Original Research

Taxus baccata as a Bioindicator of Urban Environmental Pollution

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Abstract

Concentrations of the elements Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, N, Ni, P, Pb, and Zn were measured in needles and bark of *Taxus baccata* from the urban environment of Wrocław, Poland, and from a control site relatively free from pollution. In Wrocław the concentrations of N, P, K, and Mg in needles were significantly higher than in bark, but concentrations of Cd, Co, Cr, Cu Fe, Ni, and Zn were significantly higher in bark than in needles. Concentration of Pb was comparable in needles and bark. The only exception was Mn, whose concentration was significantly higher in needles. PCCA ordination confirmed the relationship between the elemental concentrations in needle and bark, and the level of pollution. The most polluted needles and bark projected more closely with Cd, Co, Cr, Cu, Fe, Mn, Ni, and Pb and, additionally, bark projected more closely with Zn.

Keywords: bioindication, heavy metal, *Taxus*, pollution by traffic

Introduction

Air pollution with trace metals is a matter of great interest, especially in urban areas [1]. Tree foliage, both evergreen and deciduous, is regarded as a good bioindicator of the environment and has been tested for this purpose in industrialized regions [2-4]. Although trees and shrubs, contrary to lichens or mosses, are not the best indicators for air pollution monitoring, they are the major plant type found in urban areas with a high degree of pollution [5]. Both coniferous and deciduous trees can be used in the detection of aerial heavy metal pollution, but coniferous trees indicate pollution over a longer time period [1]. So trees not only have an ornamental function in urban areas, but their leaves and bark can uptake and accumulate pollutants straight from the atmosphere [5-7].

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Yew, *Taxus baccata* L., is an understory tree, a medium-sized slow-growing evergreen gymnosperm found in temperate forests in northwestern North America, East Asia, and North Africa. It also is a long-lived rare and endangered species in many European countries [8]. Although yew is widely distributed throughout Europe, it declines sharply over most of its range. In Poland, yew has been reported from about 250 natural localtions from northwestern and southern parts of the country [9, 10]. In spite of the decline, this species is frequently introduced into parks and green areas and used as ornamentals of urban environments [11]. For instance, yew is one of the most represented species growing well in many Polish cities [12]. *T. baccata* has shown promising data for implementation into a list of suitable bioindicators of polluting metals and organic compounds [13-15]. Chadwick and Keen [11] also recognize this species as highly resistant to urban air pollution and have proposed yew as a bioindicator species.

Atmospheric metal concentration monitoring can also be carried out by tree bark samples to illustrate heavy metal distribution trends in the investigated areas [16-18]. Tree bark is known to absorb and accumulate airborne contaminants and has therefore been found appropriate in indicating longer-term air pollution [19]. The changes in the chemical composition of the bark surface layers can be documented. Kuik and Wolterbeek [20] proposed the use of tree bark samples as biomonitors of heavy metal pollution in the Netherlands. Their use was recommended for larger-scale surveys because of their greater availability compared to lichens and mosses. Monitoring with barks supplies low-cost information on the composition and quantity of the deposition of pollutants [21]. No literature could be found comparing the accumulation abilities of bark with those of *T. baccata* in the investigated polluted area.

The objectives of this study were to evaluate the accumulation abilities of *Taxus baccata* needles, plus the concentrations of heavy metals in the bark of this shrub species in the polluted urban environment of Wrocław. The hypothesis is that the needle of *T. baccata* is a better bioaccumulator of metals than the bark.

Materials and Methods

Thirteen sampling sites were selected in Wrocław (Poland) based on differences in traffic intensity (Fig. 1): a highly polluted group situated along the main streets with nearly constant heavy traffic (sites 1-6), a medium polluted group situated alongside streets and within municipal parks (sites 7-10), and a less polluted group located in a suburban area (sites 11-13).

A control site without any traffic pollution was selected 40-km southeast from Wrocław (N51º01'; E17º34').

