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1 **Bioaccumulation of some trace elements in tropical mangrove plants and snails**

2 **(Can Gio, Vietnam)**

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12 **ABSTRACT**

13 Mangrove sediments can store high amount of pollutants that can be more or less bioavailable  
14 depending on environmental conditions. When in available forms, these elements can be subject  
15 to an uptake by mangrove biota, and can thus become a problem for human health. The main  
16 objective of this study was to assess the distribution of some trace elements (Fe, Mn, Co, Ni, Cr,  
17 As, and Cu) in tissues of different plants and snails in a tropical mangrove (Can Gio mangrove  
18 Biosphere Reserve) developing downstream a megacity (Ho Chi Minh City, Vietnam). In addition,  
19 we were interested in the relationships between mangrove habitats, sediment quality and  
20 bioaccumulation in the different tissues studied. Roots and leaves of main mangrove trees  
21 (*Avicennia alba* and *Rhizophora apiculata*) were collected, as well as different snail species:  
22 *Chicoreus capucinus*, *Littoraria melanostoma*, *Cerithidea obtusa*, *Nerita articulata*. Trace  
23 elements concentrations in the different tissues were determined by ICP-MS after digestion with  
24 concentrated HNO<sub>3</sub> and H<sub>2</sub>O<sub>2</sub>. Concentrations differed between stands and tissues, showing the  
25 influence of sediment geochemistry, species specific requirements, and eventually adaptation  
26 abilities. Regarding plants tissues, the formation of iron plaque on roots may play a key role in  
27 preventing Fe and As translocation to the aerial parts of the mangrove trees. Mn presented higher  
28 concentrations in the leaves than in the roots, possibly because of physiological requirements. Non-  
29 essential elements (Ni, Cr and Co) showed low bioconcentration factors (BCF) in both roots and  
30 leaves, probably resulting from their low bioavailability in sediments. Regarding snails, essential  
31 elements (Fe, Mn, and Cu) were the dominant ones in their tissues. Most of snails were  
32 “macroconcentrators” for Cu, with BCF values reaching up to 42.8 for *Cerithidea*. We suggest  
33 that high quantity of As in all snails may result from its high bioavailability and from their ability  
34 to metabolize As.

35 *Keywords: Bioavailability; Bioconcentration factor, Translocation; macroconcentrator.*

36        **1. Introduction**

37        Mangroves, complex intertidal forests, are considered as sinks for contaminants including trace  
38 metals (Tam and Wong 2000). It was previously suggested that mangrove plants can play key roles  
39 in metals removal from mangrove sediments (Alongi et al. 2004, Yang et al. 2008). On the one  
40 hand, depending on the metals properties and the mangrove species, they can provide  
41 “phytostabilization”, meaning that metals are immobilized and stored in the sediment or in the  
42 below-ground biomass (MacFarlane et al. 2007). On the other hand, they can provide  
43 “phytoextraction”, and mangrove trees can be considered as accumulators, providing that they can  
44 transfer metals from the sediment and concentrate them in above-ground tissues (Křibek et al.  
45 2011). Because of different rates in metals uptake and the specific influence of mangrove roots on  
46 sediment geochemistry, metals dynamic in mangrove sediments may be affected by the  
47 composition of plant communities (Verkleij and Schat 1990). In fact, some mangrove trees can  
48 oxidize the sediments via the movement of oxygen from their rhizosphere downwards to  
49 aerenchyma tissues (Moorhead and Reddy 1988). This oxidation process can remobilize the stable  
50 forms of metals, e.g. the ones bound to sulphides (Marchand et al. 2006, Noël et al. 2015), thus  
51 increasing metals’ bioavailability. The bioaccumulation and/or fixation of trace metals in  
52 mangrove plant tissues, especially roots which can then redistribute metals proportion into  
53 aboveground tissues (i.e. especially leaves, see review of (Weis and Weis 2004)), may limit metals  
54 concentrations in the water column and restrict the transfer of these contaminants into mangrove  
55 biota. However, the excess of essential and non-essential trace elements could affect the growth,  
56 metabolism activities and cell structure of plants (Cox and Hutchinson 1981, Wang et al. 2003).

57        Bioaccumulations of trace elements by snail species have been addressed in many research  
58 projects in the past two decades (Berandah et al. 2010, Dias and Nayak 2016, Reed-Judkins et al.

59 1997). The variations of trace metals concentrations in snails depend on their feeding regime, their  
60 digging activities, and metals bioavailability within their habitat. Snails can accumulate higher  
61 metals concentrations than any other groups of mollusks (Zhou et al. 2008) and can offer the  
62 possibility to assess metals contaminations (De Wolf and Rashid 2008, Samsi et al. 2017, Yap and  
63 Cheng 2013). It was demonstrated that elevated trace metals concentrations in sediments can  
64 influence negatively the number of snail species in an ecosystem as well as the community  
65 structure (Amin et al. 2009).

66 In Vietnam, an emerging country, the fast economic development (i.e. urbanization,  
67 industrialization, etc.) and the population growth induce high pressure on rivers and estuaries  
68 (Babut et al. 2019, Costa-Boddeker et al. 2017, Strady et al. 2017). Can Gio estuary is located at  
69 the edge of the biggest industrial city in Vietnam-Ho Chi Minh City (*i.e.* a megacity of almost 10  
70 million inhabitants), and half of the Can Gio area is covered by mangrove forests. This estuary is  
71 also a unique gate for drainages of sewages from the land to the ocean. Recently, Thanh-Nho et  
72 al. (2018) highlighted that metals can be transferred over long distance from watersheds to the  
73 mangrove forest, and that elevated inputs of metals in the estuary were the result of enhanced  
74 runoff and soil leaching during the monsoon season. It was proved that the enrichment of  
75 mangrove-derived organic matter played a key role in controlling partitioning and availability of  
76 trace elements in the sediment beneath different mangrove species (Thanh-Nho et al. 2019).  
77 Consequently, taking into account mangrove specific geochemical characteristics, the lack of  
78 wastewater treatment plants in emerging countries as Vietnam and the important local ecosystem  
79 services provided by the Can Gio Mangrove (Cormier-Salem et al. 2017, Kuenzer and Tuan 2013),  
80 more attention should be paid on metals bioaccumulation and transfer in mangrove ecosystems.  
81 Because of their persistence, trace metals may present a major threat to the mangrove diversity

82 and also to human health via food chain. Notably, the Can Gio mangrove is home to high  
83 biodiversity with 20 species of flora, in which two mangrove species are dominant: *Avicennia alba*  
84 and *Rhizophora apiculata* (Luong et al. 2015), and with more than 200 species of fauna (e.g.  
85 benthic organisms, fish, mollusks, planktonic, etc.). Thus, the knowledge of trace elements'  
86 contents accumulated by different mangrove organisms would be useful to get a better  
87 understanding on the behaviors of these contaminants in the mangrove, and to contribute to an  
88 important information on the protected species of tropical mangroves in Vietnam and their  
89 potential element poisoning.

