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The extent and applications of metal accumulation and hyperaccumulation in Philippine plants

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Summary text for the Table of Contents

Soils of the Philippines often have high concentrations of heavy metals and low nutrient content, which are conditions that are normally unfavourable for plant growth. Many plants in the area, however, have adapted to these conditions and can grow well. Here we have compiled the data that is currently available on Philippine plants that can accumulate metals in their tissue, and the potential applications of these plants in restoration efforts.

Abstract

To examine the potential applications of hyperaccumulator plants in the Philippines we reviewed current data on the extent of metal hyperaccumulation in native species, and partitioning of metals within the plant tissue.

Twenty-eight species had reported tissue concentrations above the hyperaccumulator threshold, eleven species were endemic to the Philippines. Nickel was present in higher concentrations in the aboveground tissue than the belowground tissue, but the reverse was found for copper, aluminium, and chromium.

The fact that copper accumulates belowground rather than above, and most hyperaccumulators of nickel identified were trees has implications for the potential of phytoextraction using native Philippines flora.

Key words:

Metallophyte; hyperaccumulator; phytoremediation; phytomining; phytoextraction; Philippine flora; metal tolerance; translocation factor; bioaccumulation factor

1 Introduction

The Philippines is the fifth richest country in mineral resources worldwide, including nickel, copper, chromite, and gold (Maddox et al., 2019) and mining activity is extensive in the region as a result. The ultramafic areas in the Philippines account for about 5% of its estimated total land area of 298,170 km^2 (Baker et al., 1992). Ultramafic areas are often deficient in the essential macronutrients (e.g. phosphorus, potassium and calcium) and have high concentrations of potentially phytotoxic elements (e.g. magnesium, iron, nickel, cobalt, and chromium) --- conditions that are normally adverse to plant growth (Galey et al., 2017). However, some plants called 'metallophytes' have an ability to tolerate metal toxicity and survive and reproduce in these environments (Baker and Whiting, 2008; Whiting et al., 2004). Plant species that evolved on ultramafic soils are generally metal tolerant. Such native species could be an important source of metal tolerant and accumulator plants that are most likely to be able to survive the edaphic and climatic conditions of locally contaminated lands (Carvalho et al., 2013; Claveria et al., 2020, 2019b; de Castro et al., 2020). Metallophytes are able to grow in soils with high heavy metal concentrations through two different strategies: avoidance and tolerance (Baker, 1981). Avoidance is achieved when the plant invests in external mechanisms to keep metals chelated outside of the plant tissue (Carvalho et al., 2013; Claveria et al., 2010). Whereas tolerance is developed through physiological adaptations to accumulate metals in high concentrations in the plant biomass.

Tolerance can be achieved through exclusion, or hyperaccumulation (Jaffré et al., 1976). Exclusion means there is limited translocation from the roots of the plant to the shoots (Hunt et al., 2014; Lange et al., 2017; Sanqui et al., 2020). Hyperaccumulators, have evolved the capability to accumulate certain metal elements in their shoots, especially the leaves, that are at levels 100x greater than those typically measured in shoots of the common non-accumulator plants (Brooks et al., 1998, 1977; Jaffré et al., 1976). Reeves (1992) stated that concentrations must be recorded in the dry matter of any above-ground tissue in at least one specimen growing 'in its natural habitat' i.e. not under artificial conditions, such as through metal-salt amendments to an experimental soil or hydroponic nutrient solutions (van der Ent et al., 2013). More than 700 hyperaccumulating plants have been reported worldwide, the majority of which (>70%) hyperaccumulate nickel (Reeves et al., 2017).

As a result of their unusual tolerance for heavy metals and restricted distribution, metallophytes have potential benefits for the restoration of vegetation in mined-out areas within their geographic range (Erksine et al., 2012; Reeves, 2006; Whiting et al., 2004). Hyperaccumulators have been of considerable interest in the mineral exploration (Jaffré et al., 1976) and are the optimal choice for future ‘green’ phytoremediation technologies, such as phytoextraction and phytomining. However, for plants to be applicable for phytomining or phytoextraction efforts they need to be examined in terms of: (i) their ability to bioaccumulate metals so that the concentration in the plant tissue is greater than the soil (Reeves, 2006); and (ii) translocate those metals to their aboveground biomass (Figure 1).

