Heavy metal accumulation in *Artemisia* and foliaceous lichen species from the Azerbaijan flora

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Abstract
Artemisia plants and foliaceous lichens are known to be capable of accumulating heavy metals (HM) from soil and air. These plant species are widespread on polluted sites of Azerbaijan. However, so far their capacity to accumulate HM in their shoots and roots has not been tested. Three *Artemisia* and two lichen species were collected from different contaminated sites of Azerbaijan. Plant and surface soil samples were measured for Cd, Cu, Pb, Ni and Zn concentrations by ICP-AES. The results indicated that among the *Artemisia* species *A. scoparia* showed the best HM accumulation properties. Lichen species were also distinguished by very high amounts of HM in their biomass, while in surrounding soil samples HM concentrations had higher contents than the soils occupied only with *Artemisia* species. The results indicate that on contaminated sites *Artemisia* and lichens accumulated metals in their biomass without toxicity symptoms. Taking large biomass and high adaptation ability into account, *A. scoparia* represents a good tool for a phytoremediation approach on polluted soils.

Keywords: *Artemisia,* lichens, soil contamination, heavy metals, phytoremediation

1 Introduction

As a result of increasing anthropogenic activities, the heavy metal (HM) pollution of atmosphere, soil and water is a growing environmental problem affecting crop quality and production and human health. One major approach to overcome or minimize the adverse effects of toxic metal pollution on living organisms and ecosystems is to cleanup the contaminated areas by phytoremediation (McGrath *et al.* 2002). This is a low cost and environmentally sustainable method of decontamination. To date, more than 400 plant species belonging to 45 families with a high genetical capacity to accumulate and tolerate large amounts of HM in shoots have been identified (Baker and Brooks 1989; Yang *et al.* 2004). They are classified as HM hyperaccumulator species. However, in most of these species, the growth- and shoot-biomass production rates are insufficient and therefore not suitable for efficient phytoremediation (Ebbs *et al.* 1997). Identifying metal-accumulating plants that produce higher biomass on a given area is a major goal of environmental biotechnology. The restrictions on plant importation of species between countries and the adaptation problems of different plant species to different environmental conditions influence the requirements for identifying indigenous plant species for the phytoremediation of contaminated sites in different countries.

In Azerbaijan, large chemical, petrochemical and metallurgical complexes, and on- and off-shore oil and gas exploitation for more than a century have been the major sources of contamination of air, water and soil. Azerbaijan flora has a diversity of plant species and varieties. Therefore, a survey screening for HM-tolerant and hyperaccumulating plants from the Azerbaijan flora should provide useful insights and contribute to the decontamination of polluted sites.

Artemisia plants are known to be capable of accumulating several metals from soils (MORISHITA and BORATYNSKI 1992; POREBSKA and OSTROWSKA 1999; SAMKAEVA *et al.* 2001; BASHMAKOV and LUKATKIN 2002; KIM *et al.* 2003; LI *et al.* 2003; KUDRYASHOVA *et al.* 2004; TAKEDA *et al.* 2005). Some *Artemisia* species are widespread on the contaminated sites of Azerbaijan and have a large biomass production capacity. *Artemisia* species grown naturally on contaminated sites of Azerbaijan have not been previously tested for their capacity to accumulate HM in their shoots and roots.

The sensitivity of lichens to polluted air has, on the other hand, been studied extensively (GARTY 1985; GARTY and AMMANN 1987; LAVRINENKO and LAVRINENKO 1999; IKINGURA and AKAGI 2002). The contents of some HM are known to be able to reach very high concentrations in lichen thalluses when grown on metal-rich substrates (GARTY *et al.* 1979; PURVIS and HALLS 1996). Among the 155 lichen species found in the Absheron region of Azerbaijan (ALVERDIYEVA 1983), only four species with foliaceous forms seem to be suitable research materials for developing of new HM hyperaccumulator plants.

The aims of the present study are: i) the selection of HM-tolerant and HM hyper-accumulator plants among three indigenous *Artemisia* and two foliaceous lichen species, and ii) a comparison of the *Artemisia* and lichen species for their HM accumulating capacity when grown in contaminated regions. The heavy metals studied in this research were cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn).

