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Lithium and strontium accumulation in native and invasive plants of the Sava River: Implications for bioindication and phytoremediation

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ABSTRACT

The objective of this study was to investigate the potential of native and invasive plant species for the uptake and accumulation of lithium (Li) and strontium (Sr) along the Sava River, focusing on their bioindication and phytoremediation capabilities. Sampling was carried out in riparian zones exposed to different pollution sources in Slovenia, Croatia, and Serbia. Plant samples of native (*Salix alba, Populus alba, Populus nigra, Ulmus glabra, Juglans regia*) and invasive (*Amorpha fruticosa, Reynoutria japonica, Solidago canadensis, Impatiens glandulifera*) species were collected. The content of Li and Sr was analyzed in the soils, roots, and leaves of the selected plants, as well as physical and chemical soil properties. Both Li and Sr content in the soils increased from the source to the mouth of the Sava River. The native species showed significant potential for Li and Sr accumulation based on the metal accumulation index. The highest Sr accumulation was measured in the leaves of *Salix alba* and the roots of *Juglans regia,* while the highest Li accumulation was measured in *Ulmus glabra*. Native species, especially *Salix alba,* proved to be better bioindicators of Li and Sr. Invasive species, especially *Amorpha fruticosa* and *Impatiens glandulifera*, showed a remarkable ability to translocate Sr and Li, respectively, to leaves. These results provide valuable insight into the suitability of plants for biomonitoring soil contamination and potential applications in phytoremediation strategies. In summary, the study shows the importance of native species in the context of the accumulation and bioindication of soil pollution.

1. Introduction

The Sava River, a major waterway flowing through the Balkans, hosts diverse riparian ecosystems that play a critical role in regional biodiversity and environmental health. Ecosystems in the riparian zone of the Sava River face environmental problems resulting from the influence of anthropogenic factors, settlements and industrial facilities, the expansion of agricultural land, and the development of a complex flood control system that protects fertile agricultural land (ISRBC, 2009). Pollution of rivers and riparian areas is one of the problems that researchers have been paying increasing attention to lately. Much of the research focuses on studying the harmful effects of potentially toxic chemical elements (PTEs) that remain in river sediments and in the soil of riparian areas long after they have been accumulated.

The presence of PTEs in the upper reaches of the Sava is due to the decomposition of carbonate-bearing source rocks. In the middle section, agricultural activities and biological processes related to eutrophication are the main sources of these elements. Downstream, in the lower reaches of the Sava River, the increased content of PTEs is largely due to pollution from industrial activities and discharge of untreated industrial and municipal wastewater (Markovics et al., 2010; Ščančar et al., 2015). As a result of these factors, the Sava River has been classified as a moderately polluted European river in terms of water and sediment pollution (Vidmar et al., 2017; Marković et al., 2018). There are previous findings of elevated Sr content in soils on the banks of the Sava River in the narrower area of the city of Zagreb (> 200 mg kg^{-1}; Vertačnik et al., 1995). On the other hand, to our knowledge, there are no studies on Li content in soils on the banks of the Sava River. It is expected that elevated Li content can be found in this area, considering that the Sava River is located in the metallogenic lithium-boron zone of the Western Balkans (Borojević Šoštarić and Brenko, 2023). In addition to natural sources of Li, anthropogenic sources include inadequately disposed

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municipal waste, which often contains batteries of various compositions and uses, including lithium-ion batteries, as well as waste generated during the production of plastics, glass, ceramics, various alloys, etc. Transportation is also one of the sources of Li, as this element is used in the production of a variety of lubricants in the automotive industry (Yalamanchali, 2012). Coal mining and combustion in thermal power plants is one of the most important anthropogenic sources of Li (Adeel et al., 2023), and the largest thermal power plant in Serbia is located on the banks of the Sava River. Strontium also occurs in soil from the release of coal ash and industrial waste (Gad, 2014).

Both lithium (Li) and strontium (Sr) may be beneficial elements for plants in trace amounts, but elevated levels of these elements can be toxic. Lithium toxicity can lead to impaired root and shoot growth, decreased photosynthetic activity, and altered nutrient uptake (Baran, 2019). Similarly, Sr toxicity can impair uptake of essential nutrients, disrupt enzyme activities, and negatively impact overall plant health (Burger and Lichtscheidl, 2019). Understanding toxicity levels and mechanisms of tolerance to these elements is critical to assessing the risk they pose to plant species and the surrounding environment; therefore, the question of remediation of these elements arises.

The remediation of PTE contaminated areas is of economic importance because it requires a large amount of energy and hazardous chemical reagents to remove the contaminants (Santos et al., 2022). Phytoremediation is a promising alternative that uses plants to remove PTEs. This technique uses the metabolic capacity of plants to remediate contaminated sites. Plants can immobilize contaminants in the soil through phytostabilization or extract them from the soil and store them in plant biomass through phytoremediation. This process ultimately improves the overall quality of contaminated ecosystems (Matakala et al., 2023). This is also a sustainable and cost-effective approach to metal pollution control, including remediation of Li and Sr in soils. Due to their genetic and physiological potential, some plant species can accumulate, translocate, and tolerate high concentrations of metals and are used for phytoremediation (Hasanuzzaman et al., 2015). The selection of appropriate plant species is critical to phytoremediation. Native plant species are well adapted to the local environment, which can increase their tolerance to native contaminant sources. Their inclusion in remediation projects promotes ecological restoration and supports regional biodiversity (Pavlović et al., 2004; Yoon et al., 2006; Gajić et al., 2016). On the other hand, invasive plant species tend to have higher pollutant uptake rates due to their competitive growth and adaptability. These species often have rapid growth, broad adaptability, large biomass, and robust heavy metal accumulation and tolerance capabilities (Rai and Kim, 2020; Kumar Rai and Singh, 2020; Xue et al., 2022). These traits, which enable successful invasion, are also responsible for the effective phytoremediation capacity of invasive plants. As a result, the appropriate use of invasive plant species has become a topic of concern as well as a research interest (Fu et al., 2017; Prabakaran et al., 2019; Xue et al., 2022).

The term bioindicator generally refers to any organism that provides quantitative information about the quality of the environment (Markert et al., 2003; Birke et al., 2018). The use of plants as bioindicators is a useful tool for long-term information in ecological research, especially for assessing negative impacts of anthropogenic activities (Wojtuń et al., 2018). Positive correlations between the content of PTEs in soils and plants indicate the potential of plants for bioindication and monitoring of soil contamination (Pavlović et al., 2016; Alexandrino et al., 2020). However, the correlation of PTE content in soils and plants is not always clear and linear due to the physicochemical properties of the soil and the specificity of plant species (Bañuelos et al., 2020). Certain plant species can accumulate many times higher amounts of elements in their aboveground parts than in the soil solution. In this way, plants can also be used to indicate very low PTE contents in the soil, which cannot always be easily determined by measuring total content and sometimes not even by chemical methods of element extraction (Madejón et al., 2017).

Previous studies on the uptake of Li and Sr in different plant species have been conducted in different environments such as urban and mining areas and under experimental conditions (Seregin and Kozhevnikova, 2004; Nečemer et al., 2008; Sasmaz and Sasmaz, 2017; Kavanagh et al., 2018; Burger et al., 2019; Török et al., 2021; Sasmaz et al., 2021; Bolan et al., 2021; Liang et al., 2023). However, these studies did not focus on the specific plants investigated in this study. Experimental studies have shown that toxicity of Li and Sr in plants depends on the plant species, concentration of Li and Sr in treatments, as well as duration of treatment (Shahzad et al., 2016; Dresler et al., 2018; Burger et al., 2019; Srikhumsuk et al., 2023).

To our knowledge, the specific interactions of these elements with plant species along the Sava River have not yet been studied. Therefore, this study fills a significant knowledge gap and provides region-specific information that is critical for understanding the unique dynamics of Li and Sr uptake in the Sava River ecosystem.

The objective of this study is to determine Li and Sr content in riparian soils, define soil properties that could influence uptake of Li and Sr by plants, and to determine the uptake rates of these elements in the roots and leaves of 8 plant species, native and invasive to the Sava region (*Salix alba, Populus nigra, Juglans regia, Ulmus glabra, Amorpha fruticosa, Reynoutria japonica, Solidago canadensis,* and *Impatiens glandulifera*). The application of accumulation factors to the measurements obtained will help evaluate the potential of plants for phytoremediation of Li and Sr, while the correlation of levels in plants and soils will help determine the potential of plants for the bioindication of these elements in soils in river basins. Results will provide insights into the phytoremediation and bioindication potential of the selected native and invasive plant species, based on their ability to accumulate Li and Sr in riparian soils.

2. Materials and methods

2.1. Study area and sampling

To study the changes and patterns from the source to the mouth of the river, field research was conducted in areas exposed to various sources of pollution. These areas include: Slovenia (Mojstrana (MOJ), Radovljica (RAD), Litija (LIT), Vrhovo (VRH), and Čatež (CAT)), Croatia (Zagreb (ZAG), Jasenovac (JAS), Slavonski Brod (SLB), and Županja (ZUP)), and Serbia (Sremska Mitrovica (SRM), Šabac (SAB), and Belgrade (BEO)) (Fig. 1). The criterion for selection of the sampling sites was that they contained riparian habitats under the direct influence of various types and intensities of anthropogenic pollution and degradation. Site selection was coordinated with the research program under the European Commission FP7 project 'Managing the effects of multiple stressors on aquatic ecosystems under water scarcity' (GLOBAQUA) to ensure the collection of a high-quality environmental dataset (Navarro-Ortega et al., 2015). For more details on the types of anthropogenic pollution sources at each sampling site, see previously published articles on this project, such as Mataruga et al. (2020).

The following plant species were selected as model species for these studies: native species - *Salix alba, Populus alba, Populus nigra, Ulmus glabra,* and *Juglans regia* - and invasive species - *Amorpha fruticosa, Reynoutria japonica, Solidago canadensis,* and *Impatiens glandulifera*. The criteria for the selection of the above species were their presence in more than 50% of the selected sites, their high abundance, and their accessibility for sampling.