The total number of native vascular plant species in the Philippines is currently estimated at 9,433 (Pelser et al., 2011) with ~50% endemic species. Of this, the exact number of metallophytes remains unknown and many new species of metallophytes endemic to the Philippines continue to be discovered (Fernando et al., 2018; Fernando and Wilson, 2021; Fritsch et al., 2020; Robinson et al., 2019; Tamayo et al., 2023). This paper aims to consolidate current data on the extent of metal hyperaccumulation in the Philippines, the species of heavy metal accumulating plants, and partitioning of metals within the plant tissue. We also aimed to identify any knowledge gaps and future research needs on metal hyperaccumulation in the Philippines. Our review considers solely native plant species in the Philippine flora naturally growing in the wild (rather than controlled or laboratory conditions).

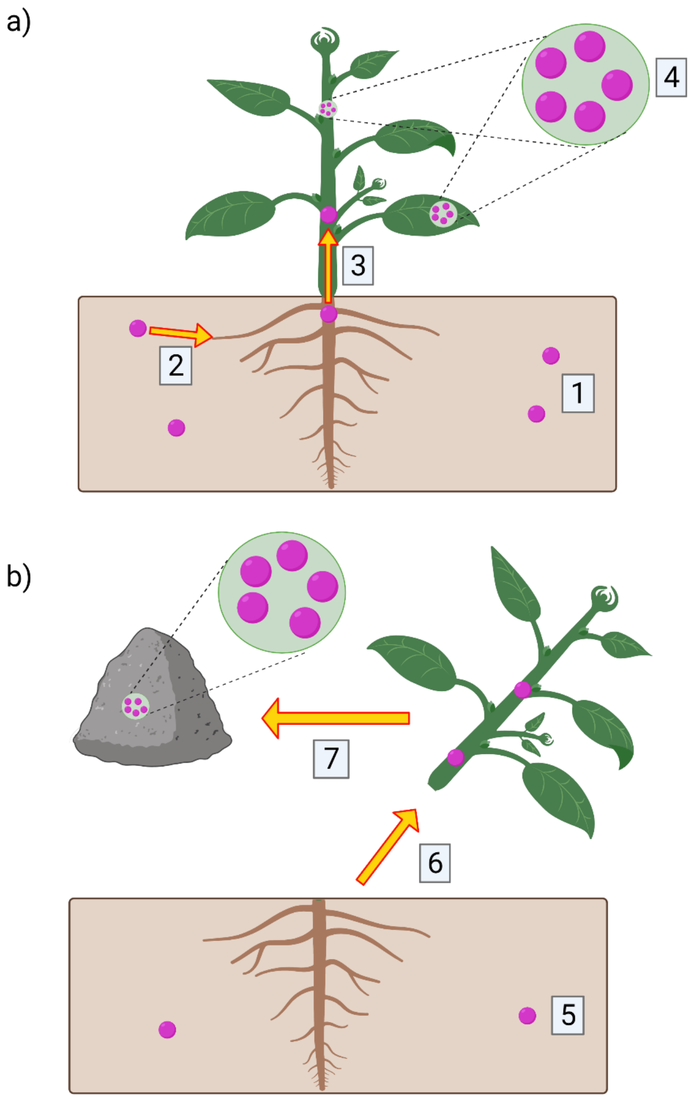

Figure 1- Schematic of principles of phytomining in phytoremediation of a given metal. a) Soils with large concentrations of a given metal present in the soil solution (1) are sown with plants. Plant uptake through the roots take place (2) and are translocated into the aboveground biomass (3). Metal accumulates in the aboveground tissue (4); b) Bioaccumulation in the plant tissue reduces the concentration of the metal in the soil (5). Aboveground biomass is harvested and removed from the site, this is phytoextraction (6) and ashed to generate a high metal concentrated material for processing for their intrinsic value, this is phytomining (7). Drawn with biorender.com

2 Materials and methods

2.1 Literature searches and data extraction

Searches on Web of Science were carried out (24th February 2023) using the terms: (i) *4ccumulate* metal* plant* AND Philippine*; (ii) metallophyte* plants AND Philippine*; and (iii) metal toleran* plants AND Philippine*. The references list in each of the papers returned were also checked to find additional papers. Observations on species that were not native to the Philippines, laboratory trials, or duplicates were not included. If a paper reported concentrations of two metals for a single plant, this was recorded as two observations, one for each metal.

