

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

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Accepted Version

Duddigan, Sarah ORCID logo ORCID: <https://orcid.org/0000-0002-6228-4462>, Quimado, Marilyn O., Fernando, Edwino S. and Tibbett, Mark ORCID logo ORCID: <https://orcid.org/0000-0003-0143-2190> (2023) The extent and applications of metal accumulation and hyperaccumulation in Philippine plants. *Australian Journal of Botany*, 71 (8). pp. 537-545. ISSN 1444-9862 doi: <https://doi.org/10.1071/BT23070> Available at <https://centaur.reading.ac.uk/114291/>

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To link to this article DOI: <http://dx.doi.org/10.1071/BT23070>

Publisher: CSIRO Publishing

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1 **The extent and applications of metal accumulation and** 2 **hyperaccumulation in Philippine plants**

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10 **Summary text for the Table of Contents**

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

16 **Abstract**

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

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

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

27 **Key words:**

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

31 **1 Introduction**

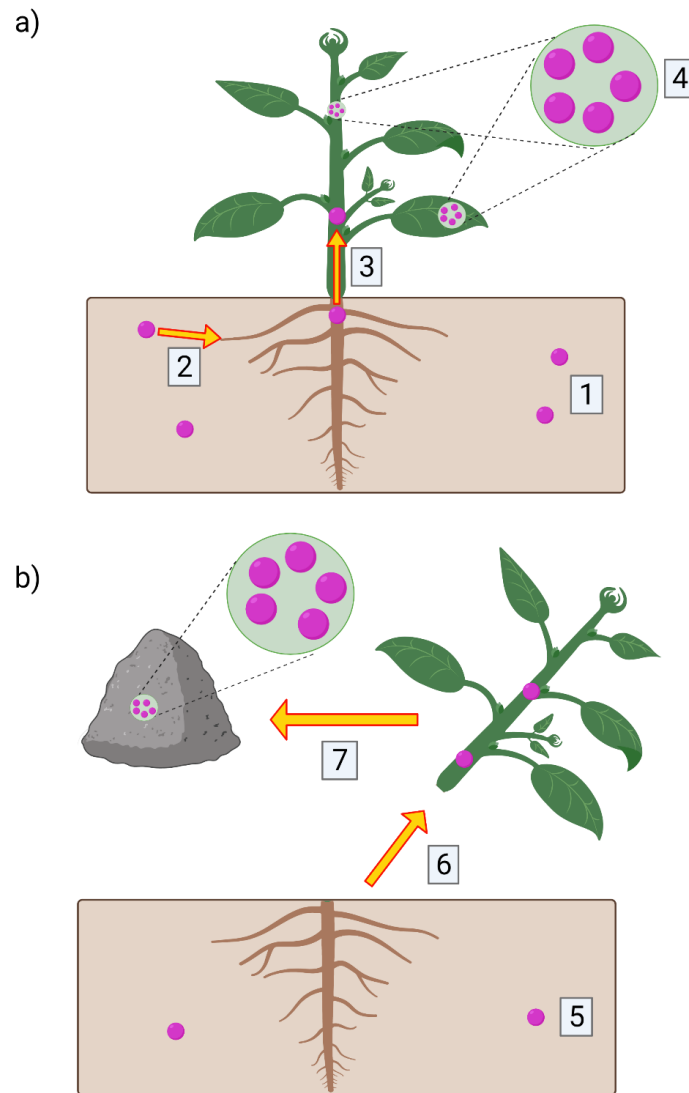
32 The Philippines is the fifth richest country in mineral resources worldwide, including nickel, copper,
33 chromite, and gold (Maddox et al., 2019) and mining activity is extensive in the region as a result.
34 The ultramafic areas in the Philippines account for about 5% of its estimated total land area of
35 298,170 km² (Baker et al., 1992). Ultramafic areas are often deficient in the essential macronutrients
36 (e.g. phosphorus, potassium and calcium) and have high concentrations of potentially phytotoxic
37 elements (e.g. magnesium, iron, nickel, cobalt, and chromium) --- conditions that are normally
38 adverse to plant growth (Galey et al., 2017). However, some plants called 'metallophytes' have an
39 ability to tolerate metal toxicity and survive and reproduce in these environments (Baker and
40 Whiting, 2008; Whiting et al., 2004). Plant species that evolved on ultramafic soils are generally
41 metal tolerant. Such native species could be an important source of metal tolerant and accumulator
42 plants that are most likely to be able to survive the edaphic and climatic conditions of locally
43 contaminated lands (Carvalho et al., 2013; Claveria et al., 2020, 2019b; de Castro et al., 2020).
44 Metallophytes are able to grow in soils with high heavy metal concentrations through two different
45 strategies: avoidance and tolerance (Baker, 1981). Avoidance is achieved when the plant invests in
46 external mechanisms to keep metals chelated outside of the plant tissue (Carvalho et al., 2013;
47 Claveria et al., 2010). Whereas tolerance is developed through physiological adaptations to
48 accumulate metals in high concentrations in the plant biomass.

