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Rhizofiltration potential of dominant macrophytes in lentic and lotic ecosystems

Lowell G. Aribal*[1], Angela Grace Toledo-Bruno[2], LeAnne J. Aribal[3], Irrah Lee L. Villaruel[1]

[1]*Forest Biological Sciences Department, Central Mindanao University, Musuan, Bukidnon, Philippines*

[2]*Environmental Science Department, Central Mindanao University, Musuan, Bukidnon, Philippines*

[3]*High School Department, Central Mindanao University, Musuan, Bukidnon, Philippines*

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Abstract

The deposition of heavy metals on aquatic ecosystems pose serious threat to humans as these toxic substances may find their way *via* food chain. The current technologies for heavy metal removal are expensive hence this study was conducted to explore the phytoremediation potential, specifically on rhizofiltration capacity, of plants and the degree of contamination in stagnant and flowing water ecosystems. The study was conducted both in the riparian zones of lentic and lotic freshwater ecosystems of Bukidnon. Lake Pinamaloy represents the lentic while the Pulangui River represents the lotic ecosystems. All vascular plants within the 1x1m^2 sampling plots along the one (1) kilometer transect were identified. The most abundant macrophyte species was determined through quantitative analysis. Subsequently, the shoot and root samples of the most dominant species were collected and subjected to analysis for lead accumulation. Macrophyte samples were analyzed via atomic absorption spectrophotometry (AAS).Results show that *Fimbristylis littoralis* Gaud., the most dominant species in the lentic ecosystem, was able to accumulate lead in the roots at 0.21 mg/kg while *Eichhornia crassipes* (Mart.) Solms. accumulated an average of 2.70 mg/kg in the lotic ecosystem implying rhizofiltration potentials of these species. This may suggest that these two macrophyte species are bioaccumulators of lead that could reduce lead contamination through rhizofiltration.

***Corresponding Author:** Lowell G. Aribal ✉ ariballowell@gmail.com

Introduction

The chemical-intensive use of agriculture and industries, improper waste disposal and mining operations are among the major activities that severely pollute freshwater ecosystems. In the Philippines, majority of the inland freshwaters are bounded with built-up areas such as residential, commercial, agriculture and industries where much of the wastewaters are disposed without treatment. Chemicals, including heavy metals, are subsequently deposited to the riparian zones resulting to contamination of heavy metal and persistent organic pollutants (POP's) from effluents. While the current available technology for heavy metal removal are not economical and produce adverse impacts to aquatic ecosystems, the emerging science of phytoremediation highlights the importance of plants in providing solutions to contamination.

Phytoremediation is the application of plant-controlled interactions with groundwater and organic molecules at contaminated sites to achieve site-specific remedial goals (Landmeyer, 2011). It is the *in-situ* use of plants and their associated micro-organisms to degrade, contain, or render harmless contaminants in the soil or water (Cunningham *et al*., 1996).The use of plants to remove toxic metal from soils and aquatic ecosystems is being developed as a method for cost-effective and environmentally-sound remediation of contaminated areas. In aquatic ecosystems, wetland plants are important tools for heavy metal removal and are preferred over other bio-agents due to their low cost frequent abundance in aquatic ecosystems, and easy handling (Rai, 2008). As such, these are considered as phytoremediators in natural aquatic ecosystems. In a study of Toledo-Bruno *et al.* (2016) conducted in a mangrove ecosystems, mangrove species also exhibit phytoremediation with higher concentration of lead in the shoot rather than roots of *Avicennia marina* and *Sonneratia alba*. The accumulation of contaminants such as heavy metals, specifically in the roots exhibit phytoremediation through rhizofiltration. Rhizofiltration is the technique of utilizing plant roots to absorb, concentrate and precipitate toxic metals from contaminated ground water or polluted effluents (Ghosh *et al*., 2005). Rawat *et al.* (2012) emphasized that rhizofiltration is a kind of phytoremediation that reduces the mobility of contaminants and prevents migration to the ground water thus reduces the bioavailability for entry into the food chain. Rhizofiltration can also be used not only for lead but also for other heavy metals such as cadmium, copper, nickel, zinc and chromium, which are primarily retained within the roots. Ghosh *et al.* (2005) stated that rhizofiltration can also partially treat industrial discharge, agricultural runoff, or acid mine drainage. Thus, this study was conducted to evaluate the phytoremediation of macrophytes through rhizofiltration in the contaminated freshwater ecosystems in Bukidnon, Philippines. The presence of lead in the macrophytes also indicates the extent of lead contamination in these ecosystems.