Each paper reported results in a different manner. The majority reported a total plant tissue concentration. A large proportion also partitioned into aboveground tissue concentration and belowground concentration. For papers that separated plant biomass into roots, shoots/stems and leaves: roots were classed as belowground biomass, shoots/stems and leaves were summed and classed as aboveground biomass. There were insufficient studies that discriminated between stems and leaves to analyse this data independently, hence these were summed to generate an aboveground concentration to provide parity with other studies. All data were converted to µg/g. A total of 440 observations of metal concentrations in the tissue of species native to the Philippines, from 59 plant families, were extracted from the literature (see supplementary information for full list of references, Table S1). More than half of the observations focused on nickel and copper (35% and 22% respectively).

Threshold aboveground concentrations for hyperaccumulation status have been established for various elements (van der Ent et al., 2013): 100 µg/g for Cd, Se and Tl; 300 µg/g for Co, Cu and Cr; 1,000 µg/g for Ni, Pb, Al and As; 3,000 µg/g for Zn; and 10,000 µg/g for Mn. If an observation had an aboveground concentration above this threshold then the species was classified as a hyperaccumulator.

2.2 Metal partitioning and translocation factor

Not all papers reported both the aboveground and belowground tissue concentrations, but those that did were collated to examine the partitioning of the metals they were reporting between the aboveground and belowground biomass. In addition, a translocation factor (TF) was also calculated as follows:

$$TF = \frac{Aboveground\ tissue\ concentration\ (\mu g\ kg^{-1})}{Belowground\ tissue\ concentration\ (\mu g\ kg^{-1})}$$

A TF >1 indicates that a plant species has the capability to extract metals, because the aboveground biomass concentrations are higher than the belowground biomass (Aribal et al., 2016; Balafrej et al., 2020; Claveria et al., 2019a; Novo et al., 2013).

2.3 Bioaccumulation factor

For papers that also reported the soil concentration from where the plant tissue was collected, a bioaccumulation factor (BF) was also calculated as follows:

$$BF = \frac{Aboveground\ tissue\ concentration\ (\mu g\ kg^{-1})}{Soil\ concentration\ (\mu g\ kg^{-1})}$$

A BF greater than one indicates that a species is a hyperaccumulator, and a BF less than one is indicative of an excluder (Ancheta et al., 2020; Claveria et al., 2020; Novo et al., 2013; Usman et al., 2019; Yashim et al., 2014).

3 Results

3.1 Species identified

Of the 115 plant species whose aboveground tissue concentrations were reported in the literature, twenty-eight were above the hyperaccumulator threshold concentrations outlined by van der Ent et al., (2013) in the introduction (Table 1). Nineteen species were found to contain more than 1,000 µg/g Ni in samples taken; four species contained more than 1,000 µg/g Al; three species had observations above 300 µg/g Cu; three species were above 300 µg/g Cr; one species had observations above 3,000 µg/g Zn; and one species was above 10,000 µg/g Mn. Some species have been observed to contain above-threshold concentrations for more than one metal. *Mitragyna speciosa,* for example, was above threshold concentrations for Aluminium, Copper and Manganese (Table 1). However, it is important to note that concentrations reported in the literature, were not always above the threshold for every species. Nickel concentrations reported for *Dichapetalum gelonioides,* for example, ranged from 39 – 25,820 µg/g Ni. Furthermore, despite, being over the aboveground tissue concentration threshold, not all species had a translocation factor or bioaccumulation factor greater than one (e.g. *Elaeocarpus merrittii* and *Pneumatopteris laevis*). Most of the species identified as hyperaccumulators in Table 1 were trees, and eleven species were endemic to the Philippines.

Table 1 – Metal hyperaccumulation in twenty-eight Philippine native plants. Aboveground tissue concentration, translocation factor (TF) and bioaccumulation factor (BF). Threshold aboveground concentrations for hyperaccumulation status (van der Ent et al., 2013); 300 µg/g for Cu and Cr; 1,000 µg/g for Ni and Al; 3,000 µg/g for Zn; and 10,000 µg/g for Mn.

