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Effect of industrial pollution and spruce forest decline on the biocenoses of Karkonosze Mts. (south-western Poland)

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BILBERRY (*VACCINIUM MYRTILLUS* L.) AS AN INDICATOR OF ENVIRONMENTAL STATE OF SPRUCE FORESTS IN KARKONOSZE MTS.

ABSTRACT: In a series of sites from the top of Mumlawski Wierch downwards (Western part of Karkonosze Mts.), properties of bilberry population as well as concentrations of heavy metals in various parts of the plant have been analysed in order to assess the state of spruce forests. It has been found that in habitats where tree stands are declined, density of bilberry population drops rapidly, the plants are becoming stunted and produce fewer flowers and fruits. Among heavy metals analysed, lead was the only one, the concentration of which in the plants exceeded permissible level, especially in sites located in the lower montane zone.

KEY WORDS: *Vaccinium myrtillus*, heavy metals, industrial pollution

1. INTRODUCTION

When assessing an effect of environmental pollution on functioning of natural systems, it is important to relate concentrations of toxic substances in the air and soils to changes observed at the level of individual organisms, populations and biocenoses. Bioindicators of environmental state include various plant and animal species that are particularly sensitive to toxic substances. Individuals of the species can accumulate the substances in their bodies and, moreover, they can respond to environmental pollution by morphological and physiological modifications, and their populations – by changes in abundance, biomass, age structure, fertility, etc.

A plant commonly accepted as indicator species is bilberry (*Vaccinium myrtillus*) (Kazimierczakowa 1975, 1988, Little and Martin 1974). It is a perennial dwarf shrub characterised by clonal growth. Estimates of maximum life time of a clone is about 20–30 years, and according to some authors – even 50–70 years (Antkowiak and Cybulko 1967, Flower-Ellis 1971). This qualifies the plant to be a very good indicator of processes, the consequences of which are visible after a relatively long time, such as effects of industrial pollution.

There are studies on both accumulation level of toxic substances in bilberry plants (Little and Martin 1974, Kazimierczakowa 1975, 1988) and its population responses to environmental pollution. For example, Buszman (1980) and Baron (1984) have found a relationship between lasting of phenological phases, as well as between flower and fruits numbers and the level of pollution and environment degradation in the most heavily industrialised region of Poland, i.e. Upper Silesia.

The objective of this work was to examine a response of bilberry population to changes in spruce forests affected by industrial pollution. Analyses of selected heavy metals in the soil, their accumulation in various parts of bilberry plants (*V. myrtillus*), and status of the plant population in sites characterised by different degeneration degree of the plant communities were examined.

2. STUDY AREA

Natural environment of the Karkonosze region has changed substantially over the last ten to twenty years. Progressive degradation of ecosystems has been observed resulting primarily from deposition of industrial pollutants derived from other parts of Poland as well as from the Czech Republic and Germany. The main components of the pollutants are sulphur and nitrogen compounds, and also heavy metals – zinc, cadmium and lead, in particular (Zwoździak et al. 1995). The studies were carried out in the region of Mumlawski Wierch situated in the westward part of the Karkonosze Mts. that is exposed to the highest degree to air pollutants.

Nine plots were selected for the studies, all situated on the slopes of Mum-

Table 1. Distribution and characteristics of study sites in the region of Mumlawski Wierch

Site No	Altitude (m a.s.l.)	Condition of plant communities
	Upper montane zone Plagiothecio-Piceetum hercynicum	
1*	1200–1180	recently declined spruce stand, stubs of trees
2*	1120–1100	spruce thicket
3*	1100–1080	old-growth spruce forest
4*	1180–1000	declined spruce forest, stubs of trees and fallen stems
	Lower montane zone man-planted spruce stand	
5*	960–900	spruce thicket
6*	900	declined spruce forest
7	900	spruce thicket
8*	920–940	old-growth spruce forest
9	900–920	declined spruce forest

* – soil sampling sites

lawski Wierch, at the foothill, or in the valley of Kamienna river (Table 1). On the same plots, studies were performed on transformations of herb-layer vegetation following forest decline (Wasiłowska 1999). Four of the plots were located in the upper montane forest belt (Plagiothecio-Piceetum hercynicum) (Matuszkiewicz 1981), and the remaining four plots – in a man-planted spruce forest in the lower montane zone. Plant communities in the sites considered differed from each other regarding degradation degree, and ranged from a community with a living forest stand, through communities with partially declined stands, to those completely deforested and overgrown by grasses: *Deschampsia flexuosa* and *Calamagrostis villosa*. The studies were additionally performed in regenerated young spruce stands in various regeneration phases.

3. METHODS

In order to assess condition of the bilberry population growing in tree stands degraded to various degrees, several parameters were examined, namely density and height of shoots, number and length of leaves, number of flowers and fruits. A single shoot (ramets) being a part of the whole polycormon was considered to be an individual. Density of *V. myrtillus* population was estimated on each selected plot by random tossing with a ring of an area 0.25 m^2. There were twenty sampling plots on each site. To assess height of the above-ground parts, number and length of leaves, and number of fruits, 10 individual shoots per plot were collected. All the shoots were in the same developmental stage, i.e. generative phase. These shoots were further used for chemical analysis.

