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# ASSESSING DIVERSITY AND PHYTOREMEDIATION POTENTIAL OF MANGROVES FOR COPPER CONTAMINATED SEDIMENTS IN SUBIC BAY, PHILIPPINES

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**ABSTRACT:** Toxic metal pollution of water and soil is a major environmental problem and most conventional remediation approaches may not provide adequate solutions. An alternative way of reducing copper (Cu) concentration from contaminated sediments is through phytoremediation. Presently, there are few research findings on the phytoremediation potential of mangroves on metals like Cu. The study was conducted to survey and identify mangroves present in Subic Bay, Philippines and to assess the phytoremediation potential of mangrove species on Cu in sediments. A total of five mangrove species were identified in the study area such as *Barringtonia racemosa, Bruguiera sp, Canophyllum inophyllum, Rhizophora apiculata* and *Sonneratia alba.* The Species Diversity Index of the mangroves in the area indicated low diversity due to low species richness and uneven distribution of different species in the study area. Nonetheless, mangrove species in our study possessed the capacity to absorb Cu, potentially aiding in the retention of toxic material and thereby reducing transport of Cu to adjacent estuarine and marine ecosystem. *Sonneratia alba, Barringtonia racemosa, Bruguiera* sp. and *Rhizophora apiculata* are potential phytoremediators of Cu from contaminated sediments in mangrove ecosystems.
**Key words**: Phytoremediation, mangroves, heavy metals, copper, sediment, roots and leaves

## INTRODUCTION

Toxic metal pollution of water and soil is a major environmental problem and most conventional remediation approaches may not provide acceptable solutions. The use of specially selected and engineered metal accumulating plants for environmental cleanup is an emerging green technology called phytoremediation [1, 2, 3]. Phytoremediation is a green technology that can be used to reduce, eliminate, or contain hazardous waste. Over the past two decades, this green technology has become widely accepted that microorganisms, and to a lesser extent plants, can transform and degrade many types of contaminants [4]. Phytoremediation is a promising new technology that uses plants to degrade, assimilate, metabolize, or detoxify metals, hydrocarbons, pesticides, and chlorinated solvents. Phytoremediation is a cost-effective and resource-conservative approach for remediating sites contaminated with a variety of hazardous chemicals [5].

The Subic Bay Metropolitan Authority (SBMA) in the Philippines was created in 1992, after the United States (US) Navy closed down its operations. The former US Naval Base was converted to a Freeport zone, utilizing the facilities left by the US Navy.

In order to keep up with the demand of a growing enterprise zone, SBMA endeavored to ensure that adequate basic services were maintained, including solid waste management [6]. Subic Bay, the Philippines' first Freeport zone continues to be one of the country's major economic engines with more than 700 investment projects, including the 4th largest shipbuilding facility in the world Hanjin Heavy Industries and Construction (HHIC). Currently, Subic Bay is upgrading its port facilities through the Subic Bay Port Development Project and forging ties with the Clark Special Economic Zone in Angeles City, Pampanga to form the Subic-Clark Corridor via the 45-kilometer Subic-Clark-Tarlac Expressway. Subic Bay facilities, once bastions of western military might are now being positioned to become the most competitive international service and logistics center in Southeast Asia.

One of the most visited and interesting Subic sightseeing spots are the mangroves ecosystems. There are numerous mangrove trees, which are good sources of income of some residents in Subic. Local people take good care of these trees because their barks contain tannin compound that are very useful in making and manufacturing leather products or handicrafts. It also plays home to numerous marine species. Mangroves are truly incredible plant species that have many traditional uses and ecological services like bioremediation and/or phytoremediation. However, the possibility of mangrove to uptake the excess Cu from water or sediments is still in progress hence this study was conducted.

Copper has been known as an environmental pollutant for several decades. It is dangerous to marine organisms and has been used in marine anti-fouling paints. The effect of Cu on fish can damage their gills, liver, kidneys and the nervous system. It also interferes with the sense of smell in fish, thus preventing them from choosing good mates or finding their way to mating areas. Copper can be toxic to human health. Humans can be exposed to Cu via inhalation of particulate, drinking Cu-contaminated water and eating Cu-contaminated food, it can cause nausea, vomiting, abdominal and muscle pain and can suffer from liver damage.