90 The main objective of this study was to assess the distribution of some trace elements (Fe, Mn,  
91 Co, Ni, Cr, As, and Cu) in the tissues of different mangrove plants and snails receiving elevated  
92 amounts of contaminants from watersheds, i.e. lateritic soils and Ho Chi Minh City. In addition,  
93 we were interested in the relationships between the bioaccumulation in the different tissues  
94 studied, mangrove stands, and sediments quality, bioconcentration factors were calculated using  
95 data published in a previous paper and concerning trace metals dynamics in the sediment of the  
96 studied mangrove stands (Thanh-Nho et al. 2019). To reach our goals, we collected and analyzed  
97 different parts (i.e. roots and leaves) of the main mangrove trees (i.e. *Avicennia alba* and  
98 *Rhizophora paticulata*) in the Can Gio Biosphere Reserve, and different snail species within  
99 mangrove stands: *Chicoreus capucinus* (*C.capucinus*), *Littoraria melanostoma* (*L.melanostoma*),  
100 *Cerithidea obtuse* (*C.obtusa*) and *Nerita articulata* (*N.articulata*). The field sampling was  
101 conducted at the end of the monsoon season in 2015, since we showed previously that elements  
102 inputs and sediment reactivity were highest at this period, and since our main objective was to  
103 compare the two main mangrove stands.

## 104 2. Materials and methods

105           2.1. Study area

106           The present study was conducted in the Can Gio mangrove Biosphere Reserve, Vietnam  
107 (10°22'-10°44'N and 106°46'-107°01'E, Fig. 1). This mangrove covers approximately 35,000 ha  
108 (Tuan and Kuenzer 2012), being usually classified as a “Mangrove afforestation and re-forestation  
109 area” (Blasco et al. 2001). It is also a district of the densely populated megacity of Ho Chi Minh  
110 City (HCMC), with almost 10 million of inhabitants. The Can Gio mangrove is situated 35 km  
111 downstream of the city urban center and industrial zones (mainly plastic and rubber production,  
112 mechanical engineering, electrical engineering, packaging, textile and dyes industry, oil activities  
113 and cement production) (Strady et al. 2017, Vo 2007). The main economic activities of the local  
114 people in Can Gio are aquacultures, salt production, fishing, and forest management. The  
115 topography of Can Gio mangrove is generally low-lying. This coastal area is subject to an  
116 asymmetric semi-diurnal tidal regime and to the typical tropical monsoon climate, with two  
117 distinct seasons. The dry season extends from November to April and the wet season lasts from  
118 May to October. The climatic conditions were not much different during consecutive years, from  
119 2014 to 2016, prior and after sampling campaign (data from HCMC statistical Years Book, 2016).  
120 The highest precipitation can reach up to 500 mm in September or October, while it is usually less  
121 than 80 mm per month during the dry season. The annual mean precipitation ranged from 1,800 to  
122 2,000 mm, with almost 90 % of the precipitation falling during the rainy season. The annual mean  
123 temperature varied from 28.4 °C to 30 °C while the annual humidity ranged from 72 to 74 %. The  
124 two dominant mangrove species are *Avicennia alba* and *Rhizophora apiculata*. Because of high  
125 commercial values, *Rhizophora apiculata* was widely replanted, being often found on elevated  
126 ground. *Avicennia alba* is a pioneering species with high salinity tolerance and ability to grow on  
127 weak, unconsolidated sediment. Consequently, there is a zonation of the ecosystem (Fig. 1) with

128 *Rhizophora* trees growing at higher elevation than the *Avicennia* ones, and being thus less  
129 immersed by tides. Many marine organisms live within and around the mangroves, e.g. shrimp,  
130 fish, snail, or crab, etc. Therefore, the mangrove ecosystem provides not only various goods and  
131 services to local people such as timber, seedlings, medicines, but also foods (Kuenzer and Tuan  
132 2013).

## 133 2.2. Field sampling

134 The sampling campaign was carried out at the end of the wet season (October 2015) in the  
135 center area of the Can Gio mangrove (Fig. 1).

136 Leaf and root samples were collected from different types of trees (saplings and mature trees  
137 of the *Rhizophora apiculata* and *Avicennia alba* species). For both species, each leaf sample  
138 consisted of 30 leaves collected from 15 trees, and we analyzed 3 samples per each type of tree.  
139 Root samples were collected in the upper 50 cm from sediment cores collected using an  
140 Eijkelkamp gouge auger (inner diameter: 80 mm) at low tide ( $n = 3$  per each type of tree). All  
141 samples were rinsed with deionized water and were then dried at 50 °C for > 48 h to constant mass  
142 in an oven. Dried samples were then ground and sieved using 100 µm pore size for trace elements  
143 analysis.

144 Four species of snails were collected in the mangrove stands: *C.capucinus*, *L.melanostoma*,  
145 *C.obtusa* and *N.articulata*. Notably for *L.melanostoma*, they were collected on mangrove trees. In  
146 the *Rhizophora* stand, due to their excessive height (> 15 m), *L.melanostoma* were collected on  
147 young trees. In the *Avicennia* stand, due to low density of saplings, *L.melanostoma* were collected  
148 on mature trees. For each species, we analyzed 3 samples per mangrove stand, and each sample  
149 comprised 15 to 20 snails. Their shell sizes (length and width) were measured prior to taking out  
150 their tissues by pegging out (using a clean pestle) the shell carefully. Due to the fragile



151 characteristic of the shell, a mild force was sufficient to break the shell (strong force might destroy  
152 the internal organ of the snail). Snails were chosen in the same range of size throughout the work  
153 to reduce possible variations in trace elements concentrations due to size (age). The whole bodies  
154 were preserved at -18 °C until performing processes of freezer-drying. Dried samples were ground  
155 and sieved through 100 µm pore size for analysis of trace elements. Snails' soft tissues are food  
156 sources for local people, and thus their trace elements contents may be a risk to human health.  
157 Therefore, only the soft tissues of snails were analyzed in the present study.

