473.2	4790.7	7259.6	2.5ns

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. ns = not significant; *** = p≤0.001.

When the results are examined, the change in B concentration in all organs on the basis of direction is not statistically significant. It is statistically significant on organ basis in all directions except west. For the north direction, it is possible to rank wood<inner bark<outer bark. In the east and south directions, the highest value was seen in the outer bark, while the lowest value was seen in the inner bark and wood. The variation of B concentration in *P. pinaster* by organ and direction is given in Table 5.

Table 5. Variation of B concentration by organ and direction in *P. pinaster*

ORGAN	North	East	South	West	F Value	Average
Outer bark	8315.2^{Cb}	9367.7^{D}	6084.6^{A}	6265.0^{Bc}	1334.4***	7508.1
Inner bark	10730.2^{Dc}	8616.0^{C}	4045.7^{A}	5373.4^{Bb}	4767.7***	7191.3
Wood	2875.4^{Aa}	6914.1^{B}	6219.7^{B}	2236.8^{Aa}	5.2**	4561.5
F Value	111.6***	0.8 ns	0.0 ns	489.7***		3.0 ns
Average	4204.9^{AB}	7329.7^{C}	5988.8^{BC}	2953.3^{A}	4.8**	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. ns = not significant; ** = p≤0.01; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

When the results in the table are examined, it is determined that the change in B concentration in *P. pinaster* is statistically significant in all organs on the basis of direction. In all directions except north and west, the change in B concentration is not statistically significant. For the outer bark, we can make the order south<west<north<east. For the inner bark, this order is south<west<east<north. In wood, the highest values were observed in the east and south directions, while the lowest values were obtained in the west and north directions. According to the mean values, the lowest value was observed in the west and the highest value in the east. According to the mean values, there is no statistically significant difference between the organs. The variation of B concentration in *P. pinaster* by period and direction is given in Table 6.

Table 6. Variation of B concentration in *P. pinaster* wood by period and direction

AGE	North	East	South	West	F Value	Average
2018-2022	2644.7^{Bd}	3191.5^{Db}	2891.2^{Ce}	2478.6^{Af}	557.8***	2801.5^{a}
2013-2017	2499.1^{Bc}	2824.4^{Da}	2736.1^{Cd}	1912.7^{Ab}	335.5***	2493.1^{a}
2008-2012	2778.2^{Ae}	15313.7^{Bh}	30022.2^{Cg}	2669.3^{Ag}	73391.6***	12695.8^{b}
2003-2007	1523.8^{Ab}	8561.2^{Dg}	1998.6^{Bc}	2255.2^{Cd}	16490.6***	3584.7^{a}
1998-2002	4007.6^{Cg}	6056.2^{Dd}	1853.6^{Ab}	2273.0^{Bd}	8690.3***	3547.6^{a}
1993-1997	4361.8^{Bh}	4934.9^{Cc}	5650.7^{Df}	1822.8^{Aa}	3721.4***	4192.5^{a}
1988-1992	3859.6^{Cf}	7687.5^{Df}	1748.1^{Aa}	2087.2^{Bc}	1281.2***	3845.6^{a}
1983-1987	1328.4^{Aa}	6743.5^{De}	2857.2^{Ce}	2395.7^{Be}	7976.9***	3331.2^{a}
F Value	2635.4***	4185.3***	78024.4***	340.6***		6.5***
Average	2875.4^{A}	6914.1^{B}	6219.7^{B}	2236.8^{A}	5.2**	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. ** = p≤0.01; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

According to the results of analysis of variance, it was determined that the change of B concentration in all woods was statistically significant in all periods on the basis of direction and in all directions on the basis of period. The highest value in the north direction was obtained in the period 1993-1997, while the highest value in the west, east and south directions was obtained in the period 2008-2012. According to the average values, the lowest value was observed in the north and west directions, while the highest value was observed in the east and south directions. The variation of B concentration in *C. arizonica* by organ and direction is given in Table 7.