49 Tolerance can be achieved through exclusion, or hyperaccumulation (Jaffré et al., 1976). Exclusion
50 means there is limited translocation from the roots of the plant to the shoots (Hunt et al., 2014;
51 Lange et al., 2017; Sanqui et al., 2020). Hyperaccumulators, have evolved the capability to
52 accumulate certain metal elements in their shoots, especially the leaves, that are at levels 100x
53 greater than those typically measured in shoots of the common non-accumulator plants (Brooks et
54 al., 1998, 1977; Jaffré et al., 1976). Reeves (1992) stated that concentrations must be recorded in the
55 dry matter of any above-ground tissue in at least one specimen growing 'in its natural habitat' i.e.
56 not under artificial conditions, such as through metal-salt amendments to an experimental soil or
57 hydroponic nutrient solutions (van der Ent et al., 2013). More than 700 hyperaccumulating plants
58 have been reported worldwide, the majority of which (>70%) hyperaccumulate nickel (Reeves et al.,
59 2017).

60 As a result of their unusual tolerance for heavy metals and restricted distribution, metallophytes
61 have potential benefits for the restoration of vegetation in mined-out areas within their geographic
62 range (Erksine et al., 2012; Reeves, 2006; Whiting et al., 2004). Hyperaccumulators have been of

63 considerable interest in the mineral exploration (Jaffré et al., 1976) and are the optimal choice for
64 future 'green' phytoremediation technologies, such as phytoextraction and phytomining. However,
65 for plants to be applicable for phytomining or phytoextraction efforts they need to be examined in
66 terms of: (i) their ability to bioaccumulate metals so that the concentration in the plant tissue is
67 greater than the soil (Reeves, 2006); and (ii) translocate those metals to their aboveground biomass
68 (Figure 1).

69 The total number of native vascular plant species in the Philippines is currently estimated at 9,433
70 (Pelser et al., 2011) with ~50% endemic species. Of this, the exact number of metallophytes remains
71 unknown and many new species of metallophytes endemic to the Philippines continue to be
72 discovered (Fernando et al., 2018; Fernando and Wilson, 2021; Fritsch et al., 2020; Robinson et al.,
73 2019; Tamayo et al., 2023). This paper aims to consolidate current data on the extent of metal
74 hyperaccumulation in the Philippines, the species of heavy metal accumulating plants, and
75 partitioning of metals within the plant tissue. We also aimed to identify any knowledge gaps and
76 future research needs on metal hyperaccumulation in the Philippines. Our review considers solely
77 native plant species in the Philippine flora naturally growing in the wild (rather than controlled or
78 laboratory conditions).



79

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

87 **2 Materials and methods**

88 **2.1 Literature searches and data extraction**

89 Searches on Web of Science were carried out (24th February 2023) using the terms: (i) *accumulate*
 90 metal* plant* AND Philippine*; (ii) metallophyte* plants AND Philippine*; and (iii) metal toleran*
 91 plants AND Philippine*. The references list in each of the papers returned were also checked to find

92 additional papers. Observations on species that were not native to the Philippines, laboratory trials,
93 or duplicates were not included. If a paper reported concentrations of two metals for a single plant,
94 this was recorded as two observations, one for each metal.