Species	**Family**	**Plant Type**	**Distribution**	**Metal**	**Aboveground tissue concentration (µg/g)**	**TF**	**BF**	**Reference**
Brackenridgea fascicularis	Ochnaceae	Tree	Philippines; endemic	Nickel	1027 – 4,489	-	-	(Fernando et al., 2020)
Brackenridgea foxworthyi	Ochnaceae	Tree	Philippines; endemic	Nickel	3,770 – 7,600	-	-	(Baker et al., 1992)
				Nickel	3,113 – 6,288	-	-	(Fernando et al., 2020)
Brackenridgea mindanaensis	Ochnaceae	Tree	Philippines; endemic	Nickel	1,546 – 3,114	-	-	(Fernando et al., 2020)
Breynia cernua	Phyllanthaceae	Tree	Philippines; also in Australia, Java, Lesser Sunda Islands, Moluccas, New Guinea & Sulawesi	Nickel	4,533	6.50	0.56	(Gotera et al., 2014)
				Nickel	4,270	1.20	-	(Gotera et al., 2020)
Breynia sp.	Phyllanthaceae	Tree		Nickel	4,195	-	0.54	(Fernando et al., 2013)
Callicarpa sp.	Lamiaceae	Tree		Nickel	1,383	-	0.18	(Fernando et al., 2013)
Cratoxylum sumatranum	Hypericaceae	Tree	Philippines; also in Borneo, Java & Thailand	Copper	200-421	2.56-7.19	10.96-57.49	(Castaňares and Lojka, 2020)
Decaspermum blancoi	Myrtaceae	Tree	Philippines; endemic	Nickel	3,841	-	0.50	(Fernando et al., 2013)
Dichapetalum gelonioides subsp. *Pilosum*	Dichapetalaceae	Shrub to Tree	Philippines; also in Borneo & Malay Peninsula	Nickel	9 – 20,300	-	-	(Baker et al., 1992)
				Zinc	390 – 26,360	-	-	(Baker et al., 1992)
Dichapetalum gelonioides subsp. *Tuberculatum*	Dichapetalaceae	Tree	Philippines; also in Borneo, Malay Peninsula, Sumatra, Thailand & Vietnam	Nickel	39 – 25,820	-	-	(Baker et al., 1992)
Elaeocarpus merrittii	Elaeocarpaceae	Tree	Philippines; endemic	Chromium	835	0.57	0.41	(Aribal et al., 2016)
Falcatifolium gruezoi	Podocarpaceae	Shrub to tree	Philippines; also in Moluccas; Sulawesi	Chromium	326	0.04	1.60	(Aribal et al., 2016)

Memecylon sp.	Melastomataceae			Aluminum	2,300	-	-	(Proctor et al., 2000)
Mitragyna speciosa	Rubiaceae	Tree	Philippines; also in Borneo, Malay Peninsula, New Guinea, Sumatra & Thailand	Aluminum	3,960	0.40	1.22	(Castaňares and Lojka, 2020)
				Copper	358	3.83	21.24	(Castaňares and Lojka, 2020)
				Manganese	39,554	3.66	2909	(Castaňares and Lojka, 2020)
*Phyllanthus balgooyi**	Phyllanthaceae	Tree	Philippines; also Borneo	Nickel	3,920 – 16,230	4.04	2.94	(Baker et al., 1992)
				Nickel	6,913	1.02	0.75	(Quimado et al., 2015)
*Phyllanthus erythrotrichus***	Phyllanthaceae	Shrub	Philippines; endemic	Nickel	18,492	-	2.40	(Fernando et al., 2013)
				Nickel	12,287	9.28	2.63	(Quimado et al., 2015)
*Phyllanthus securinegoides****	Phyllanthaceae	Tree	Philippines; endemic	Nickel	1050 – 34,750	-	-	(Baker et al., 1992)
				Nickel	13,481	2.91	1.81	(Quimado et al., 2015)
Planchonella obovata	Sapotaceae	Tree	Philippines; also in Andaman Islands, Australia, Bangladesh, China, India, Indochina, Malay Peninsula, Myanmar, Nicobar Islands, Pacific Ocean, Solomon Islands & Thailand	Nickel	2,645	-	0.34	(Fernando et al., 2013)
Pneumatopteris glabra	Thelypteridaceae	Fern	Philippines; endemic	Aluminum	3,263	0.38	0.89	(Castaňares and Lojka, 2020)
Pneumatopteris laevis	Thelypteridaceae	Fern	Philippines; endemic	Aluminum	1,035	0.12	0.35	(Castaňares and Lojka, 2020)
Polyosma integrifolia	Escalloniaceae	Tree	Philippines; also in Borneo, Java, Malay Peninsula	Chromium	780	0.21	0.79	(Aribal et al., 2016)
Psychotria sp.	Rubiaceae	Tree		Nickel	2,197	-	0.29	(Fernando et al., 2013)
Pteris sp.	Pteridaceae	Fern		Copper	371	0.76	1.46	(Claveria et al., 2010)