Table 7. Variation of B concentration in *C. arizonica* by organ and direction

ORGAN	North	East	South	West	F Value	Average
Outer bark	16103.8^{B}	23256.9^{Db}	19407.3^{Cc}	15325.2^{Ab}	1038.8***	18523.3^{c}
Inner bark	10879.2^{B}	7609.3^{Aa}	7344.3^{Ab}	15897.4^{Cb}	1502.7***	10432.6^{b}
Wood	11934.6^{C}	7886.3^{Ba}	3130.2^{Aa}	3232.7Aa	31.8***	6545.9^{a}
F Value	0.8 ns	20.8***	635.1***	955.8***		33.6***
Average	12246.0^{C}	9395.7^{B}	5179.3^{A}	5708.4^{A}	11.3***	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. ns = not significant; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

Considering the results, it was determined that the change in B concentration in *C. arizonica* was statistically significant in all directions except north, organ-wise and in all organs, direction-wise. For the outer bark, it is possible to make the order of west<north<south<east. In the inner bark, the highest value was observed in the west direction, while the lowest values were observed in the east and south directions. In wood, the lowest value was obtained in the south and west directions, while the highest value was obtained in the north direction. According to the average values, we can sort wood<inner bark<outer bark. In addition, when we look at the average values, the lowest values were obtained in the south and west directions, while the highest value was obtained in the north direction. The variation of B concentration in *C. arizonica* by period and direction is given in Table 8.

Table 8. Variation of B concentration in *C. arizonica* wood by period and direction

AGE	North	East	South	West	F Value	Average
2018-2022	19174.4^{Dg}	6615.8^{Cc}	3922.6^{Be}	2392.4^{Aa}	78162.1***	8026.3^{ab}
2013-2017	11638.7^{Dd}	6754.0^{Cc}	4208.6^{Ag}	4366.7^{Bg}	7505.4***	6742.0^{ab}
2008-2012	5389.5^{Db}	3002.7^{Ba}	4032.4^{Cf}	2481.6^{Ab}	14076.4***	3726.6^{a}
2003-2007	7801.7^{Cc}	4270.2^{Bb}	2155.5^{Aa}	3469.4^{ABe}	22.2***	4424.2^{a}
1998-2002	21696.9^{Dh}	9613.5^{Cd}	2387.1^{Ab}	4010.1^{Bf}	35215.5***	9426.9^{b}
1993-1997	11994.0^{De}	9521.0^{Cd}	3420.4^{Bd}	2750.2^{Ac}	3634.2***	6921.4^{ab}
1988-1992	13281.8^{Cf}	17234.9^{De}	2487.1^{Ac}	3212.7^{Bd}	12200.8***	9054.1^{b}
1983-1987	4499.5^{Ca}	6078.8^{Dc}	2428.1^{Abc}	3178.2^{Bd}	7351.5***	4046.1^{a}
F Value	9074.5***	145.8***	838.9***	1172.4***		2.5*
Average	11934.6^{C}	7886.3^{B}	3130.2^{A}	3232.7^{A}	31.8***	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. * = p≤0.05; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

When the values were examined, it was determined that the change of B concentration in *C. arizonica* wood was statistically significant in all periods on the basis of direction and in all directions on the basis of period. The highest value in the north direction was obtained in the period 1998-2002, the highest value in the east direction was obtained in the period 1988-1992, and the highest value in the south and west directions was obtained in the period 2013-2017. According to the average values, the highest value was observed in the period 1988-1992. According to the average values, the lowest value was observed in the south and west directions, while the highest value was observed in the north direction. The variation of B concentration in *P. orientalis* by organ and direction is given in Table 9.

Table 9. Variation of B concentration in *P. orientalis* by organ and direction

ORGAN	North	East	South	West	F Value	Average
Outer bark	9435.4^{Dc}	4709.2^{A}	6599.0^{Bb}	7482.5^{C}	503.8***	7056.5
Inner bark	5303.4^{Ab}	6301.0^{B}	10245.5^{Dc}	8825.9^{C}	10065.3***	7668.9
Wood	3224.6^{Aa}	6354.5^{AB}	2741.5^{Aa}	16472.0^{B}	2.9*	7254.4
F Value	27.9***	0.9 ns	263.5***	0.1 ns		0.0 ns
Average	4053.6^{A}	6142.2^{A}	3877.7^{A}	14808.4^{B}	3.0*	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. ns = not significant; * = p≤0.05; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

