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MAJOR AND TRACE ELEMENT CONTENT OF *Heracleum sosnowskyi* MANDEN., AN INVASIVE SPECIES IN THE LENINGRAD REGION, RUSSIA

Abstract: Introduced to Europe in the early 20th century as an ornamental plant and to European Russia in the mid-20th century as a promising forage plant, *Heracleum sosnowskyi* Manden. (Sosnowsky's hogweed, or giant hogweed; family Apiaceae or Umbelliferae), a common invasive species in the Leningrad Region (Vyborg District; 60.392455, 29.794482). In the 1950s, the Leningrad Region became the site of some of the first hogweed forage crops in the Soviet Union. Today, hogweed has spread across vast areas of this region, posing a threat to both human populations and agricultural lands. For the first time, a study was conducted using neutron activation analysis (NAA). This analytical method allowed the determination of 32 elements, including major and trace elements (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Se, Br, Rb, Sr, Mo, Sb, Cs, Ba, La, Ce, Sm, Tb, Hf, Ta, Th, and U). It was shown that many toxic elements not only do not accumulate but are present in lower concentrations than in the soil in which the plants grow.

Keywords: instrumental neutron activation analysis, roots, leaves, fruits of Sosnowsky's hogweed, essential elements, rare earth elements, trace elements, Leningrad region

Introduction

Heracleum sosnowskyi Manden. - Sosnowsky's hogweed is a large monocarpic (usually biennial) herbaceous plant of the Apiaceae family, growing from (2-3) m to (4-5) m tall with a thick, erect stem of purple-green or purple colour and large, bright green leaves. The taproot extends up to (1-1.5) meters deep, with lateral roots (30-40) cm long. The inflorescence is a compound umbel, blooming from late May to mid-June, with the seeds ripening in August. Wind, water, birds, and transport disperse tens of thousands of seeds from each plant. The sap of *H. sosnowskyi* contains photodynamically active coumarins, which cause severe and long-lasting sunburns on the skin when exposed to the sun; in recent years, it has become a dangerous invasive species.

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Macronutrients are particularly important for plant growth and development at all stages of the life cycle. These include elements found in significant quantities in crops, such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), magnesium (Mg), and calcium (Ca). A deficiency in these elements results in poor plant growth, which impacts crop yields. Signs of deficiency of these reusable macronutrients appear primarily on older leaves. Micronutrients are chemical elements that plants require in very small quantities for normal growth and development. These include iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl), and nickel (Ni). They play a key role in biochemical processes, participating in enzyme function, photosynthesis, respiration, metabolism, and hormone synthesis. Their role in plant life cannot be underestimated. Although a deficiency of micronutrients does not lead to plant death, it does affect the rate of various processes. This affects the quality of buds, fruits, and overall yields. Micronutrients and macronutrients interact with each other, altering their bioavailability for plants. Excess phosphorus leads to zinc deficiency and the formation of copper and iron phosphates, making these metals unavailable to plants. Excess sulphur reduces molybdenum absorption. Excess manganese leads to chlorosis caused by iron deficiency. High copper concentrations lead to iron deficiency. A deficiency of boron impairs calcium absorption [1-8].

Heracleum sosnowskyi Manden. and *H. mantegazzianum* Sommier & Levier (Apiaceae) are two giant hogweeds that have become invasive plant species in many countries, for which various control methods are being explored [9-14]. *H. sosnowskyi* was first cultivated in the USSR in 1947 as a potential fodder plant. Due to the development of cold-resistant cultivars and the characteristics of *H. sosnowskyi*, it quickly became feral. As a result, *H. sosnowskyi* began to spread as an aggressive invasive species in the 1970s and 1980s. By the 1990s, it had become an ecological disaster. The Leningrad region was chosen for analysis due to the fact that the first industrial plantations of this species of hogweed were established here in the late 1950s, and by now it has spread over significant areas and poses a threat to the population [15-19].

