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HEAVY METALS ACCUMULATION IN THE TISSUES OF THE COMMON REED (*PHRAGMITES AUSTRALIS*)

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Abstract

The aim of the present study was to provide a comparative analysis related to the concentration of heavy metals (Cd, Pb, Ni, Cr) in the tissues (stem, leaves, panicle) of the common reed (Phragmites australis). The reed samples were collected from 10 different sampling stations located in Danube Delta Reservation Biosphere, 2 sampling station from Lake Brateș and 2 sampling station situated on a tributary of the Danube River (Chineja River), Romania. The concentration of heavy metals varied depending on the location, the lowest values were found in plants located on the course of the Chineja River. As well, depending on the plant structure, was observed that the panicle contained the lowest concentrations of the chosen heavy metals for the experiment.

Key words: *bioaccumulation, common reed, heavy metals.*

INTRODUCTION

Reed is a perennial plant that can be found in temperate and tropical regions, especially in areas with high humidity. It spreads in all environments with water levels close to the soil surface (irrigated and drained agricultural or non-agricultural areas, swamps, ponds) (Vymazal, 2013).
The plant is dominant mainly in Europe, but also widespread in North America and various regions of South America and Australia (Srivastava et al., 2014; Mykleby et al., 2016).
Common reed (*Phragmites australis* (Cav.) Trin. ex Steud.), has a resistant rhizome system with high propagation capacity and long growth period, increased adaptability to different environmental conditions and strong resistance to pollution (Fraser et al., 2004; Liu et al., 2012).
The reed stem can grow up to 6 m with the ability to survive in high concentrations of toxic contaminants (Bragato et al., 2009).
The way in which reed adapts to environmental conditions (water depth, pH, salinity, pollutants, extreme climate) is through changes in the physiological, morphological, and behavioural characteristics. With diverse patterns in regard to the reproductive and physiological adaptations, *Phragmites australis* can be used successfully in phytoremediation of depredated wetland ecosystems (Qin et al., 2022)
Heavy metals and other pollutants end up in the Danube Delta, after being collected from the entire hydrographic basin, which represents over 800,000 km^2. The reed is an integral part of the ecology and economy of the Danube Delta by creating an important habitat and by phytoremediation of the Danube waters.
Phytoremediation represents the remediation of contaminated soil, sediments, or water using plants. Compared to other chemical and physical methods of cleaning up, phytoremediation is more environmentally friendly.
Depending on the mechanism of heavy metals removal, phytoremediation can be classified into:

- ♦ phytoextraction - heavy metals are stored in the leaves of plants (Lee, 2013);
- ♦ phytostabilization - toxic pollutants are transformed into nontoxic or less toxic substances (McSorley et al., 2016);

♦ phyto immobilization - the mobility of heavy metals is reduced by sequestering them within the rhizosphere (Yadav et al., 2018).

The species selected for phytoremediation must have the ability to accumulate a vast range of heavy metals, a high tolerance and a high growth rate (Darajeh et al., 2017; Kushwaha et al., 2018).

Phragmites australis is a macrophyte well known for the capacity to uptake, translocate, and accumulate heavy metals in the plant tissues, both from water and sediments (Bonanno & Giudice, 2010; Huang et al., 2018).

Southichak et al., 2016, reported that reed biomass is an effective biosorbent with high sorption performance even if the heavy metals are found in low concentrations.

The current study presents the heavy metals (Cd, Pb, Ni, Cr) concentrations measured in the leaves, stems and panicles of Phragmites australis, sampled from the Danube Delta, Brateș Lake and Chineja River.

MATERIALS AND METHODS

In order to evaluate the concentration of heavy metals from reed, plant samples were collected from 10 locations in the Danube Delta, 2 locations were in the Brateș Lake, and 2 locations were on the course of a tributary river, Chineja River (near the villages of Tulucești and Foltești), that flows in the Brateș Lake and connects it to the Danube.

The coordinates of the sampling points and the codes used to identify them are presented in Table 1. In Figure 1, the sampling points are represented on the map, to present their spatial distribution.

Reed stems, leaves and panicles were collected from the selected sampling points, during the autumn harvest campaign of October 2022.

Plant material was harvested from a 100 m × 100 m area in each location, and homogenous samples were obtained from randomly selecting stems, leaves, and panicles from each location.