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

106 Threshold aboveground concentrations for hyperaccumulation status have been established for
107 various elements (van der Ent et al., 2013): 100 $\mu\text{g/g}$ for Cd, Se and Tl; 300 $\mu\text{g/g}$ for Co, Cu and Cr;
108 1,000 $\mu\text{g/g}$ for Ni, Pb, Al and As; 3,000 $\mu\text{g/g}$ for Zn; and 10,000 $\mu\text{g/g}$ for Mn. If an observation had an
109 aboveground concentration above this threshold then the species was classified as a
110 hyperaccumulator.

111 2.2 Metal partitioning and translocation factor

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

$$116 \quad TF = \frac{\text{Aboveground tissue concentration } (\mu\text{g kg}^{-1})}{\text{Belowground tissue concentration } (\mu\text{g kg}^{-1})}$$

117 A TF >1 indicates that a plant species has the capability to extract metals, because the aboveground
118 biomass concentrations are higher than the belowground biomass (Aribal et al., 2016; Balafrej et al.,
119 2020; Claveria et al., 2019a; Novo et al., 2013).

120 2.3 Bioaccumulation factor

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

123
$$BF = \frac{\text{Aboveground tissue concentration } (\mu\text{g kg}^{-1})}{\text{Soil concentration } (\mu\text{g kg}^{-1})}$$

124 A BF greater than one indicates that a species is a hyperaccumulator, and a BF less than one is
125 indicative of an excluder (Ancheta et al., 2020; Claveria et al., 2020; Novo et al., 2013; Usman et al.,
126 2019; Yashim et al., 2014).

127 **3 Results**

128 3.1 Species identified

129 Of the 115 plant species whose aboveground tissue concentrations were reported in the literature,
130 twenty-eight were above the hyperaccumulator threshold concentrations outlined by van der Ent et
131 al., (2013) in the introduction (Table 1). Nineteen species were found to contain more than 1,000
132 $\mu\text{g/g}$ Ni in samples taken; four species contained more than 1,000 $\mu\text{g/g}$ Al; three species had
133 observations above 300 $\mu\text{g/g}$ Cu; three species were above 300 $\mu\text{g/g}$ Cr; one species had
134 observations above 3,000 $\mu\text{g/g}$ Zn; and one species was above 10,000 $\mu\text{g/g}$ Mn. Some species have
135 been observed to contain above-threshold concentrations for more than one metal. *Mitragyna*
136 *speciosa*, for example, was above threshold concentrations for Aluminium, Copper and Manganese
137 (Table 1). However, it is important to note that concentrations reported in the literature, were not
138 always above the threshold for every species. Nickel concentrations reported for *Dichapetalum*
139 *gelonioides*, for example, ranged from 39 – 25,820 $\mu\text{g/g}$ Ni. Furthermore, despite, being over the
140 aboveground tissue concentration threshold, not all species had a translocation factor or
141 bioaccumulation factor greater than one (e.g. *Elaeocarpus merrittii* and *Pneumatopteris laevis*). Most
142 of the species identified as hyperaccumulators in Table 1 were trees, and eleven species were
143 endemic to the Philippines.