The study should provide important information in improving the awareness of people who are living near Subic Bay on potential phytoremediation property of mangroves to lessen the toxicity build-up of Cu in their community. The people should also know the importance and benefits of mangroves in their environment. There should be conservation of mangroves in Subic Bay to maintain and sustain their coastal resources. The study could help develop the awareness of the Filipinos view on how they can enjoy the beauty of our environment for cost free technology through the process of remediating contaminated environments. The objectives of the study were: 1) to survey and identify the mangroves growing in the mangrove ecosystem in Subic Bay, Philippines; and 2) to assess the phytoremediation potential of mangrove for Cu contaminated sediments.

## MATERIALS AND METHODS

### Plant survey and identification

The study area is located in the mangrove ecosystem of Triboa Mangrove Park, Subic Bay, Philippines (Figure 1). Ten quadrats were chosen randomly in the study area. The dimension of the quadrat was about 10 m x 12 m (Figure-2). The mangrove species present in the quadrats were counted. Mangrove trees trunk's circumferences were also measured.

The preliminary identification and classification of the mangrove species in the study area consisted of external features such as leaf shape, inflorescence and phyllotaxy were completed with the use of a mangrove manual "Handbook of Mangroves in Philippines-Panay" [7]. The pneumatophores or roots, leaves and flowers of mangrove were gathered in duplicate and were stored in a clean plastic bag. Afterwards the plant samples were prepared for herbarium. The verification and identification of mangrove were done in the Institute of Biology, College of Science, University of the Philippines, Diliman, Quezon City. The overall mangrove diversity present in the study area was calculated using the different parameters as defined in equations 1 to 10 [8].

Frequency Distribution (**F**) = (Number of quadrats where the species occurred/Total number of quadrats) x100 **Equation 1**

Relative Frequency (**RF**) = (Frequency of one species of mangrove/total frequency of all species of mangrove) x 100 **Equation 2**

Density (**D**) = (No. of individual mangrove species/Total area sampled) **Equation 3**

Relative Density (**RD**) = (Density of one species of mangrove/total density of all species of mangrove) x 100 **Equation 4**

Simpson's Index of Dominance (**Do**) = $\sum n_i (n_i - 1)/N (N-1)$

where: $\sum$ = summation

$n_i$ = no. of individuals of each species

$N$ = no. of individuals

Relative Dominance (**RDo**) = (Dominance of one species of mangrove/Total dominance of mangrove) x 100 **Equation 5**

Importance Value Index (**IVI**) = RF + RD + RDo **Equation 6**

Species Diversity Index (**SDI**) **Equation 7**

SDI (Shannon Index of Diversity) $H^l = \Sigma p_i 1n (p_i)$ **Equation 8**

Where: $p_i$ = proportion of species from the total species

1n = natural logarithm

The diversity of the two study sites was determined based on the computed species diversity index (SDI) and the values were rated based on the Fernando Scale (1998):

| Shannon Index ($H^l$) | Relative Values |
|---|---|
| 3.5 and above | Very High |
| 3.0 - 3.49 | High |
| 2.5 - 2.99 | Moderate |
| 2.0 - 2.49 | Low |
| 1.9 and below | Very Low |

The crown diameter (2 measures) was determined using the average of the crown width at the widest point and a second width measurement made 90° to the diameter at the widest point. The crown cover was also calculated using the formula /4$d^2$ or 0.7854$d^2$ (d as the total crown diameter). The formula for getting the crown cover for each tree is 0.7854 x (average crown diameter)$^2$ (Table 1). The formulas for the percent crown cover and regeneration per $m^2$ of the mangroves are shown below:

Percent crown cover = (Total crown cover of mangroves/Total area sampled) x 100 **Equation 9**

Regeneration of the mangroves = (Total regeneration count/Total number of regeneration plots) **Equation 10**

