23 Temperate Weeds in Russia: Sentinels for Monitoring Trace Element Pollution and Possible Application in Phytoremediation

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CONTENTS

23.1 INTRODUCTION

Plant and soil form an integrated system and technogenic contamination of soils is reflected in parts of plants. Soil contamination by heavy metals has several implications, not only for human health but also for many organisms. Economic activities introduce essential changes to the environmental system. These changes are noticed in large cities and urban landscapes by way of pollution. Heavy metals (HMs) represent one of the major environmental pollutants and contaminants of the soil. Evaluation of metal accumulation in soils and plants is of environmental importance due to their health effects on humans and other biota [1]. Green plants are the most relevant components in the decontamination of negative effects of industrial activity. Their resistance and capacity to accumulate different pollutants determine usage of some species in phytomelioration of soils. Phytoremediation is one such important strategy to decontaminate metal-polluted soils that is based primarily on the performance of species selected [2]. In this regard, tolerable herbaceous fast growing plants capable of accumulating HM in shoots are preferred for phytoremediation.

Self-cleaning of soils does not take place or, rather, does so extremely slowly. The toxic metals in topsoil thus are accumulated in plants. Weeds are more adapted to unfavorable soil conditions, such as low moisture and presence of toxic metals, and easily become acclimatized to local situations. One such important exercise is phytoremediation to protect the environment from metal contamination [3–5]. To be successful in phytoremediation, fast growth, easy reproduction, intensive accumulation of heavy metals from soil, and concentration in plant parts are necessary. In this chapter, some weeds of the mean band of Russia (temperate zone) are studied for their capacity to accumulate heavy metals and their possible application in phytoremediation [6–11].

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23.2 MATERIALS AND METHODS

Saransk (54° northern latitude; 45° eastern longitude) is the city (254.3 km^2) that is the site of this investigation. It is located at the junction of steppes and forests in a central part of Russian flats (on high ground Privolzhskaja). Mean annual air temperature is +3.5 + 4.1°C; in July it is +19.2 +20°C, with a maximum of +39°C. Duration of a vegetation season is 175 to 180 days. The warm season accounts for 70% of the annual precipitation norms. Chernozioms, gray wood, and alluvial soils are present in the terrain of the city. About 30 heavy engineering, electrical engineering, chemical, and food-processing industries are located in Saransk. The water salinity on sewage disposal sites is 900 to 1000 mg/L with pH 6.2 to 8.0. The sewage contains high doses of organics, salts, and Cu, Zn, Pb, Hg, Ni, Cr, Mn, V, W, etc.

Roots, stems, and leaves were harvested in 100-m^2 plots of six experimental plants: dandelion (*Taraxacum officinale* Wigg.); sagebrush (*Artemisia vulgaris* L. and *Artemisia absinthium* L.); *Amaranthus retroflexus* L.; melilot (*Melilotus officinalis* L. Pall); *Calamagrostis epigeios* (L.) Roth.; and orach (*Chenopodium album* L. *s. l.*). The samples were harvested in the beginning (May 10, 1997), middle (July 3, 1997), and end (September 25, 1997) of growing seasons in regions of industrial and domestic wastes. Plant samples of 0.5 kg fresh weight were made from eight to ten individuals. The collected plants were washed with distilled water, dried, and stored in paper packets. Control samples were harvested from the Smolnij National Park (60 km from Saransk). Heavy metals were determined with the help of spectrophotometric analysis. The method involves the deposition of metal ions from aqueous solution on the residue of zirconium hydroxide at pH 6 to 7, with subsequent filtration and analysis of the residue on an x-ray spectrometer, Spectroskan. Soil samples from the experimental sites were also analyzed for pH and humus contents (Figure 23.1 and Figure 23.2).

