

Trace metals concentration in water hyacinth implicates the saltwater barrage altered hydrography of Kochi backwaters, Southwest Coast of India

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Abstract

This study in the Kochi backwaters (KBW) presents the distribution of 9 trace metals (Fe, Zn, Cu, Mn, Ni, Co, Cr, Cd, Pb) in different parts (root, stolon and leaf) of the common water hyacinth *Eichhornia crassipes* during three different seasons [Pre-Monsoon (PRM), Southwest Monsoon (SWM), and Northeast Monsoon (NEM)]. The hyacinth was collected from 4 sections upstream of the KBW where a saltwater barrage [Thannermukkom Barrage (TB)] prevents saltwater intrusion. Results showed that regardless of seasons, all the trace metals concentration in different parts of *Eichhornia* varied in the following order: roots > stolon > leaves. All the trace metals except Fe showed their highest concentration during the PRM when TB introduces stagnancy of the water upstream through flow restrictions. Instead, Fe was high during the SWM associated with increased river influx at that time. Overall results showed that the hydrographical alterations of TB upstream of KBW have clear imprints on the trace metals concentrated in the hyacinth *Eichhornia crassipes*.

Keywords: trace metals, water hyacinth, *Eichhornia crassipes*, saltwater barrage, Kochi backwaters.

1. Introduction

Eichhornia crassipes is a highly invasive water hyacinth native of the Amazon basin and now widespread in the tropical and subtropical regions of the world (Holm et al., 1977; Room and Fernando, 1992; Dickinson et al., 2014). This species belongs to the Pontederiaceae family having 9 genera and 33 species and a mature individual consists of long pendant roots, rhizomes, stolon, leaves, inflorescences and fruit clusters. It is a fast-growing plant and is quite often referred to as the 'blue devil', 'invasive weed', 'plant pest', 'prohibited weed' etc. (Ghosh, 2010). This noxious plant proliferates in the freshwater to mesohaline aquatic systems of tropical countries and is listed among the 100 most dangerous invasive species by IUCN (Muramoto et al., 1991; Tellez et al., 2008). This species grows very vigorously and forms a mat-like structure by interlocking the individual plants and multiply several folds within days. Their ability to adapt to diverse environmental conditions is one of the main reasons for being successful in infesting new habitats (El Seed, 1975) and their habitat expansion is astonishingly high during the relatively recent period (Fig. 1). Massive stock of *Eichhornia* thrives in KBW, especially in the upstream Vembanad region throughout the year causing problems for aquatic transportation, fishing and irrigation practices and facilitates the spread of diseases such as schistosomiasis and malaria (Mehra et al., 1999, Navarro and Phiri, 2000).

Trace metals enter into aquatic systems through different sources that include waste generated from varied industrial processes such as smelting, mining and refining (Denton et al., 1997; Rejomon et al., 2008a, 2008b; Robin et al., 2012; Vilhena et al., 2014; Srichandan et al., 2016). Apart from this, leachate from solid waste disposal sites, sewage sludge, domestic wastewater and combustion of fossil fuels, urban runoff are the notable sources of heavy metals into the limnetic as well as the coastal aquatic environment (Mance, 1987; Ho et al., 2007; Rejomon et al., 2008a, 2008b; Robin et al., 2012). Effluents from ports, harbours, marinas, mooring sites and as a result of recreational or fishing boating and shipping activities, etc. trace metal can reach the aquatic milieu (Denton et al., 1997; Rejomon et al., 2008a, 2008b; Robin et al., 2012). Heavy metal concentration in the KBW is an important research area and earlier studies on this aspect from Indian waters including KBW have testified the trace metal levels in the water, sediment, bivalves, mesozooplankton and fishes (George and Kureishy, 1979; Ouseph, 1992; Balachandran et al., 2002; Rejomon et al., 2008a, 2008b; Paimpillil et al., 2010; Kaladharan et al., 2011; Robin et al., 2012; Anu et al., 2014; George et al., 2016; Gandhi et al., 2017; Arunpandi et al., 2020b).

Studies show that *Eichhornia* concentrates heavy metals and hence a good indicator of heavy metal pollution (Wolverton and Mc Donald, 1979; Ajmal et al., 1985; Pfeiffer et al., 1986). Also, quantifications of the trace metal concentrations in *Eichhornia* is so far absent in KBW. Considering

all these, we initiated a seasonal study on *Eichhornia* upstream of KBW to investigate whether the flow restrictions imparted by Thannermukkom barrage (TB) has any imprints in terms of trace metal concentrated in their body. We hypothesize that the flow restrictions and altered hydrographical settings by TB have measurable imprints on the seasonal trace metals concentrations in *Eichhornia* upstream of the KBW. Considering the above this study considered the following objectives: (a) to quantify the selected trace metals (Fe, Zn, Cu, Mn, Ni, Co, Cr, Cd, Pb) concentration in different parts of *Eichhornia* in the KBW during different seasons and (b) to investigate how the TB altered hydrographical settings has imprinted on the trace metals concentrations in *Eichhornia* during different seasons.

2. Materials and methods

2.1. The study area

The KBW, the present study area, is heavily influenced by the Indian summer monsoon and considered a typical monsoonal estuary having its total runoff many times higher than the estuarine volume (Vijith et al., 2009). It is a micro-tidal estuarine system having mixed semidiurnal tides (Vijith et al., 2009; Revichandran et al., 2012). Out of six rivers emptying into the KBW, four of them (Manimala, Meenachil, Pamba and Achancovil) empty upstream of KBW. During the SWM, the rivers discharge a large quantity of freshwater into KBW and greatly transform the hydrography of the system (Sankaranarayanan and Qasim, 1969; Balachandran et al., 2002; Arunpandi et al., 2020a; Arunpandi et al., 2021). The influence of three distinct seasons can be discernible in the KBW, the largest monsoonal estuarine system along the west coast of India: PRM (February to May), SWM (June to September), and NEM (October to January). Across the narrow region upstream of KBW (Vembanad), TB was established in 1976 to prevent saltwater incursion further upstream of it (Arun, 2005; Arunpandi et al., 2021). The shutters of TB are usually kept closed from January to May every year to prevent saltwater intrusion and this exerts considerably hindrance in the natural flushing of the system by the tide, which causes environmental quality degradation through stagnancy of waters, trapping of chemical and fertilizers from nearby agricultural lands leading to eutrophication of the environment conducive for the proliferation of *Eichhornia* (Gopalan et al., 1983).

Over the years, *Eichhornia* proliferated tremendously in the KBW mainly as an aftermath of eutrophication through flow inhibitions introduced by TB (Gopalan et al., 1983). Before TB was functional, the incursion of saline water deep into the interior upstream of the KBW (Vembanad) was possible in every tidal cycle especially during the PRM, which was not conducive for the growth of *Eichhornia* as they collapse and decay within weeks in higher salinities (Imchen, 2020). The

introduction of TB upstream of KBW significantly altered the entire natural setting and flushing pattern causing eutrophication (Haridevan et al., 2015; Arunpandi et al., 2020a, b). After the TB was functional, the disconnected water upstream of the KBW favours the proliferation of *Eichhornia* (Gopalan et al., 1983). Conversely, when TB shutters are fully open during the SWM, very active downward transport of *Eichhornia* mats towards the Kochi inlet and then to the adjacent Arabian Sea is quite usual in the KBW (Imchen, 2020).

2.2. Sampling and analysis

The overall seasonal salinity distribution in the KBW was measured using a Conductivity Temperature Depth (CTD) profiler. 13 locations along the salinity gradients in the KBW was sampled in April (Pre-Monsoon), July (Southwest Monsoon) and December (Northeast Monsoon) of 2015 (Fig. 2). *Eichhornia* samples were collected from four regions upstream of KBW, where they occur abundantly (Fig. 2). From the *Eichhornia* sampling regions closer to the shoreline, the surface salinity and temperature were recorded using a salinometer and a thermometer, respectively. Turbidity (NTU) was measured using a turbidity meter (Eutech instruments TN-100) and dissolved oxygen (DO) by Winkler's method (Grasshoff and Kremling, 1983). Nutrients (nitrate, phosphate, and silicate) were analysed using standard procedures (Grasshoff and Kremling, 1983).