#### 158 *Specific features of selected snail's species*

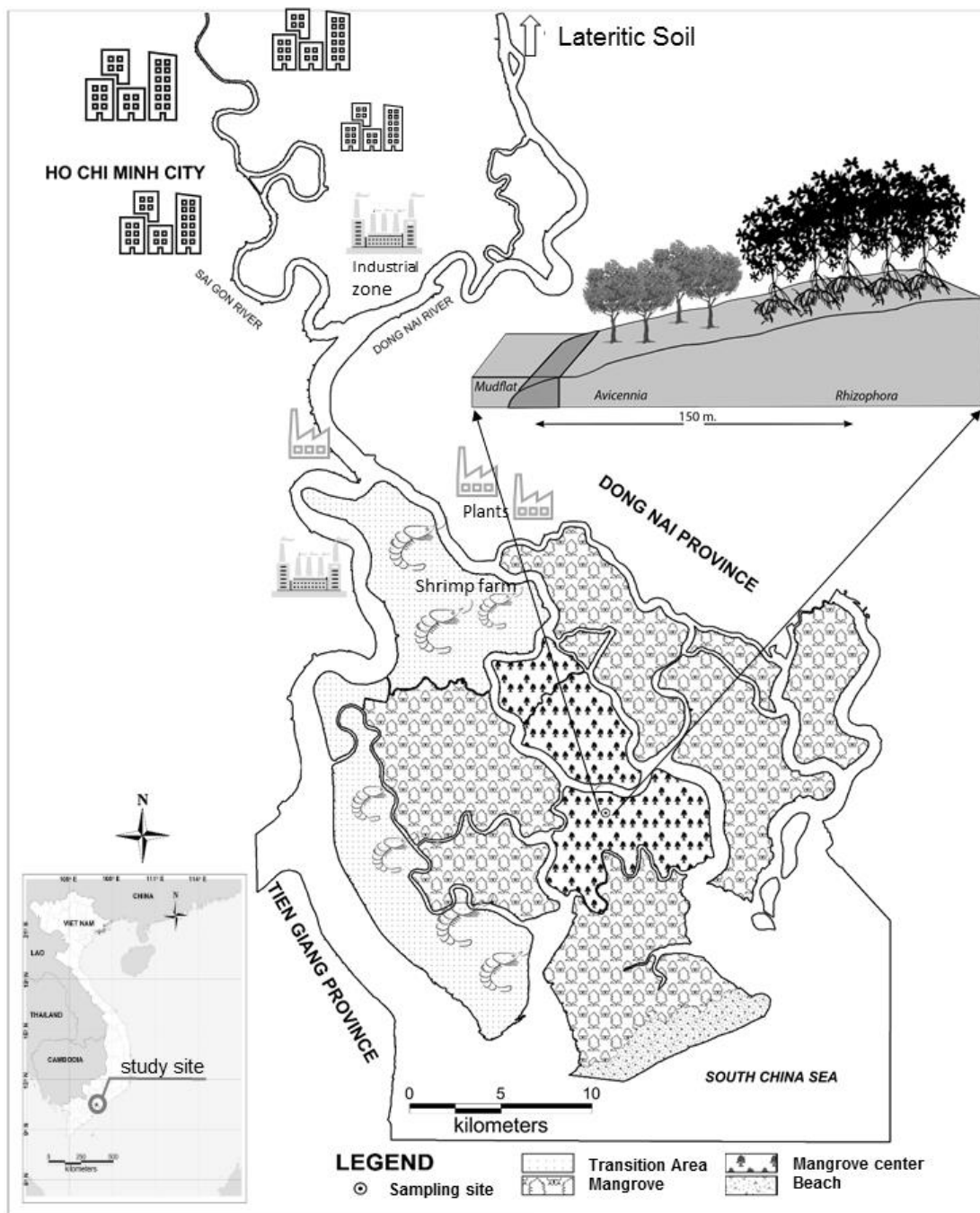
159 *C.capucinus* has elaborately textured shell with uniformly dark brown and six convex whorls.  
160 These shells are heavy and solid and can reach a size of 40 to 120 mm. They are sculptured with  
161 prominent spiral cords, axial ribs and striae. The aperture is rounded or oviform, brown tinged and  
162 the inner labial edge show 14 to 17 denticles. The siphonal canal is quite long. The operculum is  
163 dark brown.

164 *L.melanostoma* can reach 2 to 3 cm length. Shell has a narrower tip, smooth, yellowish to moss  
165 green or dark brown with fine spiral pattern of brown dots. Sometimes the shell is bleached white.  
166 "*Melanostoma*" means "black mouth". There is short fat tentacles on soft head.

167 *C.obtusa* has Obtuse Horn Shell (large, solid, broad, periphery rounded; aperture strongly  
168 thickened and flared; 14 to 37 rounded axial ribs on penultimate whorl; 5 spiral cords on spire, 5  
169 to 9 above periphery on last whorl). Shell is also known as Mud Creeper. It is a relatively common  
170 snail found in muddy coastal areas, growing to around 5 to 6 cm (Suwanjarat and Klepal 2001).

171 *N.articulata* is also known as *Nerita lineata* or *N. balteata*, with 2 to 3 cm length. Shell is  
172 sturdy oval, spire does not stick out characterized by beige, greyish or pinkish with fine, spiralling  
173 and black ribs. The flat underside is smooth, white, sometimes with yellow patches. Small notched

174 'teeth', usually three, on the straight edge at the shell opening. Operculum thick, evenly covered in  
 175 tiny bumps, pinkish with black portions. Body pale with fine black bands on the foot and long thin  
 176 black tentacles (data from wildsingapore).



177  
 178 *Fig. 1. Map of the study area showing the location of the Can Gio mangrove in Vietnam and the location of the*  
 179 *collected biological samples in the mangrove.*

180           2.3. Analytical methods and calculations

181           2.3.1. Samples digestion and analysis

182           The plant and snail samples were digested in triplicate with concentrated nitric acid and  
183 hydrogen peroxide (MacFarlane et al. 2003). The samples (250 mg to 500 mg of dried weight)  
184 were put into PTFE vessels, in which 10 mL of concentrated HNO<sub>3</sub> was added. These samples  
185 were homogenized in an ultrasonic bath for 15 min and were then digested at 110 °C for 12h on  
186 an electrical oven. After cooling, 2 mL of H<sub>2</sub>O<sub>2</sub> was added into these samples, which were again  
187 digested at 110 °C for 30 min. The residual HNO<sub>3</sub> was eliminated at 160 °C. The samples were  
188 centrifuged to reject any residues and then diluted to 25 mL using deionized water and stored at 4  
189 °C until analysis. The trace elements were determined by ICP – MS (Agilent 7700x at Institute of  
190 Public Health, Ho Chi Minh City, Vietnam), using spiked <sup>103</sup>Rh and <sup>197</sup>Au as internal standards.  
191 The precision and accuracy of analytical method were controlled using certified reference material  
192 muscle tissues (SRM-2976: certified by National Institute of Standard and Technology/NIST,  
193 USA). The recoveries of trace elements were 94 % to 106.5 % with relative standard deviation  
194 from 4.2 % to 9.8 % (Table SD1). All chemicals were analytical grade (Merck). HNO<sub>3</sub> was purified  
195 using a sub-boiling quartz distillation equipment.