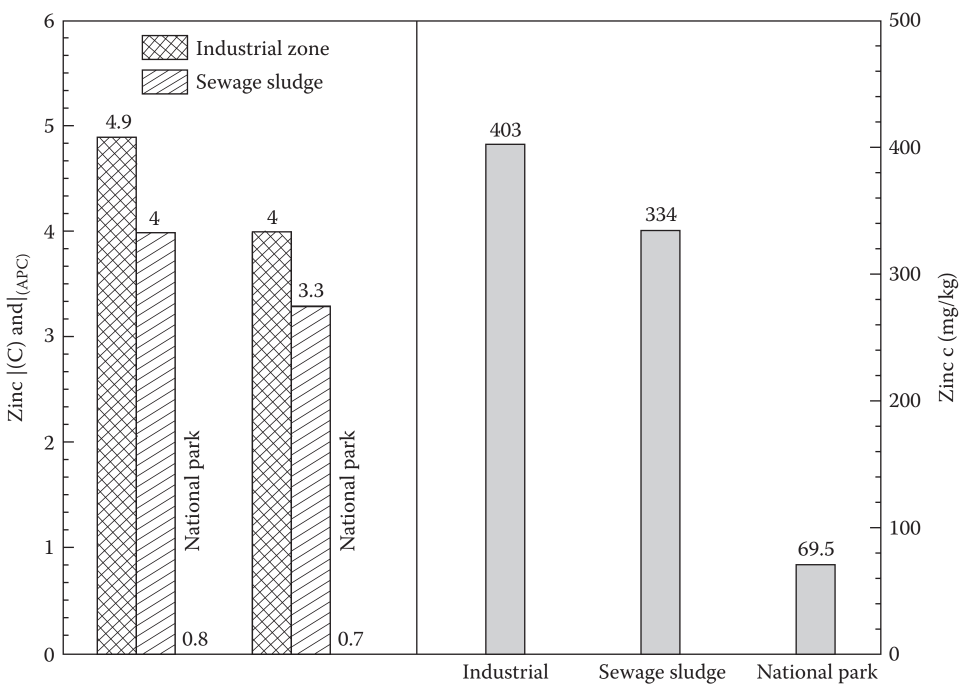

FIGURE 23.1 Zinc content in technogenically contaminated (industrial zone and sewage sludge) and clean soils (national park). Indices *Ic = heavy metal (HM) contents in the investigated sample/HM mean contents in earth crust;** I_{APC} = the HM contents in investigated sample/value of HM approximately permissible concentration (APC).

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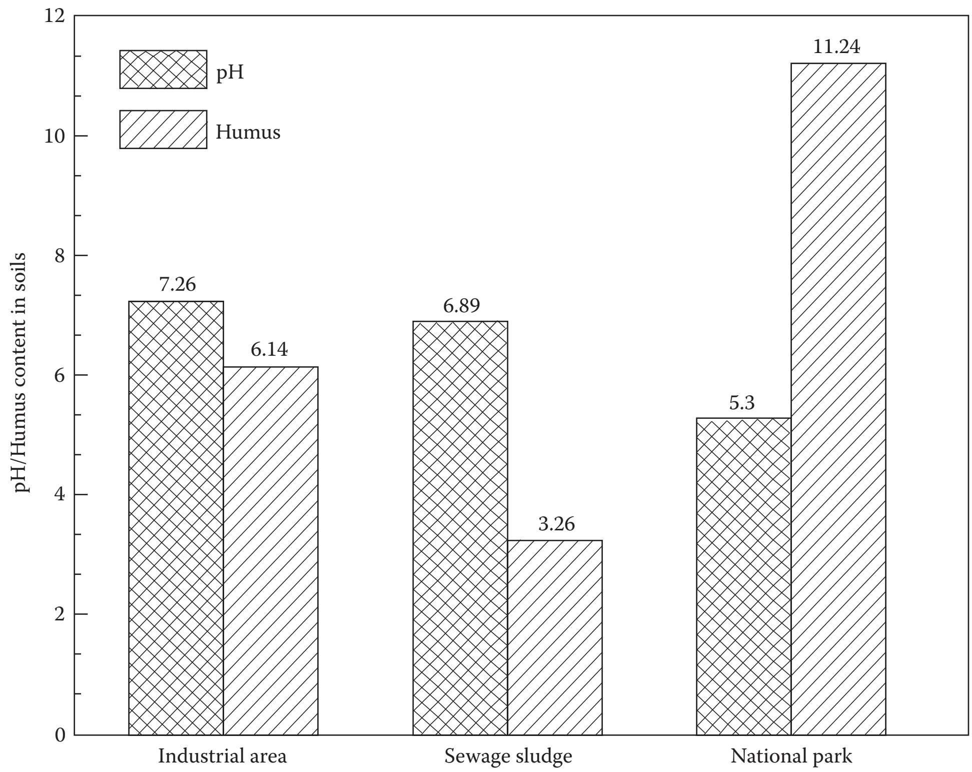

FIGURE 23.2 pH and humus content (% dry matter) in soils of industrial area, sewage sludge, and national park.

The heavy metal content (x) in plant samples (milligrams per kilogram of air-dry weight) was calculated by the formula:

$$x = \frac{(c - c_1) \cdot 100 \cdot 1000}{m \cdot 50}$$

where c is concentration of metal in analyzed sample (mg); c_1 is concentration of metal in a blank sample (mg); and m is the air-dry weight of plant sample taken for the analyzed (g).

23.3 RESULTS AND DISCUSSION

The data obtained indicate that, in the soil samples collected from industrial zone, the total contents of many heavy metals exceed the mean contents of the Earth's crust. There were very big anomalies of Ni (Kc = 10.6), Pb (9.7), and Zn (4.86); anomalies of Cu, Co, and Fe were barely seen. Neutral soil (pH 7.26) and low humus contents (6.14%) promote transition of many heavy metals in soil solution.