144 Table 1 – Metal hyperaccumulation in twenty-eight Philippine native plants. Aboveground tissue concentration, translocation factor (TF) and
 145 bioaccumulation factor (BF). Threshold aboveground concentrations for hyperaccumulation status (van der Ent et al., 2013); 300 µg/g for Cu and Cr; 1,000
 146 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
<i>Brackenridgea fascicularis</i>	Ochnaceae	Tree	Philippines; endemic	Nickel	1027 – 4,489	-	-	(Fernando et al., 2020)
<i>Brackenridgea foxworthyi</i>	Ochnaceae	Tree	Philippines; endemic	Nickel	3,770 – 7,600	-	-	(Baker et al., 1992)
				Nickel	3,113 – 6,288	-	-	(Fernando et al., 2020)
<i>Brackenridgea mindanaensis</i>	Ochnaceae	Tree	Philippines; endemic	Nickel	1,546 – 3,114	-	-	(Fernando et al., 2020)
<i>Breynia cernua</i>	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)
<i>Breynia sp.</i>	Phyllanthaceae	Tree		Nickel	4,195	-	0.54	(Fernando et al., 2013)
<i>Callicarpa sp.</i>	Lamiaceae	Tree		Nickel	1,383	-	0.18	(Fernando et al., 2013)
<i>Cratoxylum sumatranum</i>	Hypericaceae	Tree	Philippines; also in Borneo, Java & Thailand	Copper	200-421	2.56-7.19	10.96-57.49	(Castañares and Lojka, 2020)
<i>Decaspermum blancoi</i>	Myrtaceae	Tree	Philippines; endemic	Nickel	3,841	-	0.50	(Fernando et al., 2013)
<i>Dichapetalum gelonioides</i>	Dichapetalaceae	Shrub to tree	Philippines; also in Borneo & Malay Peninsula	Nickel	9 – 20,300	-	-	(Baker et al., 1992)
subsp. <i>Pilosum</i>		Tree		Zinc	390 – 26,360	-	-	(Baker et al., 1992)
<i>Dichapetalum gelonioides</i>	Dichapetalaceae	Tree	Philippines; also in Borneo, Malay Peninsula, Sumatra, Thailand & Vietnam	Nickel	39 – 25,820	-	-	(Baker et al., 1992)
subsp. <i>Tuberculatum</i>								
<i>Elaeocarpus merrittii</i>	Elaeocarpaceae	Tree	Philippines; endemic	Chromium	835	0.57	0.41	(Aribal et al., 2016)
<i>Falcatifolium gruezoii</i>	Podocarpaceae	Shrub to tree	Philippines; also in Moluccas; Sulawesi	Chromium	326	0.04	1.60	(Aribal et al., 2016)

<i>Memecylon</i> sp.	Melastomataceae			Aluminum	2,300	-	-	(Proctor et al., 2000)
<i>Mitragyna speciosa</i>	Rubiaceae	Tree	Philippines; also in Borneo, Malay Peninsula, New Guinea, Sumatra & Thailand	Aluminum	3,960	0.40	1.22	(Castañares and Lojka, 2020)
				Copper	358	3.83	21.24	(Castañares and Lojka, 2020)
				Manganese	39,554	3.66	2909	(Castañares and Lojka, 2020)
<i>Phyllanthus balgooyi</i> *	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)
<i>Phyllanthus erythrotrichus</i> **	Phyllanthaceae	Shrub	Philippines; endemic	Nickel	18,492	-	2.40	(Fernando et al., 2013)
				Nickel	12,287	9.28	2.63	(Quimado et al., 2015)
<i>Phyllanthus securinoides</i> ***	Phyllanthaceae	Tree	Philippines; endemic	Nickel	1050 – 34,750	-	-	(Baker et al., 1992)
				Nickel	13,481	2.91	1.81	(Quimado et al., 2015)
<i>Planchonella obovata</i>	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)
<i>Pneumatopteris glabra</i>	Thelypteridaceae	Fern	Philippines; endemic	Aluminum	3,263	0.38	0.89	(Castañares and Lojka, 2020)
<i>Pneumatopteris laevis</i>	Thelypteridaceae	Fern	Philippines; endemic	Aluminum	1,035	0.12	0.35	(Castañares and Lojka, 2020)
<i>Polyosma integrifolia</i>	Escalloniaceae	Tree	Philippines; also in Borneo, Java, Malay Peninsula	Chromium	780	0.21	0.79	(Aribal et al., 2016)
<i>Psychotria</i> sp.	Rubiaceae	Tree		Nickel	2,197	-	0.29	(Fernando et al., 2013)
<i>Pteris</i> sp.	Pteridaceae	Fern		Copper	371	0.76	1.46	(Claveria et al., 2010)