196           2.3.2. Data calculations

197           Bioconcentration factor (BCF) was proposed by Babukutty and Chacko (1995) to assess the  
198 bioaccumulation of pollutants into an aquatic and terrestrial organisms via any route i.e., by active  
199 or/and passive accumulations. It is defined as  $BCF = C_{tissues}/C_{sediment}$ , where  $C_{tissues}$  and  $C_{sediment}$  are  
200 total concentration of trace element in organism tissues and total concentration of trace element in  
201 the sediment, respectively. To do this calculation, we used the trace elements concentrations in the

202 sediment that we published in a previous paper (Thanh-Nho et al. 2019); sediment samples were  
203 collected at the same sites and at the same period of the present study.

#### 204 *BCF of trace elements in roots and leaves*

205 BCF was calculated from a mean concentration of trace element in sediment down to 50 cm  
206 depth (Table SD2). This depth was chosen because in mangrove environment, the highest root  
207 density is in the upper sediment, between 20 and 50 cm depth (Ha et al. 2018, Komiyama et al.  
208 2000, Tamoooh et al. 2012).

209 Translocation factors (TF) was calculated, which are used to assess the transfer of trace  
210 elements from roots to aboveground components and to evaluate the potential phytoextraction of  
211 plants (Marchiol et al. 2004). In the present study, it is defined as  $TF = C_{leaves}/C_{root}$ , where  $C_{leaves}$   
212 and  $C_{root}$  are total concentration of trace element in leaves and total concentration of trace element  
213 in roots, respectively.

#### 214 *BCF of trace elements in snails*

215 Depending on feeding regimes of individual snail species and their habitat, the BCF was  
216 calculated from a mean concentration of trace element corresponding to a mean concentration of  
217 trace element in each type of feeding source. *L.melanostoma* feeds on mangrove trees, mainly  
218 fresh leaves and materials on the plant surfaces as phylloplane and fungi (Lee et al. 2001). BCF of  
219 trace element was estimated based on the mean concentration of trace element measured in  
220 *Avicennia* and *Rhizophora* leaves. *C.obtusa* is known as sediment eater (Tue et al. 2012), BCF of  
221 trace element was calculated based on a mean concentration corresponding to a mean  
222 concentration of trace element in available fractions at the upper 5 cm of the sediment (Table SD2).  
223 *N.articulata* eats microalgae (Eichhorst 2016), and *C.capucinus* is a versatile predator, feeding on  
224 the barnacles growing on mangroves and on mussels, snails and worms in their habitat (Tan and

225 Oh 2003, Tan 2008). We were not able to sample their feeding sources, consequently, we did not  
226 calculate any BCF for two snails' species.

### 227 **3. Results**

#### 228 *3.1. Trace elements in roots and leaves of mangrove plants*

229 Mean concentrations of Fe, Mn, Co, Ni, Cr, As, and Cu ( $\mu\text{g g}^{-1}$ ) in the roots and leaves of the  
230 *Avicennia alba* and the *Rhizophora apiculata* are presented in Table 1. Trace elements in roots of  
231 the *Avicennia* saplings and mature trees presented a similar distribution: Fe > Mn > Cu > Cr > As  
232 > Ni > Co. For the roots of the *Rhizophora* trees, the concentrations of trace elements were Fe >  
233 Mn > As > Cr > Cu ~ Ni > Co in the saplings, and were Fe > Mn > Cr > Ni ~ Cu > As ~ Co in the  
234 mature trees. Most trace elements were characterized by low values of BCF in the roots, i.e. less  
235 than 1, except for Cu and As for the roots of *Avicennia* saplings (i.e. BCF: 1.02 for As and 2.95  
236 for Cu) (Fig. 2). Leaves of the *Avicennia* saplings were characterized by the following trace  
237 elements concentrations: Fe > Mn > Cu > Cr > Ni > Co ~ As, while in the mature trees, the  
238 distribution was Mn > Fe > Cu > Cr > Ni > Co ~ As. Mn presented higher concentrations in the  
239 leaves of mature trees than in the saplings. For leaves of the *Rhizophora*, the concentration of trace  
240 elements were Fe > Mn > Cr ~ Cu > Ni > Co ~ As in the saplings, and were Fe > Mn > Cu > Cr >  
241 Ni > As ~ Co in the mature trees. Mn and Cu concentrations were higher in the leaves of the mature  
242 trees than in the saplings. The bioconcentration factors were lower than 1 for most trace elements  
243 in both mangrove species, with the exception of Mn in saplings and mature trees (Fig. 2). The  
244 translocation factors (TF) were higher than 1 for Mn, Cu in the *Rhizophora* saplings and mature  
245 trees, for Cr in the *Rhizophora* saplings, while it was lower than 1 for the other trace elements  
246 studied (Fig. 3).