Large amounts of heavy metals (Table 23.1) are present in sewage precipitations (SPs) of refining facilities. For many HMs, the values are higher than prescribed limits. The greatest quantities were marked Pb (Kc = 6.4), Ni (5.2), and Zn (4.02); the least was Mn (0.7). SP had neutral pH of 6.89 and contained not enough humus (3.26). It is therefore possible to predict that SPs are characterized by noticeable forms of HMs. The soil samples from Smolnij National Park did not contain HM as compared to the mean contents in the Earth's crust and are characterized

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TABLE 23.1
HM Content in Technogenic Contaminated and Clean Soils of a Temperate Area of a Mean Band of Russia

HM	Mean content[a]			I^b			$I_{APC}{}^c$		
	Industrial zone	Refining facilities	National park	Industrial zone	Refining facilities	National park	Industrial zone	Refining facilities	National park
Pb	156.45	102.0	14.0	9.7	6.4	0.8	5.2	3.4	0.5
Zn	403.25	334.0	69.5	4.9	4.0	0.8	4.0	3.3	0.7
Cu	163.3	75.5	17.0	3.4	1.6	0.4	2.9	1.4	0.3
Ni	616.3	305.0	11.2	10.6	5.2	0.2	7.3	3.6	0.1
Co	41.95	31.0	9.0	2.3	1.7	0.5	1.7	1.2	0.4
Fe	55729	48620	20654	1.3	1.2	0.5	1.5	1.3	0.5
Mn	711.35	690.4	503.0	0.7	0.7	0.5	0.5	0.5	0.3
Cr	29.7	122.0	71.6	0.3	1.5	0.8	0.3	1.2	0.7

[a] Milligrams per kilogram.

[b] Ic = the HM contents in investigated sample/HM mean contents in Earth's crust.

[c] I_{APC} = the HM contents in investigated sample/value of HM approximately permissible concentration (APC).

by high humus contents (11.24%) with a pH of 5.3. As a whole, the analysis of the obtained data establishes that the soils of an industrial zone and refining facilities' technogenic oozes fall into the barely contaminated terrains (Table 23.1). Some substances were characterized by the superior soil APC levels designed. It is possible to consider the national park terrain clean.

Plants growing in contaminated terrains have accumulated significant amounts of HM in their organs. On the maiden place, the absolute contents were Fe. Its concentration in roots was from 3.5 up to 33.1 g/kg, and in shoot from 1.5 up to 8.1 g/kg. Plants accumulated Zn, Cu, Mn, Cr, Pb, and Ni (Table 23.2).

The HM absorption from soil by different plant species descended selectively. *Calamagrostis epigeios* was the Pb, Zn, and Cu concentrator. The medicinal dandelion accumulated Zn, Cu, Pb, and Cr. Mugwort stored predominantly Zn, Ni, and Cu and, to a lesser degree, Ni and Mn. *A. absinthium* was a hyperaccumulator of Zn, Cu, and Cr. Orach concentrated Zn, Cu, Zn. The high contents of Zn, Ni, and Cu were marked for a medicinal melilot. Different plants' organs had different levels of HMs (Table 23.2). Note that Zn, Cu, Fe, Pb, and Mn are stored in the roots and leaves and Ni and Cr in the roots and stems.

The high Pb content in the roots and leaves is apparently connected to formation of Pb phosphate complexes in the cell wall. A definite quantity of Pb from the atmosphere goes into plants through leaves. Zn accumulation is connected to its relevant physiological role. Zinc was stored in the roots of dandelion, *Calamagrostis epigeios*, and *Amaranthus retroflexus*. Maximum Cu content was observed in the roots and minimum in leaves. However, for absinthium, orach, and mugwort, the highest Cu content was established in leaves. The Fe and Mn accumulation in the roots and leaves was probably connected with antagonism between Fe and Zn, Mn, and Ni.

The index of biological absorption (I_a = HM concentration in air-dry sample/HM contents in soil) has shown that, on the contaminated soils, a process of Zn, Cu, and Cr accumulation was most intense, and less so for Mn, Fe, and Ni accumulation (Table 23.3). The present research also established that HM availability in soil decreases the intensity of absorption for some plants, but increases it for others. For example, the absinthium shoots in the national park accumulated much less Cr (I_a = 0.55) than those in the industrial zone did (I_a = 16.98).

The Zn accumulation in weeds growing in industrial areas and soils contaminated with sewage sludge is shown in Figures 23.3 and 23.4. For accumulation of other metals, refer to Table 23.1.

