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Phytoremediation potential of mangrove species at Pangasihan Mangrove forest reserve in Mindanao, Philippines

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Abstract

Mangrove ecosystems along coastal areas perform a crucial role in filtering sediments and material deposits that could otherwise directly drain into marine ecosystems. Thus, the ability of mangrove species as heavy metal hyperaccumulators is important in phytoremediation. To test whether mangrove species in Pangasihan Mangrove Forest Reserve is heavy metal hyperaccumulator or excluder, composite samples of the roots and shoots were taken from three species with the highest importance value, i.e. *Sonneratia alba*,*Rhizophora apiculata* and*Avicennia marina* var. *rumphiana*. This study revealed that *S. alba* shoots and roots had the highest concentration of lead (Pb) while *R. apiculata* had the lowest concentration. However, *Avicennia marina* var. *rumphiana* has the highest shoot-root quotient (SRQ). Based on SRQ values, both *Avicennia marina* var. *rumphiana* and *Sonneratia alba* could be classified as Pb-hyperaccumulator. These findings imply that these species can be used for phytoremediation, especially in urban and industrial zones.

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Introduction

Mangrove forests cover approximately 180,000km² of the earth (Spalding *et al.* 1997), which is roughly 0.12% of the total land surface. However, mangroves have crucial ecosystem services, providing resources with both commercial values and ecological services (Saenger, 1999). Because of their unique morphology and adaptations, mangroves thrive well in the environment where other plants cannot grow such as flooding and high salinity conditions (Harbison, 1986; Serrano *et al.* 2012).

As a transition zone between freshwater and marine ecosystems, mangroves in coastal areas act as buffer and filter of material deposition from freshwater- and marine ecosystems. This is a crucial function since most of mangrove ecosystems are vulnerable to the impacts of urban development (Tam and Wong, 2000; MacFarlane, 2002; Preda and Cox, 2002) such as urban and industrial run-off, which contains traces of heavy metals (Defew *et al.* 2005). This is exacerbated by other anthropogenic-influenced contamination from domestic, municipal and agricultural wastes as well as industrial effluents. In fact, studies found out a level of concentration of heavy metals in mangroves due to human-induced pollution (Lacerda *et al.* 1992; Perdomo *et al.* 1998; Harris & Santos 2000; Tam & Wong 2000). Specific properties of non-biodegradable trace metal have high affinity towards anoxic sediments, in which the fine clay, silt and detritial particles, high pH and sulphate reduction result to accumulation of metals in the mangrove ecosystem (Harbison, 1986). Metals that bind as metal sulphides are immobilized but may be available for root uptake in the oxidized rhizosphere of the mangroves (Youssef and Saenger, 1996).

In industrial and urban ecosystems, heavy metal is one of the most serious pollutants due to their "toxicity, persistence and bioaccumulation problems" (MacFarlane and Burchett 2000) because heavy metals do not easily degrade. According to Kramer (2000), lead (Pb) is among the three most widespread and hazardous pollutants in the biosphere, along with cadmium (Cd) and arsenic (As). Sources of Pb include automobile emissions, mining, burning of fossil fuels and manufacturing of batteries, solder, pipes, pottery, roofing materials and some cosmetics.

Phytoremediation refers to the use of plants to eliminate, reduce, degrade or immobilize pollutants in soil (Sharaki *et al.*, 2008). It is an "innovative, economical, and environmentally-friendly approach to removing toxic metals from hazardous waste sites" (Raskin and Ensley 2000). Studies have been done on phytoremediation (Brooks, *et al.* 1998; Chaney, *et al.* 1998; Kramer, 2000; Raskin, and Elsley, 2000; Reeves and Baker, 2000; Tulod, *et al.*, 2012). But phytoremediation depends on the extent of plants to absorb heavy metals in their tissues. As such, there are plants considered as heavy metal hyperaccumulators, i.e. plants that have the ability to accumulate metals. Reeves and Baker (2000) listed 418 species of vascular plants as being metal hyperaccumulators. The taxon Brassicaceae is widely known to accumulate heavy metals (Delorme *et al.*, 2001) which assumes that hyperaccumulation could be taxa-related.

Phytoremediation is applied in mangrove ecosystems. Moreira, *et al.* (2011) revealed that *Rhizophora mangle* L. has phytoremediation potential. On the other hand, Paz-Alberto *et al.* (2013) found Pb concentration in the leaves and roots of mangroves near coal-fueled power plants, i.e. *Avicennia marina, Rhizophora stylosa* and *Sonneratia alba*, indicating these species have phytoremediation properties.