According to the results in the table, the change in B concentration in *P. orientalis* is statistically significant in all organs on the basis of direction. In all directions except the north and south directions, the change in B concentration is not statistically significant. For the north direction, we can make the order of wood<inner bark<outer bark. In the south direction, this order is wood<outer bark<inner bark. The highest value in the outer bark was obtained in the north direction, the highest value in the inner bark in the south direction and the highest value in the wood in the west direction. According to the average values, the lowest values were observed in the north, south and east directions, while the highest value was observed in the west direction. The variation of B concentration in *P. orientalis* by period and direction is given in Table 10.

Table 10. Variation of B concentration in *P. orientalis* wood by period and direction

AGE	North	East	South	West	F Value	Average
2018-2022	5481.0^{Cf}	UL	3121.4^{Be}	2330.9^{Aa}	2757.1***	3644.4^{a}
2013-2017	2355.0^{Bb}	UL	2298.9^{Ac}	3900.5^{Ce}	3234.0***	2851.5^{a}
2008-2012	2671.2^{Bd}	5701.5^{Db}	1992.5^{Ac}	3137.0^{Cc}	11658.6***	3375.6^{a}
2003-2007	2369.5^{Ab}	6013.5^{Dc}	2715.0^{Cd}	2608.1^{Bb}	7782.1***	3426.5^{a}
1998-2002	2564.2^{Bc}	6967.5^{Dd}	1780.1^{Aa}	6204.9^{Cf}	3507.1***	4379.2^{a}
1993-1997	1475.6^{Aa}	5695.2^{Cb}	3491.0^{Bg}	106874.5^{Dg}	538800.5***	29384.1^{b}
1988-1992	3025.6^{Ae}	10392.5^{Ce}	3132.6^{Be}	3117.9^{Bc}	26494.4***	4917.2^{a}
1983-1987	5854.8^{Cg}	3356.7^{Aa}	3400.8^{Af}	3602.0^{Bd}	873.9***	4053.6^{a}
F Value	2802.1***	3820.3***	867.9***	466546.0***		3.2**
Average	3224.6^{A}	6354.5^{AB}	2741.5^{A}	16472.0^{B}	2.9*	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. UL = Undetectable limit; * = p≤0.05; ** = p≤0.01; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

When the variance analysis results were examined, it was determined that the change of B concentration in *P. orientalis* wood was statistically significant in all periods on the basis of direction and in all directions on the basis of period. The highest value in the northern direction was observed in the period 1983-1987, the highest value in the eastern direction in the period 1988-1992, and the highest value in the southern and western directions in the period 1993-1997. According to the average values, the highest value was obtained in the period 1993-1997.

Again, according to the average values, the lowest value was observed in the north and south directions, while the highest value was observed in the west direction. In addition, the change in B concentration in the eastern direction in the periods 2013-2017 and 2018-2022 was below the determinable limits. The variation of B concentration in *C. atlantica* by organ and direction is given in Table 11. When the results are examined, it is seen that the change in B concentration is statistically significant in all organs on the basis of direction. In all periods except north and west, the change in B concentration is not statistically significant. For the outer bark, we can rank east<south<north<west. For the inner bark, the order is south<east<west<north. In wood, the highest values were observed in the north direction, while the lowest values were observed in the east, south and west directions.

According to the average values, the lowest values were obtained in the east, south and west directions, while the highest value was obtained in the north direction. The variation of B concentration in *C. atlantica* by period and direction is given in Table 12. When the values were examined, it was determined that the change of B concentration in *C. atlantica* wood was statistically significant in all periods on the basis of direction and in all directions on the basis of period. The highest value in the north and east directions was observed in the period 1998-2002, while the highest value in the south direction was observed in the period 1988-1992. In the west direction, the highest value was obtained in the period 1988-1992, while the lowest value was obtained in the period 2013-2017. According to the average values, the highest value was observed in the 1988-1992 period and the lowest value was observed in the 2013-2017 period. Again, according to the average values, the lowest value was obtained in the east, south and west directions, while the highest value was found in the north direction. The variation of B concentration in *P. menziesii* by organ and direction is given in Table 13.