The material for chemical analyses was separated into leaves, shoots and roots. Then, after rinsing and drying, the material was ground and mineralised in a muffle furnace at the temperature of 480°C. The ash was dissolved in 20% HCl, and elements (Fe, Mn, Zn, Cu, Pb, Cd and Cr) were analysed by using ASA technique.

Soil samples were taken from genetic horizons from 7 sample plots (Table 1). The samples were mineralised in a muffle furnace at the temperature 480°C, and analysed using the same methods as applied for plant material.

4. RESULTS

4.1. CONTAMINATION OF THE SOILS OF MUMLAWSKI WIERCH BY HEAVY METALS

Analyses of the soil samples demonstrated that the highest concentrations of heavy metals were characteristic of lead, copper and cadmium (Table 2). Based on analysis of maximal levels it can be seen that the concentrations were much variable in the examined soils. Maximal lead concentration ranged between 97.2 to 284.0 mg kg^{-1} d.w. indicating 3-fold differences among the sites (Table 2). Lead concentration exceeded permissible level (100 mg kg^{-1} d.w.) (Gorlach 1991, Kabata-Pendias et al. 1993) in almost all sites, except that covered by the de-

Table 2. Concentrations of heavy metals in the soil profiles in the region of Mumlawski Wierch

Site No	Genetic horizon	Depth (cm)	Fe	Mn	Zn	Cu	Pb	Cd	Cr
			mg kg^{-1} d.w.						
			Peat-mud soil						
1	O	0 – 4	2040	86	42.2	13.6	39.8	0.94	13.5
	Ofh	4 – 6	5000	262	39.0	17.0	69.6	1.26	18.4
	Ot_1	6 –10	6520	48	44.2	26.0	184.0	1.12	12.0
	Ot_2	10 –50	3640	24	11.8	7.2	148.0	0.52	21.1
	Ot_3	50 – 60	3160	38	10.8	5.2	61.0	0.74	16.4
	Mot	60 –80	3600	46	12.4	3.6	31.0	0.50	11.6
			Spodosol						
2	O	0 – 2	2080	103	48.8	12.4	32.0	0.90	18.9
	Ofh	2 – 4	5640	210	47.2	18.4	102.4	1.42	28.1
	A	4 – 9	4840	46	15.2	9.0	85.4	0.68	7.5
	Ees	9 – 11	4360	56	9.2	2.2	22.4	0.48	5.4
	B	11 – 30	8520	214	24.6	2.0	28.2	0.32	5.6
	C	< 30	4600	142	12.4	0.9	14.6	0.38	5.2
			Spodosol						
3	O	0 – 2	2360	74	13.6	10.6	51.0	1.20	13.1
	Ofh	2 – 4	7000	76	27.8	15.8	129.6	0.48	25.9
	A	4 – 10	8600	74	20.6	11.0	114.6	0.42	9.1
	Ees	10 – 15	6920	52	6.2	3.4	29.0	0.20	6.5
	B	15 – 40	15080	94	15.6	3.4	32.8	0.24	8.5
	C	< 40	22920	196	36.0	5.4	23.4	0.16	11.2
			Ranker						
4	Od	1 – 5	3920	110	26.6	10.4	71.0	0.54	36.4
	A	5 – 10	6680	58	244	50.6	153.4	0.48	13.1
	A/C	15 – 20	1800	24	7.2	3.8	2.6	0.10	11.9
	C	<20	2160	48	8.8	2.4	1.6	0.12	11.5
			Peat–muck soil						
5	Od	0 – 10	4040	100	47.8	15.4	65.4	0.92	32.0
	Ot	10 – 20	8080	58	30.8	19.8	152.8	0.34	29.0
	Mot	20 – 35	4600	26	13.2	8.4	64.0	0.34	46.3
	MotC	< 35	2000	26	3.2	13.0	5.0	0.32	10.9
			Peat-muck soil						
6	Od	0 – 8	8960	120	57.2	20.8	94.8	1.04	28.5
	Aot	8 – 20	5760	58	29.2	12.0	97.2	0.60	33.4
	CG	<20	4280	56	20.4	16.2	9.4	0.14	26.2
			Spodosol						
8	Od	0 – 4	6800	98	35.4	17.4	50.6	0.70	20.2
	A	4 – 10	690	42	30.4	59.4	261.6	1.20	23.3
	Ees	10 – 15	2000	46	10.6	7.8	7.8	0.16	12.0
	B	15 – 20	9440	90	5.0	11.4	5.2	0.16	20.3
	C	<20	7520	84	4.4	15.8	9.2	0.08	16.1

clined tree stand of the lower montane zone (station 6). Content of this element in granite rocks of the Karkonosze region amounts to 23.7–30.3 mg kg^{-1}. Because the element is rather immobile, its concentration in the soil should reflect the level in granite given above (Sachanbiński 1994). The raised lead level in the soil had to have resulted from accumulation of anthropogenic pollutants. Similarly high lead concentrations (167.9–247.0 mg kg^{-1} dw) in the soils of the Karkonosze region were found by Skiba (1995).