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TABLE 23.2
HM Content in Shoots and Roots of Some Higher Plants of a Temperate Area of a Mean Band of Russia

Sample location	Plant species	Plant part	Mean HM content[a]						
			Pb	Zn	Cu	Ni	Fe	Mn	Cr
Industrial	*Amaranthus retroflexus*	Leaves	tr.	tr.	176.6	336.4	11,026	60.8	tr.
		Stems	tr.	tr.	tr.	85.9	tr.	tr.	tr.
		Roots	tr.	tr.	11.5	41.4	13,337	6.6	tr.
	Artemisia (absinthium)	Leaves	20.3	12.3	225.4	tr.	11,177	tr.	18.8
		Stems	5.7	92.2	192.0	tr.	6,494	5.7	749.3
		Roots	50.3	tr.	65.6	tr.	14,094	tr.	46.0
	A. retroflexus (mugwort)	Leaves	17.1	115.4	92.2	tr.	8,609	8.2	15.5
		Stems	5.7	tr.	186.7	tr.	3,323	tr.	216.2
		Roots	4.4	416.5	51.6	8.8	4,064	82.9	49.5
	Taraxucum officinale	Leaves	tr.	755.9	100.5	0.9	4,168	9.1	tr.
	(dandelion)	Roots	59.1	864.9	309.1	1.1	3,964	16.1	68.8
	Melilotus officinalis	Leaves	tr.	252.0	79.8	tr.	4,225	103.3	tr.
		Stems	26.1	363.2	231.5	44.9	2,299	36.7	24.9
		Roots	tr.	131.6	296.4	26.4	12,159	70.3	12.5
	Calamagrostis epigeios	Leaves	245.2	362.7	17.5	2.3	2,273	143.6	tr.
		Stems	5.4	152.2	265.7	10.4	690	70.4	15.3
		Roots	tr.	746.7	783.7	36.2	22,107	332.6	14.8
	Chenopodium album	Leaves	30.1	1311.0	336.9	tr.	4,463	285.2	6.6
		Stems	12.8	441.2	287.1	tr.	2,048	2.4	8.4
		Roots	94.7	71.5	97.8	tr.	7,241	37.6	16.7
Refining facilities	*A. retroflexus* (mugwort)	Shoots	8.6	1518.7	148.0	73.5	2,071	242.1	tr.
		Roots	157.2	532. 8	405.1	8.8	3,535	63.4	tr.
	Artemisia (absinthium)	Shoots	36.2	843.0	tr.	62.3	2,770	136.7	27.8
		Roots	239.3	1315.7	124.7	34.7	6,663	93.8	tr.
	T. officinale (dandelion)	Shoots	tr.	399.9	23.3	28.6	2,232	56.2	tr.
		Roots	121.9	596.2	108.4	9.5	4,661	5.6	44.1
	M. officinalis (melilot)	Shoots	tr.	1291.7	tr.	230.2	2,492	134.9	40.7
		Roots	90.8	452.2	tr.	73.4	10,942	52.0	8.9
	Calamagrostis epigeios	Shoots	120.8	652.4	28.4	70.2	1,721	149.2	58.1
		Roots	6.2	287.2	tr.	23.6	19,517	15.7	47.1
	Ch. album (orach)	Shoots	tr.	tr.	tr.	tr.	4,143	tr.	63.7
		Roots	102.3	tr.	tr.	tr.	7,796	tr.	4.5
Smolnij National Park	*Ch. album* (orach)	Shoots	tr.	350.7	478.5	0.5	3,076	91.0	66.7
	Artemisia (absinthium)	Shoots	tr.	164.8	41.9	5.7	1,306	141.7	39.9

[a] Milligrams per kilogram of dry sample weight.

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TABLE 23.3
The Heavy Metal Biological Absorption Indices[a] (I_a) of Some Higher Plants of a Temperate Area of a Mean Band of Russia