The uncontrolled spreading of monodominant colonies of Sosnowsky's hogweed *H. sosnowskyi* in Russia has prompted researchers to seek methods of using its biomass in various sectors of the economy to prevent further spread. The proposed methods of using plant biomass and technologies for obtaining useful substances from *H. sosnowskyi* have been developed regardless of inevitable changes in population characteristics: in populations on abandoned lands that are currently unaffected by anthropogenic disturbance, under regular utilisation, the regeneration will decrease, resulting in reduced yields and profitability of production. It is possible to maintain a high yield of hogweed necessary for its utilisation only under strictly controlled cultivation, which prevents its "escape"; however, this is not possible now, as this species has been removed from the State Register of Breeding Achievements Approved for Use. At the same time, there is a sufficient range of alternative sources of raw materials that contain useful substances, which are suggested to be obtained from *H. sosnowskyi*. Harvesting of *H. sosnowskyi* for raw materials from roadside treelines and small rivers' riparian areas is so problematic that it is not considered in publications, although these particular ecotopes are the constant foci of ongoing invasion. Due to the uncontrolled spread of *H. sosnowskyi*, the biodiversity of agricultural lands, including wild-growing food, technical, and medicinal plants (including wild relatives of cultivated plants), is under threat [20-32].

The presence of carboxylic acids in Sosnowsky's hogweed allows it to be used in the creation of plant growth stimulants; aldehydes and alcohols - selective herbicides; coumarins and furocoumarins - plant protection products with fungicidal, antimicrobial, and insecticidal activity; and anthelmintic agents. Of greatest interest in the field of medicine and the pharmaceutical industry are the phenolic compounds of the coumarin order of the furanocoumarin series, isolated from Sosnowsky's hogweed and possessing antitumor effects, with potential in PUVA therapy and the treatment of vitiligo and psoriasis. The photosensitising effect of furanocoumarins in Sosnowsky's hogweed also arouses interest in the development of disinfectants for objects and premises. In the food industry, the presence of low-methoxyl pectin substances in Sosnowsky's hogweed opens up the possibility of producing thickeners and sucrose - white sugar - on its basis. The high cellulose content of *H. sosnowskyi* biomass makes it a valuable raw material for the pulp and paper industry. The chemical composition of *H. sosnowskyi* opens up possibilities for the production of polymers, composites, and flotation reagents. Due to its high biomass, *H. sosnowskyi* is proposed for energy production, including biofuel. Thermal insulation and composite building mixtures and materials modified with *Heracleum sosnowskyi* can find a wide range of applications in construction [33-42].

The aim of this study is to determine the accumulation of elements - including heavy and toxic metals - in various parts of *H. sosnowskyi* plants growing in the Leningrad Region on the Karelian Isthmus.

Experimental

Study area and sampling

A distinctive feature of the Leningrad Region's soil composition is the predominance of podzolic soils, which are low in humus and rich in silicon and aluminium. The soils of the Vyborg district are predominantly podzolic, sod-podzolic, and bog soils, formed on granite and gneiss, characterised by high natural acidity (pH 4.0-5.5). High acidity is caused by nutrient leaching, climate, and the type of podzolic formation. They are characterised by a low and medium content of organic matter (humus), mainly of the podzolic type, with high acidity. The humus content in sod-podzolic soils is usually 1 % - 3 %. The mineral composition is characterised by high quartz and feldspar content, as well as an abundance of boulders and rock inclusions. The soils are highly acidic, nutrient-poor, and low in humus. The region is also characterised by the widespread occurrence of soils with high peat content and alluvial soils formed on bottom sediments, such as those of the Neva River and Lake Ladoga. The Vyborg district, Leningrad region (in the vicinity of the village of Olshaniki (N 60.392455, W 29.794482 and N 60.381475, W 29.786646), where samples were collected for elemental analysis, is characterised by significant soil diversity due to its rugged topography and proximity to the Gulf of Finland. Podzolic and sod-podzolic soils predominate in the uplands, while peat-bog soils predominate in the lowlands. Sandy and sandy loam soils are found in the coastal zone, suitable for growing potatoes and root crops, provided organic matter is added. In the composition of the mineral part of the soil, iron makes up about 3.8 %, calcium - 1.37 %, potassium - 1.36 %.

Samples were collected at the end of August, when plants were fruiting, in ruderal zones where dense thickets of *H. sosnowskyi* grow already as an invasive species. Plant samples were collected wearing rubber gloves. Several free-standing plants were randomly selected for analysis. The sample consisted of five plants. A pooled sample of the taproots

from the five plants was collected at a depth of 10 cm - 20 cm (below the root collar). Stem: sampled at a height of 50 cm above the soil surface. Leaves: petiole samples were taken from the middle section of five rosette leaves. The collected material at first pre-dried in the air, then was cleaned with plastic knives without rinsing under running water (which is generally recommended for medicinal plant roots). The plant material was cut with plastic knife and dried in the shade in a well-ventilated area on plastic sieves to prevent contact with metals. Whole fruits were taken from the central umbel for analysis. The samples were then packed in paper bags and stored in the laboratory until analysis.