Rinorea bengalensis	Violaceae	Tree	Philippines; also in Andaman Islands, Australia, Bangladesh, Borneo, Cambodia, China, India, Java, Laos, Lesser Sunda Islands, Malay Peninsula, Moluccas, Myanmar, New Guinea, Nicobar Islands, Pacific Ocean, Solomon Islands, Sri Lanka, Sulawesi, Sumatra, Thailand & Vietnam	Nickel	1,000 - >10,000	-	-	(Brooks and Wither, 1977)
Rinorea niccolifera	Violaceae	Tree	Philippines; endemic	Nickel	15,215 – 22,241	7.27	8.07	(Fernando et al., 2014)
Syzygium sp.	Myrtaceae	Tree		Nickel	1,113	-	0.14	(Fernando et al., 2013)
Walsura monophylla	Meliaceae	Tree	Philippines; endemic	Nickel	2,360 – 7,090	-	-	(Baker et al., 1992)
Xylosma luzonense	Salicaceae	Tree	Philippines, also in Lesser Sunda Islands, Moluccas, Sulawesi	Nickel	1,936	-	0.25	(Fernando et al., 2013)

*more recently known as *Nymphanthus balgooyi* (Bouman et al., 2021)

**more recently known as *Emblica erythrotricha* (Bouman et al., 2021)

***more recently known as *Dendrophyllanthus securinegioides* (Bouman et al., 2021)

3.2 Metal partitioning in hyperaccumulator species

Error! Reference source not found. Table 2 shows how metal concentrations were partitioned in the aboveground and belowground tissue (when both were reported) in the species identified as hyperaccumulators in Table 1. Whether a metal accumulated in the aboveground or belowground biomass is dependent on the metal in question. Nickel (**Error! Reference source not found.**Table 2) was present in higher concentrations in the aboveground tissue than the belowground tissue. Conversely, concentrations of copper), aluminium and chromium were higher in belowground tissue than aboveground (Table 2). However, the errors for belowground concentrations of copper and chromium were quite large. There was not sufficient data to examine the partitioning of Zinc or Manganese in hyperaccumulators.

Table 2 – Reported aboveground and belowground tissue concentrations of hyperaccumulators identified in Table 1, and plants that were not identified as hyperaccumulators

Plant Type	Metal	n	Aboveground Tissue Concentration (μg g^{-1})	Belowground Tissue Concentration (μg g^{-1})
Hyperaccumulator	Ni	8	12,912 ± 2,792	3,408 ± 836
	Cu	5	273 ± 74	562 ± 391
	Al	4	2,573 ± 882	9,145 ± 411
	Cr	3	647 ± 161	4,592 ± 2,133
Non-Hyperaccumulator	Ni	10	70 ± 24	76 ± 33
	Cu	41	60 ± 10	612 ± 211
	Al	4	471 ± 51	5,598 ± 1,816
	Cr	14	54 ± 16	117 ± 46

–It is also important to note that species that were not classed as hyperaccumulators, because their aboveground concentrations of metals was not above the threshold, still had high concentrations in their belowground biomass in the in the case of copper and aluminium (Table 2**Error! Reference source not found.**).