Maximum copper content of the soils ranged between 15.8–59.4 mg kg^{-1} d.w. (Table 2), and exceeded the allowable level (50 mg kg^{-1} d.w.) (Gorlach 1991) in few of the sites (the site with completely dead tree stand of the upper montane zone – station 4, and the old-growth living spruce forest of the lower montane zone – station 8). Similarly to lead, copper concentrations in the bedrock were low (4.2–7.0 mg kg^{-1}) (Sachanbiński 1994). Thereby, it seems that the high concentrations are an effect of atmospheric pollutant deposition. Copper concentrations found by Skiba et al. (1994) and Skiba (1995) in the upper 0–5 cm layer of the soils were lower (28.9 mg kg^{-1} dw.). Higher values found in this study resulted from the fact that copper accumulated in deeper (5–20 cm) layers of the soil profile (Table 2).

Maximum concentrations of cadmium in the soils amounted to 1.42 mg kg^{-1} d.w., and exceeded the natural level (1 mg kg^{-1} d.w.) (Kabata-Pendias et al. 1993) in as many as five sites (Table 2). Low concentrations in the bedrock (0.02 mg kg^{-1}) (Sachanbiński 1994, 1995) indicates soil accumulation of cadmium derived from the atmosphere. This is confirmed by very high concentrations of this element found in precipitation (Kmieć et al. 1994, Zwoździak et al. 1995). Even higher concentrations amounting to 6.4 mg kg^{-1} d.w. were found by Skiba et al. (1994) and Skiba (1995) in the region of Mumlawski Wierch.

Zinc, concentrations of which in atmospheric precipitation are, according to Zwoździak et al. (1995), by several times higher in the Karkonosze region than amounts typically found in rural areas, occurred in small amounts in the soils examined. Maximal contents of the element ranged between 27.8 and 57.2 mg kg^{-1} d.w. (Table 2) and were only slightly higher than zinc concentration in the granite bedrock (24.0–32.5 mg kg^{-1}) (Sachanbiński 1994, 1995), and much lower than the permissible level (300 mg kg^{-1} d.w.) (Gorlach 1991).

Chromium concentration did not exceed threshold values in any of the sites, and was even lower than the average concentration reported for podsolic soils (47 mg kg^{-1} dw.) (Kabata-Pendias et al. 1993). The element content of the soils ranged from 21.1 to 36.4 mg kg^{-1} dw. (Table 2), whereas its content in the granite bedrock is manifold higher and reaches about 145 mg kg^{-1} (Sachanbiński 1994, 1995).

Likewise, maximum concentration of manganese in the analysed soil profiles (198–262 mg kg^{-1} d.w.) was lower than mean values reported for unpolluted soils (270 mg kg^{-1} d.w.) (Kabata-Pendias et al. 1993) and did not differ much from its natural content of granites (200 mg kg^{-1}) (Sachanbiński 1994, 1995).

In spite of considerable site-to-site differences related to the levels of heavy metals in the soils, no statistically significant correlations were found between concentrations of the elements in the soil profiles and the degree of destruction of forest vegetation. However, maximum concentrations in the soil profiles tended to be slightly and negatively correlated with altitude. The tendency was characteristic of all the metals analysed, except cadmium, and was most clear-cut in the case of lead (Fig. 1).

The above description relates to maximal concentrations of heavy metals in the soils, irrespective of vertical distribution of the metals in the soil profiles. However, attention should be paid to variability of the concentrations across the soil horizons. Majority of the heavy metals has accumulated in the upper soil layers at depth of 0–10 cm, maximum 20 cm. The highest lead concentration was thus found in organic and organo-mineral