Sample preparation for NAA

All samples were dried until constant weight and homogenised using homogeniser (Pulverisette 6, Fritsch Laboratory Instruments GmbH, Germany) at 400 rpm provided with agate jar and agate balls. After each treatment, they were thoroughly cleaned to prevent sample contamination. To ensure the representativeness of the samples, approximately 0.3 g of each sample, selected at random from a large amount of homogenised plant material, was placed in plastic bags for the determination of elements with short-lived isotopes and in aluminium cups for the determination of elements with long-lived isotopes. The tables show the average data of five measurements.

Instrumental neutron activation analysis (INAA)

The analytical procedures and the basic characteristics of the employed pneumatic system REGATA at the IBR-2 reactor are described in detail elsewhere [43]. Two types of irradiations were carried out. One is a short irradiation for 3 min for plants and 1 min for soil to determine short-lived isotopes (Al, Ca, Cl, I, Mg, Mn, and V). After a decay period of 5 min - 7 min, the irradiated samples were measured 15 min. A long irradiation of 4 days was used to analyse for long-lived radionuclides. After irradiation, the samples were re-packed and measured twice: first after 4 days for 30 min to determine As, Br, K, La, Na, Mo, Sm, and U and after 20 days for 2.5 hours to determine Ba, Ce, Co, Cr, Cs, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, and Zn. The gamma spectra of induced activity were measured with a HPGe detector with a resolution of 1.9 keV for ^{60}Co 1332 keV line.

The processing of spectra data and calculation of elemental concentrations were performed using software developed in FLNP, JINR [41]. Certified reference materials and flux comparators were used to determine the concentrations of elements by the relative method of calculations.

Quality control of INAA

In order to evaluate the precision and accuracy of the results, certified reference materials and standards were used, namely OBTL-5 (Oriental basma tobacco leaves - Trace elements), SDC1 (NIST SRM Misa Schist), NIST SRM 1549 (Non-Fat Milk Powder), 1632c (NIST SRM Trace Elements in Coal), 528 (Phosphorous-Rare Earth Elements Uranium Ore), 1566b (Oyster Tissue), 1633c (NIST Trace elements in Coal Fly Ash), 667 (Eestuarine sediment), FFA1 (Fine Fly Ash), and 2711a (NIST SRM Montana Soil), which were irradiated in the same conditions with the samples. Certified and measured values of elements content in reference materials and standards (SRM) are presented in Table 1.

Table 1

Certified and measured values of elements in reference materials [mg/kg]

Element	Reference material	Certified value	Uncertainty	Measured value	Uncertainty
Al	528	29805	2.1	30674	7.1
As	FFA1	53.6	5.0	54.7	7.3
Ba	1632c	41.1	3.9	41.7	5.9
Br	1632c	18.7	2.1	21	4.5
Ca	SDC1	10000	5	10137	8.8
Ce	FFA1	120	5.8	119	6.2
Cl	1566b	5140	1.9	4715	1.2
Co	667	23	5.7	22.2	5.4
Cr	667	178	9	177	6.8
Cs	1632c	0.59	1.7	0.58	4.6
Fe	667	48900	2.2	47616	5
Hf	FFA1	6.09	7.4	5.98	4.6
K	FFA1	22000	10	22564	9.8
La	FFA1	60.7	6.6	60.5	4.7
Mg	SDC1	11739	5.9	10140	9.1
Mn	1566b	18.5	1.1	18.01	9.4
Mo	FFA1	17	15	17.2	14
Na	2711a	12000	8.3	12052	7.7
Ni	1632c	9.32	5.5	9.17	11
Rb	2711a	120	2.5	122	6.5
Sb	FFA1	17.6	14.2	17.7	7.5
Sc	2711a	8.5	1.2	8.4	5.2
Se	1633c	13.9	0.55	13.9	1,1
Sm	667	4.66	4.3	5	8.8
Sr	2711a	242	4.1	245	9.1
Ta	FFA1	2.11	7.6	1.98	3.6
Tb	FFA1	1.36	10.1	1.38	4.0
Ti	1633c	7240	22	6060	38
Th	1632c	1.4	2.1	1.39	4.7
U	1632c	0.51	2.3	0.53	7.2
V	OBTL-5	4.1	9.9	4.07	13.3
Zn	667	175	7.4	177	4.2

Results and discussion

The results obtained by INAA are presented in Table 2.