Location of samples	Plant species	Plant part	HM accumulation index						
			Pb	Zn	Cu	Ni	Fe	Mn	Cr
Industrial zone .	*T. officinale*	Shoots	tr.	1.87	0.62	0.0015	0.08	0.01	tr.
		Roots	0.38	2.14	1.89	0.0018	0.07	0.02	2.32
	Amaranthus retroflexus	Shoots	0.15	tr.	0.30	0.27	0.07	0.03	tr.
		Roots	tr.	tr.	0.07	0.07	0.24	0.01	tr.
	A. absinthium	Shoots	0.06	0.16	1.25	tr.	0.14	0.05	16.9 8
		Roots	0.32	tr.	0.4	tr.	0.25	tr.	0.15
	Ch. album	Shoots	0.13	1.90	1.88	tr.	0.05	0.16	0.26
		Roots	0.60	0.18	0.59	tr.	0.13	0.05	0.56
	Calamagrostis epigeios	Shoots	0.82	0.65	0.84	0.01	0.02	0.15	0.26
		Roots	tr.	1.85	2.96	0.06	0.39	0.47	0.49
	M. officinalis	Shoots	0.12	0.82	1.16	0.05	0.05	0.08	0.60
		Roots	tr.	0.33	1.81	0.04	0.22	0.09	0.52
Refining facilities	*T. officinale*	Shoots	tr.	1.20	0.31	0.09	0.05	0.08	tr.
		Roots	1.20	1.70	1.44	0.03	0.10	0.01	0.36
	A. retroflexus	Shoots	0.08	4.55	1.96	0.24	0.04	0.35	tr.
		Roots	1.54	1.60	5.37	0.03	0.07	0.09	tr.
	A. absinthium	Shoots	0.36	2.52	tr.	0.20	0.06	0.20	0.23
		Roots	2.35	3.94	1.65	0.31	0.14	0.14	tr.
	Ch. album	Shoots	tr.	tr.	tr.	tr.	0.09	tr.	0.52
		Roots	1.00	tr.	tr.	tr.	0.16	tr.	0.04
	Calamagrostis epigeios	Shoots	1.18	1.95	0.38	0.23	0.04	0.22	0.48
		Roots	0.06	0.86	tr.	0.08	0.40	0.02	0.39
	M. officinalis	Shoots	tr.	3.87	tr.	0.75	0.05	0.20	0.33
		Roots	0.89	1.35	tr.	0.24	0.23	0.08	0.07
National park	*A. retroflexus*	Shoots	tr.	5.05	28.14	0.04	0.15	0.18	0.93
	A. absinthium	Shoots	tr.	2.37	2.46	0.51	0.06	0.28	0.56

[a] Index of biological absorption (I_a) = HM contents in a plant organ/HM concentration in soil.

According to the data obtained, Mn and Fe fall into the category of substances of gentle and mean absorption in contaminated conditions; however, in the national park, Zn accumulation was substantial. For example, the Mn absorption by absinthium shoots was more intensive in the national park (I_a = 0.28) than on refining facilities (I_a = 0.20). In the industrial zone, I_a was only 0.05.

Pb falls to a gentle biological absorption substance (Table 23.2). However, 0n refining facilities, Pb I_a for shoots of *Calamagrostis epigeios* was 1.18. It is established that HM-accumulating capacity of plants depends on the vegetation season. For example, the Cu concentration in an absinthium's above-ground part was maximum in the beginning of the growing season and minimum in July. Pb seasonal dynamics in shoots of *Calamagrostis epigeios* has the following nature: the concentration of this metal increases in the middle of the growing season with a minimum in the spring and autumn (Table 23.4).

High seed production and fast biomass growth was observed in all the plants examined. However, the HM accumulation in an above-ground part was marked only for few species. It was

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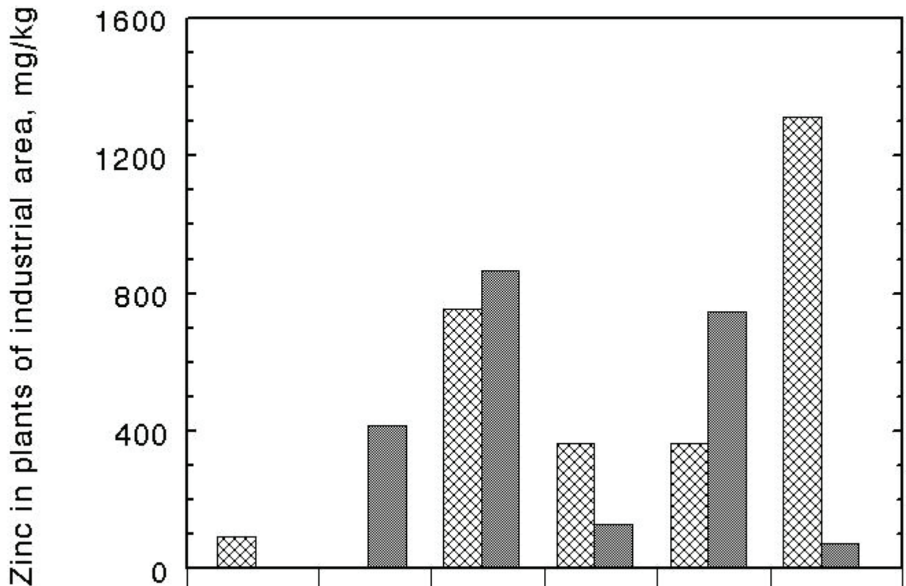