The *Eichhornia* samples (Figure 3) collected were stored in clean plastic bags which was soaked with dilute nitric acid and distilled water. The collected samples were carefully washed with in-situ water and then distilled water and transferred to the laboratory for further analysis. In the laboratory, *Eichhornia* samples were separated into roots, stolon, and leaves and then dried for 12hrs at 120°C in an oven. The dried samples were ground to powder using a pestle and mortar and stored separately in small clean plastic containers. For trace metal analysis, one gram of powdered *Eichhornia* parts (roots, stolon, and leaves) was taken in beakers. These samples were acid digested with a mixture of 1ml of 60% perchloric acid, concentrated 5 ml of nitric acid and 0.5ml sulfuric acid. And the mixture sample was heated and evaporated to near waterless condition. Then, the resultant solution was filtered by using Whatman filter paper and made to a volume of 25 ml with metal-free milli-Q water.

The processed samples were analysed for trace metals using an Atomic Absorption Spectrophotometer (AAS) for the perseverance of trace metals (PerkinElmer Analyst-700) for measuring the concentration of nine trace metals (Fe, Zn, Cu, Mn, Ni, Co, Cr, Cd, and Pb) against the standards. The standard solutions were prepared with MERCK analytical mark chemicals, which was run during the analysis to check the accuracy of the AAS. Triplicate samples and blanks were used for quality assurance and the standard reference materials were used for the sample analysis. The trace

metal concentrations obtained in the present study were also compared with the normal and excess/toxic levels of trace metals observed in plants from other parts of the world (*Kabata-Pendias, USA 2010*).

The seasonal variations in the hydrographical parameters and the trace metals concentration in different body parts of *Eichhornia* and their interrelationships were examined using ANOVA (Analysis of Variation) as a tool. Before ANOVA, the distribution and homogeneity of the data were examined. Parametric ANOVA was performed for normal distribution and non-parametric ANOVA (Kruskal- Wallis) for the other situation. The normality test and ANOVA were carried out using the software package XL-Stat Pro. The interrelationship between the metal concentration and the hydrographical parameters were realized by performing the principal component analysis (PCA) using the ordination method (Anderson et al., 2008). The biplot generated from PCA defines how the metal component varies according to its different spatial and temporal distributions. Before the PCA analysis, the trace metal concentration and the hydrographical variables were Z score transformed. The ordination significance of the PCA was tested by the Monte-Carlo permutation method with 499 replicates. The PCA analysis was done by making use of Canoco 4.5 software package (Ter Braak and Smilauer, 2002).

3. Results and discussion

The present seasonal salinity distribution in the KBW is clear in the vertical distribution of salinity based on CTD data (Fig. 4). As mentioned before, the seasonal hydrographical setting has large differences in the upstream regions of the KBW due to the flow inhibition of TB. As represented in the vertical distribution of salinity, the SWM was characterised by fully open TB whereas, the PRM and the NEM were characterised by completely closed and partially closed TB respectively. The inhibition of saline water intrusion by TB caused oligohaline to limnetic conditions on the southern upstream (Vembanad) of the KBW and this situation last for almost 6 months during the non-monsoon period. Lack of natural flushing from the upstream of KBW cause prolonged stagnant conditions to cause the availability of a high concentration of nutrients in the system (Table 1) favouring the luxuriant growth of *Eichhornia* in the system. To understand this point more evidently, the altered hydrographical setting of KBW by TB has been presented here by a comparison of the present salinity distribution data with historical data before TB was operational (Fig. 5). It is very clear in the comparison that TB has caused a notable reduction in salinity levels in the KBW during all seasons more so during the PRM. In effect, TB considerably declined the spread of mesohaline conditions in the midstream to the upstream regions of the KBW during different seasons. The lowered salinity and increased nutrient concentration due to lack of tidal flushing favoured the massive growth of

Eichhornia in the Kuttanad region of the KBW after the functioning of TB (Fig. 2). In recent decades, the proliferation of *Eichhornia* increased in KBW especially in the upstream region due to the restriction of tidal induced saline water flow from the downstream region. The environmental parameters at the locations of *Eichhornia* sampling are presented in Table 1. The spatial variations in the parameters between locations during each season were not very significant since all these locations were situated upstream of the KBW. The most striking features in these parameters were a noticeable increase in salinity and NO₃ during the PRM and a significant increase of silicate during the SWM associated with the increased river influx (Table 1).

Trace metals level in aquatic biota is a reflection of their concentration in the natural environment (Arunpandi et al., 2020b). The sources of trace metals into the KBW are mentioned in many earlier studies, which include industrial waste release, pesticides and fertilizers used in agriculture, mining, inland wastewater discharge, recreational boating, fishing and shipping activities, etc. (Balachandran et al., 2005, 2006; Rejomon et al., 2008a,b; Martin et al., 2012; Anu et al., 2014; Rejomon et al., 2016; Arunpandi et al., 2020b). Trace metals normally occur at low levels in the natural environment and organisms need most of them in very small amounts, but their high levels can be toxic affecting their health (Arunpandi et al., 2020b). The studies revealed that TB has affected the concentration and behaviour of heavy metals in KBW besides, the dredging conducted in several parts of the backwater. (Menon et al., 2000; Arun, 2005). The results of the mean trace metal concentration (Table 2) and detailed analysis of trace metal levels in different parts (leaves, stolon and roots) of *Eichhornia* are presented in (Supplementary Table 1 and Figs. 6, 7, and 8), which show that higher concentration of all trace metal was present in the root succeeded by stolon and then leaf regardless of the seasons. This is in general agreement with the earlier observations from other parts of the world (Nirmal et al., 1989; Sony and Thomas, 2015). The earlier experimental studies have stated that the absorption capacity of the metal concentration in *Eichhornia* is much more than both in water and soil. It was also proved that the uptake of trace metals by *Eichhornia* increases with the increase in metal concentrations in their experimental solution and the metal accumulation in roots were always significantly higher than that of leaves (Yahya, 1990; Mohamad and Latif, 2010; Bhrahma and Misra, 2014). The root tissues are said to be capable of holding the elements and the elements are less mobile in the other parts of the plant (Chiroma et al., 2012). The experiment on *Eichhornia* conducted by Raisa et al., (2013) showed that it is hyper absorbers of Zn, Cd, and Pb from the aquatic environment and roots exhibits more accumulation of Zn and Pb. Also, the difference in concentration of metals in different parts of the *Eichhornia* may be the translocation of the trace metals and it shows that the root

system is highly capable of accumulating metals. All these suggest that *Eichhornia* is a good accumulator of Zn and Cd (Lu et al., 2004).

Seasonally, trace metals Zn, Cu, Mn, Ni, Co, Cr, Cd, Pb showed their highest concentration in *Eichhornia* during the PRM and least concentration during the SWM. Conversely, Fe was found higher during the SWM compared to the other seasons (Table 2). ANOVA results showed that the variation in trace metals concentration in *Eichhornia* was significant over seasons (<0.05) while its spatial difference was insignificant (>0.05). This signature is also very evident in the PCA biplot (Fig. 9). PCA Biplots visualized the linkage of metals concentrations with the environmental settings during the three different seasons. Salinity and silicate were included in the biplot to represent the hydrographical settings in the study area. In PCA plots, trace metals Zn, Cu, Mn, Ni, Co, Cr, Cd, Pb were oriented towards the increasing gradients of salinity and decreasing gradients of silicate indicating their higher concentrations during the PRM Period. Similarly, Fe was oriented left side of the biplot showing their affinity with increasing gradients of silicate and decreasing gradient of salinity representing the SWM period.

During the non-monsoon season, as the TB shutters are closed, the water that is stagnant in the upstream region naturally favours the increased concentration of trace metals (Arunpandi et al., 2020b). But higher concentrations of Fe in *Eichhornia* during the SWM can be attributed to the enhanced freshwater runoff which higher concentration of these metals through land runoff (Table 2). Fe is the most abundant trace metal in the KBW and its values ranged from 822 to 3276 ug/g. From root to leaf, station 3 in the extreme upstream showed the highest value of Fe in all the seasons (Supplementary Table 1). Zn in the root was highest during PRM and Pb concentration root and stolon was the seasonal highest in station 3 round the year. A comparison of the trace metal concentrations in the present study with the normal and excess/toxic levels of trace metals in plants in other parts of the world (Kabata-Pendias, USA 2010). It showed that the trace metal concentration in *Eichhornia* hailing in the southern region of KBW was found higher than the normal cases but was well within the toxic limit suggested in plants (Kabata-Pendias, USA 2010).