2 Materials and methods

2.1 Area description

Four sites in the Binegedi district (five km northwest of Baku) and six sites in the Ali-Bayramli district (100 km southwest of Baku) in Azerbaijan were randomly selected for collecting the soil and plant samples. The sites are all contaminated with high levels of oil, chemical and metallurgical waste products. Their locations, the *Artemisia* and/or lichen species sampled, the geographical position and distance from the contaminating source are provided in Table 1.

Table 1. Description and location of the Azerbaijan sites assigned for sampling of soils, dominant higher and lower plant species.

Location	Number of sites	Plants	Environmental description
Binegedi 5 km to Northwest of Baku	Site 1	*Artemisia fragrans*	Elevation 54 m, N 40°27.575', E 049°47.653', around oil derricks, 3 m from route
	Site 2	*A. fragrans*	Elev. 10 m, N 40°27.505', E 049°50.450', around Baku Steel Company (approximatively 5 m)
	Site 3	*A. scoparia* *A. caucasica* *Argusia sibirica*	Elev. 8 m, N 40°27.513', E 049°50.446', around Baku Steel Company (approximatively 10 m)
	Site 4	*A. fragrans* *A. scoparia*	Elev. 12 m, N 40°27.847', E 049°50.401', 500–600 m from Baku Steel Company, around oil derrick
Ali- Bayramli 100 km to Southwest of Baku	Site 5	*A. fragrans* *Salsola dendroides* *Climacoptera crassa*	Elev. –6 m, N 39°53.897', E 048°55.226', 300 m from HEPS, 500 m from oil derricks
	Site 6	*A. fragrans*	Elev. –9 m, N 39°53.893', E 048°55.341', 500 m from a hydroelectric power station (HEPS), 100 m from oil derricks
	Site 7	*A. fragrans*	Elev. –5 m, N 39°53.902', E 048°55.386', 550 m from HEPS, 80 m from oil derricks
	Site 8	*Xantoria parietna* *Physcia adscendens*	Elev. –13 m, N 39°53.970', E 048°54.898', 10 m from HEPS, on iron fence
	Site 9	*Xantoria parietna*	Elev. –13 m, N 39°53.970', E 048°54.898', 15 m from HEPS, on apricot-tree
	Site 10	*Xantoria parietna* *Physcia adscendens*	Elev.–19 m, N 39°53.908', E 048°54.816', 40 m from HEPS, on hornbeam

2.2 Plant and soil material

To collect information about the extent of HM pollution in the experimental sites and HM accumulation, wormwood plants *(Artemisia)* and lichen species were selected to study soil contamination and the aerial deposition of HM, respectively. Among the *Artemisia* species belonging to the Asteraceae (Compositae) family, *A. fragrans* Willd., *A. scoparia* Waldst. and *A. caucasica* Willd. were selected as potential candidates for phytoextraction. Two foliaceous lichen species *Xantoria parietna* (L.) Th. Fr. and *Physcia adscendens* (Fr.) Oliv. were sampled from 1 to 1.5 m above the soil level. All *Artemisia* plants and one dominating attendant plant (Boraginaceae) *Argusia sibirica* (L.) Dandy were collected from the Binegedi region for comparative study of their accumulative capacity, while *A. fragrans,* two lichens and two attendant plants (Amaranthaceae) *Salsola dendroides* Pall. and *Climacoptera crassa* (Bieb.) Botsch. (= *Salsola grassa* Bieb.) were collected from the Ali-Bayramli region. In all locations 0 to 10 cm of the surface soil was sampled at each point where plant samples were taken. All soil and plant samples were analyzed for their Cd, Cu, Ni, Pb and Zn levels and the pH of the soil samples was also measured.

2.3 Analytical procedure

For estimating the plant available concentrations of five HM, soil samples were ground and passed through a 2-mm sieve and extracted by the standard DTPA-extraction method according to LINDSAY and NORWELL (1978). For the total extraction of HM, soil samples were digested by a microwave (Milestone-ETHOS, Italy) in aqua regia ($1HNO_3$:3HCl by volume).

The plant samples collected were washed thoroughly with de-ionised water for decontamination from the HM deposited on the leaf and root surface, and then separated into roots and shoots. Wormwood and lichen material was pulverised and ashed in glass vials at 550 °C in a muffle furnace. The resulting ash was digested in 4 M HCl at 125 °C on a hot plate until dry and then dissolved in 0.4 M HCl. All samples were then analysed by ICP-AES (Varian-VistaPRO, Australia) to determine the HM concentrations.