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4 Discussion

4.1 Metal partitioning and phytoextraction/phytomining potential

Metals such as nickel and copper have been suggested as good candidates for phytoextraction efforts (Mahajan et al., 2016) with the Philippines being highlighted as a potential location for such efforts (Van Der Ent et al., 2015). Nickel had the greatest concentrations in the aboveground biomass compared to the belowground parts, which is that phytomining is more suitable for the recovery of nickel. However, it is important to note that many of the papers from which data was extracted were papers specifically looking for nickel hyperaccumulators which may have skewed the results.

The finding that copper accumulated at higher concentrations in the root than the shoot, is in concordance with several studies (Ancheta et al., 2020; Chua et al., 2019; Claveria et al., 2010; Dahilan and Dalagan, 2017). High root concentrations, or low translocation factors, could indicate phytostabilisation as this process binds the substrate to the plant roots thus reducing mobility of the metal in the soil (Claveria et al., 2010) or the sequestered metal remains solely in the roots, enabling the plant to grow and mature without its health being impacted (Claveria et al., 2010). This suggests that phytomining or extraction techniques may not be appropriate for copper, chromium or aluminium in general.

In addition to performance, key aspects of social acceptance of phytoextraction or phytomining techniques are the utilisation of by-products and economic viability (Aladesanmi et al., 2019). To be economically viable it is important to have fast growing plants that have high accumulation combined with high biomass (Chua et al., 2019; Marques et al., 2009; Paz-Alberto and Sigua, 2013). The majority of species identified as hyperaccumulators are trees.While this suggests they may have high biomass, it is also possible that these are slow growing which may affect their suitability.

Transfer and accumulation of metals from soil to plants is complex and often site-specific. Factors influencing this include: the chemical forms of the heavy metal; the pH of the soil; the soil organic matter content; soil nutrient contents; root exudation of organic acids and flavonoids; soil texture (particularly clay content); mycorrhizal symbiosis, microbial activity and abundance; the plant species; the plants stage of growth; climatic conditions and irrigation with polluted waters (Aladesanmi et al., 2019; Claveria et al., 2019b; Dahilan and Dalagan, 2017; de la Torre et al., 2016; De Oliveira et al., 2020; Domingo and David, 2014; Feigl et al., 2020; Mahajan et al., 2016; Navarrete et al., 2017; Sanqui et al., 2020; Susaya et al., 2010; Tibbett et al., 2021; Yashim et al., 2014). Furthermore, although our review focused on native species to the Philippines, it is important to note that each island has developed a slightly different plant community, so not all native plants to the Philippines is found on every island of the archipelago (Romeroso et al., 2021). Therefore, it would be impossible to find a species that is appropriate in every scenario, in every community, so planning needs to be site specific (Koelmel et al., 2015).

4.2 Issues, knowledge gaps, and future research needs

4.2.1 Agreed definition of hyperaccumulators

Despite having supra-threshold aboveground concentrations, some of the plant species we have identified did not have translocation and bioaccumulation factors greater than one. As discussed below, the literature did not report the data required to calculate the bioaccumulation factor or the translocation factor in all instances. If it is agreed that the bioaccumulation factor and translocation factor are important determinants of hyperaccumulation then papers need to report these if an accurate list of hyperaccumulators is to be compiled. Alternatively, if translocation and bioaccumulation factors are deemed to not be of importance, and therefore not reported in several cases this could put into question whether they should be included in the definition of hyperaccumulators.

4.2.2 Consistency in reporting metal concentrations in plant tissue

Many papers do not distinguish between above-ground and belowground concentrations of metals. Furthermore, papers that do separate above-ground tissue do not always distinguish between different parts of the plant (stem, leaves, flowers, seeds etc.). van der Ent et al., (2013) state that above-ground tissue should be regarded as plant leaves only for establishing hyperaccumulator status. Therefore, papers that fail to distinguish between the different parts of the plant may lead to potential hyperaccumulators have been missed. The failure to report the surrounding soil concentration in several papers, combined with no distinction between above and belowground biomass also makes the calculation of the translocation and bioaccumulation factors impossible, as discussed above.

Larger errors were observed in belowground concentrations than aboveground. This could be due to the difficulty of cleaning roots of particulate soil and externally sorbed metal ions before analysis (Reeves, 2006; van der Ent et al., 2013). This will have implications for partition data and calculations of the translocation factor.