Several branches from five shrubs per site were sampled for needles in all directions from the centre of the canopy, 2-3 m above the soil. The shrubs were healthy looking (defined as having no dead branches or chlorotic and necrotic symptoms) and ca. 30-40-year-old [54, 55]. The total number of samples was N=13×5=65, from Wrocław city and five shrubs from the control site. The collected needles were separated from the branches at the laboratory. From the same shrubs, bark flakes cut at 1.5 m above ground level (all directions around the tree) were collected with a total of N=14×5=70 samples, including the 5 samples from the control site [22, 23]. Needle and bark samples were not washed as recommended by Kozlov et al. [24] and Oliva and Valdés [25], and dried to a constant weight at 50ºC and homogenized in a laboratory mill. Samples (300 mg of dry weight, in triplicate) were digested with nitric acid (ultra pure, 65%) and perchloric acid (ultra pure, 70%) in a microwave MARS5 CEN Corporation. After dilution to 50 mL, the matrix and plant digests were analyzed for Fe, Mg, Mn, and Zn using Flame and Cd, Co, Cr, Cu, Ni, Pb were analyzed using Furnace Atomic Absorption Spectrophotometry AVANTA PM GBC Scientific Equipment. Ca and K were analyzed using a

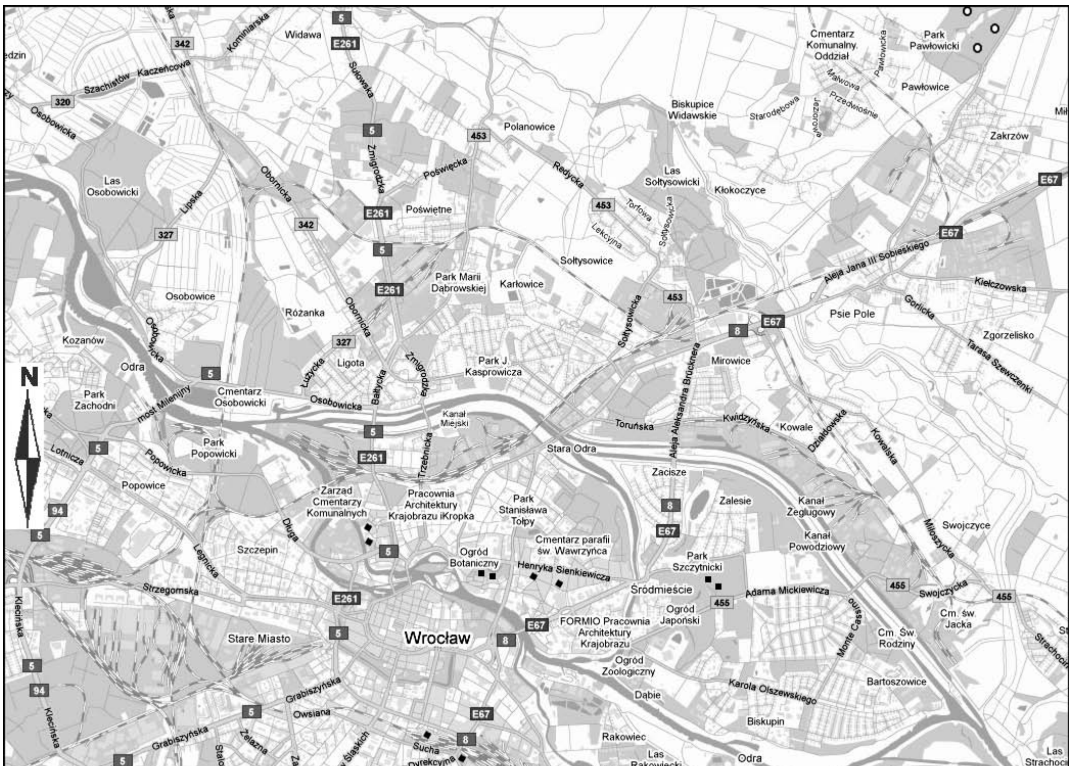

Fig. 1. Location of the *Taxus baccata* sampling sites in Wrocław. Four types of sites with a significantly different traffic intensity are discerned: a highly polluted group situated along the main streets with nearly constant heavy traffic (♦), a medium polluted group situated along side streets and within municipal parks (■), a less polluted group located in a suburban area (○), and a control site without any traffic pollution (▲).