The soil pH was measured in a soil: water suspension of 1:2.5 (JAKSON 1958).

All analyses were run in three replications. Data were evaluated by analysis of variance using MS Excel.

3 Results

3.1 Heavy metal concentrations in soil samples

The HM concentrations in all the soil samples taken from different sites and locations in Azerbaijan strongly differed both in their total and extractable levels. As expected, the total levels of all five HM significantly exceeded the extractable amounts. In the Binegedi location, the total concentration was around 8 to 26 times higher than the extractable concentration for Cd, 15 to 18 times for Cu, 14 to 62 times for Ni, 3.9 to 31 times for Pb, 15 to 79 times for Zn (Table 2). Similar results were also found in the soil samples collected from the Ali-Bayramli location. In this location the largest differences between total and extractable HM was determined in soil sampled near the *Artemisia* plants (Table 2).

In all soil samples, the total and extractable amount of Zn was relatively higher than the other HM analysed. The total amount of Zn in the soils ranged from 26 mg kg^{-1} (nearby *A. fragrans* plants widespread on Site 4) to 118 mg kg^{-1} (nearby *A. fragrans* plants widespread on Site 9). Among the HM tested, the Cd concentration was the lowest in all the soils studied. Although the high amount of total Ni in soils was as much as 84 mg kg^{-1}, the DTPA-extractable fraction of Ni was very low. In the examined soils, the total amounts of Cu and Pb showed a significant variation and ranged between 7 to 79 mg kg^{-1} for Cu and 6 to 54 mg kg^{-1} for Pb, depending on the pollution source and distance from it (Table 2). Among the sites tested, sites 8 and 9 exhibited the highest level of total HM concentrations.

3.2 Heavy metal concentrations in *Artemisia* plants

The variations between the plant species tested for their capacity to accumulate HM in their shoots and roots were highly significant. All three species of *Artemisia* accumulated large amounts of Zn in their shoots. The HM accumulation in their roots was much less than in the shoots of the *Artemisia* species growing in the Binegedi location (Table 3). Among the *Artemisia* species tested, *A. scoparia* at site 3 collected around a steel plant in the Binegedi location had the greatest capacity to accumulate all HM except Ni in its shoots.

Table 2. Total and DTPA-extractable heavy metal levels (mg kg^{-1} DW) in the surrounding soil of tested plants and lichens from different sites of Azerbaijan. Sites 1, 2, 3, 4 - Binegedi location; Sites 5, 6, 7, 8, 9, 10 - Ali-Bayramli location. Description of tested sites is given in Table 1.

HM	*Site 1*		*Site 2*		*Site 3*		*Site 4*		*Site 5*		*Site 6*		*Site 7*		*Site 8*		*Site 9*		*Site 10*	
	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract	total	DTPA-extract
Cd	0.40 ±0.02	0.02 ±0.003	0.53 ±0.12	0.07 ±0.01	0.30 ±0.04	0.04 ±0.004	0.26 ±0.05	0.01 ±0.001	0.47 ±0.03	0.03 ±0.02	0.80 ±0.05	0.03 ±0.001	0.40 ±0.05	0.02 ±0.003	0.70 ±0.03	0.02 ±0.004	0.60 ±0.1	0.04 ±0.001	0.50 ±0.11	0.02 ±0.002
Cu	15.37 ±4.82	0.82 ±0.24	33.74 ±1.98	2.35 ±0.21	18.32 ±1.06	1.06 ±0.01	7.21 ±0.96	0.48 ±0.11	30.99 ±1.40	1.40 ±1.31	42.00 ±3.34	1.89 ±0.45	33.08 ±2.17	0.84 ±0.09	79.00 ±5.78	6.80 ±2.87	42.00 ±8.43	4.11 ±0.98	35.00 ±6.34	3.09 ±0.99
Ni	22.25 ±1.18	0.10 ±0.04	17.25 ±1.01	0.06 ±0.003	15.14 ±0.05	0.05 ±0.01	19.03 ±1.13	0.13 ±0.03	65.00 ±0.65	0.65 ±0.46	64.00 ±3.27	0.40 ±0.07	63.54 ±3.67	0.48 ±0.03	84.00 ±5.69	1.24 ±0.02	63.00 ±6.99	2.02 ±0.67	57.00 ±9.36	1.26 ±0.86
Pb	9.00 ±1.29	0.29 ±0.21	23.16 ±0.96	5.95 ±0.87	13.23 ±1.44	1.44 ±0.22	5.95 ±0.83	0.40 ±0.05	13.46 ±0.97	0.97 ±0.47	15.00 ±2.86	0.74 ±0.04	12.04 ±1.78	0.74 ±0.04	54.00 ±4.93	11.47 ±3.79	36.00 ±5.34	18.35 ±7.99	13.00 ±3.77	1.47 ±0.65
Zn	48.13 ±5.61	0.61 ±0.21	80.00 ±4.12	5.11 ±0.78	49.54 ±2.63	2.63 ±0.09	26.44 ±1.78	0.57 ±0.03	65.82 ±1.65	0.65 ±0.23	81.00 ±5.98	0.78 ±0.05	63.81 ±4.09	0.58 ±0.07	92.00 ±10.98	2.87 ±0.87	118.00 ±21.98	8.52 ±2.11	76.00 ±11.68	1.85 ±0.39
pH	7.8		8.65		8.3		8.08		8.4		8.51		8.57		8.42		8.21		8.29	