Materials and methods

Study sites

Pulangi River and Lake Pinamaloy represent the lotic and lentic freshwater aquatic ecosystems, respectively. Sampling of macrophytes was done in the Pulangi River, specifically along the stretch located in the municipality of Maramag in Bukidnon, Philippines with geographic coordinates of 7.825102°N and 125.027586°E to 7.803181°N and 125.028683°E. Pulangi River is a major tributary to the Rio Grande de Mindanao (Mindanao River). As Pulangi River traverses the highly populated municipalities of southern Bukidnon, it picks up materials and contaminants. Aside from excessive siltation due to the soil erosion from headwaters and tributaries, majority of the wastewater from domestic, agriculture and industrial wastewater are discarded to the river without passing treatment facilities.

On the other hand, Lake Pinamaloy is a guitar-shaped freshwater lake located in the Municipality of Don Carlos, Bukidnon with geographic coordinates of 7.6737°N and 124.9961°E.

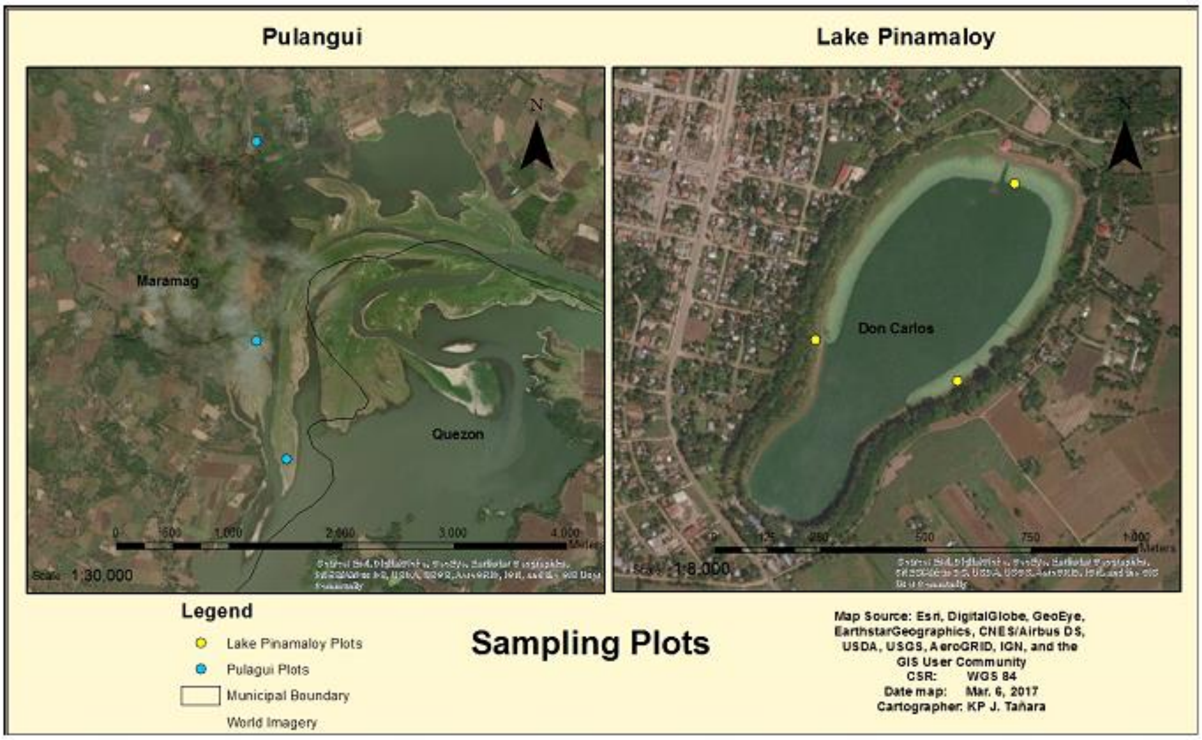

Fig. 1. Map of the study sites.

This lake is located approximately 16 kilometers from the Pulangi River study site. The lake covers an area of about 60 hectares and is fed by rainwater and local run-off. The lakeshore is planted with various forest plantation species with *Gmelina arborea* Juss. as the most dominant species. The local water district prohibited the use of the lake for washing, bathing and fishing since the Poblacion draws its potable water from this lake. However, the peripheral areas and riparian zone at the southeast side is intensively cultivated for agriculture while the northwest side of the lake is dominated with domestic and industrial built-up areas. These uses contaminate water in the lake (Fig. 1).