In order to assess the heavy metals quantity in the organs of common reed, the samples digestion is done beforehand. The digestion process is achieved using the digestion oven Topwave Analytikjena Germany. Teflon containers with the samples were subjected to a digestion protocol specific to plants.

Heavy metals were determined from the matrix resulted after the samples digestion. An ANALYTIK JENA ContrAA 700® was used, which is an atomic absorption spectral photometer. Samples were analysed in triplicate and the results are express as average ± standard deviation.

One-way classification variance analysis and ANOVA tests were used, to highlight statistical differences. When differences were statistically significant ($p \leq 0.05$), Tukey's post hoc test was applied to identify which group differs.

Table 1. The coordinates of the sampling points and the codes used to identify them

Nr.	Coordinates Danube Delta		Code	Coordinates Brateș Lake		Code	Coordinates Chineja River		Code
	Latitude	Longitude		Latitude	Longitude		Latitude	Longitude	
1	45°09'32.4"N	29°30'57.6"E	DDa	45°27'45.0"N	28°05'52.5"E	BLa	45°34'19.7"N	28°03'15.2"E	CRa
2	45°09'00.0"N	29°25'55.2"E	DDb	45°30'17.0"N	28°02'30.3"E	BLb	45°43'59.9"N	28°04'27.7"E	CRb
3	45°10'48.0"N	29°25'22.8"E	DDc	-	-	-	-	-	-
4	45°07'55.2"N	29°31'22.8"E	DDd	-	-	-	-	-	-
5	45°10'26.4"N	29°28'22.8"E	DDe	-	-	-	-	-	-
6	45°19'45.7"N	29°24'28.8"E	DDf	-	-	-	-	-	-
7	45°03'06.0"N	29°29'42.4"E	DDg	-	-	-	-	-	-
8	45°06'07.9"N	29°38'31.2"E	DDh	-	-	-	-	-	-
9	44°59'57.9"N	29°24'08.7"E	DDi	-	-	-	-	-	-
10	45°15'14.9"N	29°12'47.9"E	DDj	-	-	-	-	-	-

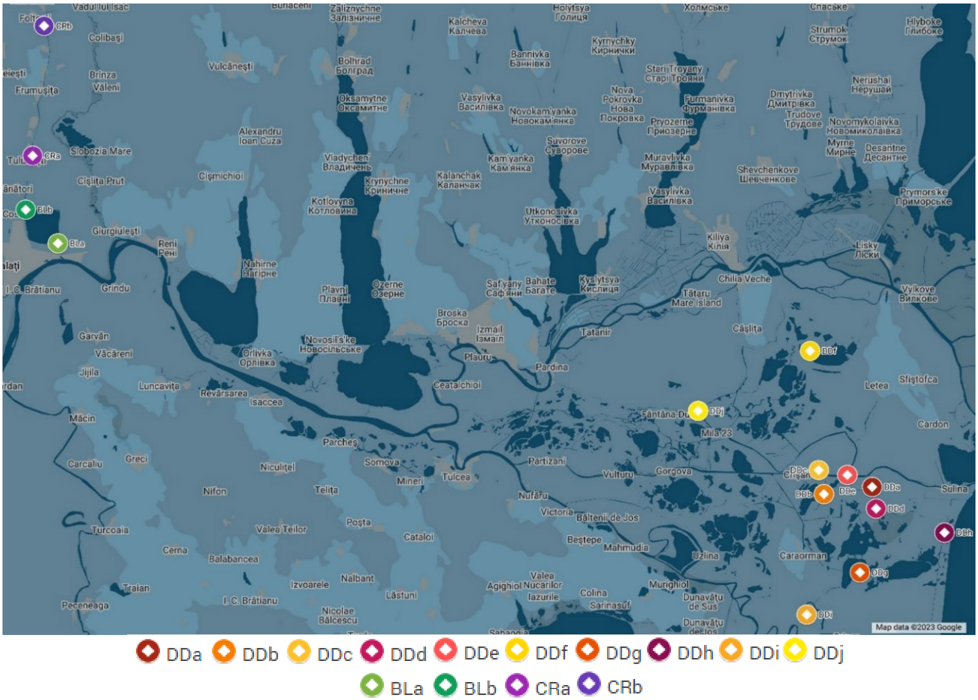

Figure 1. Map representation of the sampling points and their spatial distribution

RESULTS AND DISCUSSIONS

Cadmium was found, generally, in the highest quantity in the reed leaves, followed by stems and panicles. The highest concentration of cadmium was present in the samples from the Brateş Lake (BLa and BLb), with the lowest concentration in the samples from the Chineja River (CRa and CRb).