The understanding of the various sources of the trace metals in aquatic systems and their levels observed in the present study would provide a clear insight into their possible ecosystem interaction effects. The major source of Pb and Cd in the environment are paint, pesticide, automobile emission, burning of coal, mining, welding industries, pesticides, cadmium nickel batteries etc. In the present study, the concentration of Zn and Pb was just higher than the normal level in plants (NLP) but was lower than the toxic levels noticed in plants (TLP) (Table 2). Mining and pesticide usage are the major sources of Cu and in the present study, its highest concentration of them was found in station 3 during

PRM followed by NEM. During these closed periods of TB, the water is stagnant in the upstream region and high agricultural activities there naturally increased the trace metal concentration (Robin et al., 2012; Arunpandi et al., 2020b). The ranges (2.28 - 36.12 $\mu\text{g/g}$) of Cu concentration in the study region was within the NLP and TLP (Table 2). Cr, Ni, Co, and Pb are toxic heavy metals released by fertilizers, and pesticides in agriculture, refining, dredging, fossil fuels and electroplating industries into the surrounding aquatic environment and increases their concentration there (Ozhukayil, 2015).

The concentration of Cr and Ni found in this study was 0.33 - 5.19 $\mu\text{g/g}$ and 6.9 - 19.35 $\mu\text{g/g}$ respectively, which are comparably higher than the values reported in the NLP but certainly lower than the TLP (Kabata-Pendias, USA 2010- *Supplementary Table 1*). Likewise, Co and Mn were found in higher concentration during the closed phase of TB during the PRM (Table 2). The highest Mn concentration found in this study $757.2 \pm 64.52 \mu\text{g/g}$ was higher than the range of NLP (30 – 300 $\mu\text{g/g}$) but lower than 400 – 1000 $\mu\text{g/g}$ in TLP (Kabata-Pendias, USA 2010- *Table 2*). Undoubtedly, the higher concentration of trace metals found in the present study in different parts of *Eichhornia* is alarming as it indicates increasing contamination levels in the biota (Kabata-Pendias, USA 2010). PCA analysis also confirmed the trace metals were higher during the non-monsoon period (Fig. 9). The overall results show that the flow restriction and inhibition of saline water intrusion into the upstream of the KBW by TB cause stagnancy of the water upstream, eutrophication and concentration of trace metals in large *Eichhornia* mats. But at the same time, the trace metals concentration in *Eichhornia* observed in this study was below the toxic level and therefore, better management practices to regulate the duration and frequency of the opening of TB, especially during the PRM and NEM would be effective to limit the trace metal contamination in biota in the upstream of the KBW.

4. Conclusion

The concentration of trace metals in water hyacinth/ *Eichhornia* in the upstream region of KBW was investigated based on a seasonal sampling exercise. The study showed that the flow restrictions and stagnancy caused by TB in the upstream of the KBW are the main cause for the higher concentration of trace metal concentration (Fe, Zn, Cu, Mn, Ni, Co, Cr, Cd, Pb) in different parts (roots, stems and leaves) of *Eichhornia* during the non-Monsoon periods. During the Pre-Monsoon, the metal concentration was noticeably higher than the other seasons due to the closure of TB. Most of the trace metals were high in roots followed by stolon and leaves and the highest concentration was observed in station 3, extreme upstream of the KBW. During the Southwest Monsoon, Fe was found higher in *Eichhornia* due to enormous source waters from river influx. The study concludes that the concentration of trace metals in *Eichhornia* upstream of KBW is higher than the normal levels in plants but is within the toxic level suggested for plants. Hence efficient management practices are suggested

for the operation of TB to maintain the minimum required ventilation and flushing of the upstream (Vembanad) of the KBW.

Credit authorship contribution statement

N. Arunpandi: Conceptualization, Methodology, Data curation, Writing - original draft, Visualization, Funding acquisition. R. Jyothibabu: Conceptualization, Methodology, Data curation, Visualization, Writing - review & editing, Supervision, Funding acquisition. K.M. Savitha: Conceptualization, Methodology, Visualization, Formal analysis. S. Parthasarathi: Methodology, Visualization. C.P. Rashid: Methodology, Visualization. M.P. Josna: Methodology, Visualization. S. Santhikrishnan: Software, Visualization, Data curation. S. Sarath: Methodology, Visualization, Data curation. K.K. Balachandran: Conceptualization, Methodology.

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.

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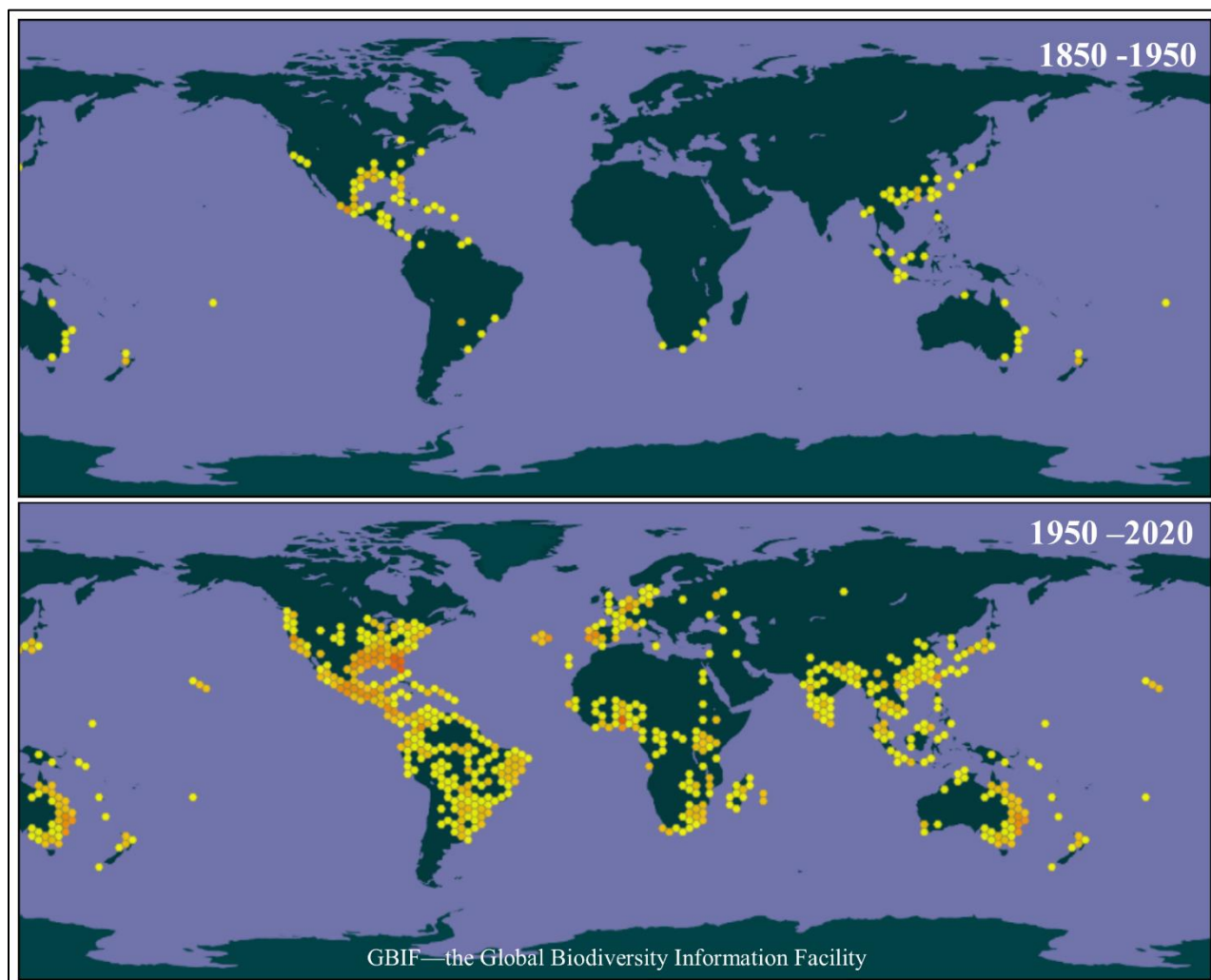


Fig. 1 - The temporal spread of *Eichhornia* from the biodiversity records available in the Global Biodiversity Information Facility (GBIF) database. (www.gbif.org). Their occurrence has significantly increased during the relatively recent period (1950-2020). Noteworthy that the Indian subcontinent does not have a biodiversity record of this species before the 1950s.