Sampling

For lotic freshwater ecosystem, sampling was done in Pulangi River within the stretch of the three Barangays of Maramag, Bukidnon, namely Dologon, Tubigon, and Bayabason. Whilst, sampling in the lotic ecosystem covers portions of the Pinamaloy Lake in the Municipality of Don Carlos. The three sampling plots in each of these two freshwater ecosystems consist of a 1x1 m^2 distributed about 100 meters apart from each other. The location of the sampling plots were pre-determined using Google earth.

Macrophytes within the established plots were recorded. The samples were then segregated per species and were identified using taxonomic keys, references and comparison to the images via www.philippineplants.org. Quantitative vegetation analysis was employed to determine the species with the highest importance value (IV) within the sampling plot. Only those species with highest IV were considered for plant analysis.

Specimen drying

Approximately 1kg of plant roots and shoots were collected. The collected samples were thoroughly washed to remove all adhering soil particles. These were segregated per sampling plots and labelled. To facilitate fast drying, the samples were chopped and air-dried for one week. Ovendrying was done for six consecutive days at 80°C.

Tissue analysis of plant samples

The plants samples were analyzed *via* Atomic Absorption Spectrometry (AAS) to determine heavy metal accumulation in a private laboratory facility in Cagayan de Oro City. The AAS is the standard technique for determining the elemental composition of an analyte by its electromagnetic or mass spectrum.

Uptake and translocation in plant tissues

The ability of plants to accumulate heavy metal is determined through the shoot/root quotient (SRQ) (Rotkittikhun *et al.*, 2006). The SRQ is the ratio of the amount of lead accumulated by the shoot over the amount accumulated by the root. In addition, the translocation factor (TF) is computed in same manner and was used as an indicator of the internal metal transport system from root to shoot systems (Deng *et al.*, 2004).

Classification of plant

Plants could be classified as hyperaccumulator and or excluder based on strict criteria set by Mganga *et al.* (2011) as shown in Table 1. Hyperaccumulator plants have the ability to accumulate and tolerate unusual high concentrations of heavy metal in their tissue (Baker *et al.* 1994) without exhibiting impaired physiological abnormalities. On the other hand, excluders are plants that either keep pollutants, such as heavy metals, completely out of the plant or keep the pollutants confined at the plant root system. Translocation Factor (TF) is also as an indicator of the internal metal transport system from root to shoot systems. TF of >1 indicates the efficiency of plant to translocate the metals from root to shoot (Stoltz and Greger, 2002).

Results and discussion

Species composition and importance value

Table 2 presents the importance values of macrophytes found in the sampling plots. Plots recorded a total of four (4) macrophyte species in the Pulangi River and twelve (12) species in the Pinamaloy Lake. *Hymenachne amplexicaulis* Rudge, *Commelina diffusa* Burm., and *Ludwigia octovalvis* (Jacq.) Ravens are the macrophytes common to both freshwater ecosystems. Quantitative analysis results shows that *Eichhornia crassipes* (Mart.) Solms. (Pontederiaceae) and *Fimbristylis littoralis* Gaud. (Cyperaceae) obtained the highest importance value (IV) within the sampling plots of Pulangi River and Lake Pinamaloy, respectively. According to DENR-PAWB (2006), *E. crassipes* along with *Nelumbo nucifera* and *Pistia stratiotes* are the common floating species found at the lowland lakes and rivers. However, *E. crassipes* has been recognized recently as among the pantropical worst invasive weed species in the world. For the lakeshore ecosystem, *Fimbristylis spp.* including *F.littoralis* and other species of Cyperaceae (*Scirpus grossus*, *Cyperus spp.*), Poaceae (*Hymenachne amplexicaulis*, *Arundo donax*, *Phragmites vallatoria*, *Pseudorhaphis squarrosa*), Fabaceae (*Sesbania cannabina*), and Sterculiaceae (*Pentapetes phoenicea*) were the most common macrophytes.

Table 1. Classification of plant species based on shoot root quotient or Translocation factor.

Category	Classification (SRQ)
>1 (greater than 1)	Hyperaccumulator Plant
<1 (less than 1)	Excluder Plant

Lead accumulation in freshwater ecosystems

Lotic ecosystem

Table3 showed the results of the heavy metal concentration from the composite samples of the roots, shoots and leaves of *E. crassipes* from the three (3) sampling plots. Based on the results, it was observed that the root samples of *E. crassipes* accumulate more lead than the leaves and shoots.