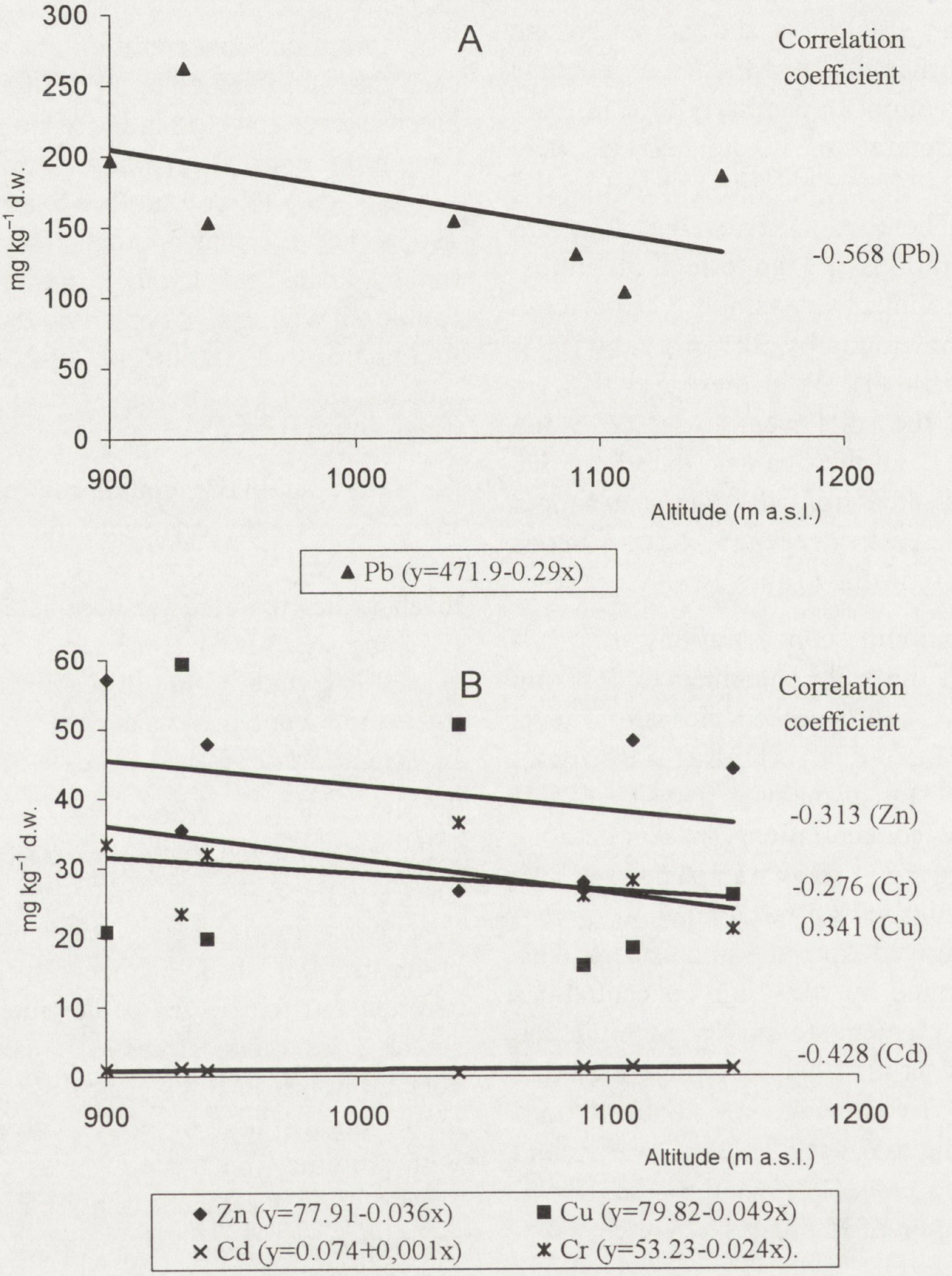

Fig. 1. Relationship between maximum concentration of heavy metals in the soil and site location. Note the different scale for A and B.

horizons of the soils. In the deeper layers, lead concentration substantially decreased, with the lowest level found in the bedrock (Table 2). Likewise, the highest copper concentration was found in the upper humus layer, while the lowest – in elluvial layers and bedrock (Table 2). Decreases in cadmium, zinc and chromium concentrations have also been observed down the soil profiles, although the latest element is considered to be the least variable regarding its vertical distribution in the soil (Table 2). Iron was the only metal that showed an opposite tendency, reaching its lowest concentrations in organic and organo-mineral horizons (Table 2).

4.2. ACCUMULATION OF HEAVY METALS BY BILBERRY PLANTS

Chemical analyses of heavy metals in leaves, shoots and roots of bilberry plants did not show any high accumulation of the elements (Table 3), except for lead, the content of that was fairly high. Lead accumulated in larger amounts in the roots (from 4.6 to 14.7 mg kg^{-1} d.w.), and in much smaller amounts in leaves (0.7–7.5 mg kg^{-1} d.w.) and shoots (2.7–9.6 mg kg^{-1} d.w.) (Table 3). Lead concentration in roots of the examined plants exceeded permissible level (10 mg kg^{-1} d.w.) for forage plants (Kabata-Pendias and Pendias 1979) in all the study sites located in the upper montane zone (sites 1–4). Except for few cases, cadmium, similarly to lead, accumulated mainly in the bilberry roots, and its concentrations ranged between 0.05 and 0.44 mg kg^{-1} dw. In leaves and shoots of the bilberry plants, the cadmium content was lower (0.02 – 0.33 mg kg^{-1} d.w.). Internal distribution of iron was also similar. The highest concentrations of the metal were found in the roots (139.6–707.2 mg kg^{-1} d.w.), and lower – in shoots and leaves. By contrast, zinc tended to accumulate in the plant shoots. Copper and chromium