Table 11. Variation of B concentration in *C. atlantica* by organ and direction

ORGAN	North	East	South	West	F Value	Average
Outer bark	14789.9^{Cb}	7685.9^{A}	10627.6^{B}	21346.2^{Db}	10228.1***	13612.4^{b}
Inner bark	16248.4^{Db}	5121.6^{B}	4053.2^{A}	5306.8^{Ca}	39509.0***	7682.5^{a}
Wood	8665.1^{Ba}	4479.7^{A}	5682.6^{A}	4105.2^{Aa}	6.3**	5733.1^{a}
F Value	6.3**	2.7 ns	1.3 ns	127.3***		16.4***
Average	10035.9^{B}	4864.6^{A}	6014.1^{A}	5949.4^{A}	6.9***	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. ns = not significant; ** = p≤0.01; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

Table 12. Variation of B concentration in *C. atlantica* wood by period and direction

AGE	North	East	South	West	F Value	Average
2018-2022	2322.9^{Aa}	3604.3^{Bd}	3910.0^{Cd}	4794.6^{Df}	2813.5***	3658.0^{ab}
2013-2017	2531.9^{Bb}	3168.3^{Cc}	3974.6^{De}	2367.7^{Aa}	772.4***	3010.6^{a}
2008-2012	11044.2^{Dd}	3039.2^{Ab}	4861.5^{Cf}	4439.0^{Be}	16343.9***	5846.0^{ab}
2003-2007	11602.7^{De}	3181.7^{Bc}	3485.7^{Cc}	2587.3^{Ab}	26829.6***	5214.4^{ab}
1998-2002	13199.1^{Dh}	9009.8^{Cf}	2050.5^{Aa}	3211.0^{Bc}	5285.2***	6867.6^{b}
1993-1997	4003.0^{Dc}	3126.4^{Ac}	3467.5^{Bc}	3616.6^{Cd}	195.3***	3553.3^{ab}
1988-1992	12595.9^{Cg}	2650.0^{Aa}	20636.0^{Dg}	8607.9^{Bg}	13267.5***	11122.4^{c}
1983-1987	12021.2^{Df}	8058.3^{Ce}	3075.1^{Ab}	3217.2^{Bc}	21018.9***	6592.9^{b}
F Value	5223.1***	19455.8***	110403.5***	2397.0***		5.9***
Average	10035.9^{B}	4864.6^{A}	6014.1^{A}	5949.4^{A}	6.9***	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. *** = p≤0.001. Capital letters indicate the difference between average values within organs.

Table 13. Variation of B concentration in *P. menziesii* by organ and direction

ORGAN	North	East	South	West	F Value	Average
Outer bark	16827.0^{Db}	10793.8^{Cb}	9361.0^{Bb}	9016.8^{A}	2056.3***	11499.6^{b}
Inner bark	2405.0^{Aa}	3569.4^{Ba}	2416.1^{Aa}	3466.2^{B}	152.4***	2964.2^{a}
Wood	3588.5^{Aa}	3061.5^{Aa}	2144.5^{Aa}	7038.0^{B}	16.8***	4017.9^{a}
F Value	123.3***	38.9***	211.5***	1.4 ns		35.1***
Average	4794.0^{A}	4091.5^{A}	2893.3^{A}	6878.7^{B}	15.9***	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. ns = not significant; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

Table 14. Variation of B concentration in *P. menziesii* wood by period and direction