The results obtained from studying the presence and concentration of elemental composition in Sosnowsky's hogweed organs provide information about the plant's physiological state, its nutrient requirements, and the level of environmental pollution (we did not observe the accumulation of heavy metals or toxic elements). These results also help us identify element deficiencies or excesses to optimise nutrition and yield, understand biogeochemical processes, and use plants in phytoremediation or medicine. Different organs concentrate different elements, reflecting their specialisation (for example, leaves for photosynthesis, roots for absorption, where the accumulation of all elements should be maximised, as the roots of Sosnowsky's hogweed also serve as storage organs).

As can be seen from Table 2, the concentrations of elements in the fruits of Sosnowsky's hogweed between two consecutive years (2019 and 2020), but growing in the same area, are practically the same (within (3-10) %), with the exception of chromium, strontium, barium and rare earth elements.

Assessment of Transfer Factor (*TF*) of determined elements from soil to plants (*TF* = Concentration $C_{(root+leaf+stem+fruit)}$ / Concentration C_{soil}) showed that the given kind of Sosnowsky's hogweed grown in Leningrad region demonstrate accumulation of K (5), Ca (3.8), Cr (11.4), Zn (11.2), Se (24.8), and Br (4.2) (see Table 2).

The basic elements of chlorophyll are carbon, hydrogen, oxygen, nitrogen, and a central magnesium atom, which form a complex molecule with a porphyrin ring, where magnesium is held by nitrogen atoms and a phytol "tail" is attached to the ring. Magnesium is the key element of chlorophyll. High chlorine levels in leaves are pointless to highlight. Chlorine, present in plant leaves, is vital for photosynthesis (water splitting and oxygen release), maintaining water balance and ionic balance in cells, participating in energy metabolism, and helping transport other ions (K, Ca, Mg). Plants rarely experience a deficiency, but excess chlorine can cause chlorosis. Markert's data [45] clearly does not apply to chlorophyll, and we can easily confuse this with fruits that lack chlorophyll.

Table 2

Concentration of the major and trace elements [mg/kg] in soil and different parts of *Heracleum sosnowskyi* Manden

Ele-ment	Vino-gradov	Soil	Root			Leaf petiole	Stem	Fruit (seeds/flowers)			Root+ Leaf+ Stem+ Fruit	*TF*	Ref plant [45]
			Whole	Bark part	Cylinder			2020	2019	Average between years			
Na	3600	17000	550	540	162	650	228	87	78	82.5	1510.5	0.09	150
Mg	6300	17000	2230	2370	1560	3760	820	3670	3610	3640	10450	0.6	2 %
Al	71300	54000	1130	1420	265	1150	123	175	89	132	2535	0.05	80
Cl		<43	900	1010	850	18600	1400	251	210	230.5	21130	**400**	0.2 %
K	13600	25700	21100	15600	15800	94000	58000	9900	11800	10850	131750	**5**	1.9 %
Ca	13700	7900	4200	4400	2900	19000	5000	6700	3300	1985	30185	**3.8**	1 %
Sc	7	5.9	0.306	0.297	0.0386	0.218	0.0222	0.0228	0.0284	0.0256	0.57	0.1	0.02
Ti	460	1840	60	73	14	72	14	16	13	14.5	160.5	0.09	0.05
V	100	21.6	0.79	0.92	0.115	0.74	0.102	0.149	0.112	0.130	1.78	0.08	0.5
Cr	200	18	1.8	1.23	0.75	202	0.85	1.27	0.7	0.98	205.6	**11.4**	1.5
Mn	850	283	26.1	29.8	21.2	51	17.1	37	25.5	31.25	125.4	0.44	200
Fe	38000	16500	710	680	182	610	92	167	155	161	1573	0.09	150
Co	8	6.1	0.325	0.308	0.115	0.381	0.067	0.098	0.137	0.117	0.89	0.15	0.2
Ni	40	7	2.05	1.73	1.57	2.5	0.8	2.5	2.16	2.33	7.68	**1.1**	1.5
Zn	50	49.2	69.2	69.4	69.7	380	21.7	69.1	94	81.5	552.4	**11.2**	50
As	5	1.85	0.083	0.076	0.03	0.056	0.04	0.032	0.053	0.042	0.221	0.12	0.1
Se	0.001	0.02	0.046	0.092	0.051	0.14	0.14	0.226	0.152	0.170	0.496	**24.8**	0.02
Br	5	4.1	1.16	0.93	1.08	13.4	14.8	1.58	1.15	1.36	17.32	**4.2**	4
Rb	100	107	24	22	22	91	85	46	32	39	239	**2.2**	50
Sr	300	2370	44	36	29.3	160	70	21.9	5.4	13.6	287.6	0.12	50
Mo	2	0.7	0.3	0.25	0.85	0.32	0.077	0.44	0.75	0.59	1.287	**1.3**	0.5
Sb		0.192	0.0167	0.052	0.0121	0.0173	0.006	0.0089	0.0165	0.0127	0.053	0.27	0.1
Cs		1.78	0.073	0.081	0.0294	0.085	0.041	0.054	0.0419	0.048	0.247	0.14	0.2
Ba		660	128	125	103	350	114	24	6.3	15.1	607	0.92	40
La		25.5	1.58	1.22	0.43	1.12	0.151	0.195	0.109	0.152	3.003	0.12	0.2
Ce		50	3.6	2.95	0.52	1.91	0.33	0.68	0.35	0.51	6.35	0.13	0.5
Sm		4.9	0.204	0.213	0.06	0.115	0.0152	0.0199	0.015	0.017	0.351	0.07	0.04
Tb		0.526	0.0353	0.0344	0.0085	0.0189	0.0025	0.0032	0.0018	0.0025	0.0592	0.11	0.008
Hf		10.2	0.238	0.221	0.04	0.248	0.039	0.011	0.01	0.01	0.535	0.05	0.05
Ta		0.532	0.0219	0.0217	0.0062	0.0209	0.002	0.003	0.001	0.002	0.0468	0.09	0.001
Th		8	0.314	0.271	0.061	0.288	0.0304	0.0417	0.029	0.035	0.6674	0.08	0.005
U		-	0.1	0.09	0.0101	0.067	0.007	0.017	0.005	0.011	0.185	-	0.01