Soil samples were collected from river floodplains where soils exhibit considerable spatial and vertical variability within a given soil profile. This variability includes differences in structure, granulometric composition, potential for contaminant accumulation, and other properties. Samples were collected at depths of 0–30 cm and 30–60 cm, with the exception of the MOJ (0–10 cm) and VRH (0–30 cm) sampling sites. Aggregate samples were formed from 5 soil samples taken in the root zone of the studied plant species at each site. The samples were air dried, ground in a stainless steel mill (Polimix, Kinematica AG), passed through

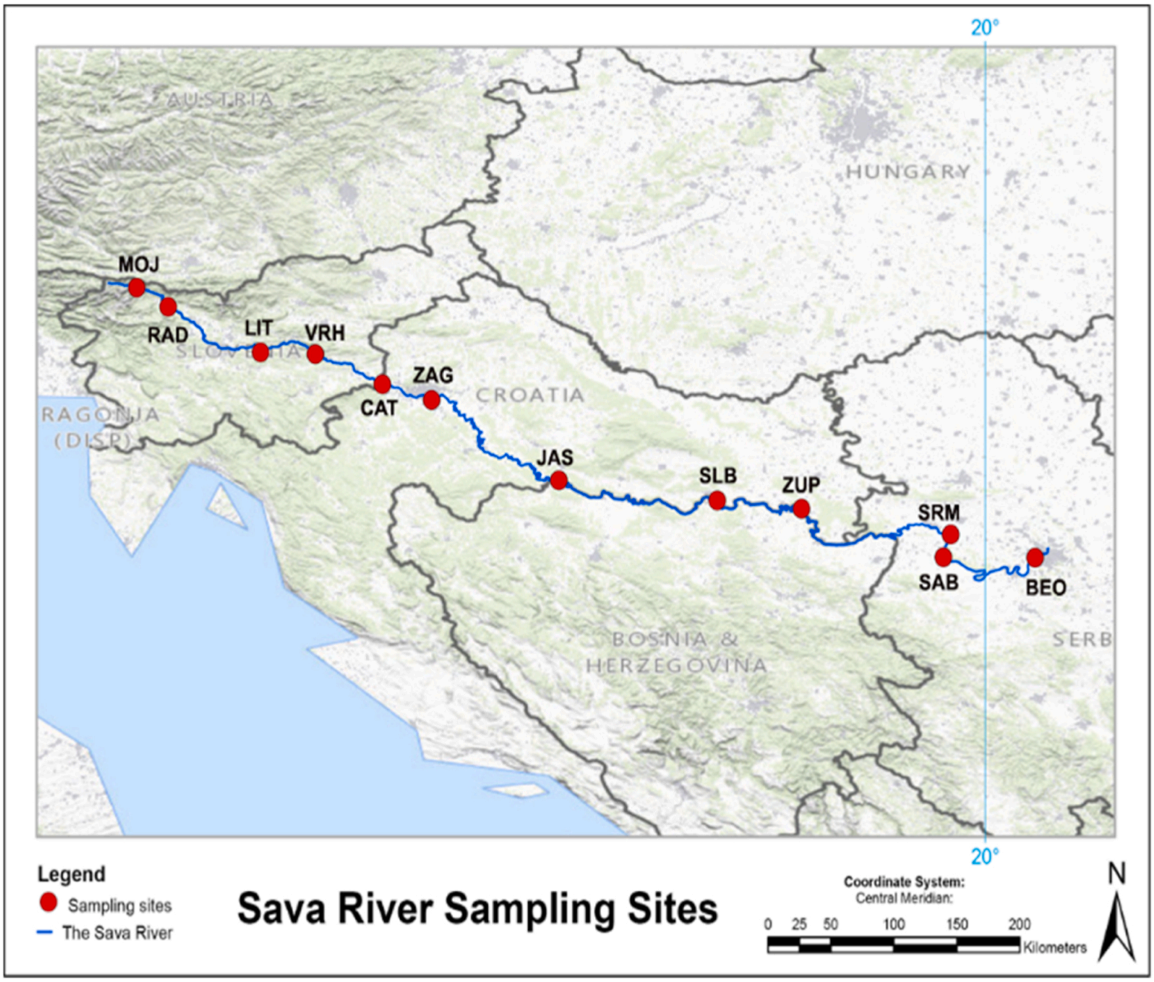

Fig. 1. The Sava River with the sampling sites marked.

a sieve with an aperture size of 2 mm and stored in clean polypropylene bags until analysis. After measuring hygroscopic moisture, samples were dried in an oven (Binder, Tuttlingen, Germany) at 105 °C until constant weight.

Thirty grams of leaves were collected from the aerial parts of three to five selected individuals and root samples were collected from the rhizosphere. Composite samples were formed from these samples for each species at each sampling site. Sampling was conducted in the beginning of the September, at the end of the growing season, to allow sufficient time for all plant species to accumulate maximum amounts of Li and Sr. The root and leaf samples were washed with distilled water and dried in an oven at 75 °C until constant weight. After grinding in a laboratory mill (Polimix, Kinematica AG), the samples were passed through a stainless steel sieve with an aperture size of 1.5 mm and further processed for analysis.

2.2. Physical and chemical properties of the soil

To determine the general physical and chemical properties of the soil at the sites studied, these properties were determined from the aggregate sample for each sampling site. The granulometric composition of the soil samples was determined by the sedimentation method using the combined pipetting technique in 0.4 M tetrasodium diphosphate ($Na_4P_2O_7$) (Atterberg, 1911). The classification of soil texture classes was based on the texture triangle (Soil Science Division Staff, 2017) in relation to the measured content of sand (2–0.06 mm), silt (0.06–0.002 mm), and clay particles (<0.002 mm). Hygroscopic soil moisture was determined by drying the soil samples at a temperature of 105 °C to constant weight. Active (pH in H2O) and substitutional acidity (pH in 0.1 M KCl) were measured using a pH meter (WTW, inoLab 7110, Germany). Soil carbon (C%) and nitrogen (N%) contents were determined by burning the samples at 1150ºC using a CNS analyzer (Vario EL III, Germany) according to the method described by Nelson and Sommers (1996). $CaCO_3$ content was determined quantitatively using a Scheibler calcimeter.

2.3. Li and Sr content

To determine the content of the elements, 0.5 g of soil was prepared using the wet digestion method with aqua regia (3 ml HNO_3 and 9 ml HCl) in a microwave oven (CEM Mars 6). The content of Li and Sr was measured using the method of optical emission spectrometry for simultaneous multi-element analysis (ICP-OES, Spectro Genesis). The accuracy of the results was checked by analyzing the standard reference material for soil (clay soil - ERM-CC141, IRMM certified by EC-JRC). The recovery values found were 95% for Li and 106% for Sr.

To determine the total content of the elements in plants, 0.3 g of plant material was prepared for analysis using the wet digestion method with a mixture of nitric acid (concentrated HNO_3, 9 ml) and hydrogen peroxide (30% H_2O_2, 3 ml) in a microwave oven (CEM Mars 6). The content of elements was determined using ICP-OES (Spectro Genesis). The accuracy of the results was checked by analyzing standard reference material (Beach leaf - BCR-100, IRMM certified by EC-JRC), and the recovery values found were 94% for Li and 109 for Sr%.

All measurements were performed in 5 replicates of each species and soil sample per sampling site, and reported as mean values. The content of elements is given in mg kg^{-1} dry weight. The detection limits of the analyzed elements in the samples were 0.037 mg kg^{-1} (Li) and 0.00116 mg kg^{-1} (Sr).

2.4. Statistics

To evaluate the potential of the studied plant species for the accumulation of PTEs, the enrichment coefficients for roots (ECR) were calculated as the ratio between the element contents in the roots of the plants and the total content of elements in the soil (Chen et al., 2005; Sasmaz and Sasmaz, 2017). Plants with higher metal content in their roots alone (ECR > 1, TF < 1) are considered excluders (Wei et al., 2002; Deepika and Haritash, 2023).

The accumulation of PTEs in leaves was determined using the enrichment coefficients for leaves (ECS), calculated by dividing the plant leaf content for each plant by the soil content. This parameter shows a plant's capacity for the accumulation of PTEs directly from the soil (Sasmaz and Sasmaz, 2017). Plants are considered to have a phytoextraction potential when the ECS is > 1 and an excluders when the ECS is < 1 (Wei et al., 2002). If the ECR and ECS values are close to 1 (e.g., 0.90 or 0.80), then the plants may be classed as good remediation plants (Sasmaz et al., 2016; Sasmaz and Sasmaz, 2017).

Translocation factor (TLF), as defined by Yoon et al. (2006) and Sasmaz and Sasmaz (2017), is calculated as the ratio of element content in leaves to that in roots. This ratio was used to evaluate the efficiency of element uptake in aboveground plant parts and the transfer capacity of the plant from roots to leaves. Plants with a TLF > 1 are considered to have a phytoextraction potential (Baker and Brooks, 1989). The TLF is an important factor for phytoremediation since it represents the ability of a plant to absorb the element from the soil and transfer it into aboveground parts that might be harvested (Yu et al, 2008).

The metal accumulation index (MAI; Liu et al., 2007) was used to evaluate the overall performance of the selected plants in terms of element accumulation in leaves. The MAI was calculated as:

$$\mathrm{MAI} = (1 \big/ \mathrm{N}) \sum_{j=1}^{N} Ij$$

where N is the total number of elements analyzed and $\mathrm{Ij} = \mathrm{x/dx}$ is the subindex for variable j obtained by dividing the mean (x) of each metal by its standard deviation (dx). In this particular case, the MAI was calculated as follows:

$$\mathrm{MAI} = (\mathrm{ILi} + \mathrm{ISr})/2 = (\mathrm{xLi/dLi} + \mathrm{xSr/dSr})/2$$

The MAI was calculated for each plant at each sampling site and presented as the average MAI value for every plant species.

The relationship between the content of the studied elements in the soil, root and leaf samples was evaluated using the nonparametric Spearman correlation (the normality test showed that there was no normal distribution). To determine statistically significant differences between the measured contents of the elements in the root and leaf samples, a one-way ANOVA with least significant difference (LSD) post-hoc test was used. The level of statistical significance of the ANOVA test and Spearman's correlations are marked with * for $p < 0.05$, ** for $p < 0.01$, and *** for $p < 0.001$.

Descriptive and multivariate statistical analyses were performed using Statistica 12.0 software (StaSoft Inc, 2013). The attached map was created using ArcGis program ArcMap 10.6.1 (Esri Inc, 2018).

3. Results and discussion

3.1. Physical and chemical properties of the soil

The physical and chemical properties of the soil affect the availability of PTEs to plants. Overall, soil pH plays a critical role in regulating the availability of elements by influencing cation exchange processes and sorption of elements to clay particles and surfaces of organic matter (Adriano, 2001). Therefore, when assessing the ecological condition of soil, it is important to understand the influence of these physical and chemical properties on element availability. In addition, plant root exudates contribute significantly to element availability (Alloway, 1995).

The soils analyzed in this study were classified as slightly to moderately alkaline in terms of pH and neutral to slightly alkaline in terms of substitution acidity (Table 1). The granulometric composition of the soil in the study area varied along the length of the river. The proportion of total sand in the soil decreased downstream, while the proportion of silt and clay increased and dominated in the middle and lower courses of the river. Such variations are typical of soils in river reaches (Jerolmack and Brzinski, 2010). In the upper and middle sections, soils fell into three textural classes: sand (LIT), loamy sand (RAD, ZAG, JAS), and sandy loam (MOJ, VRH, CAT, ZAG). In the lower course, the proportion of slit and clay increased, while the sand fraction decreased, leading to loam (SLB, ZUP, SRM), silty loam (ZUP, SRM, SAB, BEO), and silty-clay loam (BEO) soils (Table 1).