This trend is observed in all the vegetal parts of the reed. In the Danube Delta, the highest concentrations of cadmium were found in the sampling points closest to the river flow (DDe>DDb>DDc>DDj>DDa>DDd>DDi>DDh>DDf>DDg).

There were no significant differences between the locations from Chineja River, or the locations from Brateş Lake ($p \geq 0.05$).

In the Danube Delta, there were significant differences between all locations for all plant organs ($p \leq 0.05$), phenomenon explained by the considerable distance between some of the locations, the flow regime of the river, proximity to human settlements or transportation lanes. Table 2 presents the data obtained following the analysis for cadmium.

Table 2. Cadmium concentrations in the organs of common reed, *Phragmites australis*, present in the sampling locations of the experiment

µg/g	Cadmium		
	Stems	Leaves	Panicles
DDa	0.70399±0.00018	1.07435±0.00087	0.64935±0.00025
DDb	0.56465±0.00046	1.27301±0.00074	0.74599±0.00030
DDc	0.42208±0.00033	1.12328±0.00038	0.68247±0.00042
DDd	0.78989±0.00051	1.00977±0.00050	0.52130±0.00054
DDe	0.97810±0.00020	1.28461±0.00044	0.75758±0.00023
DDf	0.39432±0.00011	0.84665±0.00055	0.19883±0.00031
DDg	0.48828±0.00037	0.70770±0.00029	0.17904±0.00053
DDh	0.44479±0.00017	0.89962±0.00038	0.30804±0.00025
DDi	0.45650±0.00026	0.95462±0.00011	0.35827±0.00019
DDj	0.78449±0.00040	1.08430±0.00068	0.68019±0.00022
BLa	1.02389±0.00032	1.49960±0.00057	0.86777±0.00049
BLb	1.08836±0.00026	1.52588±0.00033	0.93618±0.00010
CRa	0.29314±0.00037	0.45532±0.00044	0.25523±0.00072
CRb	0.27168±0.00039	0.42615±0.00056	0.21535±0.00081

Data is presented as average ± standard deviation

Lead presented a similar trend of phytoaccumulation as cadmium (leaves>stems>panicles), presented in table 3. The highest concentrations were found in the samples from Danube Delta (DDe>DDd>DDc), even though the samples from the Brateş Lake had higher concentrations of lead than some locations from the Danube Delta. The lowest concentrations of lead were found in the samples from the Chineja River, for all the plant organs.

Table 3. Lead concentrations in the organs of common reed, *Phragmites australis*, present in the sampling locations of the experiment

μg/g	Lead		
	Stems	Leaves	Panicles
DDa	2.01140±0.00044	2.98431±0.00076	1.49850±0.00025
DDb	2.04583±0.00034	3.13357±0.00086	1.77173±0.00029
DDc	3.46320±0.00055	5.61640±0.00028	2.39464±0.00031
DDd	4.42338±0.00021	6.35179±0.00064	1.95976±0.00025
DDe	3.65075±0.00036	6.60013±0.00033	1.61186±0.00019
DDf	1.57729±0.00030	3.03514±0.00094	0.66278±0.00036
DDg	1.67411±0.00041	3.94997±0.00061	1.30208±0.00022
DDh	2.30061±0.00011	4.26136±0.00055	1.13489±0.00030
DDi	2.64638±0.00027	3.87382±0.00077	1.57638±0.00025
DDj	2.77918±0.00036	5.95602±0.00024	1.70474±0.00031
BLa	2.50954±0.00022	4.02576±0.00050	1.65289±0.00035
BLb	2.55138±0.00029	4.06382±0.00085	1.79135±0.00029
CRa	1.46570±0.00017	1.95137±0.00066	0.55050±0.00019
CRb	1.32943±0.00013	1.89554±0.00019	0.48392±0.00017

Data is presented as average ± standard deviation

There were no statistical differences between the samples from Chineja River (CRa and CRb), or the samples from Brateș Lake (BLa and BLb), $p \geq 0.05$. There were significant differences between all locations for all plant organs in the Danube Delta ($p \leq 0.05$).