Comparison with the Reference plant [45] shows a significant discrepancy in element concentrations, especially pronounced for elements such as rare earth elements (REEs), Tb,

Hf, Ta and Th. High concentrations of rare earth (and other) elements in the leaves may be due to the plants not yet completing their growing season, and the elements have not yet been released into the roots. The extremely limited data on elemental concentrations found in literature, mostly for essential elements, of various parts of *H. sosnowsky*i shows similarity of concentrations in this plant grown in different geographical conditions [45, 46] - see Tables 3-5.

Table 3

Leaves *Heracleum sosnowskyi*

Element	Present work [mg/kg]	Poland [46]	Features
K	94000	(1-2) % (10000-20000) mg/kg	Major nutrient
Ca	19000	(0.5-1) % (5000-10000) mg/kg	Essential; varies by soil
Mg	3760	(0.2-0.5) % (2000-5000) mg/kg	Key for chlorophyll
Fe	610	(100-500) mg/kg	Trace; essential, but can be toxic in excess
Zn	380	(20-100) mg/kg	Essential micronutrient
Mn	51	(50-200) mg/kg	Essential
As	0.056	(0.5-5.0) mg/kg	Toxic trace; depends on soil contamination
Ni	2.5	(1-10) mg/kg	Potentially toxic

Table 4

Stems *Heracleum sosnowskyi*

Element	Present work [mg/kg]	Poland [46]	Features
K	58000	(0.5-1.0) %	Lower than leaves
Ca	5000	(0.3-0.8) %	Structural role
Mg	820	(0.1-0.3) %	Lower accumulation
Fe	92	(50-300) mg/kg	Less than leaves
Zn	21.7	(10-50) mg/kg	Essential
Mn	17.1	(20-100) mg/kg	Essential
As	0.04	(0.2-3.0) mg/kg	Toxic
Ni	0.8	(0.5-5.0) mg/kg	Potentially toxic

Table 5

Roots *Heracleum sosnowskyi*

Element	Present work [mg/kg]	Russia, Ukraine [46]	Features
K	21100	(0.3-0.7) %	Storage role
Ca	4200	(0.2-0.6) %	Higher in roots for uptake
Mg	2230	(0.1-0.4) %	Essential
Fe	710	(200-1000) mg/kg	High accumulation from soil
Zn	69.2	(50-200) mg/kg	Bioaccumulated
Mn	26.1	(100-500) mg/kg	High in roots
As	0.083	(1-10) mg/kg	Toxic; As tolerant in some cases
Ni	2.05	(5-20) mg/kg	Potentially toxic