Table 1. Minimum/maximum values (mg·kg^{-1} D.W.), mean, and SD of concentrations of elements in *Taxus baccata* needles from Wrocław and control site; t $tab_{0.05(68)}$=1.995.

Element	*T. baccata* Wrocław				*T. baccata* control					
	minimum	maximum	mean	S.D.	minimum	maximum	mean	S.D.	test-t	P
N	17,500	29,400	23,623	1,502	23,800	24,990	24,300	1,200	-0.81	>0.05
P	1,988	2,694	2,425	238	2,794	3,360	2,974	250	5.3	<0.001
K	4,102	8,121	6,314	1,304	7,096	8,540	7,790	900	2.6	<0.05
Ca	3,457	9,800	7,540	1,770	3,599	4,600	3,910	970	-7.79	<0.001
Mg	650	1,474	1,152	236	703	960	730	220	-2.6	<0.05
Cd	0.04	0.2	0.07	0.03	0.02	0.04	0.03	0.01	-3.2	<0.01
Co	0.09	0.6	0.3	0.07	0.01	0.02	0.01	0.01	-3.8	<0.01
Cr	0.4	1.8	1.4	0.30	0.3	0.4	0.33	0.2	-6.7	<0.001
Cu	3.7	9.1	6.2	2.2	1.6	1.8	1.7	0.3	-4.4	<0.001
Fe	143	558	321	128	96	111	104	38	-3.2	<0.01
Mn	44	264	150	21	31	35	34	11	-2.4	<0.05
Ni	0.7	2.8	1.8	0.3	0.5	0.7	0.6	0.2	-2.9	<0.05
Pb	1.9	5.7	3.3	1.4	1.1	1.3	1.2	0.5	-3.6	<0.01
Zn	34	75	55	12	28	31	30	5.0	-4.3	<0.001

flame photometer PFP7 JENWAY Ltd. Phosphorus in the needles and bark digest was determined spectrophotometrically by the molybdate blue method using an FIAcompact MLE GmbH. Nitrogen was analyzed by Kjeldahl digestion with a VAPODEST 40 GERHARDT.

All elements were determined against standards (Atomic Absorption Standard Solution, Sigma Chemical Co.) and blanks were prepared identical to the samples. All results were calculated on a dry weight basis. Recoveries of plant reference material (bush branches and leaves DC73348 LGC standards) give information on the accuracy of the destruction procedure. The recovery data of the plant reference material fell within the recovery percentage of the standard solutions and are therefore not mentioned separately. The recovery rates were as follows for each of the investigated elements (percentages with SD): Ca (97±3), Cd (98±2), Co (96±5), Cr (98±3), Cu (97±3), Fe (99±3), K (98±2), Mg (97±3), Mn (99±3), N (99±3), Ni (99±4), P (98±2), Pb (95±4), and Zn (98±3).

Statistical Analysis

Differences between sampling sites, in terms of concentrations of elements in leaves, were evaluated by ANOVA on data that were log-transformed to obtain a normal distribution of features as proposed by Zar [26]. The normality of the analyzed features was checked by employing Shapiro-Wilk's W-test, and the homogeneity of variances was analyzed using Bartlett's test [26, 27].

Metals and samples were subjected to ordination to reveal possible gradients of element levels, using the principal component (PCA) and classification analysis (CA) to reduce data and stabilize subsequent statistical analyses [28, 29], also PCCA was earlier applied in environmental sciences [30, 31]. The plot of PCCA ordination of the plant samples and projection of the concentrations of elements in *T. baccata* needles and bark on the factor plane gives information about similarities between samples and shows correlations between the original variables and the first two factors. PCCA practically and clearly classifies a set of data for a number of objects [32]. All calculations were done using the Statistica 8.0 program [33].