This study assessed the phytoremediation potential of mangroves in a forest reserve

This mangrove forest reserve aims to protect mangroves for ecological and economic purposes, especially for fisherfolks. However, no study has been done on the phytoremediation potential of the mangroves, especially that this mangrove ecosystem is exposed to urban and industrial pollution. Generally this study was aimed to assess the hyperaccumulation potentials of some mangrove species to lead (Pb) contamination. Specifically,

it aimed to:1) determine the species composition of mangroves in Pangasihan Mangrove Forest Reserve; 2) determine the levels of lead (Pb) uptake in plant tissues; and 3) determine the phytoremediation potential of some mangroves species to lead (Pb). The data generated is a significant input to the protection of mangrove ecosystems to filter heavy metals and reduce the spread of contaminants to other coastal and marine ecosystems.

Materials and methods

Study Site

This study was conducted in Pangasihan Mangrove Forest Reserve in Misamis Oriental, Mindanao, Philippines within the geographic coordinates between 125°10' longitude and 8°51' latitude (Fig. 1).

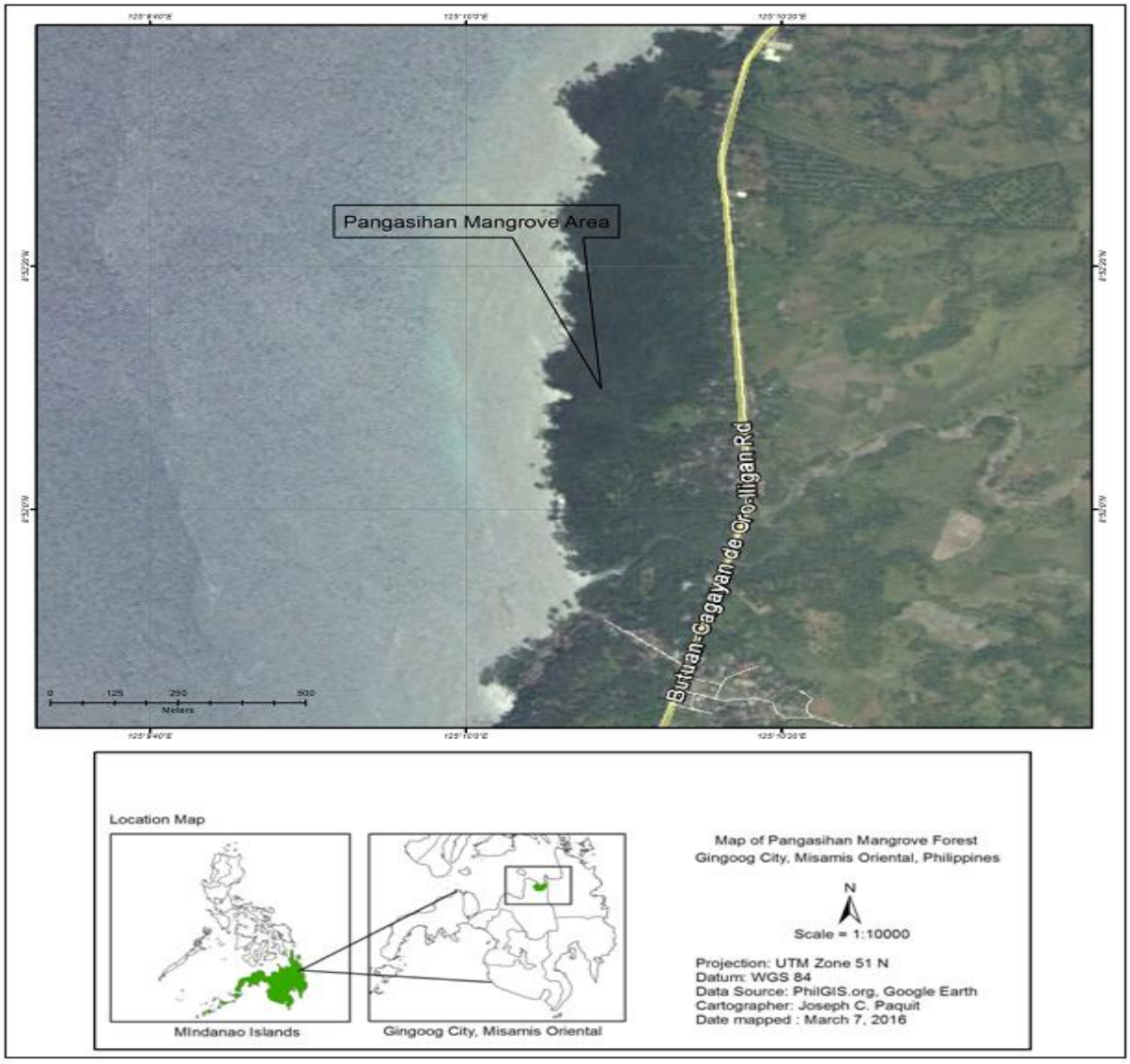

Fig. 1. Location of study site.