AGE	North	East	South	West	F Value	Average
2018-2022	4256.0^{Be}	UL	3058.2^{Af}	11268.7^{Cg}	4063.3***	6194.3^{cd}
2013-2017	3607.0^{Cd}	2553.9^{Bc}	1767.1^{Ac}	7448.6^{De}	2596.5***	3844.1^{abc}
2008-2012	4272.0^{Be}	4904.1^{Cd}	2100.7^{Ae}	10385.8^{Df}	5719.1***	5415.6^{bcd}
2003-2007	1971.8^{Ac}	2317.9^{Bb}	1975.5^{Ad}	2924.7^{Cc}	3570.1***	2297.5^{a}
1998-2002	1847.6^{Bb}	5323.4^{De}	1702.5^{Abc}	2255.7^{Cb}	11822.9***	2782.3^{a}
1993-1997	1693.5^{Ba}	1180.7^{Aa}	1689.2^{Bb}	5852.8^{Cd}	667.7***	2604.1^{a}
1988-1992	5666.1^{Dg}	2088.9^{Bb}	3263.0^{Cg}	1885.1^{Aa}	5112.8***	3225.8^{ab}
1983-1987	5393.8^{Bf}	UL	1600.3^{Aa}	14282.6^{Ch}	32543.0***	7092.2^{d}
F Value	3835.1***	477.9***	881.9***	6798.8***		4.3***
Average	3588.5^{A}	3061.5^{A}	2144.5^{A}	7038.0	16.8***	

According to results of Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction. UL = Undetectable limit; *** = p≤0.001. Capital letters indicate the difference between average values within organs.

According to the results of analysis of variance, the change in B concentration in *P. menziesii* was statistically significant in all organs by direction and by organ in all directions except west. The highest values in the north and south directions were observed in the outer bark and the lowest values in the inner bark and wood. In the east direction, the lowest value was observed in the wood, while the highest value was obtained in the outer bark. For the outer bark, it is possible to make the order of west<south<east<north. For the inner bark and wood, the lowest values were observed in the north and south directions. According to the average values, the highest value was obtained in the outer bark. The variation of B concentration in *P. menziesii* by period and direction is given in Table 14.

When the values in the table are examined, it is determined that the change in B concentration is statistically significant in all periods on the basis of direction and in all directions on the basis of period. The highest value in the north and south directions was obtained in the period 1988-1992, the highest value in the east direction was obtained in the period 1998-2002 and the highest value in the west direction was obtained in the period 1983-1987. According to the average values, the highest value was observed in the 1983-1987 period. Apart from this, the change in B concentration in the eastern direction in the periods 1983-1987 and 2018-2022 was below the determinable limits.

4. Discussion

The results of the study show that boron concentration varies significantly on the basis of species, organ, direction and year range. The lowest values were obtained in *P. menziesii* and the highest values in *C. arizonica*. Especially in some directions, differences close to five times between species were obtained. These results show that there is a great difference between the boron utilization and accumulation capacities of the species. Previous studies have shown that heavy metal accumulation potential varies greatly on species basis [27-32].

The results of the study show that the change in boron concentration in the wood is not statistically significant according to the average values. However, the change in boron concentration in the bark differs on a species basis, and even differences exceeding 3 times between species occur. This situation can be interpreted as the accumulation of boron in the bark is mainly airborne. Heavy metals in the air adhere to particulate matter, contaminating particulate matter with heavy metals, and these particulate matter settle on plant bark, increasing heavy metal concentrations [33-36].

The nutrient utilization and heavy metal accumulation potential of plants is the product of a complex mechanism shaped by the interaction of many factors. The determining factors in this process are genetic structure and environmental factors [37-41] Therefore, all factors related to these factors affect the nutrient utilization and accumulation potential of plants. This is because plant habitus and development affect plant element uptake and accumulation. Therefore, all factors affecting plant habitus also affect the uptake and accumulation of elements into the plant, and plant habitus is influenced by genetic structure and environmental factors such as climatic and edaphic factors, stress factors such as drought, frost, UV-B, radiation, heavy metals. Therefore, many of these factors directly and indirectly affect the elemental uptake and accumulation potential of plants, and knowledge on this complex mechanism is still limited [42-44].

5. Conclusion

As a result of the study, no statistically significant difference was found between the directions in any organ. This can be interpreted as the absence of a significant source of boron pollution in the study area. Similarly, when the change in the process is examined, it is seen that the boron concentration varies within a narrow range. This result can be interpreted as no significant boron pollution has occurred in the last 40 years.

Conflict of Interest

The authors have no conflicts of interest to declare.

Ethics Committee Approval

Not applicable

Author Contribution

Conceptization: BA, ŞK; methodology and laboratory analyzes: BA, ŞK; writing draft: BA, ŞK; proof reading and editing: BA, ŞK. Other: All authors have read and agreed to the published version of manuscript.

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