Results

The ranges of concentrations of elements in needles and bark are depicted in Tables 1 and 2. The examined *T. baccata* differed significantly in terms of the concentrations of the elements assessed (ANOVA, p=0.05).

All the needles of *T. baccata* from the Wrocław sites contained significantly lower concentrations of macronutrients and significantly higher concentrations of metals than those from the control site (Table 1). The only exception was nitrogen, whose concentrations were similar in the Wrocław and control sites. Concentrations of all elements were higher in bark from Wrocław than in the control site, except for the concentration of Mg, which was higher in the control bark, and Ca, which was comparable in the bark of both areas (Table 2).

Results of the PCCA ordination of sampling sites under respect of the concentration of elements in needles and bark

Table 2. Minimum/maximum values (mg·kg-1 D.W.), mean and SD of concentrations of elements in *Taxus baccata* bark from Wrocław and control site; t $tab_{0.05(68)}$=1.995.

Element	*T. baccata* Wrocław				*T. baccata* control					
	minimum	maximum	mean	S.D.	minimum	maximum	mean	S.D.	test-t	P
N	9,500	12,000	11,300	962	13,700	15,200	14,300	930	6.7	<0.001
P	1,629	2,178	1,848	160	2,220	2,450	2,300	240	6.1	<0.001
K	424	8,121	1,988	238	2,436	2,680	2,500	320	3.9	<0.01
Ca	5,600	11,055	7,696	655	7,262	7,850	7,600	570	-0.6	>0.05
Mg	351	841	478	125	818	860	840	110	6.4	<0.001
Cd	0.11	0.55	0.35	0.1	0.08	0.1	0.09	0.02	-3.9	<0.01
Co	0.24	0.76	0.45	0.1	0.08	0.09	0.08	0.01	-4.7	<0.001
Cr	1.9	5.9	3.9	1.4	1.1	1.4	1.3	0.2	-4.1	<0.001
Cu	3.5	29	17	2.1	1.4	1.7	1.5	0.1	-3.3	<0.01
Fe	279	1770	765	75	130	163	147	69	-3.2	<0.01
Mn	42	62	46	2.0	35	46	40	2.0	-4.2	<0.001
Ni	0.8	5.9	3.2	0.3	0.2	0.4	0.3	0.1	-3.4	<0.01
Pb	2.6	6.4	4.4	1.4	1.2	1.5	1.4	0.5	-4.9	<0.001
Zn	46	299	137	38	26	29	27	6.3	-3.1	<0.01

are shown in Figs. 2 and 3. The first principal component discriminates on both figures between *T. baccata* needles and bark from the highly polluted sites (negative scores), and *T. baccata* needles and bark from the medium, less polluted and control sampling sites (positive scores). Needles and bark from medium polluted sites also give negative scores of the second principal component on Figs. 2 and 3. Projection of the variables on the factor plane according to Sokal and Rohlf [27] shows that the most polluted collections of *T. baccata* needles were projecting more closely with Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, and Pb, and the medium polluted collections were projecting more closely with P (Fig. 2). The most polluted collections of *T. baccata* bark (Fig. 3) were projecting more closely with Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. The medium polluted collections were projecting more closely with Ca; medium and less polluted collections and control were projecting more closely with P. PCCA ordination confirmed the relationship between needle and bark elemental concentrations and level of pollution.

Discussion

Compared to the average values (indicated between parentheses in mg·kg-1 d.w.) as mentioned by Markert [34] for terrestrial plant concentrations (Table 1) of N (12,000-75,000) and P (120-30,000) in *T. baccata* were within the ranges. Concentration of Mg (1,000-9,000) was mostly lower in the Wrocław sites and lower in the control site. The concentration of K (5,000-34,000) was mostly within the ranges in the Wrocław sites and was within the ranges in the control site. Concentration of Ca (10,000) was lower in all sites. Compared to the average values given by Kabata-Pendias [35] for terrestrial plants, the upper concentrations (Table 1) of Co (0.08-0.1), Cu (4-5), Fe (130-350), Ni (<1), Pb (0.4-2.5), and Zn (15-30) were higher.