As for data on fruits (seeds/flowers), they are even scarcer and show similar patterns with lower concentrations overall. For example: K: (0.5-1.0) %; Fe: (100-300) mg/kg; (from general plant seed analyses); no specific *H. sosnowskyi* seed data found in 2025 literature. *H. sosnowskyi* is phytotoxic and invasive, but elemental toxicity (e.g., heavy metals) is environmental. Concentrations in *H. sosnowskyi* vary by region (e.g., higher in

industrial areas like (Poland, Ukraine)/Russia *vs.* natural sites). Soil pH affects uptake; alkaline soils reduce heavy metal absorption [46].

The correlation analysis revealed relationship between many of so-called essential elements (see Table 6). Potassium shows high positive interactions with a large number of elements: K–Ca (r = 0.85), K–Br (r = 0.91), K–Rb (r = 0.89), K–Cl (r = 0.88). The literature also indicates a high correlation of the alkaline element potassium with almost all macronutrients. There is also evidence of the correlation of the alkaline earth metal calcium and with another macronutrients Ca–Cl (r = 0.97), Ca–K (r = 0.85). A positive correlation is observed in iron with some elements Zn–Al (r = 0.98), Fe–Sc (r = 0.99), Fe–V (r = 0.99) [45, 46].

Table 6

Correlations between essential and beneficial elements

	Na	Mg	Al	Cl	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Zn	As	Se	Br	Rb
Na	1.00																		
Mg	0.05	1.00																	
Al	**0.94**	0.12	1.00																
Cl	0.61	0.40	0.42	1.00															
K	0.53	0.03	0.25	**0.88**	1.00														
Ca	0.55	0.49	0.38	**0.97**	**0.85**	1.00													
Sc	**0.92**	0.07	**0.97**	0.30	0.15	0.25	1.00												
Ti	**0.96**	0.21	**0.99**	0.54	0.37	0.50	**0.95**	1.00											
V	**0.94**	0.15	0.99	0.39	0.23	0.36	**0.99**	**0.99**	1.00										
Cr	**0.82**	0.41	0.72	0.74	0.57	0.77	0.70	**0.79**	0.74	1.00									
Mn	0.49	0.77	0.45	**0.81**	0.51	**0.88**	0.34	0.56	0.45	0.78	1.00								
Fe	**0.93**	0.17	**0.98**	0.39	0.20	0.35	**0.99**	**0.97**	**0.99**	0.77	0.45	1.00							
Co	**0.94**	0.33	**0.94**	0.61	0.39	0.56	**0.92**	**0.96**	**0.94**	**0.84**	0.61	**0.96**	1.00						
Ni	0.17	**0.94**	0.25	0.39	–0.03	0.47	0.23	0.31	0.27	0.56	0.79	0.33	0.44	1.00					
Zn	0.56	0.57	0.41	**0.97**	0.76	**0.95**	0.30	0.53	0.39	0.73	**0.87**	0.41	0.64	0.56	1.00				
As	0.75	0.08	**0.82**	0.08	0.00	0.03	**0.91**	**0.80**	**0.86**	0.50	0.12	**0.87**	0.79	0.16	0.11	1.00			
Se	–0.43	0.55	–0.45	0.10	0.10	0.29	–0.52	–0.35	–0.41	–0.05	0.38	–0.47	–0.37	0.34	0.12	–0.47	1.00		
Br	0.26	–0.20	–0.03	0.63	**0.91**	0.62	–0.11	0.08	–0.04	0.28	0.22	–0.10	0.05	–0.32	0.46	–0.19	0.23	1.00	
Rb	0.19	0.04	–0.10	0.68	**0.89**	0.73	–0.19	0.04	–0.10	0.35	0.40	–0.15	0.02	–0.10	0.54	–0.28	0.46	**0.96**	1.00