Climate is relatively dry from November to April and wet during the rest of the year (DENR, 1997). The soil type is hydrosol. The site is along the Macajalar Bay, whose coastal area is a mixture of residential and industrial zones dominated with factories engaged in manufacturing and processing, storage and fuel depots. This 64-hectare mangrove reforestation was established in the 1990s, which combines natural and planted mangrove species dominated by *Sonneratia alba, Avicennia marina var. rumphiana and Rhizophora apiculata*.

In addition, the study site is a remnant of previously depleted and disturbed ecosystem and the current existing vegetation is a product of a reforestation efforts.

Sampling Procedure

Three sampling plots with 20m x 10m dimension were established within the low to mid-tidal level, spaced 20 meters apart and 50 meters away from the seaward zone. All mangrove trees having diameter at breast height (dbh) of ≥5 cm were inventoried. Vegetation with less than 5cm were not included in the sampling. Vegetation analyses such as frequency, density, dominance and importance value were used to determine the species with the highest importance value following the formula by Ellenberg and Mueller-Dombois (1974).

A composite sample of the roots and shoots from three (3) species with the highest importance value were collected from each sampling plot. Composite samples of approximately 1 kg of the roots and shoots of the species with the highest importance value were collected for laboratory analysis. Roots and shoots of these species were collected and mixed thoroughly to obtain a representative sample of 100 grams. Prior to analysis, samples were oven-dried at 80°C and after which were subjected to Atomic Absorption Spectrophotometry (AAS) at the FAST Laboratory in Cagayan de Oro City.

Data analysis

The importance value of species found were computed as basis for the selection of three species to test whether these are hyperaccumulators of Pb based on the shoot-root quotient (SRQ) and assess their potential for phytoremediation. Results of Pb concentration in shoots and roots were quantitatively compared.

Results and discussion

The phytoremediation of mangrove species were assessed through the calculation of the SRQ to determine whether the mangroves with high importance value are heavy metal hyperaccumulator or excluder. The findings of this study imply the role of mangroves in phytoremediation especially in contaminated urban and industrial areas.

Species composition

According to Fernando and Pancho (1980), the Philippines has 39 arborescent mangrove species belonging to 26 genera and 23 families. This study had identified at least 8 species belonging to 6 genera in 5 families. Of the eight species inventoried, three species have the highest importance value (IV) namely *Avicennia marina* var. *rumphiana*, *Rhizophora apiculata* and *Sonneratia alba*. These species were all found in the three established plots and consistently obtained the highest frequency, density and dominance (Table 1).

Table 1. Species composition in the study site.

Scientific Name	Family Name	Dominance	Density	Frequency	Relative Dominance	Relative Density	Relative Frequency	Importance value
A. marina var. *rumphiana*	Acanthaceae	52251.88	99	1	33.93	40.57	18.75	93.25
R. apiculata	Rhizophoraceae	54096.19	89	1	35.13	36.48	18.75	90.35
S. alba	Lythraceae	40156.72	21	1	26.08	8.61	18.75	53.43
R. mucronata	Rhizophoraceae	2213.63	20	0.67	1.43	8.10	12.5	22.13
C. tagal	Rhizophoraceae	120.95	11	0.67	0.08	4.51	12.5	17.09
A. officinalis	Acanthaceae	5002.10	2	0.33	3.25	0.82	6.25	10.32
A. corniculatum	Premulaceae	113.10	1	0.33	0.07	0.41	6.25	6.73
X. granatum	Meliaceae	38.48	1	0.33	0.03	0.41	6.25	6.68

Note: Frequency = $\frac{\text{Number of plots where a species occur}}{\text{Total number of plots}}$

The dominance exhibited by the three species with highest importance value was primarily due to the location of the sampling plots in the landward zone of the mangrove forest. These three species, i.e. *Rhizophora apiculata*, *Avicennia marina* and *Sonneratia alba*, had been identified to favorably thrive on low to mid-tidal level.According to Primavera *et al.* (2004), *Avicennia marina* is most widely distributed in low to mid-tidal level and is associated with *Sonneratia alba* and *Rhizophora apiculata*. The abundance of these species may also be attributed to the mangrove reforestation activities, which involves mangrove replanting, since the site is a mangrove forest reserve.