	A.a	A.v	T.o	M.o	C.e	C.a
Shoot	92.7	0	756	363.2	363	1311
Root	0	416.5	865	131	747	72

FIGURE 23.3 Zinc in shoots and roots of some weeds growing in industrial area. *A. a = Artemisia absinthium*, (absinthium); *A. v. = Artemisia vulgaris* (sagebrush); *T. o =Taraxacum officinale* (dandelion); *M. o = Melilotus officinalis* (melilot); *C. e = Calamagrostis epigeios*; *C. a = Chenopodium album* (orach).

marked for Zn absorption by mugwort (I_a = 4.55, for the definition off I_a see Table 23.3 on p. 444), *Calamagrostis epigeios* (I_a = 1.95), and medicinal melilot (I_a = 3.87) from refining facilities, and for orach (I_a = 1.9) from the industrial zone; and for Cu absorption by absinthium (I_a = 16.98) from the industrial zone; for Pb absorption by terraneous (I_a = 1.18) from refining facilities (Table 23.3).

23.4 *TARAXACUM OFFICINALE* WIGG. (DANDELION): IDEAL SENTINEL FOR MAPPING METAL POLLUTION

Taraxacum officinale (dandelion) growing on metal-polluted soils has accumulated significant levels of toxic metals. Soil material and plant tissue were collected along transects in two heavily contaminated facilities; a Superfund site revealed that Cd uptake was maximal in *Taraxacum officinale* at 15.4 mg/kg [12–22]. *T. officinale* is the best example for HM accumulation in shoots on alluvial soils and chernozioms at < 7. Zn was absorbed intensively at the beginning of vegetation; Fe in the middle of summer; and Ni, Mn, and Cr in autumn (Figure 23.5 and Figure 23.6). The best time for the harvest of green mass is the end of spring.

At implementation of phytoremediation in the city, the anthropogenic landscape esthetic view is very relevant. The natural tangle of sagebrush is not in harmony with downtown, but this is not true for a dandelion. Furthermore, use of dandelion in phytoremediation has a number of advantages:

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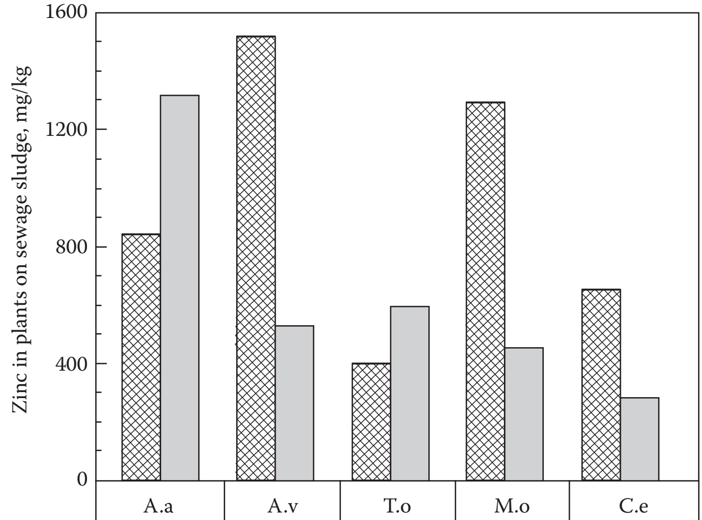

	A.a	A.v	T.o	M.o	C.e
Shoot	843	1519	400	1292	652
Root	1315	533	597	452	287

FIGURE 23.4 Zinc in shoots and roots of some weeds growing on sewage sludge. *A. a = Artemisia absinthium*, (absinthium); *A. v. = Artemisia vulgaris* (sagebrush); *T. o =Taraxacum officinale* (dandelion)*; M. o = Melilotus officinalis* (melilot); *C. e = Calamagrostis epigeios*.

- The average number of seeds produced is $1.4 \cdot 10^6$ per kilogram; they can be stored at 0° for 12 years with viability still maintained.
- Dandelion seeds do not have a dormant period and can be used for cultivation immediately after harvesting.
- Germinating capacity of seeds is 72 to 100%.
- After defoliation, the plant regrows fast.
- The greatest increment of above-ground biomass in the maiden year sowings is August; in the second year, it is from May to June.
- Dandelion is capable of surviving prolonged droughts.

Limitations also exist:

- The plant does not grow well on slopes and inclines.
- Survival of this plant depends on local ecological factors.

Taking the preceding advantages into account, HM accumulation of dandelions from 1 km^2 of soil was investigated; results are shown in Table 23.5. Thus, *T. officinale* was found to be an ideal sentinel for mapping metal pollution and may be recommended for phytoremediation of metal-contaminated soils [6,7,12–22].