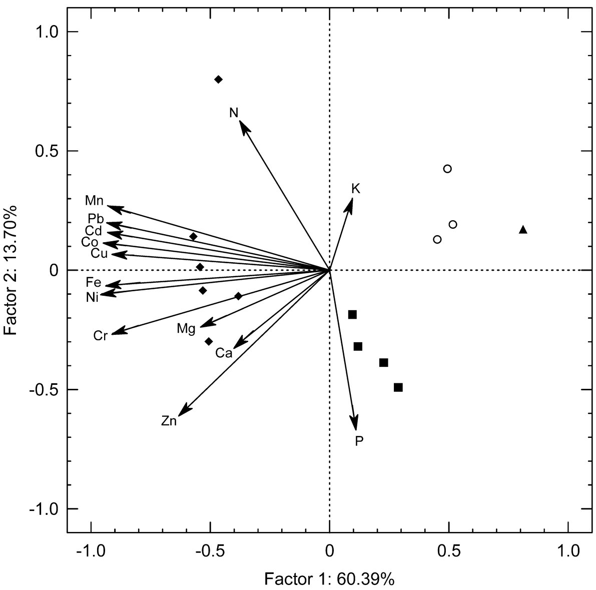

Fig. 2. Ordination of concentrations of 14 elements in 70 samples of needles of *Taxus baccata* by PCCA and projection of these concentrations on the factor plane. See Fig. 1 for the legend of the various types of sampling sites.

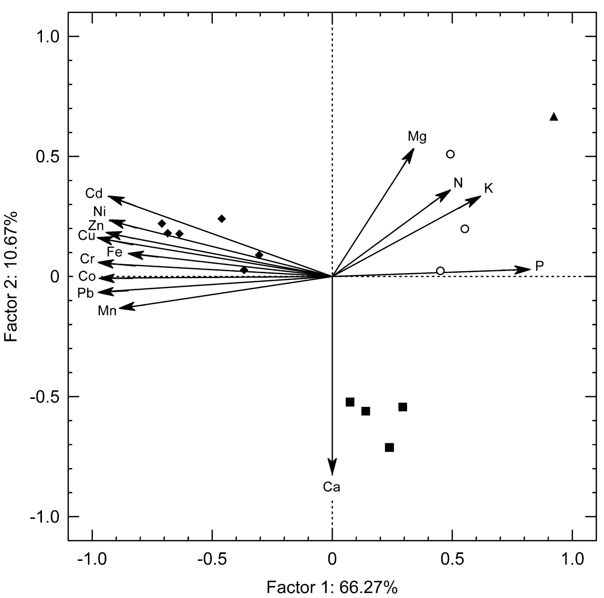

Fig. 3. Ordination of concentrations of 14 elements in 70 samples of bark of *Taxus baccata* by PCCA, and projection of these concentrations on the factor plane. See Fig. 1 for the legend of the various types of sampling sites.

Background values for heavy metal contents in bark of Scots pine collected by Migaszewski et al. [18] in Wigierski National Park (NE Poland) were (mg/kg) 3-5 Cu, 27-68 Fe, 18-48 Mn, and 9-16 Zn. Concentrations of these elements in bark of *T. baccata* from Wrocław (Table 2) were higher for all these elements.

Concentrations of elements in bark of *Pinus sylvestris* in the vicinity of a a metal smelter and black coal power factory in Stalowa Wola [36] were higher for Cd, Cr, Cu, and Pb. Therefore, it may be concluded that *T. baccata* grew in a polluted urban environment in Wrocław.