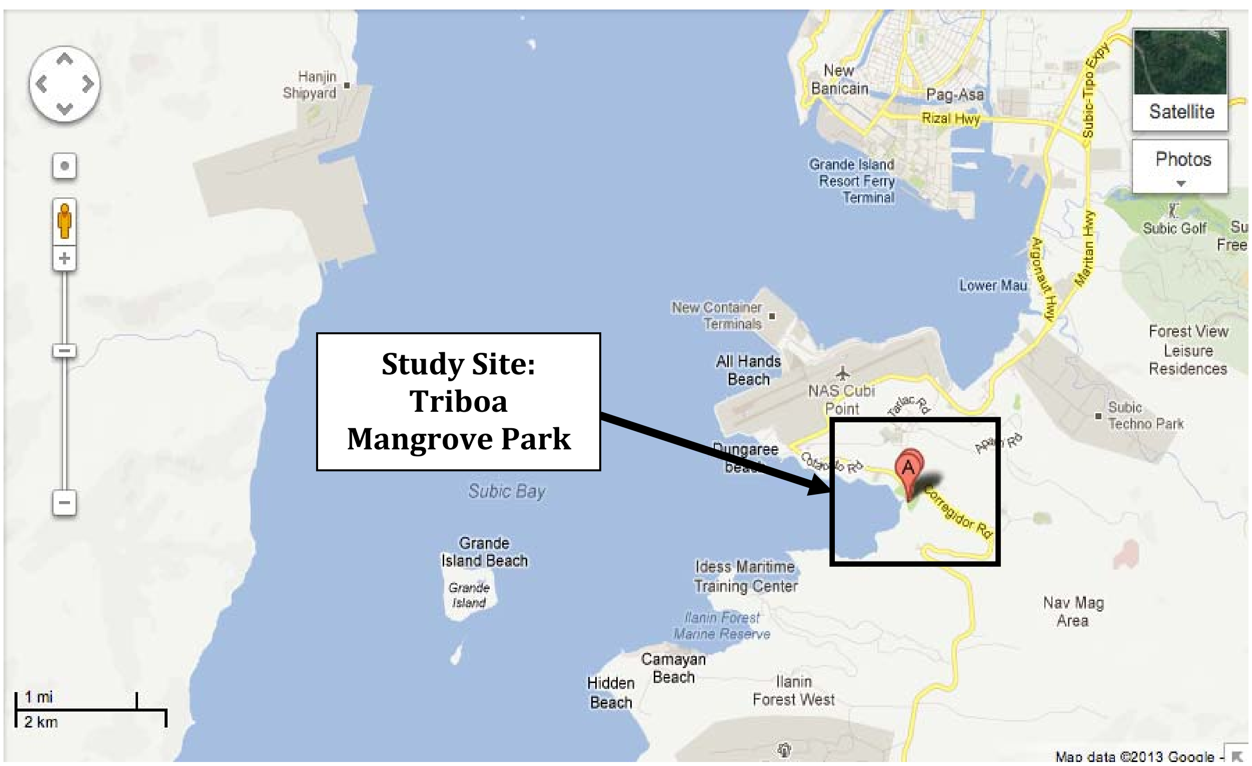


**Figure 1. General vicinity map of the study area.**

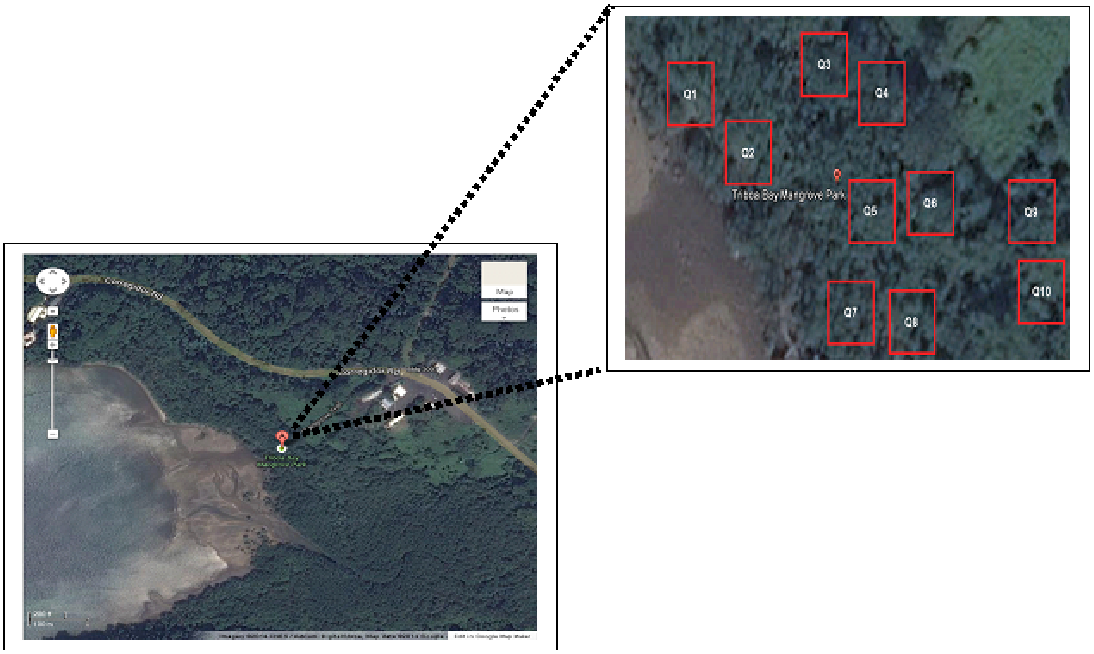


**Figure 2. Satellite image of Triboa Mangrove Park and the location of the ten quadrats (Q1 to Q10) in the study area in Subic Bay, Philippines.**

**Table 1. Habitat criteria rating chart for mangroves.**

| CONDITION | CRITERIA |
|---|---|
| **Excellent** | 76% and above in % Crown Cover<br>1 Regeneration per m2 Undisturbed to negligible Disturbance |
| **Good** | 51% - 75% Crown Cover<br><1-0.76 regeneration per m2 Slight disturbance and few cuttings |
| **Fair** | 26% - 50% Crown Cover<br>0.50 - 0.75 regeneration per m2 Moderate disturbance and noticeable cuttings |
| **Poor** | 0 - 25% Crown Cover<br><0.50 regeneration per m2 Heavy disturbance/ cuttings/ pollution, rampant conversion to other uses, nearly destroyed |

**Source: BFAR, Participating Coastal Resource Assessment Training Guide**

## Sampling method and water analysis

The water samples from each quadrat were gathered using composite sampling. The bottle submersion method, which is adopted from the CRL Environmental Corporation protocol on water sampling method, was used to collect water samples. One hundred (100) milliliters of water sample were filled into clean sample bottles. Collections of the sample carefully below the surface water were done to prevent disturbance of the underlying sediment. Ten sample bottles were used to gather samples randomly in the area. Then, the water from each composite location was transferred into a plastic bottle, sealed and labeled properly. The plastic bottles with marine water were stored in an ice chest filled with bagged ice. The preparation of the water samples and determination of Cu using Flame Atomic Absorption Spectrophotometer (AAS) were done in the CRL Environmental Corporation Laboratory, Clarkfield, Pampanga.

## Determination of copper in sediments

### Sampling method, preparation and analysis of sediment

The mangrove sediment samples were gathered using composite sampling. The dipper method which was adopted from CRL Laboratory protocol on sediment sampling was used to collect sediment samples. A stainless steel dipper were used to collect sample by pushing it firmly downward into the sediment, and then quickly lifting it upward to reduce the amount of fine grainer sediment lost to the water current. One scoop of sediment were dug every quadrat during the survey totaling ten scoops per station. Sediment samples from each composite location were transferred in a stainless steel bowl, homogenized using stainless steel spoon and were stored in an ice chest filling with bagged ice. The preparation of the sediment samples and determination of Cu using Flame AAS were done in the CRL Environmental Corporation Laboratory Clarkfield, Pampanga.