Table 3. HM concentrations (mg kg^{-1} DW) in shoots and roots of *Artemisia* species, collected from various locations of Azerbaijan. Sites 1, 2, 3, 4 - Binegedi location; Sites 5, 6, 7, 8, 9, 10 - Ali-Bayramli location. Description of tested sites is given in Table 1.

			Shoot concentration					Root concentration				
Locations	**Sites**	**Plants**	**Cd**	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Cu**	**Ni**	**Pb**	**Zn**
Binegedi	Site 1	***A. fragrans***	0.21 ± 0.08	12.1 ± 3.98	4.84 ± 1.61	2.62 ± 1.1	69.74 ± 23.06	0.26 ± 0.08	12.55 ± 2.13	5.40 ± 0.58	2.67 ± 1.27	43.24 ± 8.55
	Site 2	***A. fragrans***	1.17 ± 0.23	24.55 ± 3.56	4.98 ± 1.61	63.87 ± 13.83	376.6 ± 82.95	0.48 ± 0.08	21.60 ± 5.66	2.78 ± 1.64	10.61 ± 1.10	112.24 ± 4.1
	Site 3	***A. scoparia***	4.02 ± 0.89	34.01 ± 8.32	5.34 ± 1.32	160.08 ± 42.41	735.93 ± 129.6	0.97 ± 0.53	15.38 ± 2.70	3.64 ± 3.23	19.61 ± 10.66	200.71 ± 87.9
		A. caucasica	2.19 ± 0.39	29.98 ± 1.87	19.59 ± 1.77	59.91 ± 6.59	416.84 ± 10.96	0.22 ± 0.14	23.07 ± 1.67	5.21 ± 0.92	6.53 ± 1.19	80.98 ± 8.66
		Argusia sibirica	0.8 ± 0.19	22.77 ± 1.07	3.93 ± 0.15	46.69 ± 3.68	300.9 ± 20.7					
	Site 4	***A. fragrans***	0.43 ± 0.15	13.56 ± 1.4	3.72 ± 0.85	6.53 ± 2.52	78.2 ± 10.14	0.38 ± 0.18	8.88 ± 0.30	1.51 ± 0.63	0.39 ± 0.06	19.66 ± 4.43
		A. scoparia	0.34 ± 0.12	10.38 ± 0.99	2.06 ± 0.26	5.89 ± 1.05	78.62 ± 19.74	0.43 ± 0.23	10.77 ± 1.33	2.98 ± 1.25	1.54 ± 0.78	36.33 ± 15.07
Ali-Bayramli	Site 5	***A. fragrans***	0.17 ± 0.11	7.33 ± 0.91	3.51 ± 1.07	0.94 ± 0.18	20.2 ± 7.51	0.19 ± 0.06	10.06 ± 0.69	4.21 ± 1.81	0.69 ± 0.09	21.05 ± 5.58
		Salsola dendroides	0.12 ± 0.05	4.30 ± 0.56	2.41 ± 0.01	0.85 ± 0.42	11.67 ± 0.80	0.15 ± 0.04	7.85 ± 0.05	3.34 ± 0.27	0.81 ± 0.01	12.67 ± 1.72
		Climacoptera crassa	0.08 ± 0.01	4.50 ± 0.45	1.45 ± 0.67	0.51 ± 0.23	12.60 ± 2.41					
	Site 6	***A. fragrans***	0.06 ± 0.02	8.14 ± 0.4	2.53 ± 0.53	1.05 ± 0.35	25.29 ± 2.06	0.15 ± 0.06	12.14 ± 1.50	4.49 ± 0.20	1.27 ± 0.55	28.94 ± 6.44
	Site 7	***A. fragrans***	0.09 ± 0.03	10.92 ± 1.61	3.53 ± 0.55	1.08 ± 0.16	30.42 ± 3.38	0.23 ± 0.05	9.13 ± 1.11	3.19 ± 1.56	0.90 ± 0.23	19.47 ± 5.19