Nickel is the metal with the highest concentration, from the analysed 4 heavy metals, measured in the biological samples. The Brateș Lake has the highest concentration of nickel in the tissues of common reed, more than twice the amount measured in the Chineja River. There were no significant differences between the locations from the Chineja River (CRa and CRb, $p \geq 0.05$), and significant differences for nickel found in the reed leaves and panicles from the locations in the Brateș Lake ($p \leq 0.05$). In the Danube Delta, the differences varied greatly with statistical significance, $p \leq 0.05$.

Table 4. Nickel concentrations in the organs of common reed, *Phragmites australis*, present in the sampling locations of the experiment

μg/g	Nickel		
	Stems	Leaves	Panicles
DDa	3.60375±0.00055	7.33288±0.00059	2.59740±0.00046
DDb	5.31915±0.00068	7.63807±0.00046	3.82320±0.00022
DDc	4.87013±0.00081	8.84583±0.00019	3.35249±0.00047
DDd	4.26540±0.00063	8.30619±0.00031	2.48236±0.00096
DDe	4.86766±0.00044	9.65873±0.00032	1.77305±0.00055
DDf	2.99685±0.00071	5.91054±0.00048	1.59067±0.00025
DDg	2.37165±0.00040	5.43120±0.00017	1.62760±0.00033
DDh	2.45399±0.00033	5.99747±0.00019	1.29702±0.00043
DDi	4.96196±0.00040	6.64084±0.00044	2.14961±0.00055
DDj	4.29510±0.00028	8.70495±0.00088	3.06853±0.00018
BLa	5.11945±0.00013	9.86312±0.00093	7.85124±0.00010
BLb	5.18659±0.00027	10.11699±0.00077	8.00593±0.00066
CRa	2.83369±0.00009	4.25298±0.00006	0.90081±0.00028
CRb	2.77594±0.00042	4.01019±0.00011	0.84668±0.00031

Data is presented as average ± standard deviation

Chromium was found with the lowest concentration in the samples from the Chineja River (CRa and CRb), with no significant differences between locations, for all reed organs ($p \geq 0.05$). The leaves of *Phragmites australis* accumulated the highest concentration of chromium, followed by stems and panicles. The highest value measured for the concentration of chromium was in the leaves of common reed from the location BLb. The highest concentrations of chromium from stems and panicles were also measured in the same location BLb. Data collected from the Danube Delta presented significant differences between locations, for all the vegetal organs ($p \leq 0.05$).

Table 5. Chromium concentrations in the organs of common reed, *Phragmites australis*, present in the sampling locations of the experiment

μg/g	Chromium		
	Stems	Leaves	Panicles
DDa	2.34663±0.00049	3.49591±0.00082	1.39860±0.00011
DDb	1.39116±0.00057	3.81904±0.00076	0.65274±0.00011
DDc	1.29870±0.00066	3.36984±0.00093	0.59866±0.00024
DDd	2.05371±0.00022	3.42020±0.00021	1.17586±0.00019
DDe	2.58594±0.00035	3.86349±0.00050	1.12830±0.00005
DDf	1.89274±0.00041	3.67412±0.00068	0.79533±0.00038
DDg	1.39509±0.00021	3.29164±0.00034	0.81380±0.00019
DDh	1.22699±0.00010	2.99874±0.00028	0.64851±0.00016
DDi	1.32319±0.00061	2.49032±0.00071	0.85985±0.00024
DDj	1.38959±0.00013	3.35980±0.00015	0.85237±0.00011
BLa	2.60992±0.00022	3.92512±0.00025	1.85950±0.00029
BLb	2.75292±0.00010	4.16285±0.00033	1.90047±0.00021
CRa	1.17256±0.00011	2.40168±0.00048	0.25023±0.00009
CRb	1.16014±0.00017	2.37629±0.00061	0.24012±0.00009

Data is presented as average ± standard deviation

Heavy metals decreased in the order leaves > stems > panicles, in all the locations selected for the experiment. This trend was also observed by Vymazal and Březinová (2016), Parzych et al. (2016), Rzymski et al. (2014), Ganjali el al. (2014).

The heavy metals uptake by the organs of P. australis were: stems Ni>Pb>Cr>Cd, leaves Ni>Pb>Cr>Cd and panicles Ni>Pb>Cr>Cd.

Bonanno, 2013, found more Pb and Cr than Ni in the stems and the same order in leaves, when comparing the capacity of heavy metals removal by P. australis.

These results are like those obtained by Astel et al. (2014), Jiang et al. (2018), Dan et al. (2017).