## Copper analysis of mangrove tissues

### Collection of plant parts

The mangrove species collected were based on the species importance value and crown cover. These were utilized in the detection of Cu. The plant parts specifically, prop roots or pneumatophores with a length of five to seven inches and matured leaves were gathered randomly for each of the mangrove species with a total weight of 200 grams per species. The collection of samples was done in the station. The roots were carefully cut and handpicked from above the sediment. The leaves were collected using a pair of clean scissors.

The roots and the leaves of each mangrove species were washed first with tap water [9]. Then about three to five drops of phosphate free soap were added to the plant samples and rinsed with tap water twice followed by deionized water. The plant samples were stored in clean plastic bags properly labeled with date and location of sampling.

### Plant sample preparation and copper analysis

The different plant parts were oven dried at 80°C for four hours or until completely dried. Leaves of the same species were homogenized and pulverized into powder [9] and were placed in a clean Ziploc plastic bag. The same procedure was followed for the root samples. The plant samples were delivered to the CRL Environmental Corporation Laboratory, Clarkfield, Pampanga and were subjected to their sample preparation protocol for Cu analysis. The analysis of Cu was determined using a Flame AAS.

### Statistical analyses

The three stage nested design in completely randomized design was used as the experimental design of the study. Concentrations of Cu in water, sediments and plants were analyzed by the analysis of variance using PROC ANOVA from the Statistical Analysis Software (SAS 2000). Where the F-test indicated a significant ($p \leq 0.05$) effect, means were separated following the method of Duncan's Multiple Range Test, using the appropriate error mean square (SAS 2000).

## RESULTS

### Diversity Assessment of Mangroves

Five species of mangroves were identified in the coastal ecosystem of Subic Bay, Philippines. The five species of mangrove are: *Sonneratia alba; Calophyllum inophyllum; Rhizophora apiculata; Bruguiera sp.;* and *Barrington racemosa.* Table 2 shows the number of individuals, frequency (F), relative frequency (RF), density (D), relative density (RD), dominance (Do), relative dominance (RDo) and species importance value (SIV) of different mangroves and Simpson's diversity index (SDI).

Results showed that the mangrove species that attained the highest relative density, relative dominance and species importance value is *R. apiculata* (Table 2). This species has the highest species importance value of 129.8 % since it obtained the highest relative density (44%), relative dominance (52.84%) and relative frequency (33%). *S. alba* has the second highest species importance value of 124.7%. The two mangrove species: *R. apiculata* and *S. alba* had the highest importance value because of their total number of mangrove species present and the total area they covered in the study area. The average Species Diversity Index of mangroves in the area was 0.64, which indicated low diversity due to low species richness and uneven distribution of different species in the study area. Human settlement, pollution from aquaculture and household wastes could contribute to the degradation of the mangrove ecosystem [10].

The average regeneration potential of mangroves in the study area was excellent (18.5 mangrove tree per $m^2$) (Table 3). Moreover, the study area had 64% crown cover, which indicates that the crown cover was in good condition.

### Copper analysis of marine water and sediments in Subic Bay

The Cu analysis of marine water in Subic Bay, Philippines showed that Cu was undetected, but Cu was present in the sediments (Table 4). The average concentration of Cu in the sediments was about 19.21 mg $kg^{-1}$. The results of Cu analysis in water and sediment samples from our study corroborate with the study of Sing (2010) [11]. They reported the presence of Cu in the sediments of mangrove ecosystems from their study area.

**Table 2. Ecological parameters gathered in the mangrove ecosystem in Subic Bay, Philippines.**

| Species | No. of Ind. | F | RF (%) | D | RD (%) | Do | RDo (%) | SIV (%) | SDI |
|---|---|---|---|---|---|---|---|---|---|
| *Rhizophora apiculata* | 79 | 0.7 | 33 | 0.066 | 44.00 | 0.19 | 52.84 | 129.8 | 0.64 |
| *Sonneratia alba* | 71 | 0.9 | 43 | 0.059 | 39.23 | 0.15 | 42.62 | 124.7 | |
| *Bruguiera sp* | 23 | 0.3 | 14 | 0.019 | 12.71 | 0.02 | 4.39 | 31.3 | |
| *Barringtonia racemosa* | 4 | 0.1 | 5 | 0.003 | 2.21 | 0.00037 | 0.10 | 7.1 | |
| *Calophyllum inphyllum* | 4 | 0.1 | 5 | 0.003 | 2.21 | 0.00037 | 0.10 | 7.1 | |
| **Total** | **181** | **2.1** | **100** | **0.151** | **100** | **0.35795** | **100** | **300** | |