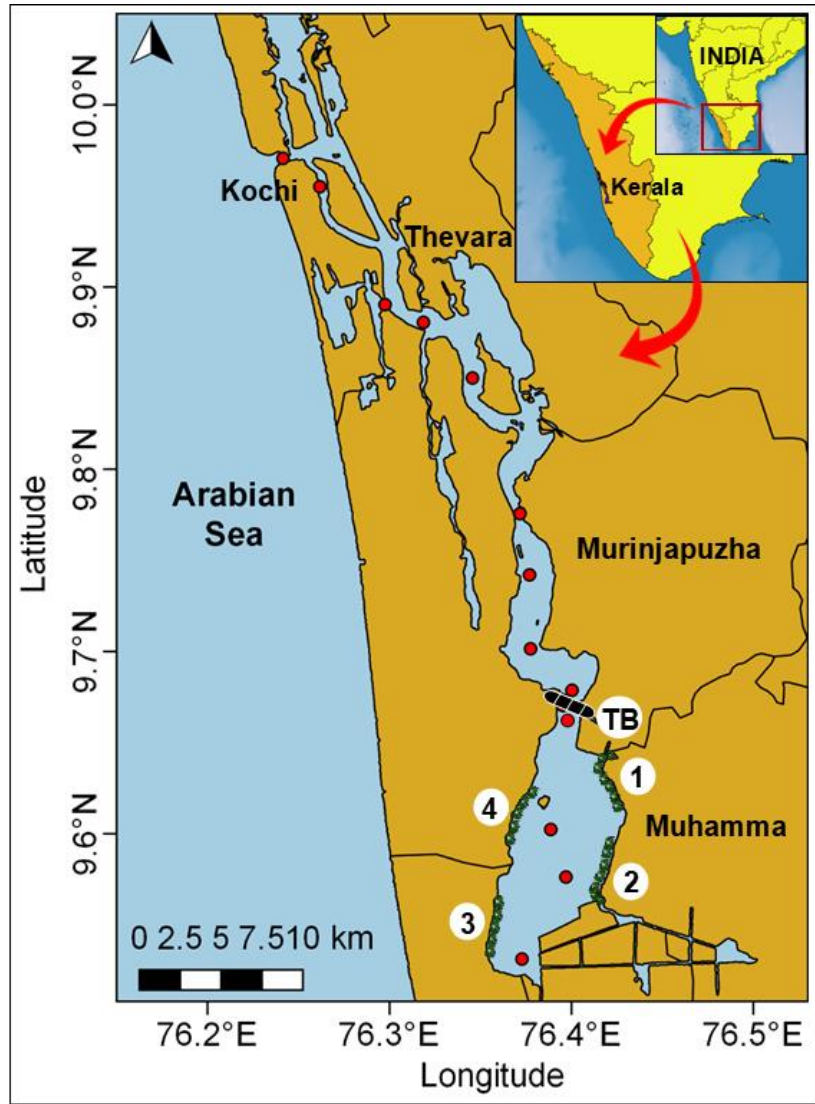


Fig. 2 - Sampling locations in the study area. Thirteen locations (red filled circles) along the KBW is sampled for salinity distribution using a CTD and four locations upstream of Kochi Backwaters (1- 4) represent *Eichhornia* sample collections. TB - Thannermukkom barrage.



Fig. 3 - The spread of water hyacinth (*Eichhornia crassipes*) upstream of the KBW with TB in the background. The inset shows the parts of the water hyacinth used for the present analyses.

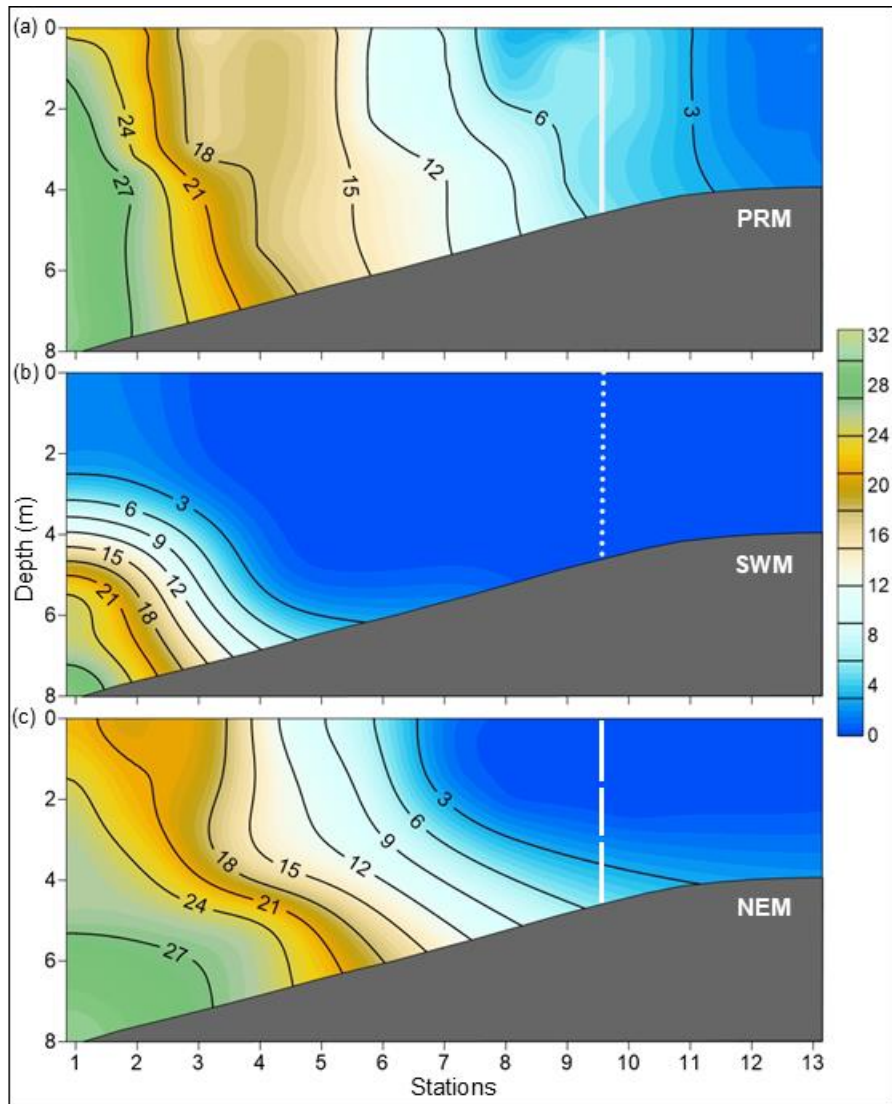


Fig. 4 - The CTD based vertical distribution of salinity in the KBW during the Pre-Monsoon (PRM), Southwest Monsoon (SWM) and the Northeast Monsoon (NEM). White coloured vertical lines upstream of KBW represent TB.