23.5 CONCLUSIONS

On the basis of the data obtained, the following propositions are made: for Cr-contaminated soils, detoxification is possible by cultivating *A. absinthium* and by making use of the biomass in the middle of a growing season. Cu and Zn in soils can be decontaminated by *Chenopodium album* and *A. absinthium*. For better biomass, it is necessary to apply the green manure to sagebrush before the flowering starts. Common garden snail (*Helix aspersa*) feeding on *Taraxacum officinale*

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TABLE 23.4
Vegetation Season Influence on HM Accumulation by Plants Collected on Contaminated Terrain (Industrial Zone) of a Temperate Area of a Mean Band of Russia

Plant species	Plant part	Mean HM content[a]						
		Pb	Zn	Cu	Ni	Fe	Mn	Cr
Amaranthus retroflexus	Shoots	tr.	33.7	tr.	tr.	2,078.05	tr.	tr.
	Roots	tr.	271.9	tr.	2.5	6,641	8.9	tr.
	Shoots	tr.	399.2	tr.	57.3	5,058	129.7	19.1
	Roots	tr.	819.1	0.1	96.5	7,932	71.5	2.5
	Shoots	23.2	tr.	48.6	169.3	3,671	20.3	tr.
	Roots	tr.	tr.	11.5	41.4	13,337	6.6	tr.
Taraxacum officinale	Shoots	tr.	289.0	tr.	tr.	4,535	tr.	tr.
	Roots	tr.	369.4	95.5	37.7	1,885	20.3	tr.
	Shoots	2.5	tr.	41.8	11.1	7,132	tr.	50.3
	Roots	tr.	tr.	tr.	tr.	5,969	tr.	tr.
	Shoots	tr.	755.9	100.5	0.9	4,168	8.1	tr.
	Roots	59.1	864.9	309.1	1.1	3,964	16.00	68.8
Calamagrostis epigeios	Shoots	0.5	tr.	tr.	tr.	0.061	tr.	1.1
	Roots	tr.	tr.	tr.	0.01	0.46	tr.	2.8
	Shoots	0.6	tr.	tr.	tr.	0.051	0.01	1.3
	Roots	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Shoots	129.9	260.6	137.9	6.2	1,505	105.9	7.4
	Roots	tr.	746.7	483.7	36.2	22,107	332.6	14.8
Artemisia absinthium	Shoots	10.6	65.4	204.5	tr.	8,063	3.8	504.6
	Roots	50.3	tr.	65.6	tr.	14,094	tr.	46.0
	Shoots	0.4	2.6	1.3	tr.	0.12	0.04	tr.
	Roots	0.1	0.2	0.1	0.04	0.36	tr.	6.5

[a] Milligrams per kilogram of dry sample weight.

growing on metal-polluted soils has accumulated significant levels of toxic metals in its gastric system [12–22].

Metal-accumulating plants are of phytoremediation importance. Phytoremediation is one of the strategies to decontaminate toxic levels of metals in the environment and is an upcoming and novel technology. It was observed that some of these temperate weeds are natural hyperaccumulators of toxic metals. Metal accumulation has been investigated in plant roots and shoots of selected weeds: *Calamagrostis epigeios, Taraxacum officinale* (dandelion), *Artemisia absinthium* (absinthium), *Artemisia vulgaris (*sagebrush), *Amaranthus retroflexus* (mugwort), *Chenopodium album* (orach), and *Melilotus officinalis* (melilot). Heavy metal content in plant parts and soil samples was quantified following x-ray spectrometry. Soil samples were also analyzed for humus content and pH.

It was noted that *Calamagrostis epigeios* was a Pb, Zn, and Cu concentrator. *Taraxacum officinale* accumulated Zn, Cu, Pb, and Cr. *Artemisia absinthium* was a hyperaccumulator of Zn, Cu, and Cr, whereas *Artemisia vulgaris* accumulated predominantly Zn, Ni, and Cu. *Chenopodium album* concentrated Zn, Cu, and Zn; appreciable quantities of Zn, Ni, and Cu were observed in *Melilotus officinalis*. The metal accumulation pattern indicates that Zn, Cu, Fe, Pb, and Mn were stored more often in roots and leaves, and Ni and Cr were stored in roots and stems. It was also observed that the metal accumulation capacity of plants depended on the vegetation season. The data from this investigation may thus be useful for phytoremediation of metal-polluted soils in temperate regions [6,7,12–22].