Sandy soils in the upper and middle sections of a river experience greater leaching of particles and elements during precipitation and flooding due to their higher water permeability (Dvořák and Novák, 1994). Consequently, the studied sites with higher sand content had lower hygroscopic moisture contents (HM %) (Table 1). In contrast, soils with higher clay content have a larger adsorptive surface area, which allows them to bind more hygroscopic moisture and PTEs. Organic matter also contributes to higher moisture retention (Antić et al., 1982), as observed in sites with higher carbon content (Table 1).

In addition, carbon and nitrogen contents in soil samples were found to be low, most likely due to leaching during flooding and precipitation. Favorable carbon to nitrogen (C:N) ratios for organic matter decomposition ($<$20; Esmaeilzadeh and Ahangar, 2014) were calculated for MOJ in the upper course and for ZUP, SRM, SAB and BEO in the lower course of the river (Table 1). In contrast, RAD, LIT, ZAG and JAS had higher C:N ratios, which may lead to nitrogen immobilization and lower nitrogen availability, negatively affecting plant growth and development (Esmaeilzadeh and Ahangar, 2014; Hagemann et al., 2016).

3.2. Li and Sr content in soils

The average content of Li in soils of the world is 13–28 mg kg^{-1}, with the highest values measured in those with heavier mechanical composition and the lowest in sandy soils (Kabata-Pendias, 2011). In the Foregs Geochemical Atlas of Europe, the average Li content of floodplain sediments is reported to be 27.5 mg kg^{-1} (Salminen, 2005). Soil Li content values measured at all sampling sites except MOJ and RAD were higher than global averages for soils and values reported in the Foregs Geochemical Atlas of Europe (Table 2). The Li content in the studied soils exhibited an increasing trend from the source to the river mouth. Lithium has been reported as phytotoxic at soil in concentrations above 50 ppm (Franzaring et al., 2016). Since the results of Li content in soils show that Li is present at concentrations greater than 50 mg kg^{-1} at most sampling sites, possible toxic effects on plants are expected to occur (Table 2).

Strontium content in soils is estimated to range from 87 mg kg^{-1} to 210 mg kg^{-1} worldwide (Kabata-Pendias and Mukherjee, 2007). According to the Foregs Geochemical Atlas of Europe, the average Sr content in topsoil is 130 mg kg^{-1}, while the value in subsoil increases to 143 mg kg^{-1} (Salminen, 2005). The analyzed soils had a relatively uniform Sr content, except for the soils in the upper course of the river (Table 2). The maximum Sr content was measured in Zagreb (205.10 mg kg^{-1}). The most of the measured Sr content in soils were above the values given in Foregs Geochemical Atlas of Europe (Table 2). Calcium content in soils largely determines the chemistry of Sr and a Ca:

Table 1
Physical and chemical characteristics of soil.

Site	Depth cm	pH (H2O)	pH (KCl)	C %	N%	C:N	$CaCO_{3\%}$	HM %	Sand (%)	Silt (%)	Clay (%)	Texture class
MOJ	0-10	7.37	6.92	24.09	1.34	15.37	28.88	5.5	58.54	37.26	4.20	Sandy loam
RAD	0-30	8.06	7.64	9.72	0.12	41.90	39.23	1.5	79.24	16.75	4.01	Loamy sand
	30-60	7.44	7.48	8.60	0.07	48.89	31.06	1.3	82.84	13.42	3.74	Loamy sand
LIT	0-30	8.17	7.96	5.74	0.08	35.20	23.77	0.9	90.09	9.29	0.62	Sand
	30-60	8.02	7.81	5.29	0.05	51.73	25.66	0.8	91.82	7.28	0.90	Sand
VRH	0-30	7.87	7.49	5.68	0.14	25.51	16.63	0.7	69.99	25.69	4.32	Sandy loam
CAT	0-30	7.98	7.44	5.38	0.16	20.91	16.23	2.6	55.34	37.94	6.72	Sandy loam
	30-60	7.53	7.08	5.26	0.14	24.38	15.16	3.7	48.93	43.82	7.25	Loam
ZAG	0-30	8.00	7.69	6.33	0.08	39.89	25.56	1.8	76.75	18.41	4.84	Loamy sand
	30-60	7.70	7.36	6.08	0.08	41.59	22.24	2.2	71.35	22.86	5.79	Sandy loam
JAS	0-30	8.03	7.75	5.87	0.06	40.72	27.61	1.7	80.76	14.99	4.25	Loamy sand
	30-60	7.70	7.53	5.48	0.04	58.05	26.19	2.3	80.44	8.73	2.75	Loamy sand
SLB	0-30	7.92	7.37	4.60	0.13	20.83	16.62	2.7	42.70	42.10	15.20	Loam
	30-60	7.68	7.17	4.26	0.11	21.10	16.63	3.5	49.59	39.56	10.85	Loam
ZUP	0-30	7.88	7.29	3.68	0.14	15.09	12.94	3.5	26.08	56.68	17.24	Silty loam
	30-60	7.81	7.15	3.08	0.11	13.89	12.73	3.6	29.50	49.13	21.37	Loam
SRM	0-30	7.88	7.42	3.41	0.15	11.00	11.09	3.6	22.26	55.57	22.17	Silty loam
	30-60	7.78	7.25	3.37	0.13	12.25	14.96	3.7	43.94	43.61	12.45	Loam
SAB	0-30	7.86	7.32	3.34	0.15	12.72	11.82	3.2	20.49	63.15	16.36	Silty loam
	30-60	7.74	7.06	3.20	0.14	12.51	11.39	4.5	19.80	61.09	19.11	Silty loam
BEO	0-30	7.82	7.21	4.28	0.23	11.17	10.77	4.2	7.91	64.75	27.34	Silty-clay loam
	30-60	7.70	7.07	3.04	0.17	11.13	9.53	4.4	10.80	63.47	25.73	Silty loam

Table 2
The content of Li and Sr in soil; mean with standard deviation in parentheses; in mg kg^{-1}.

Site	Depth (cm)	Li	Sr	Site	Depth (cm)	Li	Sr
MOJ	0-10	12.42 (0.89)	63.23 (4.23)	SLB	0-30	52.09 (0.08)	180.76 (1.92)
RAD	0-30	19.92 (1.29)	105.01 (6.53)		30-60	63.66 (0.81)	184.49 (1.78)
	30-60	27.53 (0.36)	196.41 (3.43)	ZUP	0-30	60.23 (0.81)	158,62 (0.47)
LIT	0-30	49.10 (0.34)	95.11 (3.45)		30-60	80.92 (1.71)	158.76 (2.19)
	30-60	46.60 (1.69)	64.85 (0.64)	SRM	0-30	76.14 (1.02)	166.59 (0.95)
VRH	0-30	54.72 (0.21)	165.34 (2.22)		30-60	83.93 (0.73)	186.20 (1.89)
CAT	0-30	63.95 (0.56)	182.13 (2.15)	SAB	0-30	72.21 (0.69)	158.52 (0.71)
	30-60	76.27 (0.99)	183.40 (3.54)		30-60	85.74 (0.92)	166.88 (1.71)
ZAG	0-30	43.36 (0.17)	205.10 (1.28)	BEO	0-30	93.77 (2.17)	163.84 (3.74)
	30-60	51.91 (2.48)	202.72 (2.67)		30-60	97.58 (0.48)	164.93 (2.43)
JAS	0-30	37.35 (0.30)	166.45 (1.27)	Mean value for the entire stretch		56.96	156.08
	30-60	29.21 (0.20)	164.89 (1.18)	Average for world soils[a]		13-28	87-210

[a] Kabata-Pendias and Mukherjee (2007)

Sr ratio of less than 8 in soil indicates Sr toxicity (Kabata-Pendias, 2011). Although the Ca content in soil and plants was not a subject of the research in this work, determining the content of chemical elements in soil also included the content of this element. The results showed that the Ca:Sr ratio varied from 630 in BEO to 1730 in LIT - much higher than 8, indicating that there is no risk of toxicity of this element in soil.

In general, soil minerals absorb more Sr than Li and higher Li levels in soil could lead to Sr precipitation and lower uptake of this element by plants (Burger and Lichtscheidl, 2019). High $CaCO_3$ content in soils reduces the uptake of Li and Sr by plants (Anderson, 1990; Burger and Lichtscheidl, 2019). On the other hand, increased hygroscopic soil moisture leads to higher availability of Sr to plants (Burger and Lichtscheidl, 2019). The uptake of strontium by plants is the highest in sandy soils with low clay and organic matter content (Baes et al., 1986). Considering that investigated soils have relatively high percent of the sand and low percent of carbon and $CaCO_3$ (Table 1), it is expected to have high Sr accumulation in plants.

3.3. Li and Sr content in plants

The uptake of these elements by plants is influenced by both the physical and chemical properties of the soil and the unique morpho-physiological characteristics of plants. These include the structure of roots and leaves and species-specific mechanisms of uptake and accumulation (Mitrović et al., 2008; Franzaring et al., 2016; Pavlović et al., 2017). Plants are also used to indicate and monitor the content of these elements in habitats so as to identify the spatial and temporal distribution of contaminants. Plant adaptations to elevated PTE levels vary. While some accumulate the toxic elements at the root level, others transport them to the aboveground parts (translocation), especially the leaves, and accumulate them there (Markert et al., 2003; Gajić et al., 2020). Despite numerous limitations in using plants for bioindication and biomonitoring of soil pollution, they have significant advantages over chemical analyses of soil quality, especially when research is conducted on large spatial scales (Madejón et al., 2006).

The amount of lithium in plants usually ranges from 0.2 and 30 mg kg^{-1} and is species-specific (Aral and Vecchio-Sadus, 2008; Tanveer et al., 2019). In the available literature, there are no accurate empirical data on reference values for Li concentrations in plant tissues, including toxic levels of this element. There are data that species from the Fabaceae family (*A. fruticosa* in our study) grow successfully on lithium rich soils, while some species from the Asteraceae family (family of *S. canadensis*), e.g. *Cirsium vulgare*, have high Li uptake (Ezdakova, 1964; Kastori et al., 2022). In terms of toxicity, previous studies show that the threshold concentrations of Li vary widely. Moderate to severe toxic effects were observed at Li concentrations of 4 to 40 mg kg^{-1} in leaves of woody species, e.g. citrus plants (Gough et al., 1979), while toxic symptoms in avocados occurred at 6 mg kg^{-1} and reduced growth by 25% (Bingham et al., 1964; Shahzad et al., 2016). Therefore, the range of toxic levels was set at the wide range of 5 to 50 mg kg^{-1} proposed by Kabata-Pendias (2011), which is often used as a general guide for assessing accumulated toxic Li levels in plants. That implies that additional research into the toxicity of Li in plants needs to be conducted.