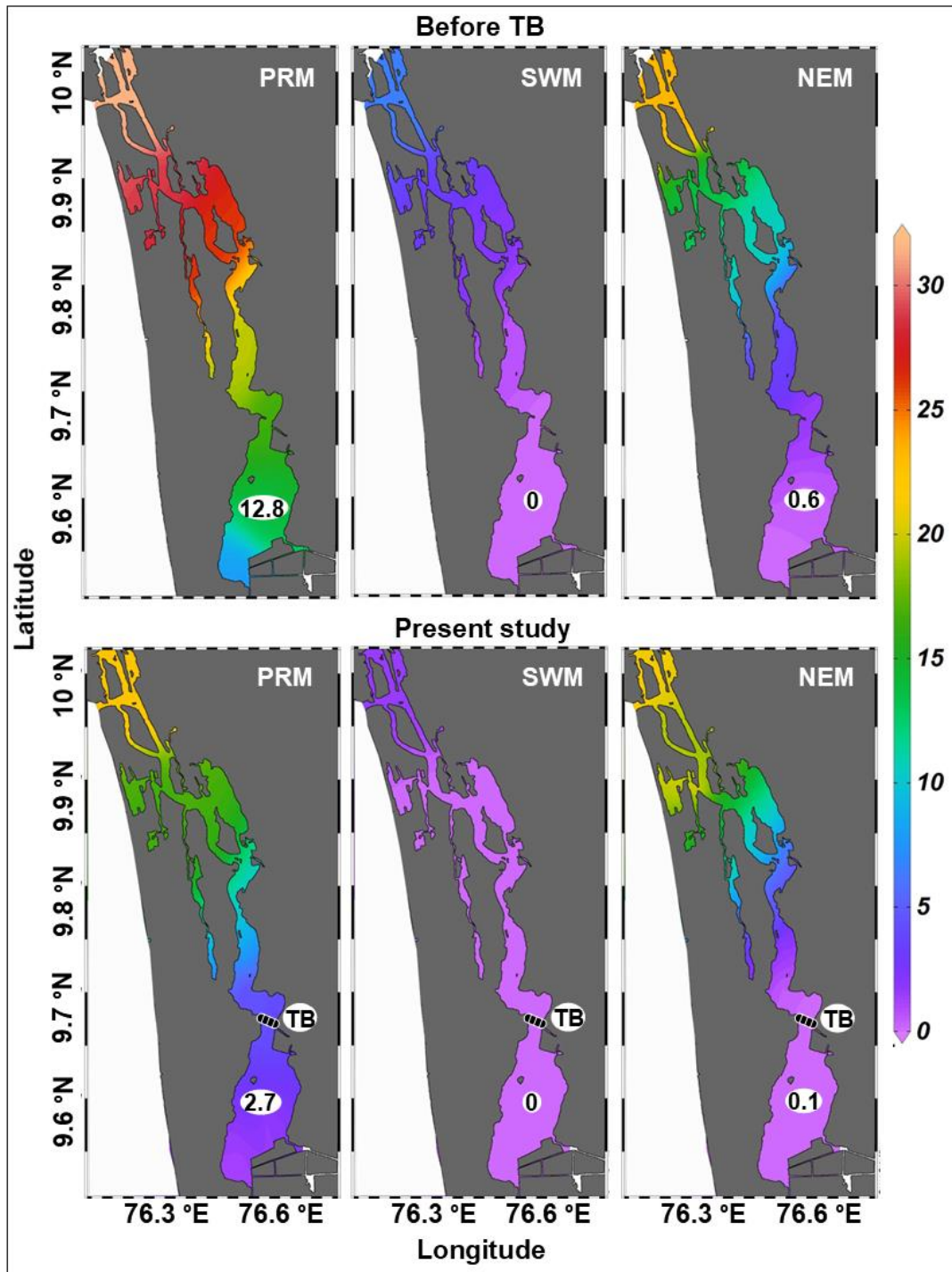


Fig. 5 - The changes in salinity distribution caused by TB in the KBW during different seasons. The present seasonal data was compared with the one before the functioning of the TB (Haridas et al., 1973). Pre-Monsoon, (PRM), Southwest Monsoon (SWM) and Northeast Monsoon (NEM) seasons. The mean salinity values south (upstream) of the TB is represented as numbers on white background.

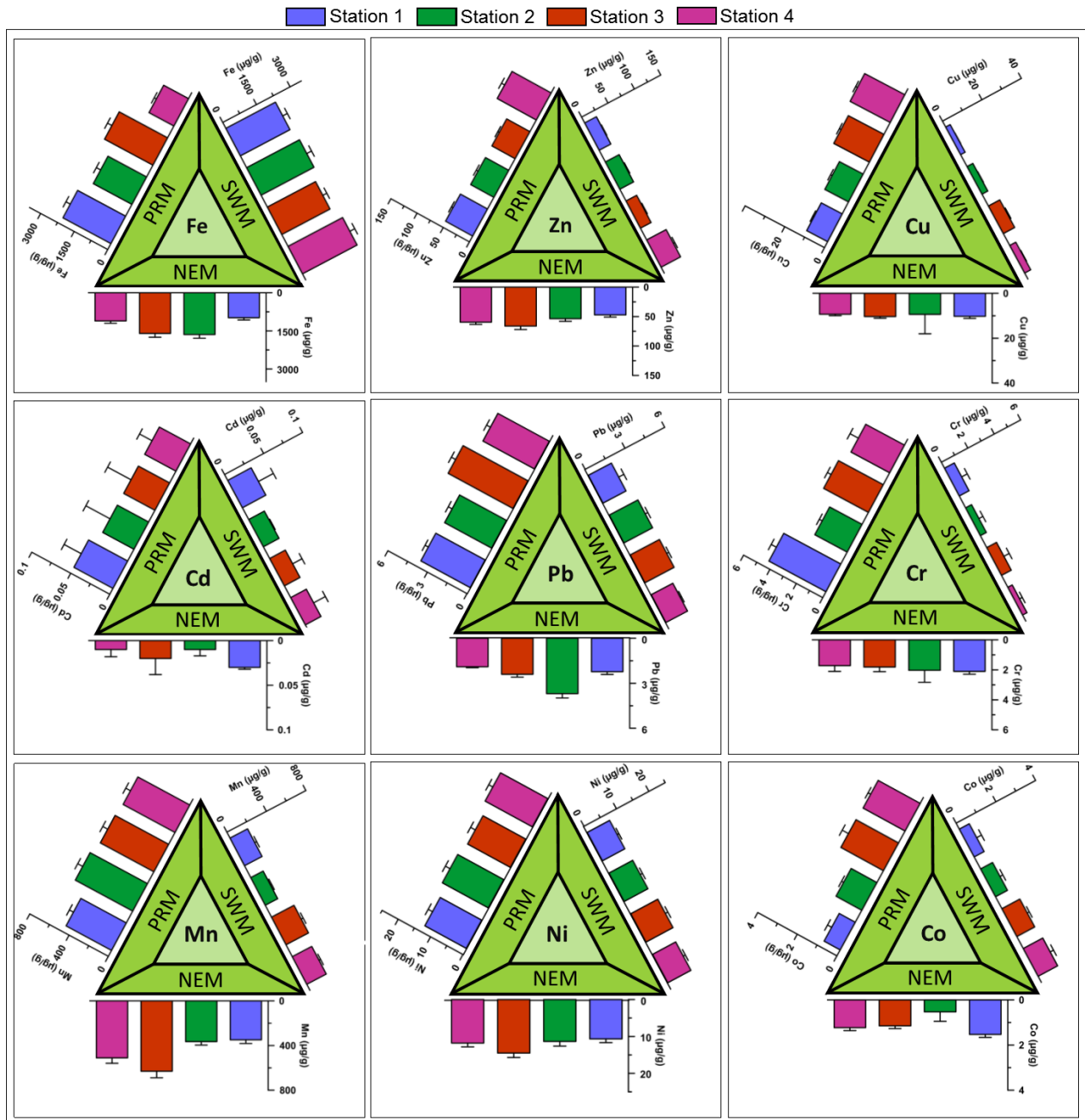


Fig. 6 - Trace metals (dry weight- µg/g) concentration in the leaf of *Eichhornia*. The outer triangle indicates seasons (PRM - Pre- Monsoon, SWM - Southwest Monsoon, and NEM - Northeast Monsoon), the inner triangle indicates the analyzed trace metal and the outer bars indicates the concentration of trace metal in each station. Station 1 (blue bars), station 2 (green bars), station 3 (red bars), and station 4 (pink bars).