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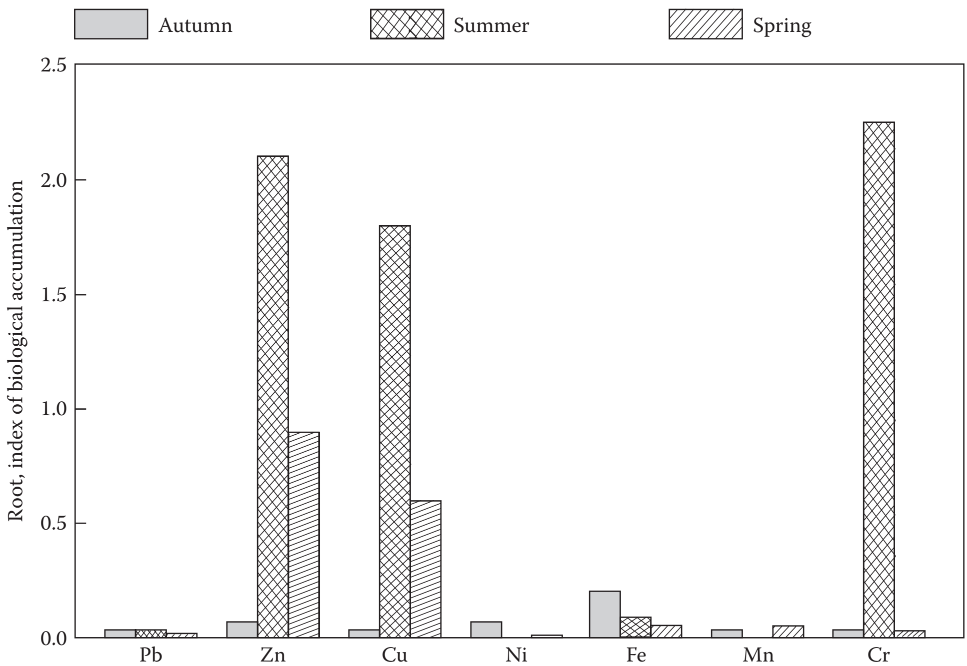

FIGURE 23.5 Seasonal accumulation of heavy metals in shoots of *T. officinale*; index of biological accumulation = contents of a metal in a plant organ (mg/g dry weight)/metal content in the soil (milligrams per kilogram).

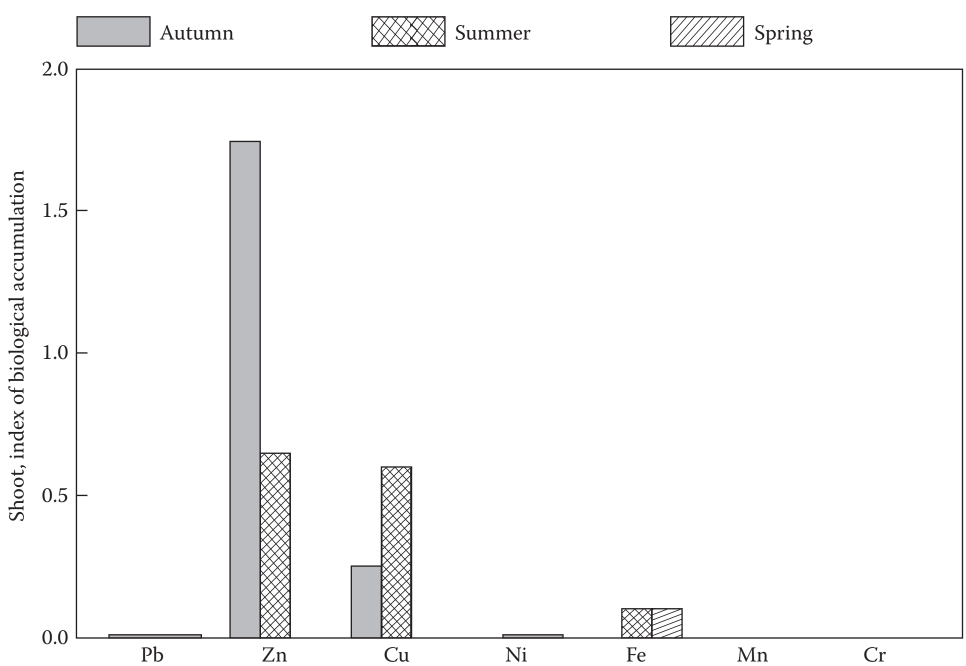

FIGURE 23.6 Seasonal accumulation of heavy metals in roots of *T. officinale*.

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TABLE 23.5
Heavy Metal Accumulation by *T. officinale*

	HM accumulation (kg km^{-2})	
Heavy metal	**Minimum (from rather clean regions)**	**Maximum (from the contaminated soils)**
Pb	87.53–125.04	108.21–154.59
Zn	123.86–340.37	211.34–3016.20
Cu	35.31–50.44	152.02–217.17
Ni	1.39–1.99	171.99–245.70
Fe	3375.83–4822.61	9974.35–14249.07
Mn	13.79–19.70	525.89–751.27
Cr	30.48–43.55	38.83–55.48

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