Table 2. Total Lead (Pb) concentration of roots and shoots of *Avicennia alba*, *Rhizophora apiculata* and *Sonneratia alba*.

Species	Shoot (µg/g)	Root (µg/g)	SRQ
A. marina var. *rumphiana*	1.46	0.84	1.74
R. apiculata	<0.5*	<0.5*	-
S. alba	2.44	1.57	1.55

Heavy metal uptake

Table 2 shows the concentration of lead (Pb) on the shoots and roots of the three species with highest importance value. *Sonneratia alba* shoots and roots had the highest concentration of Pb while *Rhizophora apiculata* had the lowest concentration, which is below the detection limit. On the other hand, the species with the highest shoot-root quotient (SRQ) was *Avicennia marina* var. *rumphiana*. Rotkittikhun *et al.* (2006) explains that shoot-root quotient (SRQ) can be used to evaluate the ability of the plant species to accumulate heavy metals in their tissue. A SRQ value greater than 1 is classified as a hyperaccumulator, otherwise they are heavy metal excluder. Based on the findings, both *Avicennia marina* var. *rumphiana* and *Sonneratia alba* could be classified as Pb-hyperaccumulator.

As inferred on this study, *Avicennia marina* is a potential hyperaccumulator to Pb than *Rhizophora apiculata*. Similarly, the study of Kamaruzzaman *et al.* (2011) in Malaysia reported that *A. marina* accumulated more Pb than *R. apiculata*. Morever, the genus *Sonneratia* is also Pb-hyperaccumulator based on the findings of Tam and Wong (1997), Nazli and Hashim (2010), and Singh *et al.* (2011). According to Lacerda *et al.* (1984), the plants belonging to Rhizophoraceae family exhibit relatively low concentration of metals due to the salt-exclusion mechanism that is operative in the species.

The data generated from this study revealed that *Sonneratia alba* and *Avicennia marina* var. *rumphiana* have phytoremediation potentials. This implies that these species can reduce, eliminate or degrade Pb, and possibly other heavy metals, that could contaminate the mangrove ecosystem as well as the adjacent other marine coastal areas. Due to its phytoremediation potential, *Sonneratia alba* and *Avicennia marina* var. *rumphiana* can reduce further damage to the Macajalar Bay, which is important for the livelihood of fishing-dependent communities in the area.

The findings of this study are important to highlight the role of mangrove species in phytoremediation. Mangroves thrive in coastal ecosystems to perform a crucial role in filtering sediments and other material deposits that otherwise would eventually drain in marine ecosystems. This can have significant impacts, particularly in ecosystems that are exposed to urban and industrial zones. Thus, these mangrove species in the Pangasihan Mangroce Forest Reserve can be planted to protect marine ecosystems from further destruction due to urban and industrial development along the Macajalar Bay.

Conclusions and recommendations

The study site harbors at least 8 species in 6 genera and 5 families of mangroves, which is highly dominated by *Avicenniamarina* var. *rumphiana, Rhizophora apiculata* and *Sonneratia alba*. Based on the results, *Sonneratia alba* shoots and roots had the highest concentration of Pb with 2.44µg/g and 1.57µg/g, respectively. This was followed by *Avicennia marina* var. *rumphiana* with 1.46µg/g and 0.84µg/g, respectively while *Rhizophora apiculata* had the lowest concentration of less than 0.5µg/g which is below the detection limit.

This study confirms the ability of *Sonneratia alba* and *Avicennia marina* var. *rumphiana* to act as Pb-hyperaccumulators, with SRQ values greater than 1. These findings show the ability of these two mangrove species to sequester heavy metals and act as phytoremediators. The role of mangroves in phytoremediation will prevent further damage to coastal and marine ecosystems especially those that are exposed to urban and industrial development.

Based on the results of this study, the following are recommended:

1. extend sampling to other mangrove species as well as other understory herbaceous plants in coastal ecosystems on their ability as hyperaccumulators of heavy metals;
2. related studies can also test for the accumulation of other heavy metals, specifically Cadmium (Cd) and Arsenic (As), which are considered widespread and highly toxic;
3. soil sampling should be done to assess the extent of heavy metal contamination and up to what extent the mangroves are able to sequester concentration of heavy metals;
4. advocate mangrove species with high hyperaccumulation and phytoremediation potentials in reforestation/rehabilitation programs, particularly in contaminated urban and industrial zones; and
5. intensify campaigns to protect mangrove ecosystems to prevent further damage of marine and coastal ecosystems.

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