Table 7

Correlation between some trace metals and rare earth elements

	Sr	Mo	Sb	Cs	Ba	La	Ce	Sm	Tb	Hf	Ta	Th	U
Sr	1												
Mo	–0.45	1.00											
Sb	–0.07	–0.18	1.00										
Cs	0.54	–0.56	0.58	1.00									
Ba	**0.96**	–0.37	0.12	0.63	1.00								
La	0.37	–0.36	0.54	**0.82**	0.56	1.00							
Ce	0.21	–0.42	0.60	0.82	0.39	0.97	1.00						
Sm	0.18	–0.35	0.72	0.77	0.40	**0.96**	**0.97**	1.00					
Tb	0.18	–0.37	0.69	0.78	0.40	**0.97**	**0.98**	1.00	1.00				
Hf	0.57	–0.47	0.55	**0.90**	0.73	**0.96**	**0.91**	**0.90**	**0.90**	1.00			
Ta	0.48	–0.39	0.61	0.88	0.66	**0.98**	**0.93**	**0.94**	**0.94**	**0.99**	1.00		
Th	0.49	–0.41	0.56	**0.90**	0.66	**0.98**	**0.94**	**0.92**	**0.93**	**0.99**	**0.99**	1.00	
U	0.31	–0.46	0.63	**0.88**	0.49	**0.98**	**0.99**	**0.97**	**0.98**	**0.95**	**0.97**	**0.97**	1

Table 7 shows that determined lanthanides correlate with each other: La–Sm (r = 0.96), Ce–Sm (r = 0.97). Th and U demonstrate correlation with the majority of the elements determined.

Our research shows it has moderate to strong accumulation potential for certain trace elements, including rare earths, due to its robust root system and bioaccumulation from polluted soils. This makes it a candidate for phytoremediation (using plants to clean contaminated sites), though its invasiveness limits practical use.

Below is a summary of the literature evaluating elements with accumulation potential:

Cadmium: Strong hyperaccumulator. Roots can reach (100-500) mg/kg in polluted soils (*e.g.*, near industrial sites in Poland/Russia). Shoots (stems/leaves) translocate (20-200) mg/kg. Study: [46] reported Cd levels up to 300 mg/kg in roots from Ukrainian mining areas, exceeding EU soil remediation thresholds. It's tolerant to Cd toxicity via sequestration in vacuoles.

Lead: Moderate accumulation, primarily in roots (up to (1,000-5,000) mg/kg in contaminated sites). Shoots accumulate (100-1,000) mg/kg. [46] found Pb accumulation in stems/leaves (200-800 mg/kg) in zinc smelter vicinities, suggesting use for Pb-phytoremediation.

Other elements:

Iron: Roots hyperaccumulate up to (5,000-10,000) mg/kg in iron-rich soils (essential but toxic in excess).

Manganese: Similar to Fe; roots > 2,000 mg/kg.

Arsenic: Emerging data shows roots accumulating (100-500) mg/kg in As-contaminated sites (e.g., Bangladesh analogs, but limited *H. sosnowskyi*-specific).

In our research carried out by means of multi-element epithermal neutron activation analysis (ENAA) we have observed significant excess of concentrations for lanthanides (REEs) La, Ce, Sm, as well as for Tb, Hf, Ta, and both actinides, Th and U.

Conclusion

For the first time, instrumental neutron activation analysis was used to analyse various parts of the plant (Sosnowsky hogweed), a common invasive species in the Leningrad Region (Vyborg District).

The concentration of elements with rare exceptions, varies in the following range: K > Ca > Cl > Mg > Al > Na > Fe > Ba > Zn > Cr > Sr > Rb > Ti > Mn > Br > Ni > Ce > La > Co > V > Mo > Th > Hf > Se >Cs > As > Sb > Sm > Ta > Tb > U.

The analysis showed that many toxic elements not only do not accumulate, but are present in lower concentrations than in the soil in which the plants grow.

Considerably higher concentrations in comparison with reference plant are noticed for La, Ce, Sm and for Tb, Hf, Ta, Th.

A correlation was found between the content of the essential elements and between lantanides and actinides with a varied composition.

Sosnowsky's hogweed, having become a wild source of raw materials for various industries, can be regularly harvested, which can reduce its distribution and prevent negative environmental impacts. Due to the wide range of substances contained in *H. sosnowskyi*, its processing offers great potential for the production of valuable products and materials in agriculture, medicine, pharmaceuticals, food, pulp and paper, chemical, mining, energy, and construction as well as for phytoremediation of contaminated soils.

For future research, it would be worthwhile (based on our current data) to analyse the root material of this plant before wintering, after the end of the growing season and the death of the aboveground part, and in early spring - at the very beginning of regrowth (the beginning of vegetation).

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