**Table 3. Condition of mangrove ecosystem in Subic Bay, Philippines.**

| Criteria | Index Values | Condition |
|---|---|---|
| Regeneration per $m^2$ | 18.5 | Excellent |
| % Crown Cover | 64 % | Good |

**Table 4. Copper concentration of marine water (mg $L^{-1}$) and sediment mg $kg^{-1}$) in the mangrove ecosystem in Subic Bay, Philippines.**

| Substrate | Sampling place | Copper Concentration |
|---|---|---|
| Marine Water | Subic Bay, Philippines | 0** |
| Surface Sediment | Subic Bay, Philippines | 19.21++ |

*indicates Minimum Detection Limit on sediment <0.40ppm
**indicates Minimum Detection Limit on water <0.02ppm
+indicated above Minimum Detection Limit on sediment > 0.40ppm
++indicated above Minimum Detection Limit on water > 0.02ppm

## Copper analysis of different mangrove plant parts

Table 5 shows the concentration of Cu absorbed by mangrove species in their combined leaves and roots using random sampling. It is very interesting to note that Cu is present in four mangrove species namely: *Sonneratia alba* with 73.6 g $kg^{-1}$; *Bruguiera sp* with 13.4 g $kg^{-1}$; *Barringtonia* racemosa with 7.3 g $kg^{-1}$; and *Rhizophora apiculata* with 2.8 g $kg^{-1}$. Table 6 shows the mean Cu concentration in leaves and in roots particularly in the pneumatophores of *Rhizophora apiculata, Sonneratia alba* and *Barringtonia racemosa*. The mangrove species that accumulated Cu in their roots which exceeded the average Cu concentration of 0.40 g $kg^{-1}$ were *Sonneratia alba* and *Barringtonia racemosa* with 2.8 and 2.7 g $kg^{-1}$ of Cu, respectively.

**Table 5. Amount of copper absorbed in the combined leaves and roots of the mangrove species in the mangrove ecosystem in Subic Bay, Philippines.**

| Mangrove Species | Copper Content (g $kg^{-1}$) |
|---|---|
| *Sonneratia alba* | 7 |
| *Rhizophora apiculata* | 2 |
| *Barringtonia racemosa* | 7 |
| *Bruguiera sp.* | 1 |
| *Calophyllum inophyllum* | 0 |

*means with the same letter superscript are not significantly different at 5% level by DMRT

**Table 6. Mean concentration (mg $kg^{-1}$) of copper in the different plant parts of mangrove species in the mangrove ecosystem in Subic Bay, Philippines.**

| Mangrove Species | Plant Parts | Mean Concentration |
|---|---|---|
| *Rhizophora apiculata* | Roots | $0^{c*}$ (ND) |
| | Leaves | $0^{c}$ (ND) |
| *Sonneratia alba* | Roots | $2.8^{a}$ (ND) |
| | Leaves | $0^{c}$ (ND) |
| *Barringtonia racemosa* | Roots | $2.7^{a}$ (ND) |
| | Leaves | $0^{c}$ (ND) |

MDL (Method Detection Limit) – 0.40; ND – Below MDL
*means with the same letter superscript are not significantly different at 5% level by DMRT

## DISCUSSION

Results indicated that mangroves in Triboa Mangrove Park, Subic Bay, Zambales had low diversity due to several anthropogenic activities near the study area. Human settlement, pollution from aquaculture and household wastes, fishpond conversion and cutting of trees for timber and fuel could contribute to the degradation and destruction of the mangrove ecosystem [10, 12]. This mangrove ecosystem is near the SBF. Subic Bay Freeport, which is located in Central Luzon Region of the Philippines, is one of the growth and economic development areas in the region. Subic Bay Freeport is a supplier of services and products for the Central Luzon Development Program (CLDP), a regional growth area composed of the provinces of Bulacan, Nueva Ecija, Tarlac, Pampanga, Bataan and Zambales.