<i>Rinorea bengalensis</i>	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)
<i>Rinorea niccolifera</i>	Violaceae	Tree	Philippines; endemic	Nickel	15,215 – 22,241	7.27	8.07	(Fernando et al., 2014)
<i>Syzygium sp.</i>	Myrtaceae	Tree		Nickel	1,113	-	0.14	(Fernando et al., 2013)
<i>Walsura monophylla</i>	Meliaceae	Tree	Philippines; endemic	Nickel	2,360 – 7,090	-	-	(Baker et al., 1992)
<i>Xylosma luzonense</i>	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)

147

148

149 3.2 Metal partitioning in hyperaccumulator species

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

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

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

161

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

166 –

167 **4 Discussion**

168 **4.1 Metal partitioning and phytoextraction/phytomining potential**

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

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

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

190 Transfer and accumulation of metals from soil to plants is complex and often site-specific. Factors
191 influencing this include: the chemical forms of the heavy metal; the pH of the soil; the soil organic
192 matter content; soil nutrient contents; root exudation of organic acids and flavonoids; soil texture
193 (particularly clay content); mycorrhizal symbiosis, microbial activity and abundance; the plant
194 species; the plants stage of growth; climatic conditions and irrigation with polluted waters
195 (Aladesanmi et al., 2019; Claveria et al., 2019b; Dahilan and Dalagan, 2017; de la Torre et al., 2016;
196 De Oliveira et al., 2020; Domingo and David, 2014; Feigl et al., 2020; Mahajan et al., 2016; Navarrete
197 et al., 2017; Sanqui et al., 2020; Susaya et al., 2010; Tibbett et al., 2021; Yashim et al., 2014).

198 Furthermore, although our review focused on native species to the Philippines, it is important to
199 note that each island has developed a slightly different plant community, so not all native plants to

200 the Philippines is found on every island of the archipelago (Romeroso et al., 2021). Therefore, it
201 would be impossible to find a species that is appropriate in every scenario, in every community, so
202 planning needs to be site specific (Koelmel et al., 2015).

203 4.2 Issues, knowledge gaps, and future research needs

204 4.2.1 *Agreed definition of hyperaccumulators*

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

214 4.2.2 *Consistency in reporting metal concentrations in plant tissue*

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

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

228 4.2.3 *Large scale screening*

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

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

237 4.2.4 *Botanical explorations*

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

247 4.2.5 *Physiological characteristics and toxicity thresholds*

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

262 4.2.6 *Potential impacts on higher trophic levels*

263 The concept of phytomining is that metals accumulate in the aboveground biomass, which is more
264 easily harvested and removed. However, elevated concentrations in the aboveground biomass could

265 lead to exposure of herbivores, and subsequently other species in the food chain (Koelmel et al.,
266 2015; Tibbett et al., 2021), including humans. It has been suggested that plants may develop the
267 ability to hyperaccumulate metals, as a means of protecting themselves from herbivorous predators
268 and pathogens that would experience serious toxic side effects from ingesting large concentrations
269 of metals in the plants above-ground biomass (Fones et al., 2019; Paz-Alberto and Sigua, 2013;
270 Remigio et al., 2020). In addition, hyperaccumulators can also lead to an increased metal
271 concentration in the topsoil through high metal concentration litterfall (Tisserand et al., 2021), which
272 could have an impact on soil biology. Metal rich pollen could also have potential risks for pollinators,
273 an important consideration when planning large-scale cultivation of high metal containing plants
274 (Schiavon and Pilon-Smits, 2017). Due to the potential risk to human health, edible agricultural crops
275 should not be used for phytomining (Pasricha et al., 2021).

276 **5 Conclusions**

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

283 **Data availability statement**

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

285 **Conflicts of interest**

286 The authors declare no conflicts of interest.

287 **Declaration of funding**

288 This work was funded by the Natural Environment Research Council (NERC), project reference
289 NE/W006820/1.

290

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