The strategies used for the uptake of heavy metals are dependent on several factors: pH, metal type, temperature, and depth of the contamination (Ashraf et al., 2017; da Conceição et al., 2016).

Phragmites australis is a valuable plant that can be used successfully for the phytostabilization of trace metals due to the high bioaccumulation capacity, the ability to translocate these metals, and limited mobility. This is because of the different accumulation levels and transport systems, with very specific metal-affinity patterns (Klink, 2017; Pérez-Sirvent et al., 2017).
The capacity of P. australis to bioaccumulate is also dependent on the season, as observed by Grisey et al., 2012.

CONCLUSIONS

The present study confirms that *P. australis* is a suitable candidate for biomonitoring of heavy metals pollution in aquatic environments. As well, the capacity to bioaccumulate heavy metals in the tissues above the ground and the resistance to metal toxicity, makes this plant a perfect solution for phytoremediation of contaminated environments.
The heavy metals uptake by the organs of *P. australis* were: stems Ni>Pb>Cr>Cd, leaves Ni>Pb>Cr>Cd and panicles Ni>Pb>Cr>Cd.
Further studies should be conducted in an integrated manner, considering different biotic and abiotic components of aquatic environments to obtain a clear view on heavy metals accumulation, transfer and dispersion in water systems.

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REFERENCES

Ashraf, M.A., Hussain, I., Rasheed, R., Iqbal, M., Riaz, M., Arif, M.S. (2017). Advances in microbe-assisted reclamation of heavy metal contaminated soils over the last decade: a review. *Journal of Environmental Management, 19.* 132–143.

Astel, A., Obolewski, K., Skorbiłowicz, E., Skorbiłowicz, M. (2014). An assessment of metals content in *Phragmites australis* (Cav.) Trin. ex Steudel grown in natural water reservoirs according to climate zone and salinity. *Desalination and Water Treatment, 52.* 3928–3937.

Bonanno, G., Lo Giudice, R. (2010). Heavy metal bioaccumulation by the organs of *Phragmites australis* (common reed) and their potential use as contamination indicators. *Ecological Indicators, 10.* 639–645.

Bonanno, G. (2013). Comparative performance of trace element bioaccumulation and biomonitoring in the plant species *Typha domingensis*, *Phragmites australis* and *Arundo donax*. *Ecotoxicology and Environmental Safety, 97.* 124–130.

Bragato, C., Schiavon, M., Polese, R., Ertani, A., Pittarello, M., Malagoli, M. (2009). Seasonal variations of Cu, Zn, Ni and Cr concentration in *Phragmites australis* (Cav.) Trin ex Steudel in a constructed wetland of North Italy. *Desalination, 246.* 35–44.

da Conceição, G., Maria, A., Hauser-Davis, R.A., de Souza, A.N., Vitória, A.P. (2016). Metal phytoremediation: general strategies, genetically modified plants, and applications in metal nanoparticle contamination. *Ecotoxicology and Environmental Safety, 134.* 133–147.

Dan, A., Oka, M., Fujii, Y., Soda, S., Ishigaki, T., Machimura, T., Ike, M. (2017). Removal of heavy metals from synthetic landfill leachate in labscale vertical flow constructed wetlands. *Science of the Total Environment, 584.* 742–750.

Darajeh, N., Idris, A., Fard Masoumi, H.R., Nourani, A., Truong, P., Rezania, S. (2017). Phytoremediation of palm oil mill secondary effluent (POMSE) by *Chrysopogon zizanioides* (L.) using artificial neural networks. *International Journal of Phytoremediation, 19.* 413–424.

Fraser, L.H., Carty, S.M., Steer, D. (2004). A test of four plant species to reduce total nitrogen and total phosphorus from soil leachate in subsurface wetland microcosms. *Bioresource Technology, 94.* 185–192.

Ganjali, S., Tayebi, L., Atabati, H., Mortazavi, S. (2014). *Phragmites australis* as a heavy metal bioindicator in the Anzali wetland of Iran. *Toxicological & Environmental Chemistry, 96.* 1428–1434.

Grisey, E., Laffray, X., Contoz, O., Cavalli, E., Mudry, J., Aleya, L. (2012). The bioaccumulation performance of reeds and cattails in a constructed treatment wetland for removal of heavy metals in landfill leachate treatment (Etueffont, France). *Water Air Soil Pollut., 223.* 1723–1741.