Sr content in plants also varies widely, with the highest concentrations usually found in above-ground plant parts. The accumulation of this element is also species-specific. Low amounts of Sr are found in plants used as food (1–4 mg kg^{-1}; D′Archivio et al., 2019) or medicine (*Hypericum perforatum*: 7–19 mg kg^{-1}; Bonari et al., 2019). Plants growing in mining areas, such as plants from the genera Onosma, Anchusa, Alyssum, and Silene, have high levels of this element (100–600 mg kg^{-1}; Sasmaz and Sasmaz, 2017). The proposed threshold concentrations for Sr are above 30 mg kg^{-1} (Shacklette et al., 1978; Kabata-Pendias, 2011) and it will be used as a guideline for assessing accumulated toxic Sr content in plants.

In this study, all native species analyzed showed significant potential for the accumulation of Li and Sr at levels within a range considered toxic to plants in roots and leaves (Li: 5–50; Sr: >30; Brooks, 1972; Shacklette et al., 1978, Kabata-Pendias, 2011). The highest accumulation of Li in roots was measured in *Ulmus glabra* and in leaves in *Salix alba*. The highest Sr content in roots was measured in *Juglans regia* and in leaves in *Populus nigra* (Table 3). The potential for accumulation of Li and Sr in a range considered toxic to plants was also measured in the roots and leaves of the invasive species. The highest accumulation of Li in roots and leaves was measured in *Solidago canadensis*, while the highest Sr content in roots and leaves was measured in *Impatiens*

Table 3
The content of Li and Sr in the roots and leaves of the examined plants; mean values in mg kg^{-1} dry mass, with standard deviation in parentheses.

Native species

Site	Salix alba				Populus nigra				Ulmus glabra				Juglans regia			
	Roots		Leaves		Roots		Leaves		Roots		Leaves		Roots		Leaves	
	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr
MOJ	<LoQ	20.91 (0.42)	7.23 (1.64)	74.78 (0.55)	<LoQ	22.83 (2.41)	<LoQ	47.88 (0.55)					<LoQ	17.42 (0.09)	<LoQ	52.79 (0.23)
RAD	<LoQ	20.18 (0.38)	<LoQ	48.91 (0.28)					9.47 (1.03)	52.44 (5.30)	<LoQ	44.17 (0.29)	<LoQ	51.26 (0.35)	<LoQ	43.77 (0.54)
LIT	17.58 (2.41)	23.00 (0.89)	9.39 (0.23)	34.11 (0.28)					<LoQ	25.36 (0.07)	<LoQ	31.11 (0.11)	<LoQ	69.59 (0.20)	<LoQ	59.45 (0.11)
VRH	<LoQ	33.17 (1.75)	6.86 (0.42)	59.46 (0.36)	<LoQ	18.20 (2.56)	<LoQ	38.71 (0.55)					<LoQ	30.63 (0.28)	<LoQ	38.84 (0.29)
CAT	<LoQ	36.63 (0.17)	8.80 (0.69)	91.44 (1.45)	<LoQ	29.64 (0.75)	<LoQ	63.80 (0.37)	<LoQ	13.84 (0.33)	<LoQ	46.14 (1.98)	13.92 (1.88)	69.45 (1.38)	10.58 (0.35)	96.50 (0.70)
ZAG	<LoQ	29.19 (1.20)	6.89 (0.33)	61.44 (0.58)	<LoQ	43.10 (0.35)	<LoQ	65.77 (1.03)	<LoQ	23.57 (1.49)	<LoQ	46.73 (0.25)				
JAS	<LoQ	21.33 (0.51)	7.19 (0.69)	46.43 (0.20)	7.38 (0.54)	37.58 (1.55)	<LoQ	50.85 (0.76)	50.21 (2.28)	58.16 (8.00)	16.31 (0.18)	49.69 (0.80)	9.19 (0.37)	53.24 (0.41)	<LoQ	48.73 (0.24)
SLB	16.39 (1.57)	26.09 (0.29)	12.58 (2.67)	53.44 (2.82)					15.50 (0.64)	45.76 (0.40)	19.50 (0.77)	60.92 (1.38)				
ZUP	21.73 (1.75)	36.19 (1.14)	8.58 (1.52)	61.53 (0.13)	<LoQ	25.13 (0.10)	<LoQ	96.15 (0.39)	8.16 (0.50)	31.12 (0.30)	<LoQ	48.11 (0.67)				
SRM	19.72 (2.37)	41.88 (0.75)	<LoQ	107.66 (0.65)	8.93 (0.48)	33.58 (0.09)	<LoQ	113.11 (1.01)	10.10 (1.78)	35.83 (0.32)	<LoQ	47.83 (1.28)	11.72 (0.49)	40.26 (0.74)	<LoQ	62.19 (0.93)
SAB	21.03 (1.97)	39.08 (1.02)	22.01 (5.64)	86.89 (0.48)	13.90 (0.53)	53.11 (3.99)	<LoQ	64.64 (0.50)	<LoQ	34.14 (0.19)	<LoQ	53.03 (0.24)				
BEO	9.18 (1.03)	32.88 (0.75)	<LoQ	68.81 (0.75)	9.78 (1.05)	51.82 (1.01)	<LoQ	48.93 (0.33)	15.53 (0.79)	24.50 (0.45)	<LoQ	51.74 (0.15)				

Invasive species

Site	Amorpha fruticosa				Solidago canadensis				Reynoutria japonica				Impatiens glandulifera			
	Roots		Leaves		Roots		Leaves		Roots		Leaves		Roots		Leaves	
	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr
MOJ					<LoQ	19.37 (1.26)	<LoQ	23.75 (1.39)	<LoQ	40.00 (5.20)	<LoQ	47.94 (1.62)	8.54 (1.40)	31.84 (1.28)	7.43 (1.27)	75.80 (1.62)
RAD					<LoQ	13.89 (1.05)	<LoQ	17.83 (1.36)	<LoQ	28.61 (3.59)	<LoQ	31.23 (1.34)	19.27 (1.79)	74.29 (6.63)	<LoQ	61.55 (1.09)
LIT					21.08 (4.13)	34.66 (2.51)	18.66 (1.54)	40.29 (0.42)	8.80 (1.98)	21.33 (1.86)	<LoQ	39.62 (1.10)	7.21 (0.83)	33.45 (2.35)	<LoQ	66.51 (2.29)
VRH					8.33 (2.49)	27.39 (1.99)	<LoQ	26.30 (1.54)	<LoQ	22.25 (1.98)	<LoQ	29.27 (0.20)	8.57 (2.04)	51.10 (2.45)	11.13 (1.48)	47.58 (0.52)
CAT					<LoQ	30.73 (4.16)	7.91 (1.28)	36.83 (0.26)	<LoQ	29.86 (1.33)	<LoQ	48.11 (0.72)	6.71 (0.53)	43.75 (3.35)	<LoQ	68.83 (2.09)
ZAG					<LoQ	24.36 (0.48)	17.28 (1.58)	45.99 (1.95)	<LoQ	17.89 (2.00)	<LoQ	42.66 (0.48)	20.10 (3.21)	87.33 (4.98)	8.87 (1.66)	80.53 (1.74)
JAS	<LoQ	18.50 (1.08)	<LoQ	39.03 (0.41)	<LoQ	14.03 (0.22)	<LoQ	25.58 (0.36)								
SLB	8.66 (2.78)	18.04 (0.64)	<LoQ	41.66 (0.90)												
ZUP	<LoQ	20.83 (0.25)	<LoQ	43.84 (0.55)												
SRM	<LoQ	12.55 (1.98)	<LoQ	37.69 (2.09)												
SAB	<LoQ	12.56 (1.85)	<LoQ	41.79 (0.38)												
BEO	<LoQ	12.52 (1.22)	<LoQ	55.32 (1.02)												
Normal content in plants[a]: Li: 3-5; Sr: 1-10									Toxic content in plants[a]: Li: 5-50; Sr: > 30							

[a] Kabata-Pendias (2011); <LoQ – below the limit of quantification

glandulifera (Table 3).

The average Li accumulation in the roots of the studied species followed this order: *Ulmus glabra* > *Salix alba* > *Solidago canadensis* > *Impatiens glandulifera* > *Juglans regia* > *Populus nigra* > *Reynoutria japonica* > *Amorpha fruticosa*. In leaves, the average accumulation order was: *Ulmus glabra* > *Solidago canadensis* > *Salix alba* > *Impatiens glandulifera* > *Juglans regia* > *Populus nigra* = *Amorpha fruticosa* = *Reynoutria japonica*. For Sr accumulation, the average values in roots decreased as follows: *Impatiens glandulifera* > *Juglans regia* > *Populus nigra* > *Ulmus glabra* > *Salix alba* > *Reynoutria japonica* > *Solidago canadensis* > *Amorpha fruticosa*. In leaves, the order of average accumulation was: *Impatiens glandulifera* > *Salix alba* > *Populus nigra* > *Juglans regia* > *Ulmus glabra* > *Amorpha fruticosa* > *Reynoutria japonica* > *Solidago canadensis*.

Due to the relatively low clay content in the soils studied, which is a critical factor in the availability of Li to plants, it was expected that plants would accumulate this element at lower levels compared to Sr. The Li uptake in plants was lower, especially in the upper reaches of the river, which could also be due to higher $CaCO_3$ levels in the soils, as Ca reduces the availability of Li to plants (Tables 1 and 3; Burger and Lichtscheidl, 2019).

The results of the ANOVA test showed no significant differences between the uptake of Li in the roots of native species and those of invasive ones. On the other hand, there were significant differences when it came to Sr uptake in the studied species and also Li uptake in leaves (Table 4). The most interesting differences were in Sr content in roots, with *Impatiens glandulifera* showing statistically significant differences from all the other species studied, with the exception of *Juglans regia*. These two species had the highest Sr accumulation in roots when compared to the other species studied. Moreover, Sr uptake in the roots of *Amorpha fruticosa* was statistically significantly different from all the other species studied, except *Solidago canadensis* and *Reynoutria japonica*, with these three species having the lowest Sr uptake in roots (Tables 3 and 4). *Salix alba, Populus nigra,* and *Impatiens glandulifera,* which accumulated the highest amounts of Sr in their leaves, showed the most significant differences ($p < 0.01$ and $p < 0.001$) from *Amorpha fruticosa, Solidago canadensis,* and *Reynoutria japonica*, which accumulated the lowest Sr levels in their leaves. *Salix alba* exhibited statistically significant differences from the other species, apart from *Ulmus glabra, Solidago canadensis,* and *Impatiens glandulifera*, based on Li uptake in leaves. These species accumulated high Li levels in leaves at some sampling sites, whereas we can observe that the other species did not accumulate Li in their leaves (Tables 3 and 4).