4.2.3 Large scale screening

There were no hyperaccumulators identified in the literature for rare earth elements, and only one each for manganese and zinc. Historically, discoveries of trace element hyperaccumulator plants relied on destructive and time-consuming chemical analysis, however recent advances in hand held

Xray fluorescence spectroscopy (XRF) systems have enabled nondestructive analysis of herbarium samples in other regions (van der Ent et al., 2019; Isnard et al., 2020; Belloeil et al., 2021;). This will allow larger scale rapid assessment of Philippine flora and may lead to the discovery of more hyperaccumulator species, and species that accumulate more than one element, as XRF will allow for rapid analysis of multiple elements at the same time.

4.2.4 Botanical explorations

Hyperaccumulators are often rare species and are often endemic to small regions (Reeves, 2006), eleven of the reported hyperaccumulators in our review are endemic to the Philippines. Therefore to locate hyperaccumulators, extensive botanical surveys are needed. The reviewed papers only reported botanical surveys in small portions of ultramafic areas in Palawan, Surigao, Zambales, Bicol, Samar, and north central Mindanao. Considering the extent of ultramafic forest in the Philippines, more botanical surveys are necessary to identify metal accumulators. In addition, there can be significant variation among isolated populations of hyperaccumulators (Reeves, 2006). Therefore, collection of plant samples of the same species from multiple locations will provide better information on their potential to hyperaccumulate.

4.2.5 Physiological characteristics and toxicity thresholds

It is important to note that there are potential trade-offs in the use of hyperaccumulators. For example, hyperaccumulator species may have essentially substituted one defence mechanism (e.g. metal tolerance) for another (e.g. defence against pathogens) which may impact on the overall health of the plant (Boyd, 2013; Fones et al., 2019). Although many papers report the metal concentrations of the plant tissue, there was no comment on the health of the plants they measured. It is important that hyperaccumulators accumulate metal without evidence of physiological stress or impaired plant growth (Pasricha et al., 2021; Quimado et al., 2015). Therefore, moving forward, surveys should assess the health of the plants as well as the tissue analysis. There is also a need for research into the physiological processes that govern absorption, translocation and accumulation of metals in plants to gain understanding of the phytoremediation capacity of plants (Nescu et al., 2022). This will also give some indication of the nutrient requirements of hyperaccumulators, and whether fertilization would be necessary in a large scale phytoremediation effort. Phytoextraction/ phytomining, for example, could also lead to removal of soil nutrients alongside the target metal (Van Der Ent et al., 2015).

4.2.6 Potential impacts on higher trophic levels

The concept of phytomining is that metals accumulate in the aboveground biomass, which is more easily harvested and removed. However, elevated concentrations in the aboveground biomass could lead to exposure of herbivores, and subsequently other species in the food chain (Koelmel et al., 2015; Tibbett et al., 2021), including humans. It has been suggested that plants may develop the ability to hyperaccumulate metals, as a means of protecting themselves from herbivorous predators and pathogens that would experience serious toxic side effects from ingesting large concentrations of metals in the plants above-ground biomass (Fones et al., 2019; Paz-Alberto and Sigua, 2013; Remigio et al., 2020). In addition, hyperaccumulators can also lead to an increased metal concentration in the topsoil through high metal concentration litterfall (Tisserand et al., 2021), which could have an impact on soil biology. Metal rich pollen could also have potential risks for pollinators, an important consideration when planning large-scale cultivation of high metal containing plants (Schiavon and Pilon-Smits, 2017). Due to the potential risk to human health,edible agricultural crops should not be used for phytomining (Pasricha et al., 2021).

5 Conclusions

Metals such as nickel and copper have been suggested as good candidates for phytoextraction efforts and the Philippines has been highlighted as a potential location for such activities. While several species endemic to the Philippines have been highlighted as hyperaccumulators, the majority of these are woody plants. More research on the ecology and physiology of these species will be necessary to explore their potential for large-scale planting and subsequent development of phytomining or agromining in the Philippines.

Data availability statement

The data that support this study is available upon reasonable request to the corresponding author.

Conflicts of interest

The authors declare no conflicts of interest.

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