However, Agunbiade *et al.* (2009) reported higher concentration of lead in the shoot than the roots of *E. crassipes* with 0.65 and 0.39µg/g, respectively. Likewise, Soni and Thomas (2015) found out that the leaves of *E. crassipes* accumulated more lead than the roots with 0.127% and 0.008%, respectively. In similar study, Singh *et al.* (2012) reported that *E. crassipes* accumulated lead mainly in the roots and the petiole contents comparable at high concentrations than the other parts. The relatively low leaf content, until drastic conditions are used, indicated the presence of a prevention mechanism to inhibit lead uptake (Reales-Alfaro *et al.*, 2013). Sutclife (1962) stated that *E. crassipes* would probably have high tolerance and should be capable of removing large amounts of lead.

Table 2. Importance value of species.

Study site	Family	Species	Importance value
Pulangi River	Pontederiaceae	*Eichorrnia crassipes* (Mart.) Solms.	90.60
	Poaceae	*Hymenachne amplexicaulis* Rudge	6.45
	Commelinaceae	*Commelina diffusa* Burm.	1.25
	Onagraceae	*Ludwigia octovalvis* (Jacq.) Raven	1.70
Pinamaloy Lake	Cyperaceae	*Fimbristylis littoralis* Gaud.	87.76
	Nelumbonaceae	*Nelumbo nucifera* Gaertn.	30.12
	Cyperaceae	*Cyperus* sp.	19.76
	Asteraceae	*Mikania micranta* Kunth.	18.35
	Fabaceae	*Neptunia oleracea* Lour.	11.29
	Poaceae	*Cynodon dactylon* L.	8.23
	Commelinaceae	*Commelina diffusa* Burm.	6.35
	Poaceae	*Hymenachne amplexicaulis* Rudge	5.51
	Fabaceae	*Centrosema pubescens* Benth.	4.71
	Asteraceae	*Chromolaena odorata* L.	2.82
	Poaceae	*Imperata cylindrica* L.	2.35
	Onagraceae	*Ludwigia octovalvis* (Jacq.) Raven	1.41

The higher accumulation of lead in roots implies that *E. crassipes* has potential for rhizofiltration to lead toxicity. Thus, its proliferation in the freshwater ecosystems has ecological benefits, particularly in water purification to reduce contamination in surface and ground waters as well as its potential to reduce biomagnification.

The computed SRQ of 0.49 implies that *E. crassipes* could be classified as excluder plant and not a hyperaccumulator.

As seen on the results, there is higher lead accumulation in the roots compared to shoots. This implies that *E. crassipes* exhibits rhizofiltration.

Table 3. Total lead concentration from the samples of *E. crassipes*.

Sampling plot	Roots	Shoots	SRQ	Classification
1	2.02	1.22	0.60	
2	3.44	1.28	0.37	Excluder Plant
3	2.65	1.31	0.49	
Average	2.70	1.27	0.49	Excluder Plant

The TF value <1 also indicates that *E. crassipes* is not effective in translocating the metal pollutants to the shoot system contrary to earlier report of Soni and Tomas (2015) that *E. crassipes* was proven to the best phytoaccumulator species for heavy metals, exhibited by highest translocation factor for Pb, Zn, Sr, and Zr. In addition, *E. crassipes* is considered better remediator species for mobility of Pb, Zr and Sr metals, hence can be used as an effective abatement of contaminated freshwater ecosystems.

Table 4. Total lead concentration in roots and shoots of *F. littoralis*.

Sampling plot	Roots	Shoots	SRQ	Classification
1	0.21	<0*	-	Excluder Plant
2	0.19	<0*	-	
3	0.23	<0*	-	
Average	0.21			Excluder Plant

*Below detection limit.

Lentic ecosystem

Table 4 shows the lead concentration from the composite samples of the roots and shoots of *F. littoralis*. Results show that only the roots of *F. littoralis* were able to accumulate an average of 0.21 mg/kg of lead. It was observed that there is a greater lead concentration in the roots as compared to the shoots. According to Drzewiecka *et al.* (2010), lead contamination is usually accumulated mainly in roots, and a small amount is transported to aboveground organs of plants. However, earlier report of Liu *et al.* (2007) mentioned that *F. littoralis* can also accumulate heavy metals like Zn aside from its active role in flood control. Recently, Nwaichi *et al.* (2015) also reported the phytoremediation potentials of *F. littoralis* for heavy metals such as As, Cd and Polycyclic Aromatic Hydrocarbons (PAHs) in the crude polluted soil in Nigeria. The findings of this study may suggest that *F. littoralis* could be used as phytoremediation via rhizofiltration of lead in natural freshwater conditions. Further, this species is not effective in translocating lead from roots to shoot, with a TF value <1.