Concentrations of Zn ranged from 600 to 900 mg kg^{-1} in the shoots, with an average of 735 ± 130 mg kg^{-1} DW, and from 100 to 330 mg kg^{-1} in the roots, with an average of 200 ± 87.9 mg kg^{-1} DW (Table 3). The amounts of all five metals in the *Artemisia* plants decreased with the distance from the source of contamination (Table 3).

The degree of metal accumulation by plants is represented by their shoot/soil concentration ratio (bio-accumulation factor). Figure 1 shows the bio-accumulation factors for metals for different *Artemisia* species and collection sites. All three *Artemisia* species collected around the steel plant in Binegedi, in particular plants growing at distance of 10 m from the polluting source (Site 3) had the highest bio-accumulation factor for all HM except Ni. In *A. scoparia* sampled from Site 3, the highest bio-accumulation factors were detected for Zn (14.9), Cd (13.4), Cu (1.9), Pb (12.1) and Ni (0.4).

The comparative data on the HM accumulation capacity of *Artemisia* and attendant plant species *(Argusia sibirica, Salsola dendroides, Climacoptera crassa)* growing in the same sites at both locations indicates that all *Artemisia* species were superior to the attendant plants in accumulating HM in their shoots (Table 3).

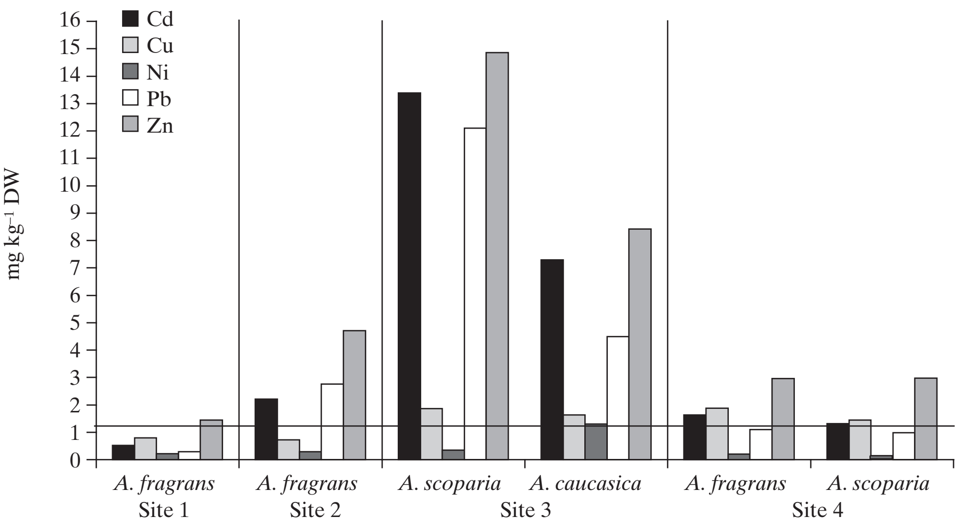

Fig. 1. bio-accumulation factors for heavy metals in shoots of *Artemisia* species in the Binegedi location, which vary with distance from the polluting source. Descriptions of tested sites (1–4) are given in Table 1.

3.3 Heavy metal concentrations in lichens

There were slight differences between the two lichens in their capacity to accumulate HM at all the sites tested (Fig. 2).