Table 3. Concentrations of heavy metals in bilberry plants

Site No.	Part of plant	Fe	Zn	Cu	Pb	Cd	Cr
				mg kg^{-1}d.w.			
1	Leaves	373.0	17.2	8.6	4.9	0.22	3.70
	shoots	126.3	42.2	10.2	5.4	0.33	0.71
	roots	274.4	19.3	9.7	14.7	0.21	3.78
2	Leaves	414.0	20.5	10.1	7.5	0.12	2.57
	shoots	198.4	39.3	11.1	9.6	0.13	2.09
	roots	159.3	18.8	9.9	12.1	0.28	1.76
3	leaves	310.5	19.3	12.0	6.0	0.18	1.85
	shoots	263.9	48.3	12.7	7.2	0.29	8.49
	roots	707.2	16.7	10.2	13.3	0.44	2.48
4	leaves	202.4	17.2	9.5	4.6	0.11	3.55
	shoots	101.2	50.5	8.6	3.7	0.28	0.66
	roots	703.4	32.8	10.0	10.5	0.24	5.35
5	leaves	284.3	19.9	8.0	3.7	0.04	0.84
	shoots	89.8	56.9	9.3	2.7	0.21	0.79
	roots	139.6	25.7	8.4	5.2	0.26	3.16
6	leaves	118.1	16.3	9.4	0.7	0.02	1.24
	shoots	102.5	47.5	9.5	3.8	0.18	0.61
	roots	149.1	15.3	8.0	7.5	0.05	2.04
7	leaves	156.0	17.1	10.4	2.9	0.06	2.87
	shoots	130.5	46.8	9.2	3.2	0.14	1.59
	roots	141.8	19.6	8.0	4.6	0.12	1.06
8	leaves	182.7	33.7	10.4	7.1	0.15	1.24
	shoots	107.7	29.1	9.2	7.3	0.20	0.86
	roots	147.4	15.5	8.3	9.7	0.26	0.93

were more or less evenly distributed within the plants (Table 3).

No statistically significant differences were found in mean concentrations of heavy metals in bilberry plants between the sites covered by living and declined trees. Concentrations of the elements in the soil did not correlate with those in the plants, either. Differences in heavy metal concentrations within the bilberry plants seemed to be related rather with location of the sites above see level. The highest mean concentrations of heavy metals were found in the plants collected from the uppermost localities (Fig. 2). The tendency was true for all the elements analysed, and was least marked