247

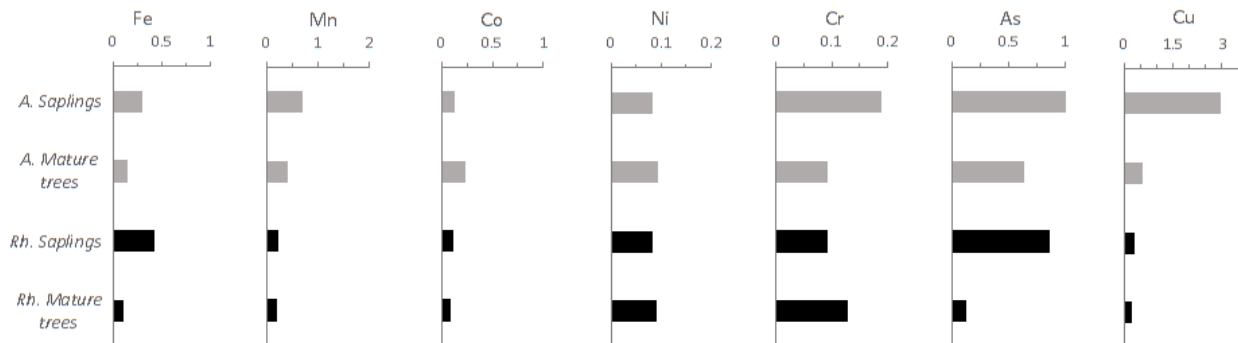
248 *Table 1. Mean concentrations of trace elements (n = 3) in the roots and leaves of the Avicennia alba and the*  
 249 *Rhizophora apiculata, expressed in  $\mu\text{g g}^{-1}$  (mean, SD). The roots of trees were collected in the upper part of 50 cm*  
 250 *depth in the sediments.*

<b>Roots</b>									
	Depth (cm)	Type of trees	Fe	Mn	Co	Ni	Cr	As	Cu
<i>Avicennia</i>	< 50	Saplings	<b>14,948 ± 239</b>	<b>376 ± 4</b>	2.8 ± 0.06	5.1 ± 0.16	17.8 ± 0.11	<b>11.9 ± 0.12</b>	<b>54.7 ± 1.8</b>
	< 50	Mature trees	7,433 ± 308	<b>217 ± 1.7</b>	5.0 ± 0.13	5.8 ± 0.09	8.9 ± 0.42	7.5 ± 0.19	10.2 ± 0.29
<i>Rhizophora</i>	< 50	Saplings	<b>19,897 ± 1,265</b>	60 ± 1.2	2.4 ± 0.05	5.0 ± 0.11	8.8 ± 0.25	<b>12.7 ± 0.15</b>	6.3 ± 0.12
	< 50	Mature trees	5,458 ± 145	57 ± 1.1	2.0 ± 0.01	5.4 ± 0.08	11.9 ± 0.33	2.0 ± 0.05	4.7 ± 0.13

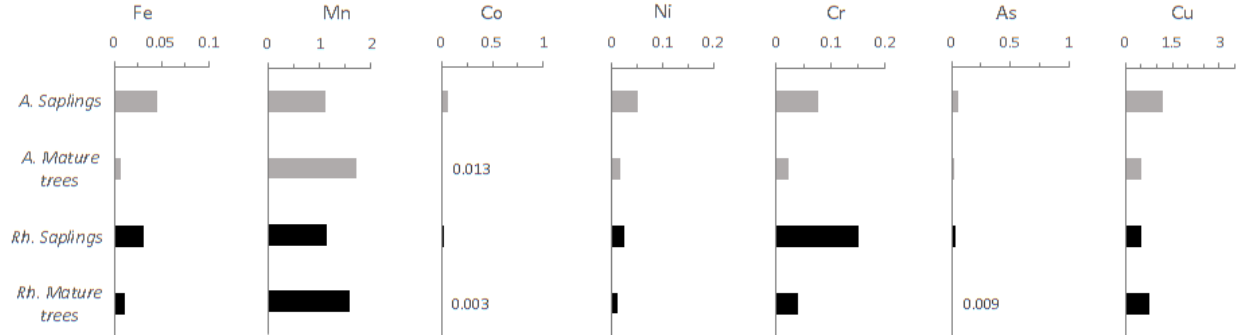
  

<b>Leaves</b>									
	Height of tree	Type of trees	Fe	Mn	Co	Ni	Cr	As	Cu
<i>Avicennia</i>	< 80 cm	Saplings	<b>2,287 ± 39</b>	583 ± 5	1.43 ± 0.01	3.18 ± 0.28	7.31 ± 0.22	0.61 ± 0.02	<b>22.14 ± 0.30</b>
	> 7 m	Mature trees	359 ± 21	<b>908 ± 20</b>	0.29 ± 0.10	1.09 ± 0.14	2.13 ± 0.29	0.30 ± 0.03	8.93 ± 0.30
<i>Rhizophora</i>	< 80 cm	Saplings	<b>1,416 ± 50</b>	267 ± 3	0.48 ± 0.02	1.60 ± 0.02	13.19 ± 0.79	0.40 ± 0.01	10.63 ± 0.55
	> 15 m	Mature trees	498 ± 21	<b>405 ± 38</b>	0.07 ± 0.03	0.70 ± 0.25	3.72 ± 0.30	0.14 ± 0.03	15.92 ± 0.80

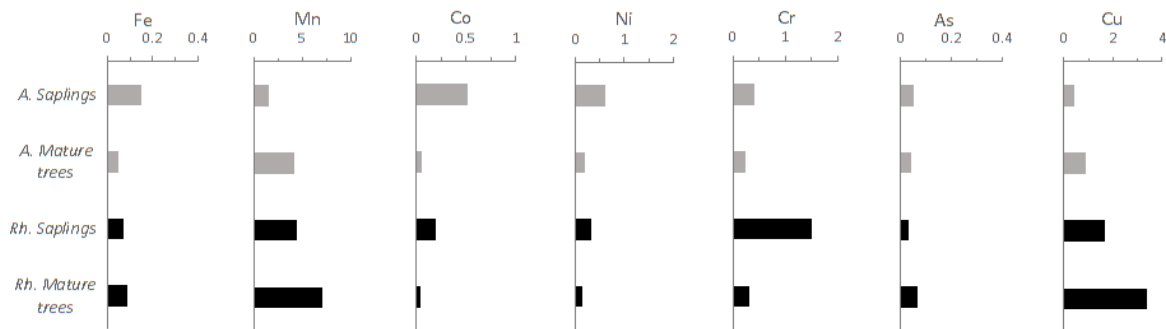
**BCF in Roots**



**BCF in Leaves**



251  
 252 *Fig. 2. Bioconcentration factors (BCF = concentration of trace element in tissues/ concentration of trace*  
 253 *element in sediment) of the Avicennia alba (gray column) and the Rhizophora apiculata (black column).*