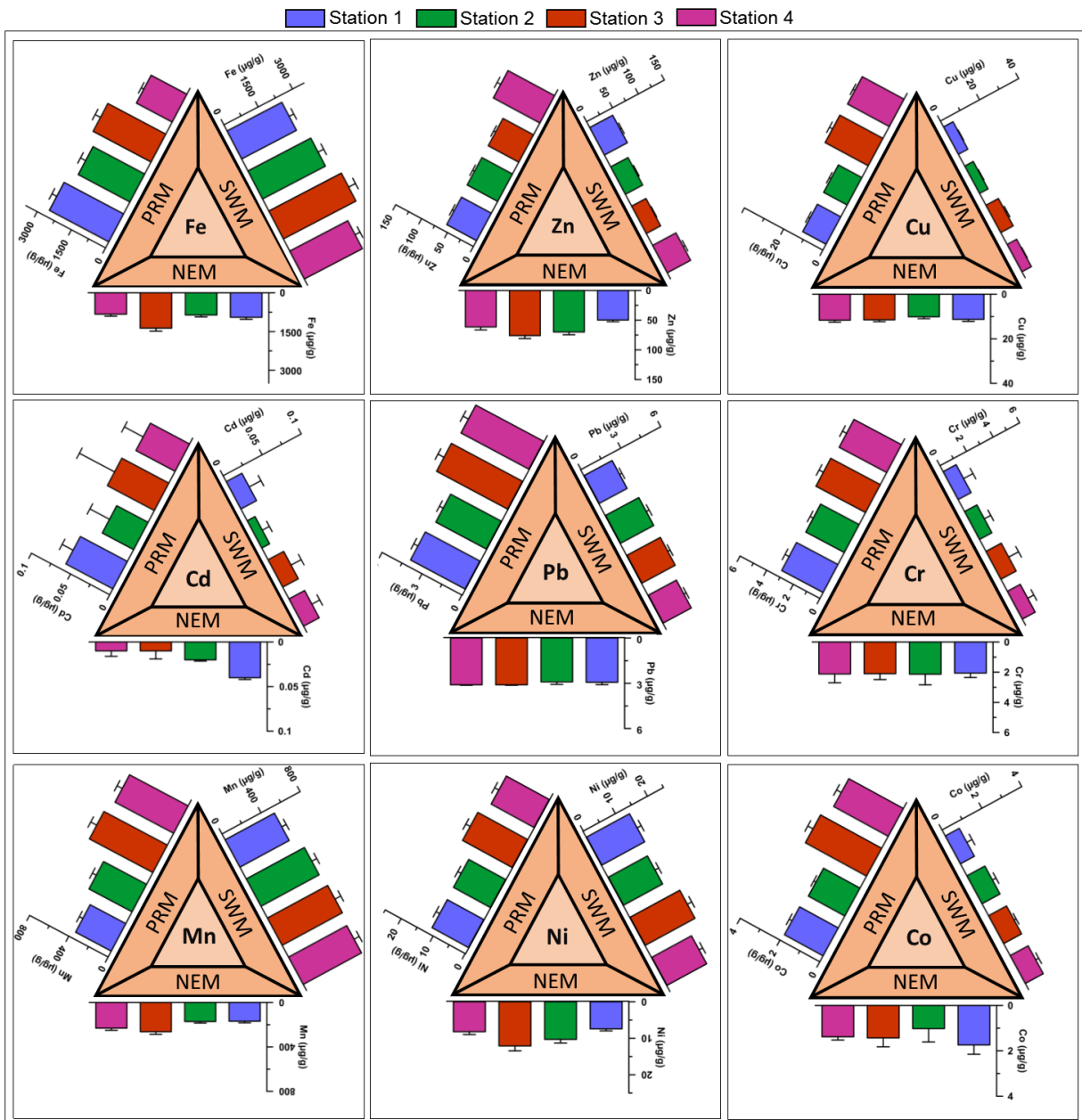


Fig. 7 - Trace metals (dry weight- $\mu\text{g/g}$) concentration in the stolon of *Eichhornia*. The outer triangle indicates seasons (PRM - Pre- Monsoon, SWM - Southwest Monsoon, and NEM - Northeast Monsoon), the inner triangle indicates the analyzed trace metal and the outer bars indicates the concentration of trace metal in each station. Station 1 (blue bars), station 2 (green bars), station 3 (red bars), and station 4 (pink bars).

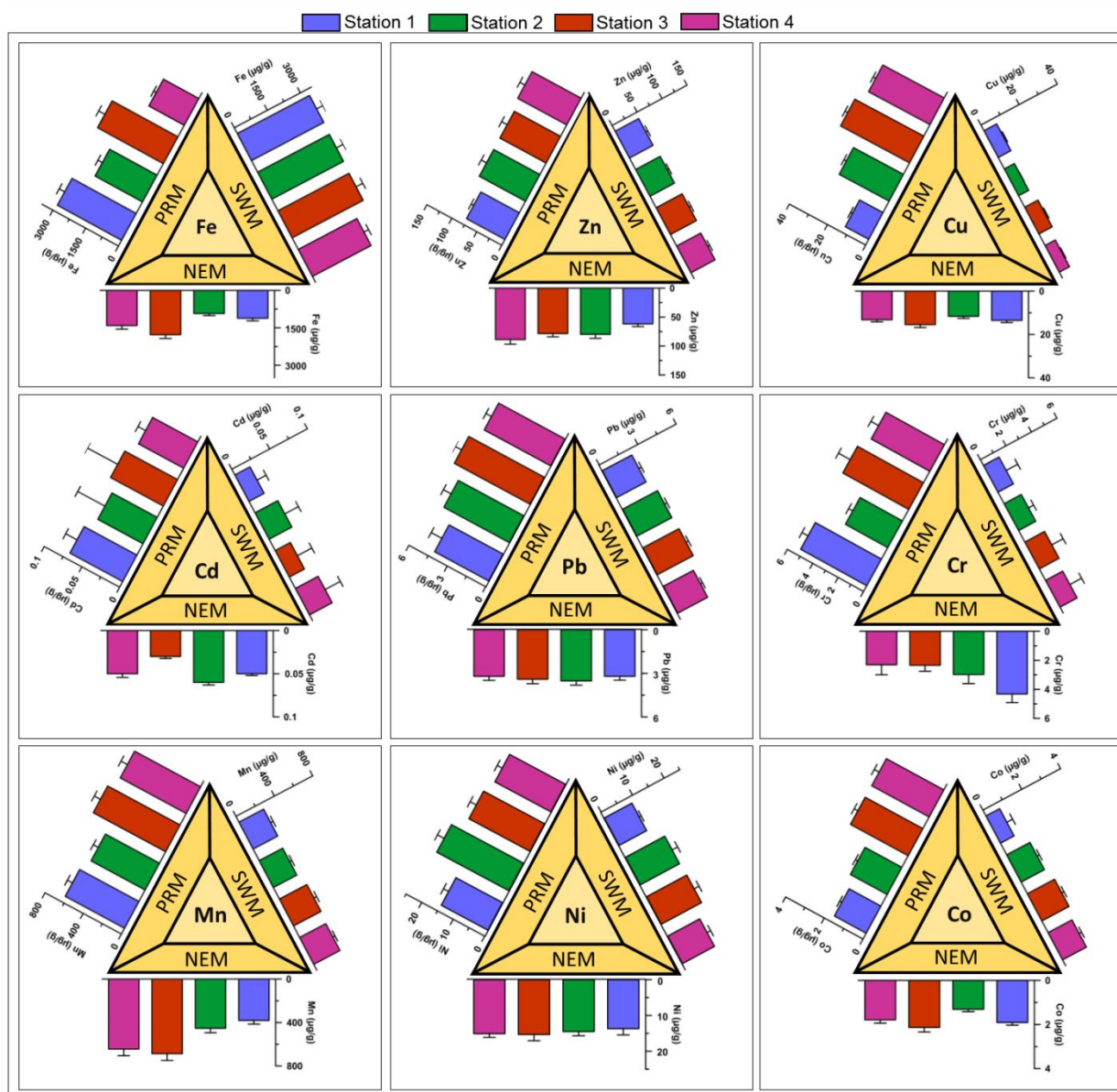


Fig. 8 - Trace metals (dry weight- $\mu\text{g/g}$) concentration in the root of *Eichhornia*. The outer triangle indicates the seasons (PRM - Pre- Monsoon, SWM - Southwest Monsoon, and NEM - Northeast Monsoon), the inner triangle indicates the analyzed trace metal and the outer bars indicates the concentration of trace metal in each station. Station 1 (blue bars), station 2 (green bars), station 3 (red bars), and station 4 (pink bars).