To analyze and evaluate the potential of the studied species for the bioindication of Li and Sr contamination, the levels of these elements in soil and plant material (roots and leaves) were correlated. The results indicated that the roots of *Salix alba, Populus nigra* and *Juglans regia* could be used for the bioindication of Li content in the riparian soils of the Sava River, while the roots of *Impatiens glandulifera* could be used for the bioindication of Sr (Table 5). The leaves of *Salix alba* could be used for the bioindication of Sr content in these soils, while the leaves of *Solidago canadensis* could be used for the bioindication of Li and Sr in the surface layer of the soil (0–30 cm). The leaves of *Juglans regia* also have significant potential for the bioindication of Sr in the surface layer of the soil (Table 5).

Despite the accumulation of Li and Sr in levels that could be considered toxic to plants in the roots and leaves of the plants studied, ECR and ECS values were generally lower than 1 (Fig. 2). The highest ECR value for Li was calculated for *Ulmus glabra* at the JAS sampling site (1.34 for 0–30 cm soil depth and 1.72 for 30–60 cm soil depth), with this being the only ECR value higher than 1. The highest ECR value for Sr was calculated for *Juglans regia* at the LIT sampling site (0.73 for 0–30 cm soil depth and 1.07 for 30–60 cm soil depth). *Impatiens glandulifera* had the highest ECS values for both Li and Sr at the MOJ sampling site (0.60 for Li and 1.20 for Sr). The same species also had the highest TLF for Li at the VRH sampling site (1.30). On the other hand, TLF values for Sr were higher than 1 in all the analyzed plant species, thus indicating the great potential for plants to transfer Sr from roots to

Table 4
ANOVA comparison of the uptake of Li and Sr between the studied species.

Li content in leaves								
Species	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
Salix alba {1}		0.003**	0.098	0.024*	0.008**	0.642	0.008**	0.288
Populus nigra {2}	0.003**		0.153	0.580	1.000	0.025*	1.000	0.113
Ulmus glabra {3}	0.098	0.153		0.439	0.203	0.316	0.203	0.723
Juglans regia {4}	0.024*	0.580	0.439		0.616	0.104	0.616	0.311
Amorpha fruticosa {5}	0.008**	1.000	0.203	0.616		0.041*	1.000	0.147
Solidago canadensis {6}	0.642	0.025*	0.316	0.104	0.041*		0.041*	0.574
Reynoutria japonica {7}	0.008**	1.000	0.203	0.616	1.000	0.041*		0.147
Impatiens glandulifera {8}	0.288	0.113	0.723	0.311	0.147	0.574	0.147	
Sr content in roots								
Species	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
Salix alba {1}		0.418	0.456	0.051	0.044*	0.321	0.624	0.001**
Populus nigra {2}	0.418		0.934	0.247	0.011*	0.103	0.255	0.013*
Ulmus glabra {3}	0.456	0.934		0.208	0.011*	0.111	0.276	0.009**
Juglans regia {4}	0.051	0.247	0.208		0.001***	0.010*	0.036*	0.176
Amorpha fruticosa {5}	0.044*	0.011*	0.011*	0.001***		0.322	0.179	0.000***
Solidago canadensis {6}	0.321	0.103	0.111	0.010*	0.322		0.681	0.000***
Reynoutria japonica {7}	0.624	0.255	0.276	0.036*	0.179	0.681		0.001**
Impatiens glandulifera {8}	0.001**	0.013*	0.009**	0.176	0.000***	0.000***	0.001*	
Sr content in leaves								
Species	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
Salix alba {1}		0.916	0.007**	0.085	0.004**	0.000***	0.001***	0.942
Populus nigra {2}	0.916		0.014*	0.124	0.007**	0.000***	0.002**	0.875
Ulmus glabra {3}	0.007**	0.014*		0.451	0.548	0.026*	0.302	0.019*
Juglans regia {4}	0.085	0.124	0.451		0.223	0.007**	0.107	0.123
Amorpha fruticosa {5}	0.004**	0.007**	0.548	0.223		0.150	0.697	0.009**
Solidago canadensis {6}	0.000***	0.000***	0.026*	0.007**	0.150		0.297	0.000***
Reynoutria japonica {7}	0.001***	0.002**	0.302	0.107	0.697			0.003**
Impatiens glandulifera {8}	0.942	0.875	0.019*	0.123	0.009**	0.000***	0.003**	

Table 5
Correlations between Li and Sr contents in soils and roots and leaves of the plant species studied.

		Roots															
		S. alba		*P. nigra*		*U. glabra*		*J. regia*		*A. fruticosa*		*S. canadensis*		*R. japonica*		*I. glandulifera*	
		Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr
Soil	0-30	0.509***	0.143	0.599***	0.193	-0.048	-0.203	0.635***	0.088	-0.154	0.180	0.256	0.125	0.220	0.106	-0.299	0.501**
	30-60	0.558***	-0.033	0.677***	0.199	-0.060	0.103	0.707***	-0.615***	-0.003	-0.268	0.071	-0.571***	-0.121	0.707***	-0.566**	0.754***
		Leaves															
		S. alba		*P. nigra*		*U. glabra*		*J. regia*		*A. fruticosa*		*R. japonica*		*S. canadensis*		*I. glandulifera*	
		Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr	Li	Sr
Soil	0-30	0.004	0.322**	/	-0.052	-0.319*	0.250	-0.353*	0.427**	-0.259	-0.214	/	-0.035	0.363*	0.432**	0.040	0.010
	30-60	0.063	0.285*	/	0.241	-0.318*	-0.086	-0.338	-0.179	-0.338*	-0.432**	/	0.012	0.349	-0.248	0.014	0.279

leaves, meaning these plants could be considered to have a Sr phytoextraction potential (TLF >1; Baker and Brooks, 1989). According to Pulford and Watson (2003), plants with accumulation and translocation factors less than 1 are considered excluders. The results obtained indicate that all the plants studied are Li excluders. The MAI results (Fig. 2) indicated a significant difference between native and invasive species, revealing that native species have a higher capacity to accumulate Li and Sr in their leaves.

Salix alba has been shown to have the ability to accumulate Li and Sr contents in its roots and leaves that could be considered toxic. In addition, this species has shown efficient translocation of these elements, particularly Sr, from roots to leaves. With a TLF greater than 1, *S. alba* can be considered to have a Sr phytoextraction potential. The leaves of this species could be used for the bioindication of Sr, while the roots could be good bioindicators of Li in soils near rivers. Previous studies on Sr accumulation in Salix species focused on *Salix viminalis* as an experimental treatment for radiostrontium Sr-90 (von Fircks et al., 2002) and *Salix caprea* (Dutton and Humphreys, 2005) and showed that these Salix species accumulate Sr in leaves. High translocation of Sr in leaves was also found in *S. viminalis* in a heavily contaminated area in the suburbs of Debrecen, Hungary (Tőzsér et al., 2018). Another study on *Salix viminalis* found a bioaccumulation factor below 1 and a translocation factor for Sr above 1 (Mleczek et al., 2018). In *Salix reticulata*, the accumulation of Sr in leaves was also higher than in stems (Myrvang et al., 2016). Salix sp. affected by mining and municipal wastewater (Elazig, Turkey) accumulated similar Sr levels in its roots and leaves (Sasmaz et al., 2021). To the best of our knowledge, Li content in Salix species has not yet been studied.

Populus nigra accumulated Sr in a toxic range in its leaves and roots, while it accumulated toxic levels of Li only in its roots. This species also has a high ability to transfer Sr from its roots to its leaves, and with a TLF above 1, it could be considered to have a Sr phytorextraction potential. On the other hand, the roots of *Populus nigra* could be good bioindicators of Li in soils near rivers. Previous studies on Sr accumulation in Populus species have included investigating the uptake of radiostrontium Sr-90 by *Populus tremula*, as conducted by Dutton and Humphreys (2005), and the results indicated the accumulation of Sr in the leaves of this species. *Populus alba* was also found to be a good phytoextractor of Sr in Sr-contaminated soils (Liang et al., 2023). Zhang et al. (2017) concluded that poplars are adapted to environmental stress resulting from the presence of Sr. To our knowledge, this is the first study on Li content in Populus species.

Ulmus glabra also accumulated contents of Li and Sr that could be considered toxic in its leaves and roots, with high root-leaf translocation of Sr. With a TLF above 1, this species could be considered to have a phytoextraction potential for Sr. An earlier study of this species also found that extremely high levels of Sr accumulated in its leaves (up to 17650 mg kg^{-1}; Bowen and Dymond, 1955) on soils that are medium rich in this element in Britain. The Li content in leaves and soils of *U. glabra* is significantly negatively correlated. In addition, we did not find any studies on the content of Li in Ulmus species during a literature search.

Juglans regia may also have phytoextraction potential for Sr, with a TLF above 1 and accumulated levels of this element in its roots and leaves that could be considered toxic. Previous experimental studies have also shown the potential for Sr accumulation in its leaves (up to 44 mg kg^{-1}; Nečemer et al., 2008). This species accumulated Li levels in its roots that could be considered toxic at the sampling sites CAT, ZAG, and SRM, but further studies are needed to investigate the ability of this species to accumulate and transfer Li in leaves. At the JAS sampling site, only one TLF factor was calculated for Li (1.15), which is insufficient to determine the potential for phytoremediation of this element with *J. regia*. On the other hand, the roots of this species could be good bioindicators of Li content in soils. As far as we know, the content of Li in Juglans species has not yet been studied.