254

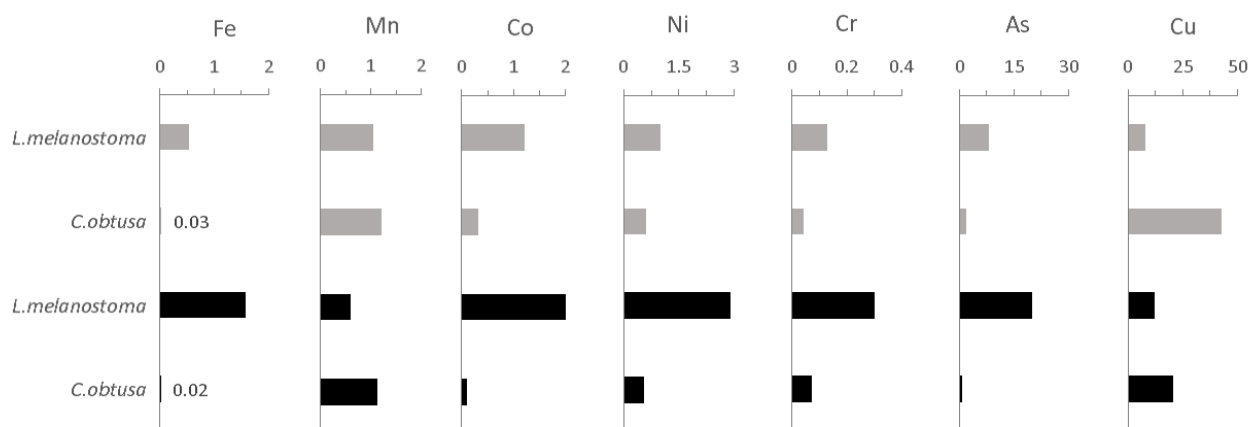
255 *Fig. 3. Translocation factors (TF = concentration of trace element in leaves/ concentration of trace element in*  
 256 *roots) of the Avicennia alba (gray column) and the Rhizophora apiculata (black column).*

257 **3.2. Trace elements in snails**

258 Mean concentrations of Fe, Mn, Co, Ni, Cr, As, and Cu ( $\mu\text{g g}^{-1}$ ) in snails' soft tissues are given  
 259 in Table 2. The *C.capucinus* and *N.articulata* presented similar trace elements concentrations  
 260 beneath two mangrove stands:  $\text{Fe} > \text{Cu} > \text{Mn} > \text{As} > \text{Ni} \sim \text{Cr} \sim \text{Co}$  for *C.capucinus* and  $\text{Fe} > \text{Mn}$   
 261  $> \text{Cu} > \text{As} \sim \text{Ni} \sim \text{Cr} > \text{Co}$  for *N.articulata*. *L.melanostoma* and *C.obtusa* exhibited higher  
 262 concentrations in Fe, Mn and Cu than As, Ni, Cr, and Co, and concentrations differed between  
 263 mangrove stands (*Avicennia alba* and *Rhizophora apiculata*). Bioconcentration factors of all trace  
 264 elements are presented in Fig. 4. The BCF of each trace element varied between snail species,  
 265 ranging from 0.02 to 1.58; 0.6 to 1.13; 0.1 to 5.09; 0.56 to 2.9; 0.04 to 0.3; 0.85 to 20.1 and 7.7 to  
 266 42.8 for Fe, Mn, Co, Ni, Cr, As, and Cu respectively.

267 *Table 2. Concentrations of trace elements in soft tissues of various snails (expressed in  $\mu\text{g g}^{-1}$ ): C.capucinus*  
 268 *(predator), L.melanostoma (leaves eater), C.obtusa (sediment eater) and N.articulata (algae eater).*

Mangrove stand	Species	Length (cm)	Width (cm)	Fe	Mn	Co	Ni	Cr	As	Cu
Avicennia	<i>C.capucinus</i>	2.5 - 4	1 - 1.5	536 ± 40	139 ± 10	0.88 ± 0.11	1.52 ± 0.16	1.11 ± 0.17	<b>10.9 ± 1.1</b>	<b>481 ± 38</b>
	<i>L.melanostoma</i>	1.5 - 2.5	1 - 2	<b>714 ± 95</b>	<b>766 ± 29</b>	1.04 ± 0.03	2.14 ± 0.08	0.61 ± 0.12	3.64 ± 0.17	120.6 ± 9.1
	<i>C.obtusa</i>	2 - 4	1 - 1.5	360 ± 44	<b>780 ± 81</b>	2.64 ± 0.26	5.93 ± 0.44	0.70 ± 0.11	4.32 ± 0.88	113.9 ± 5.7
	<i>N.articulata</i>	2 - 2.6	1.5 - 2	271 ± 26	42.5 ± 2.6	0.20 ± 0.13	1.16 ± 0.15	0.90 ± 0.25	2.83 ± 0.22	7.84 ± 0.65
Rhizophora	<i>C.capucinus</i>	3 - 4	1.5 - 2.5	885 ± 80	119 ± 11	1.14 ± 0.03	2.07 ± 0.12	1.27 ± 0.31	<b>14.3 ± 2.2</b>	<b>389 ± 13</b>
	<i>L.melanostoma</i>	1.5 - 3	1 - 2	<b>1,517 ± 120</b>	<b>201 ± 20</b>	1.41 ± 0.02	3.34 ± 0.30	2.5 ± 1.3	5.39 ± 0.25	163 ± 17
	<i>C.obtusa</i>	3 - 4	1 - 1.2	338 ± 29	<b>158 ± 16</b>	0.99 ± 0.09	6.15 ± 0.74	1.58 ± 0.41	6.95 ± 1.15	120 ± 20
	<i>N.articulata</i>	1.8 - 2.5	1.2 - 1.5	795 ± 82	96 ± 14	0.88 ± 0.27	3.58 ± 1.74	5.99 ± 1.43	6.45 ± 1.69	16.6 ± 0.9



269

270 *Fig. 4. Bioconcentration factors (BCF = concentration of trace element in soft tissues/ concentration of trace*  
 271 *element correspond to its concentration in feeding of individual species) of various snails living in the Avicennia*  
 272 *alba (gray column) and the Rhizophora apiculata (black column).*

#### 273 4. Discussions

##### 274 4.1. Bioaccumulation of trace elements in roots and leaves of *Avicennia alba* and

##### 275 *Rhizophora apiculata*

##### 276 4.1.1. Essential elements: *Fe, Mn, Cu*

277 Iron is an important component of chlorophyll, being useful for protein synthesis and root  
 278 growth (Jones Jr et al. 1991). In the present study, despite low bioconcentration factors (BCF), Fe  
 279 was the most abundant element in the roots whatever the mangrove species, reaching up to 19,897  
 280  $\mu\text{g g}^{-1}$  (Table 1). These mean concentrations of Fe in the plants' roots of the Can Gio mangrove  
 281 were substantially higher than in most mangroves, like for instance in Indian mangroves  
 282 (Kathiresan et al. 2014). We suggest that the high concentrations of measured Fe in the roots  
 283 resulted from the high iron concentrations in the sediments (Table SD2) and in pore-waters  
 284 (Thanh-Nho et al. 2019) (e.g. where it can be highly bioavailable (Abohassan 2013)), as observed  
 285 for *Avicennia marina* and *Rhizophora stylosa* in New Caledonian mangroves, where the mangrove  
 286 sediments are rich in iron because these ecosystems develop downstream lateritic soils (Marchand