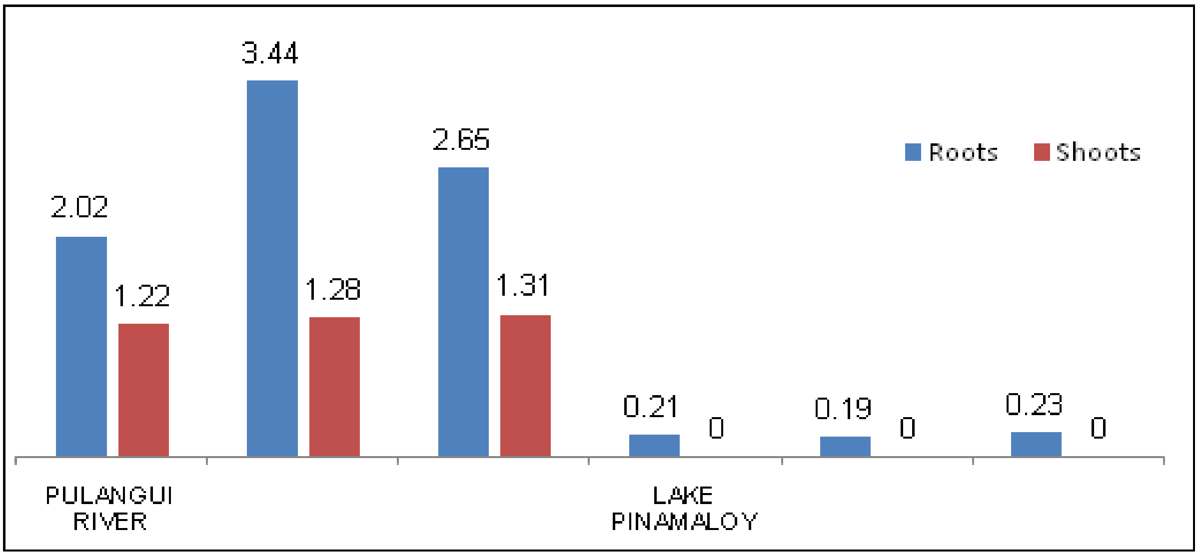

Fig. 2. Extent of contamination in plant tissues.

Extent of contamination

The accumulation of lead in the plant parts of the macrophytes, particularly *E. crassipes* and *F. littoralis* clearly indicate lead contamination in the two natural lotic and lentic freshwater ecosystems in Bukidnon. The amount of lead contamination in Pulangui River is much higher compared to that of Lake Pinamaloy. This could be due to various point and non-point sources of contamination that are easily carried due to the flow of water, being a lotic freshwater ecosystem. The absence of riparian vegetation and the presence of settlers in most of the riverbanks of Pulangi River account to increased contamination. In contrast, the level of lead contamination in Lake Pinamaloy is much lower.

The lakeshore vegetation seemingly limits or restrained the contamination from the surrounding areas to be deposited directly to the lake. In addition, lake as a lentic ecosystem can allow contaminants to settle to the bottom (Fig. 2).

Conclusion

The findings of the study show that *E. crassipes* and *F. littoralis* obtained the highest importance value (IV) in the sampling plots in Pulangi River and Pinamaloy lake ecosystems, respectively. The root samples of *E. crassipes* accumulate more lead compared to leaves and shoots. Similary, *F. littoralis* contains higher lead concentration in the roots as compared to the shoots. The results imply that both macrophytes exhibit rhizofiltration. In addition, the SRQ value revealed that these are excluder plants, i.e. it confines lead concentration in the roots. This is further validated with TF values of <1, which means these macrophytes are not effective in translocating lead from roots to shoots. The results of this study stressed the ecological roles of macrophytes in absorbing and reducing pollutants, particularly heavy metals, in contaminated freshwater ecosystems. Indeed, these macrophytes may be considered in the rehabilitation of degraded and contaminated lakes or rivers. The rhizofiltration potentials of other macrophytes, not necessarily those with high IV, may also be explored. The data can provide comparative analysis on the SRQ and TF values and their phytoremediation potentials. To validate findings, this study can be extended to other freshwater ecosystems to test the consistency of the findings in other areas or conditions. However, it is equally important to test the extent of contamination in water and substrate of the aquatic ecosystems by conducting soil sampling and analysis. The data generated on these suggested studies can provide a science-based policy intervention on the role of macrophytes in filtering contaminated water or soil. As such, these plants are useful in the rehabilitation of contaminated and degraded freshwater ecosystems.

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