Amorpha fruticosa accumulated Li contents in its roots that could be

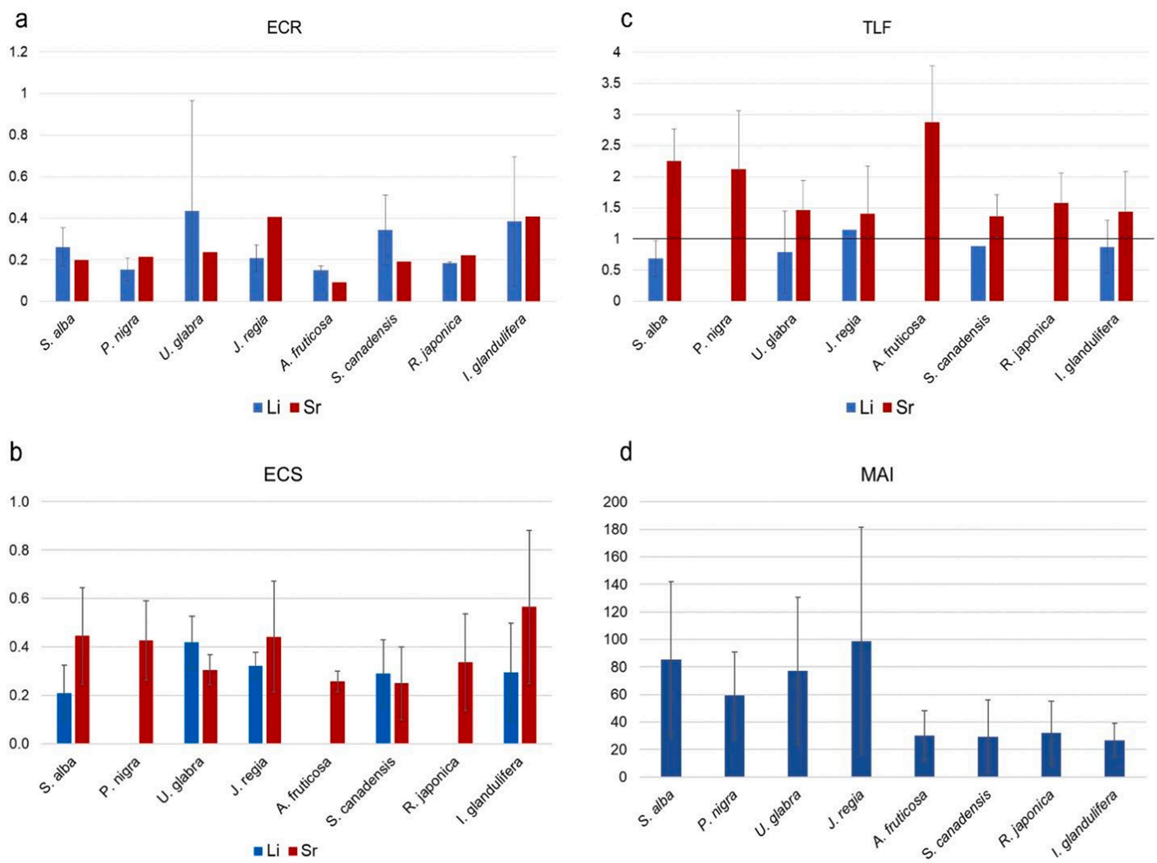

Fig. 2. a – ECR values, accumulation capacity of roots; b – ECS values, accumulation capacity of leaves; c – TLF values, ability to transfer elements from roots to leaves; d – MAI values, metal accumulation index for Li and Sr in the examined plants.

considered toxic at only one sampling site, SLB; otherwise, this species did not accumulate this element at all. On the other hand, toxic Sr levels were measured in its leaves, with the highest TLF of all the species studied (4.42 at the BEO sampling site). Therefore, it could be considered to have a high phytoextraction potential for Sr. Based on the results of correlation analyses, this species cannot be used for the bioindication of Li and Sr in riparian soils because there was no significant correlation between the contents of these elements in plants and soils.

Reynoutria japonica, similar to *A. fruticosa*, accumulated Li levels in its roots that could be considered toxic at only one sampling site (LIT), while this species did not accumulate Li at all in its leaves. Sr contents that could be considered toxic were measured in its leaves at all the sampling sites except VRH, but in its roots only at the MOJ site. Most of the Sr accumulated by this plant was transferred to the leaves. With a TLF greater than 1, this species could also be considered to have a Sr phytoextraction potential, but it cannot be used for the bioindication of Li and Sr. To the best of our knowledge, no research has been conducted on the content of Li and Sr in Amorpha and Reynoutria species.

Solidago canadensis accumulated contents of Li and Sr in its roots and leaves that could be considered toxic at some sampling sites (Table 3). Most of the accumulated Sr was translocated from roots to leaves and, with a TLF above 1, this species could be considered to have a Sr phytoextraction potential. In *Solidago virgaurea*, the accumulation of Sr in leaves was also higher than the accumulation in stems (Myrvang et al., 2016). Correlation analyses indicated that the roots of this species are not suitable for the bioindication of Li and Sr content in riparian soils, while the leaves could be used for the bioindication of Li and Sr content in the surface layer of the soil (0–30 cm).

Impatiens glandulifera accumulated contents of Li and Sr in its roots and leaves that could be considered toxic. With a TLF greater than 1, this species could be considered to have a phytoextraction potential for Sr. In addition, the roots of this species could be a good bioindicator of Sr content in riparian soils. To our knowledge, this is the first study on Li and Sr content in Impatiens species.

In general, the results suggest that native species are better bioindicators of Li and Sr than invasive species. This is most likely due to their greater adaptation to habitat conditions (Gajić et al., 2016). Invasive species, especially *Amorpha fruticosa*, are very good at translocating Sr in leaves while accumulating toxic contents of this element. This makes Amorpha the most suitable candidate for the phytoremediation of Sr from soils in river basins. Considering the fact that this species is *invasive* in Slovenia (Thuja 2, 2012), Croatia (Boršić et al., 2008) and Bosnia and Herzegovina (Maslo, 2016) and *highly invasive* in Serbia (Lazarević et al., 2012), appropriate environmental protection measures must be taken if this species is to be used for soil remediation.

4. Conclusion

In summary, this study shows the differences in the potential of native and invasive species for lithium (Li) and strontium (Sr) accumulation in riparian soils along the Sava River. Native species have shown excellent accumulation abilities for Li and Sr, with the highest accumulation of both elements measured in these plants. Also, based on the metal accumulation index, native species showed a significantly higher potential to accumulate Li and Sr compared to invasive species. According to the obtained correlations, a significant potential for bioindication of these elements in soils was found in native species. In particular, *Salix alba* appears to be a promising candidate for bioindication of Sr and Li in riverbank soils. Among the invasive species, *Amorpha fruticosa* has shown potential for phytoextraction of Sr, as it impressively translocates this element from the roots to the leaves. Among the all species studied, there is no strong candidate for the phytoremediation of Li, so further research is needed. These results contribute to the overall understanding of the role of plant species in ecosystem health and their potential for environmental bioindication and the phytoremediation of Li and Sr in soils.

CRediT authorship contribution statement

Zorana Miletić: Conceptualization, Writing – original draft, review and editing; Milica Marković: Data curation, Methodology; Snežana Jarić: Validation, Supervision; Natalija Radulović: Visualization, Investigation; Dimitrije Sekulić: Software, Investigation; Miroslava Mitrović: Writing - Reviewing and Editing; Pavle Pavlović: Funding acquisition, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

Adeel, M., Zain, M., Shakoor, N., Ahmad, M.A., Azeem, I., Aziz, M.A., Tulcan, R.X.S., Rathore, A., Tahir, M., Horton, R., Xu, M., Yukui, R., 2023. Global navigation of Lithium in water bodies and emerging human health crisis. In: npj Clean Water, Vol. 6. Nature Research. https://doi.org/10.1038/s41545-023-00238-w.

Adriano, D.C., 2001. Trace elements in terrestrial environments. Biogeochemistry, bioavailability and risk of metals. Springer,, New York.

Alexandrino, K., Viteri, F., Rybarczyk, Y., Guevara Andino, J.E., Zalakeviciute, R., 2020. Biomonitoring of metal levels in urban areas with different vehicular traffic intensity by using *Araucaria heterophylla* needles. Ecol. Indic. 117 (March), 106701 https://doi.org/10.1016/j.ecolind.2020.106701.

Blackie Academy and Profession, London. In: Alloway, B.J. (Ed.), 1995. Heavy metals in soils. https://doi.org/10.1007/978-94-011-1344-1.

Anderson, C.E., 1990. Lithium in plants. In: Bach, R.O., Gallichio, V.S. (Eds.), In Lithium and Cell Physiology. Springer –Verlag, pp. 25–46.

Soil Science Division Staff, 2017. Soil survey manual. In: Ditzler, C., Scheffe, K., Monger, H.C. (Eds.), USDA Handbook 18. Government Printing Office, Washington, D.C.

Antić, M., Joviš, N., Avdaloviš, V., (1982). Pedologija. Naučna knjiga. Beograd (in Serbian).

Aral, H., Vecchio-Sadus, A., 2008. Toxicity of lithium to humans and the environment—a literature review. Ecotoxicol. Environ. Saf. 70 (3), 349–356. https://doi.org/10.1016/J.ECOENV.2008.02.026.

Atterberg, A., 1911. Die Plastizitat der Tone. Int Mitt. Bodenkd. 1, 10–43.

Baes, C.F., Garten, C.T., Taylor, F.G., Witherspoon, J.P., 1986. Longterm environmental problems of radioactively contaminated land. Environ. Int. 12, 543–553.

Baker, A.J.M., Brooks, R.R., 1989. Terrestrial higher plants which hyperaccumulate metallicelements - a review of their distribution, ecology andphytocheistry. Biorecovery 1, 81–126.

Bañuelos, G.S., 2020. Factors influencing field phytoremediation of selenium-laden soils. In: Terry, N., Bañuelos, G.S. (Eds.), Phytoremediation of Contaminated Soil and Water. CRC Pr., Boca Raton, FL, pp. 41–59.

Baran, E.J., (2019). Lithium in plants. In: Advances in Plant Physiology, Hemantaranjan, A. (Ed), 18(18): 153.

Bingham, F., Bradford, G., Page, A., 1964. Toxicity of lithium to plants. Calif. Agric. 18.9, 6–7.

Birke, M., Rauch, U., Hofmann, F., 2018. Tree bark as a bioindicator of air pollution in the city of Stassfurt, Saxony-Anhalt, Germany. J. Geochem. Explor. 187, 97–117. https://doi.org/10.1016/j.gexplo.2017.09.007.

Bolan, N., Hoang, S.A., Tanveer, M., Wang, L., Bolan, S., Sooriyakumar, P., Robinson, B., Wijesekara, H., Wijesooriya, M., Keerthanan, S., Vithanage, M., Markert, B., Fränzle, S., Wünschmann, S., Sarkar, B., Vinu, A., Kirkham, M.B., Siddique, K.H.M., Rinklebe, J., 2021. From mine to mind and mobiles – Lithium contamination and its risk management. Environ. Pollut. 290, 118067 https://doi.org/10.1016/j.envpol.2021.118067.

Bonari, G., Monaci, F., Nannoni, F., Angiolini, C., Protano, G., 2019. Trace Element Uptake and Accumulation in the Medicinal Herb *Hypericum perforatum* L. Across Different Geolithological Settings. Biol Trace Elem Res 189, 267–276. https://doi.org/10.1007/s12011-018-1453-4.

Borojević Šoštarić, S., Brenko, T., 2023. The Miocene Western Balkan lithium-boron metallogenic zone. Min. Depos. 58, 639–658. https://doi.org/10.1007/s00126-022-01151-x.

Boršić, I., Milović, M., Dujmović, I., Bogdanović, S., Cigić, P., Rešetnik, I., Nikolić, T., Mitić, B., 2008. Preliminary check-list of invasive alien plant species (IAS) in Croatia. Nat. Croat. 17 (2), 55–71.

Bowen, H.J.M., Dymond, J.A., 1955. Strontium and Barium in Plants and Soils. P. Roy. Soc. B - Biol. Sci. 144 (916), 355–368. https://doi.org/10.1098/rspb.1955.0063.