Concentrations of N, P, K, and Mg in needles was significantly higher than in bark of *T. baccata* in Wrocław (test t $P<0.05$), but concentrations of Cd, Co, Cr, Cu Fe, Ni, and Zn were significantly higher in bark than in needles. The concentration of Pb was comparable in needles and bark. The only exception was Mn, whose concentration was significantly higher in needles. This is in agreement with Kabata-Pendias [35] that Mn is likely concentrated in leaves, whereas all other metals are distributed variably among the various parts of trees. Mn is one of the most abundant trace elements in the lithosphere [37], whose uptake is metabolically controlled, but passive absorption of Mn is likely to occur. This element is known to be rapidly taken up and translocated within plants [38, 39], but it can be leached from either dead or live tissue [40].

Concentrations of heavy metals in bark were significantly higher than in needles, which is in accordance with Reimann et al. [41]. Bark shows the strongest impact of urban pollution due to a long exposure time (years) when compared to leaves, even taking into consideration the lower surface area of bark [41]. Although the longevity of needles of *T. baccata* is 6-8 years, it is still shorter than the lifespan of bark.

Concentrations of all investigated heavy metals were higher in needles and bark of *T. baccata* from Wrocław than from the control site. The results of PCCA for concentrations of Cd, Co, Cr, Cu, Fe, Mn, Ni, and Pb in needles and bark, and Zn in bark positively correlated with the traffic intensity in Wrocław. These results are in agreement with literature stating that principally Pb from leaded gasoline, but also Cu, Cr, Cd, Zn, etc. from motor oil additives, tires, brake liners, metal corrosion, pavement, and motorway material are the main polluting heavy metals in the urban roadway environment [42-45]. Due to phasing out of leaded petrol, Zn has been proposed to be a more reliable tracer of motor vehicle emissions than Pb [46]. Also, Mn contamination of urban environments was significantly correlated with traffic density [47]. Urban dust was evidenced by Lorenzini et al. [48], and Cr, Mn, Ni, and Zn were the most represented metals. According to Fernández Espinosa and Rossini Oliva [49], Fe and Cu may be assumed to be tracers of anthropogenic air pollution.

T. baccata in Wrocław was influenced not only by heavy metals from traffic of different intensity, but also from emissions from all sorts of industrial facilities in the city. In addition, long-range emissions from copper smelters or power plants in southwestern Poland cannot be excluded. The long-range transport of particulate matter could also contribute to the elevated levels of Fe, Mn, and Zn in leaves, and is confirmed by Lin et al. [47] and Suzuki [50]. According to Fernández Espinosa and Rossini Oliva [49], these elements are easily transported via air and deposited on plant surfaces. All these metals accumulated in needles of *T. baccata* reflect pollution in Wrocław.

Comparison of concentrations of metals between *T. baccata* and *Betula pendula* collected in Wrocław [51] indicates that the last tree was a much better bioaccumulator containing significantly higher (test t, $p<0.05$) concentrations of all heavy metals. Especially the concentration of Zn was 15 times higher in *Betula pendula*. For heavy metals, significant translocation from roots to leaves has been reported only for Cu, while foliar accumulation of Cd, Cr, and Pb is essentially due to aerial deposition [48]. Therefore, metals accumulated in leaves come from a restricted translocation from roots, and from deposition directly from air. For instance, according to Kozlov [52], surface accumulation contributes up to 70-90% of the total Ni and Cu in samples of birch leaves from heavily polluted sites near Monchegorsk (thereby exceeding the internal concentrations). Leaves of *Betula pendula* have a larger surface area than needles of *T. baccata,* and therefore accumulate more by surface. Surface accumulation can result from both precipitation of atmospheric aerosols and capture of soil dust by sticky birch leaves. *T. baccata* needles covered with a cuticle that consists of cutin and smooth wax surfaces are less effective at trapping metals [53]. These factors may be a reason for the mentioned differences in metal concentrations between these two species.

Conclusions

1. Needles and bark of *T. baccata* from most, medium, and less polluted sites were clearly distinguished by the principal component and classification analysis (PCCA). The most polluted needles projected more closely with Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, and Pb, and the most polluted bark projected more closely with Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn.
2. Bark was a better bioindicator of urban pollution in Wrocław than needles of *T. baccata*.

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