Huang, X., Wang, L., Zhu, S., Ho, S.-H., Wu, J., Kalita, P.K., Ma, F. (2018). Unraveling the effects of arbuscular mycorrhizal fungus on uptake, translocation, and distribution of cadmium in *Phragmites australis* (Cav.) Trin. ex Steud. *Ecotoxicology and Environmental Safety,149.* 43–50.

Jiang, B., Xing, Y., Zhang, B., Cai, R., Zhang, D., Sun, G. (2018). Effective phytoremediation of low-level heavy metals by native macrophytes in a vanadium mining area, China. *Environmental Science and Pollution Research, 25.*

Klink, A. (2017) A comparison of trace metal bioaccumulation and distribution in Typha latifolia and *Phragmites australis*: implication for phytoremediation. *Environmental Science and Pollution Research, 24.* 3843–3852.

Kushwaha, A., Hans, N., Kumar, S., Rani, R. (2018). A critical review on speciation, mobilization and toxicity of lead in soil-microbe-plant system and bioremediation strategies. *Ecotoxicology and Environmental Safety, 147.* 1035–1045.

Lee, J.H. (2013). An overview of phytoremediation as a potentially promising technology for environmental pollution control. *Biotechnology and Bioprocess Engineering, 18.* 431–439.

Liu, X., Huang, S., Tang, T., Liu, X., Scholz, M. (2012). Growth characteristics and nutrient removal capability of plants in subsurface vertical flow constructed wetlands. *Ecological Engineering, 44.* 189–198.

McSorley, K., Rutter, A., Cumming, R., Zeeb, B.A. (2016). Phytoextraction of chloride from a cement kiln dust (CKD) contaminated landfill with *Phragmites australis*. *Waste Management, 51.* 111–118.

Mykleby, P.M., Lenters, J.D., Cutrell, G.J., Herrman, K.S., Istanbulluoglu, E., Scott, D.T., Twine, T.E., Kucharik, C.J., Awada, T., Soylu, M.E. (2016). Energy and water balance response of a vegetated wetland to herbicide treatment of invasive *Phragmites australis*. *Journal of Hydrology, 539.* 290–303.

Parzych, A., Sobisz, Z., Cymer, M. (2016). Preliminary research of heavy metals content in aquatic plants taken from surface water (Northern Poland). *Desalination and Water Treatment, 57.* 1451–1461.

Pérez-Sirvent, C., Hernández-Pérez, C., Martínez-Sánchez, M.J., García- Lorenzo, M.L., Bech, J. (2017). Metal uptake by wetland plants: implications for phytoremediation and restoration. *Journal of Soils and Sediments, 17.* 1384–1393.

Qin, H., Jiao, L., Li, F., Zhou, Y. (2022). Ecological adaptation strategies of the clonal plant *Phragmites australis* at the Dunhuang Yangguan wetland in the arid zone of northwest China, *Ecological Indicators, 141*. https://doi.org/10.1016/j.ecolind.2022.10910

Rzymski, P., Niedzielski, P., Klimaszyk, P., Poniedziałek, B. (2014). Bioaccumulation of selected metals in bivalves (Unionidae) and *Phragmites australis* inhabiting a municipal water reservoir. *Environmental Monitoring and Assessment, 186.* 3199–3212.

Southichak, B., Nakano, K., Nomura, M., Chiba, N., Nishimura, O. (2006). *Phragmites australis*: a novel biosorbent for the removal of heavy metals from aqueous solution. *Water Research, 40.* 2295–2302.

Srivastava, J., Kalra, S.J., Naraian, R. (2014). Environmental perspectives of *Phragmites australis* (Cav.) Trin. ex. Steudel. *Applied Water Science, 4.* 193–202.

Vymazal, J. (2013). Emergent plants used in free water surface constructed wetlands: a review. *Ecological Engineering, 61.* 582–592.

Vymazal, J., Březinová, T. (2016). Accumulation of heavy metals in aboveground biomass of Phragmites australis in horizontal flow constructed wetlands for wastewater treatment: a review. *Chemical Engineering Journal, 290.* 232–242.

Yadav, K.K., Gupta, N., Kumar, A., Reece, L.M., Singh, N., Rezania, S., Khan, S.A. (2018). Mechanistic understanding and holistic approach of phytoremediation: a review on application and future prospects. *Ecological Engineering,* 120. 274–298.