287 et al. 2016). However, if the Fe concentrations were high in the roots, the translocation factors to  
288 the leaves were low for this element (Fig. 3), suggesting that the root acted as a barrier preventing  
289 iron translocation to aerial parts. Machado et al. (2005) suggested that the seedlings of mangrove  
290 species can exclude some trace elements through iron plaque formation on the roots. The oxygen  
291 released by the roots of some mangrove species may promote oxidizing conditions within the  
292 rhizosphere, which results in trace elements precipitation at the root surface, creating iron-rich root  
293 coatings, generally called iron plaques (Chaudhuri et al. 2014, Koch and Mendelssohn 1989, Zhou  
294 et al. 2011). Machado et al. (2005) also demonstrated that the washing of the roots prior to analysis  
295 influences the fixation of the iron plaque on the roots: in contrary to distilled water, the dithionite–  
296 citrate–bicarbonate (DCB) solution is able to extract the iron plaque from the roots. Considering  
297 that we only washed the roots with deionized water, the presence of iron plaques at the root surface  
298 may be a possible explanation for the elevated iron concentrations in the plants' roots in the Can  
299 Gio mangrove. For the mature trees, iron concentrations were higher in the *Avicennia* roots than  
300 the *Rhizophora* ones, which may be the results of the higher iron concentrations both in the solid  
301 and the dissolved phases (Table SD2) in the sediment of the *Avicennia* stand (Thanh-Nho et al.  
302 2019). Also, the *Avicennia* root system is known to release oxygen (Marchand et al. 2004,  
303 Scholander et al. 1955), which may increase iron plaque precipitation. Notably, whatever the  
304 mangrove species, iron concentrations in saplings leaves presented higher values than the mature  
305 ones as a result of higher iron concentrations in saplings roots (Table 1). We suggest that iron  
306 plaque may be a source of Fe for plants uptake by bacterial reductive dissolution of plaque during  
307 organic matter decay processes on dead roots surface. Additionally, the root system of the saplings  
308 may develop in the upper layer, and not as deep as the one of the mature trees. This upper layer is  
309 more subject to variations in the redox conditions, and possibly to enhanced alternation of

310 precipitations/dissolution processes. Consequently, elements, specifically iron, may be more  
311 available at the depth of the saplings' roots. Eventually, it is possible that the adaptation strategy  
312 of the mangrove trees was not fully developed at the sapling stage, as a result, the role in barrier  
313 of the root system may be limited.

314 Manganese is a major contributor to various biological processes, including photosynthesis  
315 (Millaleo et al. 2010). In Can Gio mangrove, whatever the mangrove species, Mn was the second  
316 abundant element in their tissues, with average concentrations in the range of those measured  
317 worldwide in mangroves (see review of Lewis et al. (2011) and Bayen (2012)). Conversely to Fe,  
318 Mn accumulated more in the leaves than in the roots (Table 1), as previously observed in New  
319 Caledonia by Marchand et al. (2016). TF values (i.e. maximum TF: 4.08) and Mn concentrations  
320 in roots and leaves of mangrove plants measured in New Caledonia were lower than in the present  
321 study (e.g. TF reached up to 7.07). We suggest that the high dissolved Mn concentrations measured  
322 in the pore-waters and the difference of Mn partitioning in the mangrove sediments may be  
323 responsible for the elevated values measured in the present study. Within the top 50 cm of the  
324 sediments in the Can Gio mangrove, approximately 60 % of Mn was associated with the  
325 bioavailable fractions (Table SD2) whereas in New Caledonia, 90 % of Mn was bound to the  
326 refractory fraction, preventing its transfer to mangrove plants (Marchand et al. 2016). In the Can  
327 Gio mangrove, Mn was only the element to potentially present an ecological risk due to its high  
328 bioavailability (ratio in concentrations of trace element in the bioavailable fractions  
329 (exchangeable/carbonate bound) to the total concentrations of trace element) (Thanh-Nho et al.  
330 2019). Since high TF of Mn was already reported for *Rhizophora* species, we suggest that it may  
331 be related to metabolic requirements, this element playing an important role in enzymes reactions

332 is also needed for water splitting at photosystemII (McEvoy and Brudvig 2006). Consequently,  
333 *Rhizophora* trees have a high potential for Mn phytoextraction.

334       Regarding copper, it is known as an essential element for plants growth, being required in  
335 enzyme system related to photosystemII electron transport, mitochondria and chloroplast reaction,  
336 carbohydrate metabolism, cell wall lignification, and protein synthesis (Yruela 2009). Cu  
337 concentrations in the roots and leaves of mangrove plants measured in the present study were in  
338 the range of those in other mangroves (Bayen 2012) such as in China (He et al. 2014), in southern  
339 Brazil (Madi et al. 2015), or in Indonesia (Martuti et al. 2016). It was reported that the Cu  
340 partitioning in sediments of the Can Gio mangrove was mainly related to sulphide precipitation  
341 and to its complexes with organic compounds (Thanh-Nho et al. 2019). Thus, we suggest that the  
342 low Cu concentrations measured in the mangrove roots may be related to Cu association with  
343 sulphide, which limit its bioavailability. However, this element presented the second highest values  
344 of TF, beside Mn, with TF reaching 1.69 for *Avicennia* mature trees and 3.37 for *Rhizophora*  
345 mature ones. MacFarlane and Burchett (2002) showed that Cu can be toxic to plants growth if its  
346 concentration in the sediments exceeds 400  $\mu\text{g g}^{-1}$ , which is almost 20 fold higher than the  
347 concentrations measured in the Can Gio mangrove sediments. Consequently, we suggest that the  
348 high values in TF of Cu resulted from specific metabolic requirements (Baker 1981, Dudani et al.  
349 2017) as Cu has a direct impact on photosynthesis I, being a constituent of plastocyanin, which is  
350 involved in the photosynthetic electron transport chain (Maksymiec 1998).