Subic Bay Freeport Zone's greatest asset is in terms of economic potential to be its deep-water natural harbor, currently being utilized as a gateway for their high-end shipbuilding facility where over 7000 workers are employed. This state-of-the-art ship building facility is valued at over $1 billion and produces huge containerized transport ships. Aside from the shipyard, more than 610 companies are based in the Subic Bay Freeport Zone. Subic is divided into four key investment areas, namely, the Central Business District, Subic Gateway, the Subic Bay Industrial Park, and the Subic Techno Park. Additional commercial activities driving the Freeport Zone's economic engine are manufacturing-related businesses, electronic communications and computer industries, warehousing and transshipment, banking, education and, of course, a vibrant tourism, resort and lodging industry. All of these development activities in the Subic Bay Freeport Zone lead to urbanization of this area.

Due to the growing rate of urbanization and economic development in many tropical coastal areas, there continues to be an increasing concern in relation to the impact of anthropogenic activities such as domestic wastes, industrial wastes and heavy metal pollution on mangrove forests which pose the most threat to the regeneration and growth of the mangrove [13, 14]. Studies revealed that the population and diversity of mangroves are declining due to low species richness and uneven distribution of different species in the study area. Similar findings were obtained by Paz-Alberto et al (2014) [3] on the low diversity and population of mangroves in Masinloc, Zambales due to human activities.

Findings from our study revealed that Cu concentrations in the sediments of mangrove ecosystem is above the minimum detection limit, which could be potentially harmful to the marine organisms thriving in the coastal resources as well as to the people living nearby Subic Bay, Philippines. Copper has been well known as an environmental pollutant for several decades. It is dangerous to marine organisms and has been used in marine anti-fouling paints. The effect of Cu on fish can damage their gills, liver, kidneys and the nervous system. It also interferes with the sense of smell in fish, thus preventing them from choosing good mates or finding their way to mating areas. In humans, Cu can be toxic to human health. Humans can be exposed to Cu via inhalation of particulate, drinking Cu-contaminated water and eating Cu- contaminated food, it can cause nausea, vomiting, abdominal and muscle pain and can suffer from liver damage.

Copper is continuously released into the biosphere by volcanoes and natural weathering of rocks. Numerous anthropogenic activities, such as mining, combustion of fuels, industrial and urban sewage and agricultural practices can be major source of elevated Cu in the soils and sediments of mangrove ecosystems. On a global scale, there are evidences that anthropogenic activities have polluted the environment with heavy metals from the poles to the tropics and from the mountains to the depths of the oceans [15]. Copper compounds have been widely used in industrial processes and agriculture. As a result, elevated Cu concentrations can be found in certain areas of the biosphere [16].

Toxic metal pollution of waters and soils is a major environmental problem, and most conventional remediation approaches do not provide acceptable solutions.

Contaminated soils and waters pose a major environmental and human health problem, which may be partially solved by the emerging green technology called phytoremediation [1, 2, 3]. This cost-effective plant-based approach to remediation takes advantage of the remarkable ability of plants to concentrate elements and compounds from the environment and to metabolize various molecules in their tissues. Toxic heavy metals and organic pollutants are the major targets for phytoremediation.

Phytoremediation is the use of plants to extract, sequester, and/or detoxify pollutants. Phytoremediation is widely viewed as the ecologically responsible alternative to the environmentally destructive physical remediation methods currently practiced. Plants have many endogenous genetic, biochemical, and physiological properties that make them ideal agents for soil and water remediation. Because elements are immutable, phytoremediation strategies for radionuclide and heavy metal pollutants focus on hyper accumulation aboveground. In contrast, organic pollutants can potentially be completely mineralized by plants [17].