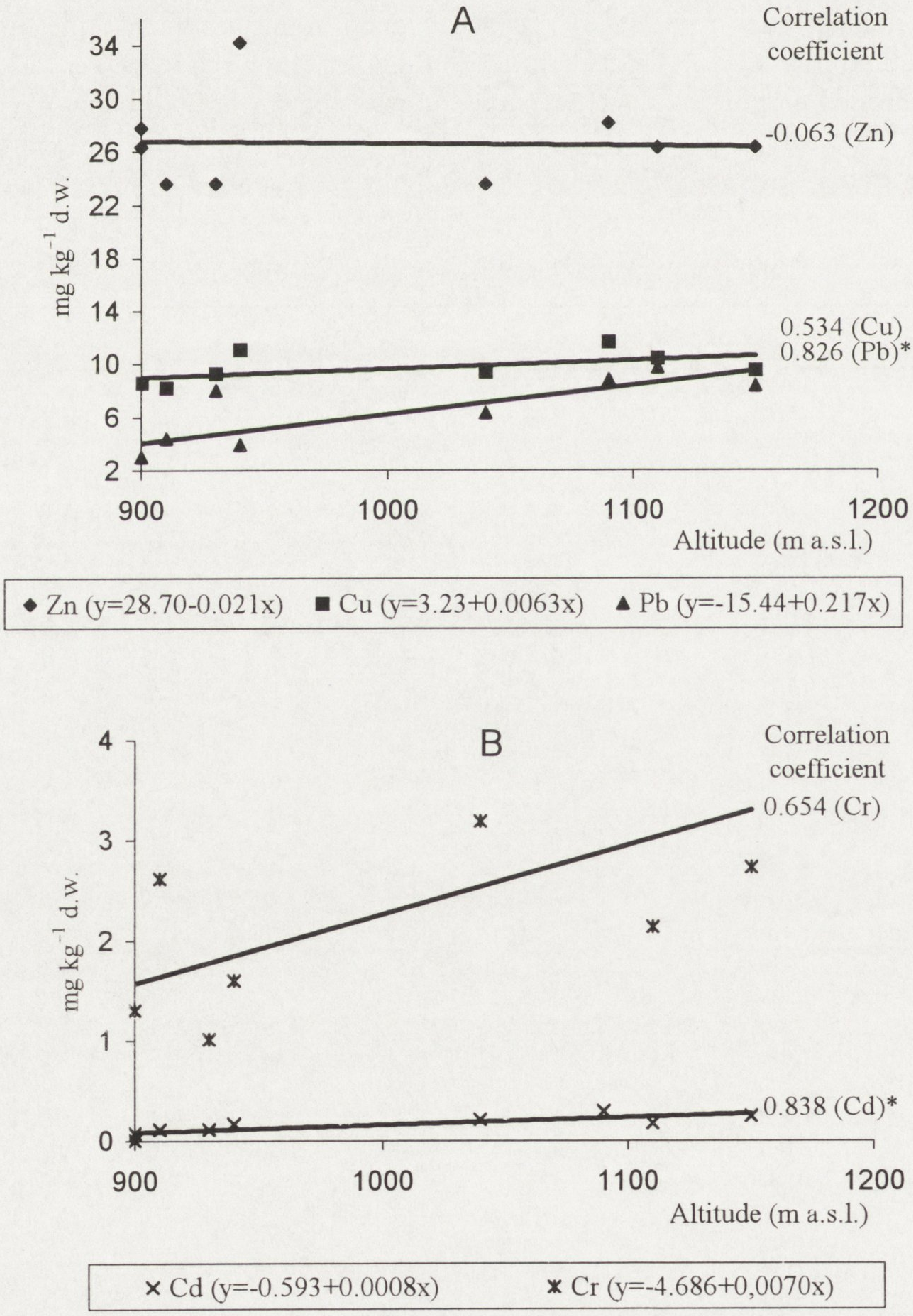

Fig. 2. Relationships between mean heavy metal contents of bilberry plants and site location. *– significant correlation. Note the different scale for A and B.

for zinc. Statistical significance of the phenomenon was confirmed for lead and cadmium. The lack of statistically significant correlations between heavy metal contents of the soil and plants, and even opposite tendencies in the distribution pattern with altitude indicate that plant concentrations of the heavy metals were determined by other factors.

4.3. CHARACTERISTICS OF *V. MYRTILLUS* POPULATION GROWING IN THE SPRUCE STANDS OF VARIOUS STAGES OF DESTRUCTION

The bilberry populations investigated were characterised by using a few parameters: density, height of individual shoots, number and length of leaves, and number of fruits.

The highest densities of the bilberry plants were found in regenerated spruce stands, whereas the lowest and, at the same time, the most variable – in the areas completely devoid of trees (Table 4). In the living spruce forests, density of bilberry plants was fairly little variable and slightly lower than that found in the thickets, but the difference was not statistically significant (Tables 4, 5).

The least favourable conditions for development of *V. myrtillus* population occurred in the deforested sites. The individuals growing there were significantly shorter than those in the thickets or mature forests, had shorter leaves and lower number of fruits (the differences were statistically significant only between the deforested areas and thickets) (Tables 4, 5). The bilberry population grew best in the regenerated forests where some of the parameters (number and length of leaves, number of fruits) reached higher values than in the old-growth spruce forests (Tables 4, 5).

The above results showed that the population properties, density and mean number of fruits and leaves per individual in particular, differed significantly among the sites compared (thickets, declined forests, living forests). A question arises whether particular sites within the same type of environment differ among each other. It turned out that in the thickets values of the parameters were the higher, the older was the stand. In the declined stands the values were the lower, the earlier was the stand declined, while in the living forests the bilberry population developed much better at lower elevations (Fig. 3).

5. DISCUSSION

The results presented indicate that despite considerable air pollution (Zwoździak et al. 1995) concentrations of heavy metals in the soil do not differ from the normal levels. Among the elements considered, lead and cadmium, and in few cases also copper were the only metals exhibiting elevated concentrations when compare with their allowable levels (Czarnowska et al. 1983, Kabata-Pendias et al. 1993, Konecka-Betley et al. 1994). The concentrations were however by several times lower than those reported for other, industrialised parts of Poland, e.g. for Upper Silesia (Kulesza and Sztrantowicz 1987). Contamination occurred usually in organic horizons of the soils. Skiba et al (1994) and Skiba (1995) have also found elevated concentrations

Table 4. Indicators of the quality of *V. myrtillus* populations in the region of Mumlawski Wierch. Average values for three different habitat types. Detail data for particular sites – see fig. 3.

Indicators	Spruce thickets (3 sites)		Declined spruce forests (3 sites)		Living spruce forests (2 sites)	
	$\bar{x}$±SD	Variability coefficient	$\bar{x}$±SD	Variability coefficient	$\bar{x}$±SD	Variability coefficient
Density (indv. m^{-2})	49.4±66.3	1.34	17.4±39.5	2.27	33.50±39.6	1.18
Mean heigth of shoots (cm)	24.7±5.9	0.24	20.9±5.9	0.28	24.9±10.6	0.43
Mean number of fruits $indv.^{-1}$	5.2±6.6	1.27	1.4±2.3	1.64	2.3±5.2	2.26
Mean number of leaves $indv.^{-1}$	349.6±239.9	0.69	254.5±200.8	0.79	140.8±101.1	0.72
Mean length of leaf of an indiv. (mm)	13.9±2.3	0.17	12.6±3.2	0.25	16.0±4.3	0.27

Table 5. Significance of differences in properties of *V. myrtillus* population among the groups of sites examined (U Mann-Whitney's test, p=0.05)

	Density	Mean heigth of shoots	Mean number of fruits	Mean number of leaves	Mean length of leaf
Spruce thickets/Declined spruce forests	+	+	–	+	+
Spruce thickets/Living spruce forests	–	–	+	+	+
Living spruce forests/Declined spruce forests	+	+	+	+	–