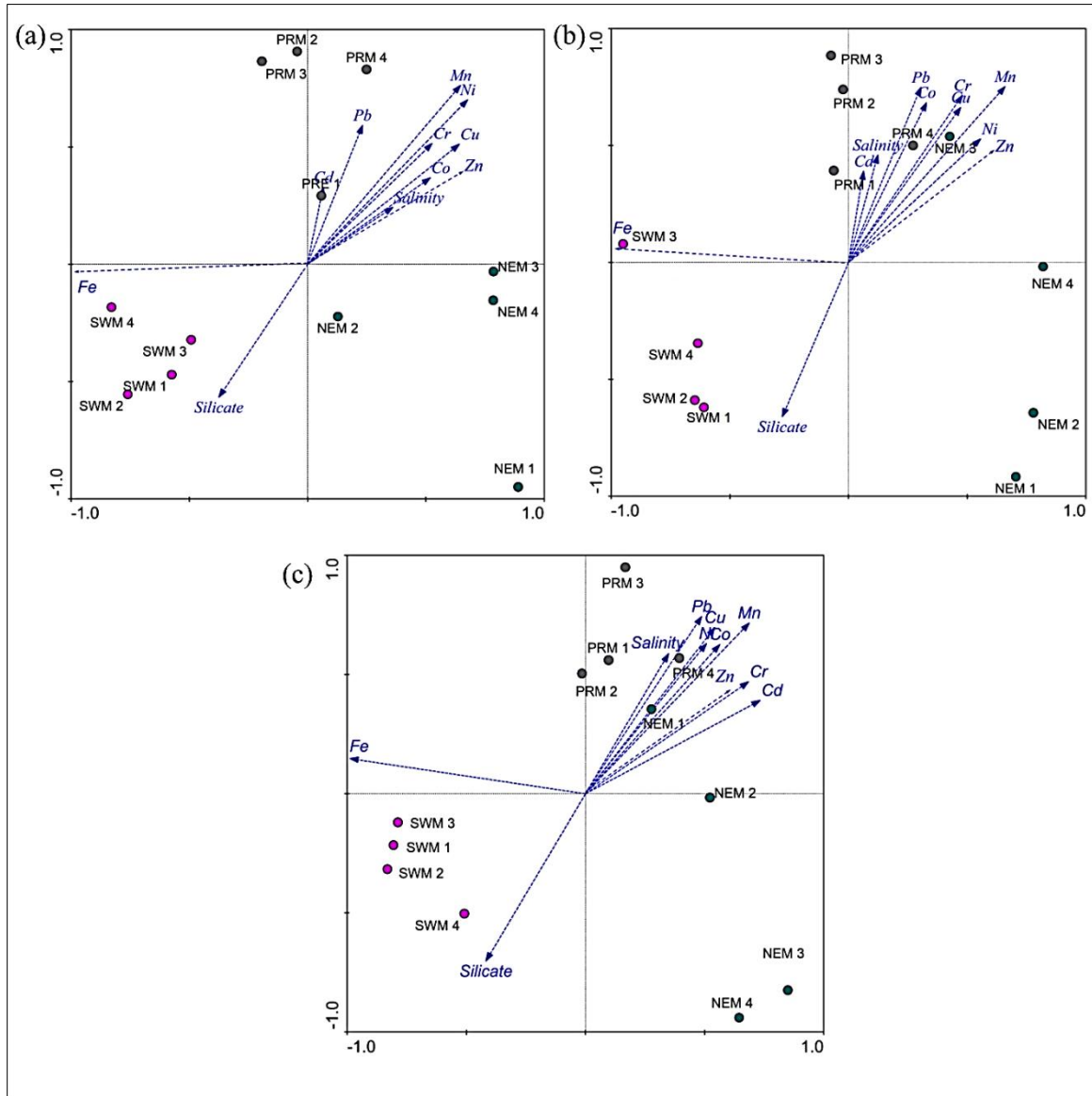


Fig. 9 - PCA biplot showing the interrelationships between the hydrographical parameters and trace metal concentration in *Eichhornia* (a) leaf, (b) stolon and (c) root. PCA biplot stations are in filled circles, while the parameters are represented in blue-dotted arrows. The direction of the arrows represents their increasing gradients. SWM – Southwest Monsoon; NEM – Northeast Monsoon; PRM- Pre-Monsoon. Numbers in season ex- SWM 1 represents the station of sampling.

Table 1 - Seasonal changes in environmental parameters in *Eichhornia* locations

	Parameters	1	2	3	4
PRM	Temperature (°C)	32.2	32.3	32.8	32.1
	Salinity	3.6	0.89	1.01	3.07
	DO (mg/L)	5.24	5.92	6.00	5.06
	NO ₃ (μM)	10.93	7.43	9.55	11.21
	PO ₄ (μM)	0.24	0.19	0.15	0.16
	Sio ₄ (μM)	38.65	49.10	41.25	37.00
	Turbidity (NTU)	12.4	11.26	13.3	12.8
	Chl <i>a</i> (mg/ m ⁻³)	2.1	3.05	2.35	5.23
SWM	Temperature (°C)	30.64	30.92	30.62	30.3
	Salinity	0.08	0.06	0.08	0.09
	DO (mg/L)	8.47	7.06	8.5	7.98
	NO ₃ (μM)	1.5	3.6	1.2	3.1
	PO ₄ (μM)	1.05	1.19	1.17	1.07
	Sio ₄ (μM)	101.6	121.3	107.2	124.7
	Turbidity (NTU)	9.9	11.8	12.1	14.15
	Chl <i>a</i> (mg/ m ⁻³)	4.2	1.11	1.63	2.66
NEM	Temperature (°C)	30.16	30.3	31.2	30.22
	Salinity	0.64	0.12	0.12	0.16
	DO (mg/L)	7.04	7.36	7.01	7.02
	NO ₃ (μM)	1.4	1.96	1.78	1.46
	PO ₄ (μM)	0.73	0.39	0.79	0.8
	Sio ₄ (μM)	96.48	75.1	99.43	105.7
	Turbidity (NTU)	10.2	12.23	11.2	13.19
	Chl <i>a</i> (mg/ m ⁻³)	1.96	4.2	6.61	3.17

Table 2 – Mean concentration of trace metals in different parts of *Eichhornia crassipes* (dry weight $\mu\text{g/g}$) in KBW during different seasons. Pre- Monsoon (PRM), Southwest Monsoon (SWM) and Northeast Monsoon (NEM). The normal level in plants (NLP) and Toxic level in plants (TLP) and - no data available.
 * Kabata-Pendias. Boca Raton, FL, USA: CRC Press, 2010.

Season	Parts	Fe	Zn	Cu	Cd	Pb	Cr	Mn	Ni	Co
PRM	Root	2432.4	90.1	26.7	0.07	5.1	4.6	658.4	18.7	2.4
	Stolon	2246.4	66.3	16.8	0.05	4.6	3.3	578.0	13.0	2.4
	Leaf	1787.2	53.7	15.2	0.04	4.0	3.3	530.1	13.7	1.6
SWM	Root	3103.0	49.1	6.1	0.03	2.5	1.4	271.9	11.1	1.1
	Stolon	2714.0	37.6	5.1	0.02	2.3	1.0	208.2	9.5	0.9
	Leaf	2286.0	26.3	3.5	0.02	1.9	0.6	181.7	7.4	0.7
NEM	Root	1307.0	77.2	13.4	0.05	3.3	3.0	540.8	14.7	1.8
	Stolon	1001.0	64.3	11.1	0.02	3.0	2.1	511.4	13.4	1.4
	Leaf	1333.0	56.6	9.8	0.02	2.6	1.9	463.4	12.1	1.1
NLP*		-	27-150	5-30	-	5-10	0.1-0.5	30-300	0.1-5	0.02-1
TLP*		-	100-400	20-100	-	30-300	5-30	400-1000	10-100	15-50

Supplementary Table 1 - Trace metals concentration in *Eichhornia crassipes* (dry weight µg/g) in KBW during different seasons. Pre-Monsoon (PRM), Southwest Monsoon (SWM) and Northeast Monsoon (NEM). The normal level in plants (NLP) and Toxic level in plants (TLP) and - no data available. * *Kabata-Pendias. Boca Raton, FL, USA: CRC Press, 2010*