It is very interesting to note that Cu is present in the four mangrove species namely *Sonneratia alba, Bruguiera sp.*, *Barringtonia racemosa* and *Rhizophora apiculata*. According to the studies of Sing (2010), Nazli and Hashim (2005), Kamaruzzaman et al. (2009), Koller et al. (2007) [11, 13, 18, 19] both leaves and roots or pneumatophores of mangroves can absorb Cu, therefore mangroves are good phytoremediators for Cu. Studies indicated that mangrove species possessed the capacity to absorb Cu, potentially aiding in the retention of toxic material and thereby reducing transport to adjacent estuarine and marine ecosystem [19]. Our study showed that *Sonneratia alba, Barringtonia racemosa, Bruguiera* sp. and *Rhizophora apiculata* are potential phytoremediators of Cu in the mangrove ecosystems.

Copper accumulation in the pneumatophores of *Sonneratia alba* corroborated with the study the study of Koller et al. (2007) [19] who reported higher accumulation of Cu in the roots than in the aerial parts of the mangrove. However, in another study the total concentrations of Cu in both the roots and leaves of *Sonneratia caseolaris* exceeded the general normal upper range in plants [12]. Sing (2010) reported Reports stated that roots and pneumatophores of *Sonneratia caseolaris* immobilized Cu [11].

One factor that could affect Cu absorption is location. The results show that there is no definite amount of Cu on different parts of the study area. Some exhibited very high amount of concentration on sediments and some in plants. Results show that the mangrove species near the source of pollution tend to accumulate Cu. The study area is described as a cove, there are rivers flowing downstream from the mountain part of Subic. *Barringtonia racemosa* and *Sonneratia alba* are the two mangrove species that are most exposed to the source of pollution. Copper contaminants may come from underground wires near the study area. Moreover, the distribution and accumulation of heavy metals still depends on plant species, heavy metal concentration and exposure duration.

Root structure of *Sonneratia alba* grow vertically up from the underground root system, cone root of the mangrove species can grow in a radius of more than 10 meters around the trunk. *Barringtonia racemosa* develops spreading large roots that can also occupy large radius around the trunk. *Rhizophora apiculata* on the other hand, develops small branching stilt roots. One function of the root is to uphold the mangrove and insure its growing space.

Due to the growing rate of urbanization in many tropical coastal areas, there continues to be an increasing concern in relation to the impact of anthropogenic activities such as domestic wastes, industrial wastes and heavy metal pollution on mangrove forests which pose the most threat to the regeneration and growth of the mangrove [13, 14]. Studies revealed that the population and diversity of mangroves are declining due to low species richness and uneven distribution of different species in the study area. Similar findings were obtained by Paz-Alberto et al. (2014) on the low diversity and population of mangroves in Masinloc, Philippines due to human activities [3].

Studies have shown that the livelihood of local inhabitants largely depend on renewable natural resources which is environment dependent, thus, it is imperative that the environment should be sustainably managed in order to continue serving this function through comparatively cheaper means, through the use of green technology such as phytoremediation [20]. Phytoremediation studies using in-situ techniques and their potentials as a remediation technique that utilizes the age long inherent and innate abilities of living plants to get rid of pollutants from the environment but which is yet to become a common available technology in many parts of the world particularly developing countries like the Philippines should be further explored to conserve the endemic and indigenous plants such as the mangroves for utilization in the purging of pollutants in the environment.

## CONCLUSIONS

Mangroves thriving in marshy ecosystems have potential phytoremediation properties because they act as pollutant eradicators, which are critical for the protection of adjacent coastal ecosystems and nearby communities from the potential buildup of Cu in sediments at Subic Bay. Based on the results of the identification of mangroves of Subic Bay and the determination of their phytoremediation potential, the following conclusions were made:

1. There were only five mangrove species present and identified namely *Barringtonia racemosa, Bruguiera sp, Calophyllum inophyllum, Rhizophora apiculata* and *Sonneratia alba*;
2. The mangrove ecosystem had low species diversity, but excellent regeneration and good percent crown cover;
3. *Sonneratia alba* and *Barringtonia racemosa* had the most accumulations of Cu in their roots; and
4. The four mangrove species, *Sonneratia alba, Rhizophora apiculata, Bruguiera sp,* and *Barringtonia racemosa* are potential phytoremediators of Cu.

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