Brooks, R., 1972. Geobotany and Biogeochemistry in Mineral Exploration. Harper and Row,, New York.

Burger, A., Lichtscheidl, I., 2019. Strontium in the environment: Review about reactions of plants towards stable and radioactive strontium isotopes. *Sci. Total Environ.* 653, 1458–1512. https://doi.org/10.1016/J.SCITOTENV.2018.10.312.

Burger, A., Weidinger, M., Adlassnig, W., Puschenreiter, M., Lichtscheidl, I., 2019. Response of Arabidopsis halleri to cesium and strontium in hydroponics: Extraction potential and effects on morphology and physiology. Ecotoxicol. Environ. Saf. 184 https://doi.org/10.1016/j.ecoenv.2019.109625.

Chen, S.B., Zhu, Y.G., Hu, Q.H., 2005. Soil to plant transfer of 238U, 226Ra and 232Th on U mining-impacted soil from southeastern China. J. Environ. Radioact. 82, 223–236.

Deepika, Haritash, A.K., 2023. Phytoremediation potential of ornamental plants for heavy metal removal from contaminated soil: a critical review. Hortic. Environ. Biotechnol. https://doi.org/10.1007/s13580-023-00518-x.

Dresler, S., Wójciak-Kosior, M., Sowa, I., Strzemski, M., Sawicki, J., Kováčik, J., Blicharski, T., 2018. Effect of long-term strontium exposure on the content of phytoestrogens and allantoin in soybean. Int. J. Mol. Sci. 19 (12) https://doi.org/10.3390/ijms19123864.

Dutton, M.V., Humphreys, P.N., 2005. Assessing the potential of short rotation coppice (SRC) for cleanup of radionuclide-contaminated sites. Int. J. Phytoremediat. 7 (4), 279–293. https://doi.org/10.1080/16226510500327137.

Dvořák, J., Novák, L., 1994. Chapter 2 Erosion of the Soil. In: Dvořák, J., Novák, L. (Eds.), Developments in Soil Science Vol 23. Elsevier, pp. 25–38.

Esmaeilzadeh, J., Ahangar, A.G., 2014. Influence of soil organic matter content on soil physical, chemical and biological properties. Int. J. Plant Anim. env. Sci. ⟨https://api.semanticscholar.org/CorpusID:46540054⟩.

Esri Inc. (2018). ArcMap (version 10.6.1). Software. Esri Inc, Redlands, CA. ⟨https://www.esri.com⟩.

Ezdakova, L.A., 1964. Litii v rastenijah. Bot. žurnal 12, 1798–1810.

Franzaring, Schlosser, S., Damsohn, W., Fangmeier, A., 2016. Regional differences in plant levels and investigations on the phytotoxicity of lithium. Environ. Pollut. 216, 858–865. https://doi.org/10.1016/j.envpol.2016.06.059.

Fu, W., Huang, K., Cai, H.H., Li, J., Zhai, D.L., Dai, Z.C., Du, D.L., 2017. Exploring the potential of naturalized plants for phytoremediation of heavy metal contamination. Int. J. Environ. Res. 11, 515–521. https://doi.org/10.1007/s41742-017-0045-z.

Gad, S.C., 2014. Strontium. In: Wexler, P. (Ed.), Encyclopedia of Toxicology (Third Edition). Academic Press, pp. 405–406. https://doi.org/10.1016/B978-0-12-386454-3.00931-3.

Gajić, G., Djurdjević, L., Kostić, O., Jarić, S., Mitrović, M., Stevanović, B., Pavlović, P., 2016. Assessment of the phytoremediation potential and an adaptive response of Festuca rubra L. sown on fly ash deposits: Native grass has a pivotal role in ecorestoration management. Ecol. Eng. 93, 250–261. https://doi.org/10.1016/j.ecoleng.2016.05.021.

Gajić, G., Djurdjević, L., Kostić, O., Jarić, S., Stevanović, B., Mitrović, M., Pavlović, P., 2020. Phytoremediation Potential, Photosynthetic and Antioxidant Response to Arsenic-Induced Stress of *Dactylis glomerata* L. Sown on Fly Ash Deposits. *Plants* (Basel) 9 (5), 657. https://doi.org/10.3390/plants9050657.

Gough, L.P., Shacklette, H.T., Case, A.A., 1979. Element concentrations toxic to plants. Anim., Man. U. S. Geol. Surv. Bull. 1466, 80.

Hagemann, N., Harter, J., Behrens, S., 2016. Elucidating the Impacts of Biochar Applications on Nitrogen Cycling Microbial Communities. In: Komang Ralebitso-Senior, T., Orr, C.H. (Eds.), Biochar Application. Elsevier Ltd, pp. 163–198. https://doi.org/10.1016/B978-0-12-803433-0.00007-2.

Hasanuzzaman, M., Nahar, K., Hakeem, K.R., Öztürk, M., Fujita, M., 2015. Arsenic Toxicity in Plants and Possible Remediation. Soil Remediation and Plants: Prospects and Challenges (Khalid Rehman Hakeem, Muhammad Sabir, Münir Öztürk, Ahmet Ruhi Mermut Eds). Academic Press,, pp. 433–501. https://doi.org/10.1016/B978-0-12-799937-1.00016-4.

ISRBC (2009). Sava River Basin analysis report. ⟨https://www.savacommission.org/UserDocsImages/05_documents_publications/water_management/eng/SavaRBMPlan//sava_river_basin_analysis_report_high_res.pdf⟩ Accessed 19 July 2023.

Jerolmack, D.J., Brzinski, T.A., 2010. Equivalence of abrupt grain size transitions in alluvial rivers and eolian sand seas: A hypothesis. Geology 38 (8), 719–722. https://doi.org/10.1130/G30922.1.

Kabata-Pendias, A., 2011. Trace Elements in Soils and Plants, Fourth ed..,. CRC Press,, Boca Raton.

Kabata-Pendias, A., Mukherjee, A.B., 2007. Trace elements from soil to human. Springer-Verlag,, Berlin Heidelberg, New York.

Kastori, R., Maksimović, I., Putnikdelić, M., 2022. Lithium in the Environment and its Effects on Higher Plants. Contemp. Agric. 71 (3–4), 226–239. https://doi.org/10.2478/contagri-2022-0030.

Kavanagh, L., Keohane, J., Cabellos, G.G., Lloyd, A., Cleary, J., 2018. Induced plant accumulation of lithium. Geosci. (Switz.) 8 (2). https://doi.org/10.3390/geosciences8020056.

Kumar Rai, P., Singh, J.S., 2020. Invasive alien plant species: their impact on environment, ecosystem services and human health. Ecol. Indic. 111, 106020 https://doi.org/10.1016/j.ecolind.2019.106020.

Lazarević, P., Stojanović, V., Jelić, I., Perić, R., Krsteski, B., Ajtić, R., Sekulić, N., Branović, S., Sekulić, G., Bjedov, V., 2012. Preliminarni spisak invazivnih vrsta u Srbiji, sa opštim merama kontrole i suzbijanja kao potpora budućim zakonskim aktima. Zaštita Prir. 62, 5–31.

Liang, Z., Zeng, H., Kong, J., 2023. Contrasting Responses and Phytoremediation Potential of Two Poplar Species to Combined Strontium and Diesel Oil Stress. Plants 12 (11), 2145. https://doi.org/10.3390/plants12112145.

Liu, Y.J., Zhu, Y.G., Ding, H., 2007. Lead and cadmium in leaves of deciduous trees in Beijing, China: Development of a metal accumulation index (MAI). Environ. Pollut. 145 (2), 387–390. https://doi.org/10.1016/j.envpol.2006.05.010.

Madejón, P., Marañón, T., Murillo, J.M., 2006. Biomonitoring of trace elements in the leaves and fruits of wild olive and holm oak trees. Sci. Total Environ. 355, 187–203. https://doi.org/10.1016/j.scitotenv.2005.02.028.

Madejón, P., Marañón, T., Navarro-Fernández, C.M., Domínguez, M.T., Alegre, J.M., Robinson, B., Murillo, J.M., 2017. Potential of *Eucalyptus camaldulensis* for phytostabilization and biomonitoring of traceelement contaminated soils. PLoS ONE 12 (6), 1–22. https://doi.org/10.1371/journal.pone.0180240.

Markert, B.A., Breure, A.M., Zechmeister, H.G., 2003. Definitions, strategies and principles for bioindication/biomonitoring of the environment. In: Markert, B.A., Breure, A.M., Zechmeister, H.G (Eds.), Bioindicators and Biomonitors. Elsevier Science, Amsterdam, pp. 3–39.

Marković, M., Zuliani, T., Belanović-Simić, S., Mataruga, Z., Kostić, O., Jarić, S., Vidmar, J., Milačič, R., Ščančar, J., Mitrović, M., Pavlović, P., 2018. Potentially toxic elements in the riparian soils of the Sava River. J. Soils Sediment. 18 (12), 3404–3414. https://doi.org/10.1007/s11368-018-2071-7.

Markovics, R., Kanduč, T., Szramek, K., Golobočanin, D., Milačič, R., Ogrinc, N., 2010. Chemical dynamics of the Sava riverine system. J. Environ. Monit. 12, 2165–2176. https://doi.org/10.1039/C0EM00121J.

Maslo, S., 2016. Preliminary List of Invasive Alien Plant Species (Ias) in Bosnia and Herzegovina. Herbol.: *Int. J. Weed Res. Control* 16 (1), 1–14. https://doi.org/10.5644/herb.16.1.01.

Matakala, N., Chirwa, P.W., Mwamba, T.M., Syampungani, S., 2023. Species richness and phytoremediation potential of mine wastelands-native trees across the Zambian Copperbelt Region. Heliyon 9 (3). https://doi.org/10.1016/j.heliyon.2023.e13585.

Mataruga, Z., Jarić, S., Kostić, O., Marković, M., Jakovljević, K., Mitrović, M., Pavlović, P., 2020. The potential of elm trees (Ulmus glabra Huds.) for the phytostabilisation of potentially toxic elements in the riparian zone of the Sava River. Environ. Sci. Pollut. Res. 27 (4), 4309–4324. https://doi.org/10.1007/s11356-019-07173-9.

Mitrović, M., Pavlović, P., Lakusić, D., Djurdjević, L., Stevanović, B., Kostić, O., Gajić, G., 2008. The potential of *Festuca rubra* and *Calamagrostis epigejos* for the revegetation of fly ash deposits. Sci. Total Environ. 407 (1), 338–347. https://doi.org/10.1016/j.scitotenv.2008.09.001.

Mleczek, M., Gąsecka, M., Waliszewska, B., Magdziak, Z., Szostek, M., Rutkowski, P., Kaniuczak, J., Zborowska, M., Budzyńska, S., Mleczek, P., Niedzielski, P., 2018. *Salix viminalis* L. - A highly effective plant in phytoextraction of elements. Chemosphere 212, 67–78. https://doi.org/10.1016/j.chemosphere.2018.08.055.