	Station	Parts	Fe	Zn	Cu	Cd	Pb	Cr	Mn	Ni	Co
PRM	1	Root	2936 ± 250.15	76.90 ± 4.95	12.26 ± 0.96	0.07 ± 0.015	4.23 ± 0.83	5.1 ± 0.47	620.6 ± 52.25	14.80 ± 1.62	1.64 ± 0.11
	1	stolon	2608 ± 210.74	57.60 ± 3.65	11.91 ± 0.85	0.06 ± 0.014	4.1 ± 0.310	3.11 ± 0.30	504.4 ± 45.63	11.40 ± 1.12	1.94 ± 0.14
	1	leaf	2144 ± 195.84	51.70 ± 2.85	10.55 ± 0.56	0.05 ± 0.022	3.74 ± 0.25	4.32 ± 0.39	462.6 ± 41.25	12.80 ± 1.34	0.81 ± 0.21
	2	Root	2168 ± 203.62	92.6 ± 10.5	26.14 ± 1.23	0.06 ± 0.036	5.12 ± 0.60	3.33 ± 0.32	565.2 ± 51.63	22.90 ± 2.13	1.90 ± 0.12
	2	stolon	2268 ± 222.64	58.90 ± 3.65	11.97 ± 0.86	0.04 ± 0.025	3.8 ± 0.280	2.89 ± 0.23	594.6 ± 50.75	11.50 ± 1.05	1.83 ± 0.11
	2	leaf	1728 ± 189.48	44.25 ± 3.42	11.93 ± 0.75	0.04 ± 0.031	3.56 ± 0.29	2.45 ± 0.22	584.2 ± 50.61	14.20 ± 1.43	1.30 ± 0.10
	3	Root	3008 ± 278.85	92.6 ± 10.96	36.12 ± 1.36	0.07 ± 0.040	5.92 ± 0.49	5.19 ± 0.92	757.2 ± 64.52	19.35 ± 1.93	2.98 ± 0.19
	3	stolon	2540 ± 234.23	58.93 ± 3.86	21.97 ± 1.52	0.06 ± 0.045	5.34 ± 0.45	3.72 ± 0.32	616.6 ± 58.49	15.50 ± 1.35	3.07 ± 0.26
	3	leaf	2164 ± 193.25	44.25 ± 2.75	17.93 ± 0.85	0.04 ± 0.030	4.92 ± 0.32	3.39 ± 0.28	544.8 ± 50.42	13.20 ± 1.46	2.15 ± 0.31
	4	Root	1617.6 ± 113.52	98.3 ± 9.86	32.13 ± 1.32	0.06 ± 0.010	5.2 ± 0.430	4.61 ± 0.60	690.6 ± 66.48	17.80 ± 1.58	2.97 ± 0.25
	4	stolon	1569.6 ± 109.54	89.8 ± 6.85	21.32 ± 0.96	0.05 ± 0.024	5.1 ± 0.410	3.57 ± 0.31	596.2 ± 51.63	13.40 ± 1.29	2.74 ± 0.24
	4	leaf	1112.8 ± 93.32	74.7 ± 5.85	20.21 ± 0.86	0.04 ± 0.016	3.9 ± 0.290	2.93 ± 0.63	528.6 ± 47.68	14.60 ± 1.26	2.12 ± 0.13
SWM	1	Root	3276 ± 283.20	47.2 ± 3.75	6.65 ± 0.53	0.02 ± 0.012	2.3 ± 0.190	1.21 ± 0.90	256.6 ± 24.86	8.78 ± 0.62	0.70 ± 0.30
	1	stolon	2396 ± 200.20	44.3 ± 2.75	4.83 ± 0.26	0.02 ± 0.015	2.1 ± 0.170	0.98 ± 0.70	168.4 ± 14.86	7.43 ± 0.54	0.70 ± 0.26
	1	leaf	2208 ± 206.85	22.1 ± 0.96	2.28 ± 0.11	0.03 ± 0.019	1.74 ± 0.39	0.74 ± 0.42	177.2 ± 18.63	6.90 ± 0.52	0.50 ± 0.24
	2	Root	3252 ± 304.54	49.0 ± 3.12	5.26 ± 0.12	0.03 ± 0.018	2.72 ± 0.18	1.34 ± 0.40	245 ± 21.35	12.50 ± 1.75	1.20 ± 0.11
	2	stolon	2748 ± 244.65	33.4 ± 1.96	4.34 ± 0.25	0.01 ± 0.009	2.5 ± 0.210	0.93 ± 0.48	170.8 ± 14.33	10.30 ± 1.01	0.90 ± 0.17
	2	leaf	2356 ± 212.63	26.08 ± 1.25	2.93 ± 0.16	0.02 ± 0.001	2.16 ± 0.19	0.45 ± 0.30	125.2 ± 11.82	7.30 ± 0.64	0.60 ± 0.14
	3	Root	3224 ± 300.85	51.96 ± 3.4	6.94 ± 0.54	0.02 ± 0.019	2.8 ± 0.180	1.54 ± 0.89	286.4 ± 26.98	12.8 ± 1.52	1.40 ± 0.11
	3	stolon	3172 ± 298.36	27.57 ± 1.25	6.35 ± 0.63	0.02 ± 0.013	2.51 ± 0.17	1.15 ± 0.74	263.0 ± 23.42	12.1 ± 1.36	0.90 ± 0.10
	3	leaf	2148 ± 175.62	20.19 ± 1.32	5.73 ± 0.43	0.02 ± 0.012	2.2 ± 0.150	0.74 ± 0.40	227.4 ± 19.62	8.31 ± 0.76	0.90 ± 0.10
	4	Root	2660 ± 204.32	48.25 ± 3.6	5.35 ± 0.41	0.03 ± 0.020	2.34 ± 0.15	1.34 ± 0.91	272.8 ± 21.75	10.20 ± 1.1	1.23 ± 0.12
	4	stolon	2540 ± 216.35	45.01 ± 3.4	4.82 ± 0.25	0.02 ± 0.010	2.11 ± 0.17	0.97 ± 0.46	230.6 ± 19.86	8.20 ± 0.78	0.9 ± 0.150
	4	leaf	2432 ± 215.63	36.8 ± 2.6	3.05 ± 0.22	0.02 ± 0.015	1.63 ± 0.09	0.33 ± 0.20	196.8 ± 16.48	7.12 ± 0.62	0.98 ± 0.17
NEM	1	Root	1116 ± 105.38	61.68 ± 4.63	13.5 ± 0.98	0.05 ± 0.002	3.2 ± 0.270	4.32 ± 0.59	380.0 ± 34.85	13.70 ± 1.74	1.91 ± 0.12
	1	stolon	948 ± 80.35	49.75 ± 2.86	11.3 ± 0.85	0.04 ± 0.002	2.93 ± 0.16	2.06 ± 0.29	363.4 ± 34.9	13.40 ± 1.26	1.74 ± 0.41
	1	leaf	980 ± 89.32	47.20 ± 3.75	10.25 ± 0.93	0.03 ± 0.002	2.23 ± 0.18	2.10 ± 0.19	348.6 ± 32.75	10.67 ± 1.00	1.53 ± 0.13
	2	Root	928 ± 81.30	79.80 ± 6.75	11.62 ± 0.95	0.06 ± 0.003	3.52 ± 0.29	2.98 ± 0.62	452.4 ± 41.32	14.52 ± 1.14	1.31 ± 0.11
	2	stolon	860 ± 69.45	69.90 ± 4.62	10.1 ± 0.89	0.02 ± 0.001	2.91 ± 0.16	2.13 ± 0.71	438.6 ± 39.85	12.20 ± 1.11	1.02 ± 0.59
	2	leaf	1644 ± 142.85	53.55 ± 4.52	9.35 ± 8.65	0.01 ± 0.007	3.69 ± 0.29	2.03 ± 0.80	364.4 ± 31.25	11.35 ± 1.27	0.53 ± 0.42
	3	Root	1776 ± 149.35	78.45 ± 5.62	15.45 ± 1.35	0.03 ± 0.002	3.4 ± 0.310	2.34 ± 0.41	686.6 ± 62.85	15.32 ± 1.75	2.13 ± 0.21
	3	stolon	1368 ± 115.35	75.95 ± 4.98	11.46 ± 0.84	0.01 ± 0.009	3.1 ± 0.030	2.10 ± 0.39	646.3 ± 60.48	15.50 ± 1.34	1.43 ± 0.39
	3	leaf	1600 ± 148.36	66.15 ± 5.85	10.34 ± 0.75	0.02 ± 0.018	2.4 ± 0.190	1.81 ± 0.31	630.0 ± 58.32	14.50 ± 1.21	1.15 ± 0.12
	4	Root	1408 ± 143.25	88.80 ± 7.95	13.21 ± 0.96	0.05 ± 0.004	3.2 ± 0.280	2.30 ± 0.69	644.3 ± 61.53	15.10 ± 1.05	1.79 ± 0.15
	4	stolon	828 ± 76.50	61.45 ± 4.85	11.64 ± 0.85	0.01 ± 0.006	3.1 ± 0.030	2.12 ± 0.58	597.2 ± 52.82	12.35 ± 1.12	1.38 ± 0.14
	4	leaf	1108 ± 92.60	59.50 ± 3.86	9.32 ± 0.64	0.01 ± 0.008	1.9 ± 0.060	1.72 ± 0.38	510.4 ± 48.63	11.80 ± 1.02	1.23 ± 0.13
NLP*	-	-	27-150	5-30	-	5-10	0.1-0.5	30-300	0.1-5	0.02-1	
TLP*	-	-	100-400	20-100	-	30-300	5-30	400-1000	10-100	15-50	