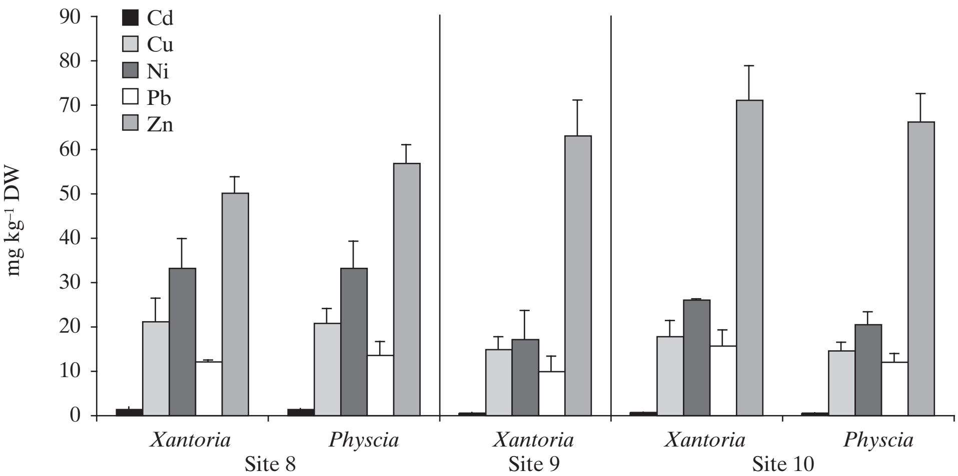

Fig. 2. Heavy metal concentrations in lichens in the Ali-Bayramli location depending on the distance from the polluting source. Description of tested sites (8, 9, 10) is given in Table 1.

4 Discussion

The soils collected from the polluted areas of Azerbaijan were not found to be strongly contaminated with HM (Table 2). The total amount of HM measured differs little from the generally accepted critical toxicity concentrations (CEC 1986; LOBNIK 2004). In spite of this, the *Artemisia* species collected around a steel plant (sites 2, 3) accumulated large amounts of HM in their shoots, particularly Cu, Pb and Zn (Table 3). Their values considerably exceeded the widely accepted critical toxic levels (MARSCHNER 1995; STEINBORN and BREEN 1999; LOBNIK 2004), but no sign of HM toxicity symptoms was found on the leaves or whole shoots. This indicates that the tested *Artemisia* species have high HM tolerance. Among the tested *Artemisia* species, *A. scoparia* showed the highest capacity to accumulate HM, especially Zn in its shoots (Table 3), with concentrations several times higher than that considered to be toxic for plants: namely 150 to 200 mg kg^{-1} according to SAUERBECK (1982 see LOBNIK 2004) or 300 mg kg^{-1} according to MARSCHNER (1995). Judging from data shown in Figure 1, the bio-accumulation factors for Zn, Cd, Pb, and Cu are much higher than 1, which suggests that these species have considerable potential of phytoextraction. The bio-accumulation factor (BF) is well known to be more important for phytoextraction than the shoot concentration *per se* (ZHAO *et al.* 2003), and in metal hyperaccumulator species the bio-accumulation factor is always greater than 1 (BAKER 1981). However, there is a clear tendency for the bio-accumulation factor to decrease with increasing levels of total HM in the soil, which is in agreement with earlier results (ZHAO *et al.* 2003).

The ability to accumulate and tolerate HM varied greatly between ecotypes and markedly depended on the local habitat (BASHMAKOV and LUKATKIN 2002). Results obtained in the present study showed that there are significant differences between the three *Artemisia* species in both the bio-accumulation factors for Zn, Cd, Cu, Ni and Pb and the concentrations of these HM in their shoots (Fig. 1, Table 3). All *Artemisia* species from Binegedi in the vicinity of the steel plant (sites 2, 3, 4) showed a high HM accumulation capacity, but they differed from each other regarding the degree of accumulation of the metals. In the Ali-Bayramli region (sites 5, 6, 7), where the total levels of HM in the soil were considerably higher than in Binegedi, the *A. fragrans* species showed distinctly low values in the bio-accumulation factor for all metals.