+ significant difference; – insignificant difference

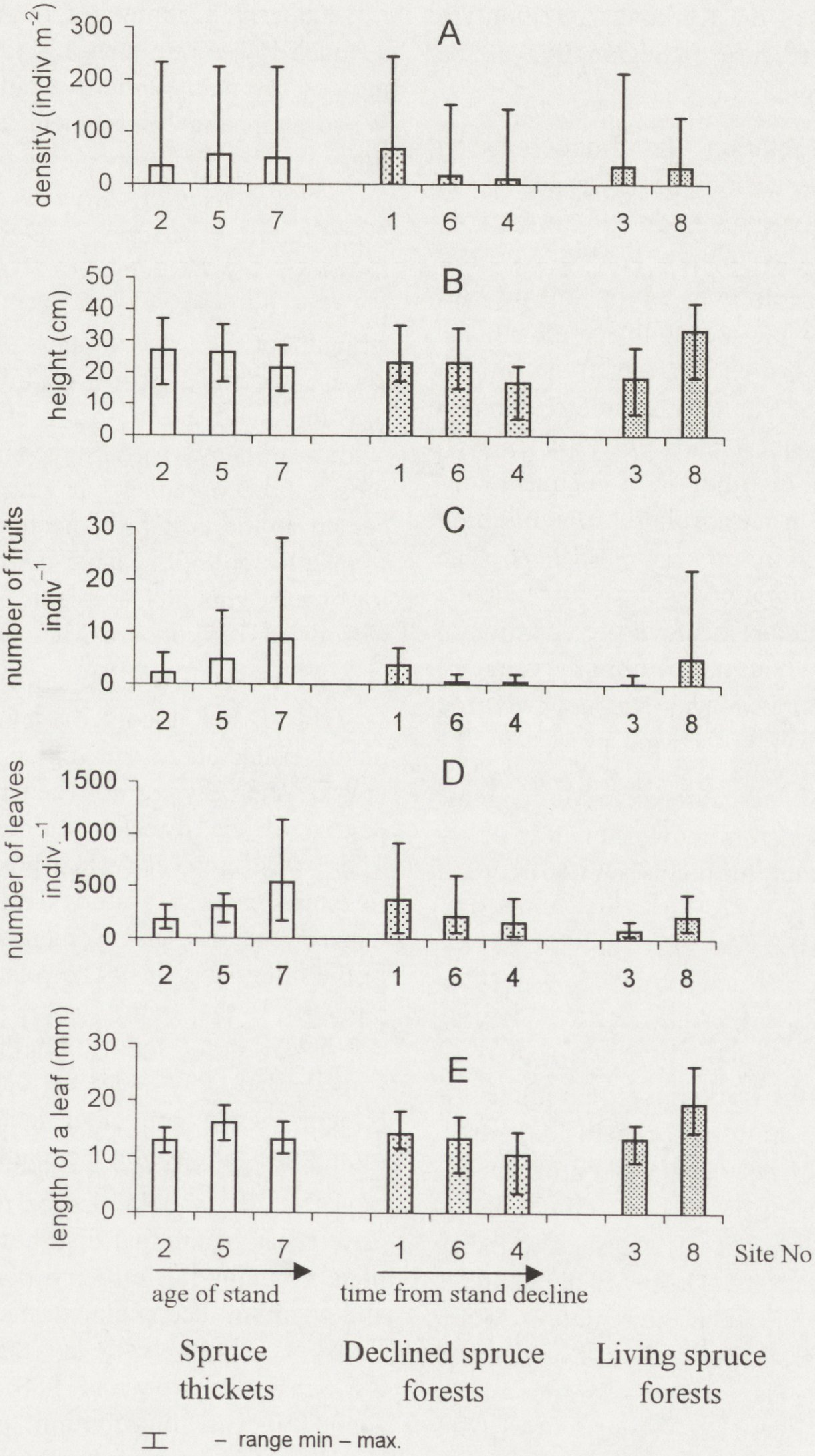

Fig. 3. Characteristics of V. myrtillus population in the region of Mumlawski Wierch A – population density, B – mean height of above-ground parts, C – mean number of fruits, D – mean number of leaves, E – mean length of a leaf. Data from 20 sampling plots (0,25 m^2) each site.

of the elements, lead and cadmium in particular, in the soils of Karkonosze Mts. However, in the authors' opinion, the present levels of heavy metals in the forest soils of the Karkonosze region are not a direct cause of degradation of the forest ecosystems.

No correlation was found between degree of destruction of the spruce stands and the heavy metal contents in the soil. However, the metals tended to have higher concentrations in the soil profiles of the sites located at lower elevations. Skiba (1995) who examined the soils in the region of Mumlawski Wierch found a similar tendency. This corresponds well with spatial distribution of chemical contaminants in atmospheric precipitation given by Kmieć et al. (1994). The authors have noticed a clear-cut tendency of total pollutant loads in precipitation to decrease with altitude within the range of 900–1300 m a.s.l. The tendency occurred in open as well as forested areas.