Myrvang, M.B., Hillersøy, M.H., Heim, M., Bleken, M.A., Gjengedal, E., 2016. Uptake of macro nutrients, barium, and strontium by vegetation from mineral soils on carbonatite and pyroxenite bedrock at the Lillebukt Alkaline Complex on Stjernøy, Northern Norway. J. Plant. Nutr. Soil Sci. 179 (6), 705–716. https://doi.org/10.1002/jpln.201600328.

Navarro-Ortega, A., Acuña, V., Bellin, A., Burek, P., Cassiani, G., Choukr-Allah, R., Dolédec, S., Elosegi, A., Ferrari, F., Ginebreda, A., Grathwohl, P., Jones, C., Rault, P. K., Kok, K., Koundouri, P., Ludwig, R.P., Milacic, R., Muñoz, I., Paniconi, C., Paunović, M., Petrovic, M., Sabater, S., Skoulikidis, N.T., Slob, A., Teutsch, G., Voulvoulis, N., Barceló, D., 2015. Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project. Sci. Total Environ. 503–504, 3–9. https://doi.org/10.1016/j.scitotenv.2014.06.081.

Nečemer, M., Kump, P., Ščančar, J., Jaćimović, R., Simčič, J., Pelicon, P., Budnar, M., Jeran, Z., Pongrac, P., Regvar, M., Vogel-Mikuš, K., 2008. Application of X-ray fluorescence analytical techniques in phytoremediation and plant biology studies. Spectrochim. Acta Part B 63 (11), 1240–1247. https://doi.org/10.1016/j.sab.2008.07.006.

Nelson, D., Sommers, L., 1996. Chemical methods soil science society of America book series. Soil science society of America. In: Bigham, J.M. (Ed.), Methods of soil snalysis. Part 3. Chemical Methods. SSSA, Madison.

Pavlović, M., Pavlović, D., Kostić, O., Jarić, S., Čakmak, D., Pavlović, P., Mitrović, M., 2017. Evaluation of urban contamination with trace elements in city parks in Serbia using pine (*Pinus nigra* Arnold) needles, bark and urban topsoil. In: Int. J. Enviro. Res, 11, pp. 625–639. https://doi.org/10.1007/s41742-017-0055-x.

Pavlović, P., Mitrović, M., Djurdjević, L., 2004. An ecophysiological study of plants growing on the fly ash deposits from the "Nikola Tesla-A" thermal power station in Serbia. Environ. Manag. 33 (5), 654–663. https://doi.org/10.1007/s00267-004-2928-y.

Pavlović, P., Mitrović, M., Đorđević, D., Sakan, S., Slobodnik, J., Liška, I., Csanyi, B., Jarić, S., Kostić, O., Pavlović, D., Marinković, N., Tubić, B., Paunović, M., 2016. Assessment of the contamination of riparian soil and vegetation by trace metals - A Danube River case study. Sci. Total Environ. 540, 396–409. https://doi.org/10.1016/j.scitotenv.2015.06.125.

Prabakaran, K., Li, J., Anandkumar, A., Leng, Z., Zou, C.B., Du, D., 2019. Managing environmental contamination through phytoremediation by invasive plants: a review. Ecol. Eng. 138, 28–37. https://doi.org/10.1016/j.ecoleng.2019.07.002.

Pulford, I., Watson, C., 2003. Phytoremediation of heavy metal-contaminated land by trees-a review. Environ. Int. 29, 529–540. https://doi.org/10.1016/S0160-4120(02)00152-6.

Rai, P.K., Kim, K.H., 2020. Invasive alien plants and environmental remediation: a new paradigm for sustainable restoration ecology. Restor. Ecol. 28 (1), 3–7. https://doi.org/10.1111/rec.13058.

Salminen, R. (Ed.), 2005. Geochemical Atlas of Europe. Part 1: Background Information, Methodology and Maps. Geological Survey of Finland, Espoo.

Santos, J.L.A., Busato, J.G., Pittarello, M., da Silva, J., Horák-Terra, I., Evaristo, A.B., Dobbss, L.B., 2022. Alkaline extract from vermicompost reduced the stress promoted by As on maize plants and increase their phytoextraction capacity. Environ. Sci. Pollut. Res. 29 (14), 20864–20877. https://doi.org/10.1007/s11356-021-17255-2.

Sasmaz, M., Sasmaz, A., 2017. The accumulation of strontium by native plants grown on Gumuskoy mining soils. J. Geochem. Explor. 181, 236–242. https://doi.org/10.1016/j.gexplo.2017.08.001.

Sasmaz, M., Akgül, B., Yıldırım, D., Sasmaz, A., 2016. Mercury uptake and phytotoxicity in terrestrial plants grown naturally in the Gumuskoy (Kutahya) mining area, Turkey. Int. J. Phytoremediat. 18 (1), 69–76. https://doi.org/10.1080/15226514.2015.1058334.

Sasmaz, M., Uslu Senel, G., Obek, E., 2021. Strontium accumulation by the terrestrial and aquatic plants affected by mining and municipal wastewaters (Elazig, Turkey). Environ. Geochem. Health 43 (6), 2257–2270. https://doi.org/10.1007/s10653-020-00629-9.

Ščančar, J., Heath, E., Zuliani, T., Horvat, M., Kotnik, J., Perko, P., Milačič, R., 2015. Elements and persistent organic pollutants in the sediments of the Sava River. In: Milačič, R., Ščančar, J., Paunović, M. (Eds.), The Sava River. Dodrecht. Springer, pp. 95–123.

Seregin, I.V., Kozhevnikova, A.D., 2004. Strontium transport, distribution, and toxic effects on maize seedling growth. Russ. J. Plant Physiol. 51 (2), 215–221. https://doi.org/10.1023/B:RUPP.0000019217.89936.e7.

Shacklette, H.T., Erdman, J.A., Harms, T.F., 1978. In: Oehme, F.W. (Ed.), Trace elements in plant foodstuffs, in Toxicity of Heavy Metals in the Environments, Part I. Marcel Dekker, New York, p. 25.

Shahzad, B., Tanveer, M., Hassan, W., Shah, A.N., Anjum, S.A., Cheema, S.A., Ali, I., 2016. Lithium toxicity in plants: Reasons, mechanisms and remediation possibilities – A review. Plant Physiol. Biochem. 107, 104–115. https://doi.org/10.1016/j.plaphy.2016.05.034.

Srikhumsuk, P., Peshkur, T., Renshaw, J.C., Knapp, C.W., 2023. Toxicological response and bioaccumulation of strontium in Festuca rubra L. (red fescue) and Trifolium pratense L. (red clover) in contaminated soil microcosms. Environ. Syst. Res. 12 (1) https://doi.org/10.1186/s40068-023-00297-5.

StaSoft Inc. (2013). StatSoft. Statistica Data analysis software system, version 12. ⟨http://www.statsoft.com⟩.

Tanveer, M., Hasanuzzaman, M., Wang, L., 2019. Lithium in Environment and Potential Targets to Reduce Lithium Toxicity in Plants. In: In *Journal of Plant Growth Regulation*, Vol. 38. Springer New York LLC,, pp. 1574–1586. https://doi.org/10.1007/s00344-019-09957-2.

Thuja 2 (2012). Tujerodne vrste v Sloveniji (Alien species in Slovenia). ⟨https://www.tujerodne-vrste.info/en/alien-species-slovenia/alien-plants/⟩ (Accessed 03 August 2023).

Török, A.I., Moldovan, A., Levei, E.A., Cadar, O., Tănăselia, C., Moldovan, O.T., 2021. Assessment of lithium, macro-and microelements in water, soil and plant samples from karst areas in Romania. Materials 14 (14). https://doi.org/10.3390/ma14144002.

Tőzsér, D., Harangi, S., Baranyai, E., Lakatos, G., Fülöp, Z., Tóthmérész, B., Simon, E., 2018. Phytoextraction with Salix viminalis in a moderately to strongly contaminated area. Environ. Sci. Pollut. Res. 25 (4), 3275–3290. https://doi.org/10.1007/s11356-017-0699-2.

Vertačnik, A., Prohić, E., Kozar, S., Juračič, M., 1995. Behaviour of some trace elements in alluvial sediments, Zagreb water-well field area, Croatia. Water Res 29 (1), 237–246. https://doi.org/10.1016/0043-1354(94)E0114-L.

Vidmar, J., Zuliani, T., Novak, P., Drinčić, A., Ščančar, J., Milačič, R., 2017. Elements in water, suspended particulate matter and sediments of the Sava River. J. Soils Sediment. 17 (7), 1917–1927. https://doi.org/10.1007/s11368-016-1512-4.

von Fircks, Y., Rosén, K., Sennerby-Forsse, L., 2002. Uptake and distribution of 137Cs and 90Sr in *Salix viminalis* plants. J. Environ. Radioact. 63 (1), 1–14. https://doi.org/10.1016/S0265-931X(01)00131-X.

Wei, C.Y., Chen, T.B., Huang, Z.C., 2002. Cretan brake (*Pteris cretica* L.): An arsenic-accumulating plant. Acta Ecol. Sin. 22, 777–782.

Wojtuń, B., Samecka-Cymerman, A., Kosiba, P., Kempers, A.J., Rajsz, A., 2018. Trace elements in Polytrichum commune and Polytrichastrum formosum from the Karkonosze Mountains (SW Poland). Ecotoxicol. Environ. Saf. 153, 1–7. https://doi.org/10.1016/j.ecoenv.2018.01.047.

Xue, C., Sun, L., Qu, B., Gao, Y., Liu, Z., Guo, C., Liu, W., Chang, W., Tai, P., 2022. Grafting with an invasive *Xanthium strumarium* improves tolerance and phytoremediation of native congener *X. sibiricum* to cadmium / copper / nickel tailings. Chemosphere 308. https://doi.org/10.1016/j.chemosphere.2022.136561.

Yalamanchali, B.C. 2012. Lithium, an emerging environmental contaminant, is mobile in the soil-plant system. A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Applied Science at Lincoln University.

Yoon, J., Cao, X., Zhou, Q., Ma, L.Q., 2006. Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Sci. Total Environ. 368 (2–3), 456–464. https://doi.org/10.1016/j.scitotenv.2006.01.016.

Yu, X.Z., Gu, J.D., Xing, L.Q., 2008. Differences in uptake and translocation of hexavalent and trivalent chromium by two species of willows. Ecotoxicology 17 (8), 747–755. https://doi.org/10.1007/s10646-008-0224-y.

Zhang, Y., Yang, Y., Li, H., Chen, K., 2017. Comparison of Strontium Accumulation Among Three Poplar Species Under Soil Strontium and Diesel Contamination. J. Nucl. Agric. Sci. 31 (6), 1159–1165.