The Ali-Bayramli soils differed from the Binegedi soils in that the contents of the plant available DTPA-extractable fractions of all HM were low. In contrast with the Binegedi location, the ecotypes of *A. fragrans* widespread in the Ali-Bayramli region accumulated slightly larger amounts of all metals in their roots than in their shoots. In other words, in this ecotype a restricted translocation of HM from roots to shoots was observed. Probably, the biological characteristics of this species make it a tolerant/excluder plant, rather than an accumulator. Possibly, different soil factors are also involved in such differential accumulation of HM in the Binegedi and Ali-Bayramli locations (HESSE 1971; HARTER 1983; BLAKE and GOULDING 2002; AL-NAJAR *et al.* 2003). Soil pH is one of the most important factors that strongly influences metal solubility (HARTER 1983). Generally, most HM are less available to plants under alkaline conditions (HESSE 1971; MANTOVI *et al.* 2003; AIYEN 2004). The soils of site 3 had a pH of 8.3; but *A. scopario* in this site could accumulate Zn up to 736 mg kg^{-1} shoot dry weight (Table 3) despite such high soil pH (Table 2). This indicates a better ability of this species to acquire Zn from the soil.

The comparative data on the accumulation capacity of the dominant *Artemisia* species and attendant plants *(Argusia sibirica, Salsola dendroides, Climacoptera crassa)* growing in the same sites at both locations (Table 3) indicated that all *Artemisia* species had much higher HM concentrations in their organs, especially Zn. Among the attendant plants, only *Argusia sibirica* had high BF for Zn (6), Pb (3), Cd (2,7) and Cu (1,2) in the vicinity of the steel plant in Binegedi, but still lower than that of the *Artemisia* species from the same site. This result demonstrates again the distinctive HM accumulative ability of the *Artemisia* species.

Lichens have a higher capacity to accumulate and store HM for a long time because of their morphological and ecological peculiarities. Lichens are widely used as plant material to investigate or biomonitor airborne HM. The *Artemisia* species and lichens *(Xantoria parietna, Physcia adscendens)* growing on the different substrates at different distances from a Hydroelectric Power Station were compared for their HM accumulation capacity. The results indicate that both lichen species accumulated higher amounts of 5 HM in their thalluses than *A. fragrans* situated in the vicinity, which was assumed to be a tolerant/excluder plant (Fig. 2, Table 3). The HM concentrations found in *Xantoria* and *Physcia* considerably exceed the values reported for other species of lichens (LAVRINENKO and LAVRINENKO 1999). Data from the literature indicates there is a close correlation between the levels of HM in the lichens and atmospheric deposition (KYSELOVA and MANKOVSKA 1985; KOBAYASHI *et al.* 1986). It seems likely then that the high HM contents in our tested lichen species provide evidence of a high level of air contamination in the Ali-Bayramli location.

In the soil samples collected around the lichens (sites 8, 9, 10), the concentrations of both the total amount and the extractable fraction of HM were higher than in the soils collected around the *Artemisia* species (sites 1–7) (Table 2). However, *Artemisia* species at sites 2, 3 contained more HM (Table 3) than the lichens (Fig. 2), indicating that *Artemisia* species have a better capacity to absorb and accumulate HM in their shoots.

The results obtained in the present study show that the *Artemisia* species markedly differ in their HM accumulation capacity, depending on the locations. The ecotype of *A. fragrans* from Binegedi was distinguished by its high accumulative ability, which was higher than that of other ecotypes of this species from Ali-Bayramli indicating that is a rather tolerant/excluder plant. At the same time all the *Artemisia* species tested (*A. fragrans, A. scoparia* and *A. caucasica*) growing at different distances from a polluting source in the Binegedi location were found to be accumulator plants. But among them *A. scoparia* showed the highest capacity to accumulate all HM in their shoots, as the high values of the bio-accumulation factors for all HM tested, except Ni also revealed. The results of this study demonstrate that all *Artemisia* species are better accumulators of HM in their organs than all the investigated attendant plants from the same contaminated sites. The two lichen species differed slightly in how much they accumulated metals (from air pollution), but they accumulated more in their biomass than did the *Artemisia* from the same location. *Artemisia* species (especially *A. scoparia*) growing in contaminated soils therefore could, given their larger biomass, be promising for use in heavy metal-phytoremediation, whereas lichens have more potential for monitoring HM deposition.

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