One of indicators of anthropogenic pressure on natural environment is heavy metal content of plants (Antonovics et al. 1971, Bradshaw and Mcnelly 1981, Fabiszewski et al. 1983, Godzik 1991, Grodzińska 1978, Kazimierczakowa 1975, 1988, Litle and Martin 1974). However, in the case of the Karkonosze region there is difficult to draw any conclusions about the effect of heavy metals on organisms on the basis of the element accumulation in leaves, shoots or roots of bilberry plants. Except lead, heavy metal contents of bilberry shoots in the region of Mumlawski Wierch (Table 3) did not exceed permissible levels for forage plants (Kabata-Pendias and Pendias 1979) and were slightly lower than the values found by Panek et al. (1996) in *V. myrtillus* shoots from Podhale region, and much lower than those reported by Kazimierczakowa (1988) for Olkusz region.

Bilberry accumulates heavy metals at much lower rate than e.g. lichens and mosses, or many other vascular plants. When analysing heavy metal accumulation in a few plant species (*Arabis arenosa, Viola tricolor, Thymus serpyllum, Vaccinium vitis-idaea, Deschampsia flexuosa, Vaccinium myrtillus*), Kazimierczakowa (1988) demonstrated that the least amounts of the metals are accumulated just by bilberry. On the other hand, Żołnierz's et al. (1994) studies on heavy metal concentrations in mosses, the organisms having been accepted as the best bioindicators of environmental pollution, have confirmed the low metal contents of plants in various regions of Karkonosze Mts. when compare with e.g. Tatra Mts.

Heavy metal contents of bilberries plants collected in the region of Mumlawski Wierch were not related with the degree of the forest stand destruction. There was however a clear positive relationship between altitude and the contents of majority heavy metals analysed in the bilberry plants. The relationship is a reverse to that found for the metal concentrations in the soil. It may thus be presumed that the element contents of bilberry depend on other factors determining their uptake by the plants.

Attention should also be paid to the differences in internal distribution of the metals within the bilberry plants. Lead and cadmium accumulated mainly in the roots, and zinc – in the shoots. Kazimierczakowa (1988) has also found uneven distribution pattern of heavy metals in plants. She found concentrations of lead, and occasionally zinc, to be highest in below-ground parts of various plant species.

Properties of bilberry populations alter primarily due to changes in the environment following by tree stand degradation. In the sites covered by dead trees, population density was clearly reduced. Moreover, growth of the plants was stunted, and production of fruits was lowered. This can be easily explained in the context of ecological demands of *V. myrtillus*. Based on Zarzycki's (1984) system of ecological indicator numbers, bilberry can be regarded as a species requiring at least periodical shading and fresh or moist soils. Destruction of the tree stands has increased light penetration, wind speed and soil drying, and all the factors could possibly contribute to bilberry withdrawal from the habitats. The mean density of bilberry population in the deforested sites was not only very low, but also most variable as it occurred almost exclusively around stubs of tree stems and cut boles.

Another cause of weak condition of the bilberry population in the sites with declined tree cover may be poor competitive ability in relation to light-demanding species of grasses that intensively expand throughout the sites. Fabiszewski et al. (1993) revealed existence of relationship between expansion of *Calamagrostis villosa* and disappearing of bilberry populations from the degraded spruce forests.

This study indicates that these are changes in bilberry population characteristics, not pollutant accumulation by the plants, which can be a better indicator of environment quality.

6. SUMMARY

Concentrations of heavy metals (Fe, Zn, Pb, Cu, Cd, Mn, Cr) were analysed in various organs of bilberry (*V. myrtillus*) and in the soils of the region of Mumlawski Wierch (1219 m a.s.l.) and at its foothill in the valley of Kamienna river (900 m a.s.l.). Study plots were established in living spruce forests, declined stands and spruce thickets (Table 1). In the soil, lead and cadmium, and copper in some of the sites, were the only metals, concentrations of which exceeded values accepted as natural. The elements accumulated in the upper layers of the soil profiles (to 10 cm) (Table 2). No correlation was found between the metal concentrations in the soil and the degree of spruce stand degradation. There was however a tendency of the metal concentrations in the soil profile to decrease with altitude (Fig. 1). Heavy metal contents of plants were rather low, except lead concentration in the roots, this exceeding the natural level. Clear differences were found in the concentrations of heavy metals among different plant organs (Table 3). Heavy metal contents of neither soil nor plants correlated with the degree of tree stand degradation. On the other hand, heavy metal concentrations in the bilberry plants were positively related to altitude (Fig. 2).

In the same sites, quality of the bilberry population was assessed. In the sites where spruce trees were dead, the bilberry plants rapidly decreased their densities, altered their shape (dwarf) and lowered fruit production when compare with the old-growth living spruce forests (Tables 4, 5). The parameters had the lower values, the longer time had passed since deforestation (Fig. 3). The changes are not irreversible. In spruce thickets, bilberry population has gradually regenerated (Table 4): the older the stand, the higher the population index Fig. 3).

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