#### 351           4.1.2. *Non-essential elements: Co, Ni, Cr, As*

352       Non-essential elements such as Co, Ni, Cr, and As mainly accumulated in the roots (Table 1),  
353 with low translocation to the leaves (Fig. 3). This phenomenon may result from different  
354 mechanisms developed by mangrove plants to prevent the uptake of toxic elements and to limit

355 their transport within the components of plants (Almeida et al. 2006), notably through cell wall  
356 immobilization and/or sequestration in the epidermal layers (MacFarlane et al. 2007). They, thus,  
357 accumulate in the perennial tissues, especially the roots (Carbonell et al. 1998, Zhou et al. 2011).

358 Concerning Arsenic, some forms can be subject to plant uptakes, involving arsenites-As(III)  
359 and arsenates-As(V) (Asher and Reay 1979). However, arsenites can be toxic for radicular  
360 membranes because of As reaction with sulfhydryl groups in proteins, causing disruption of roots  
361 functions and cellular death (Speer 1973, Wu et al. 2015). In the present study, arsenic  
362 concentrations in the roots and leaves of mangrove plants were higher than those of other  
363 mangroves like in the Indian Sundarban (Chowdhury et al. 2015), or in the Chinese Futian (He et  
364 al. 2014). Arsenic was also characterized by higher BCF in the roots, specifically for the *Avicennia*.  
365 These results may be related to the high As concentrations in bioavailable fractions in the Can Gio  
366 mangrove sediments (Table SD2). In Vietnam, soils are naturally rich in As (Gustafsson and Tin  
367 1994, Nguyen et al. 2016), which may explain its accumulation in mangrove sediments and then  
368 its transfer to mangrove roots. We suggest that As may be incorporated into iron plaque at the roots  
369 surface, which restricted As transfer to aerial parts. This hypothesis may be supported by a positive  
370 correlation between the concentrations of Fe and As in the roots (i.e.  $r = 0.92$ , Pearson correlation).  
371 Like iron, As was more bioavailable beneath the *Rhizophora* stand, where the sediment was more  
372 enrich in organic matter and the oxidizable fraction represented up to 36 % of total As  
373 concentrations. However, BCF of As was higher for the *Avicennia* than *Rhizophora* roots, which  
374 comforts our hypothesis in enhanced plaque formation beneath the *Avicennia* rhizosphere due to  
375 specific redox conditions resulting from oxygen release via the roots system. Similar to Fe, As  
376 concentrations in sapling's leaves of both *Avicennia* and *Rhizophora* species were higher than  
377 mature ones. We suggest that the As incorporated in iron plaque could be a As source for plant

378 uptake from plaque reductive dissolution by bacteria during organic matter decay processes of  
379 death roots tissues. Arsenic uptake by mangrove leaves may concomitantly occur to Fe (i.e. a  
380 positive correlation was observed between concentration of As and Fe in the leaves,  $r = 0.91$ ,  
381 Pearson correlation). Again, the extension of the root system in the upper layer, and possibly the  
382 less developed adaptation strategy of saplings may also be responsible for the As transfer to  
383 saplings' leaves.

384       Regarding Ni and Cr, their concentrations in the roots and leaves of *Avicennia* and *Rhizophora*  
385 in the Can Gio mangrove were in the range of those presented in the review of Lewis et al. (2011)  
386 but lower than those measured in the Indian Sundarban mangroves (Chowdhury et al. 2017) or in  
387 New Caledonia (Marchand et al. 2016). In the later environments, the authors reported higher Ni  
388 concentrations in plants tissues, with values up to  $700 \mu\text{g g}^{-1}$  due to high Ni concentrations in  
389 mangrove sediments resulting from the proximity of lateritic soils enriched in Ni. Thus, we suggest  
390 that the moderate Ni and Cr concentrations in the Can Gio mangrove plants may result from their  
391 association to the refractory fraction (i.e. more than 80 %, Table SD2). For plants, Ni is a  
392 micronutrient that is required at very low concentrations (Gajewska and Skłodowska 2007), and  
393 which can inhibit plant growth at high concentrations (Rao and Sresty 2000). The effect of Ni on  
394 plants varies according to plant species as well as the Ni concentration in sediment; one example  
395 of its toxic symptom is chlorosis or yellowing of the leaves (Mishra and Kar 1974). Cr is also toxic  
396 for plant growth (Shanker et al. 2005). When mangrove seedlings are exposed to excessive Cr  
397 concentrations, their roots would be shortened, and their height and biomass would be limited  
398 (Fang et al. 2008). However, considering the low BCF and the low concentrations of those trace  
399 elements in the Can Gio mangrove plants, their impacts on plant growth are probably limited. Cr  
400 concentrations in the roots of *Rhizophora* trees were lower although its concentrations in

401 bioavailable forms were higher than in the *Avicennia* (Table SD2). This phenomenon, supported  
402 by higher TF values in the *Rhizophora* trees, may be related to a more intense phytoextraction of  
403 *Rhizophora* species. In addition, translocation factor of Cr in the saplings of both *Avicennia* and  
404 *Rhizophora* trees were higher than in the mature ones, which may be due to higher allocation of  
405 this element to leaf (Weis and Weis 2004) in the saplings. Similar result was also observed for Ni  
406 (Fig. 3).

407 Co is a micronutrient, which can be used in redox processes to stabilize molecules through  
408 electrostatic interactions as components of various plant enzymes. However in excess, it can be  
409 toxic, inducing enzyme modification, disturbing cellular function (Palit et al. 1994). In the present  
410 study, Co concentrations in the roots and leaves of the different mangrove species were higher  
411 than in Australian mangroves (Nath et al. 2014), in French Guianan mangroves (Marchand et al.  
412 2006), or New Caledonian mangroves (Marchand et al. 2016). We suggest that high Co  
413 concentrations in the Can Gio mangrove plants may result from its high concentrations in the  
414 bioavailable fractions in the sediments, reaching up to 44 % (Table SD2). However, if Co  
415 concentrations in the roots were relatively high, TF were lower than 0.5 (Fig. 3), which suggest its  
416 limited physiological role and/or the fact that the roots acted as a physical barrier. As a  
417 consequence, the present study showed a narrow range of Co level in the leaves (i.e. 0.07 to 1.43  
418  $\mu\text{g g}^{-1}$ ). The BCF values of Co in the tissues of *Avicennia* were much higher than in the *Rhizophora*,  
419 which may reflect the specific physiological requirements of the trees, considering that its  
420 bioavailability was higher beneath *Rhizophora* stand (Table SD2).

#### 421 4.2. Bioaccumulation of trace elements in snails

422 In the Can Gio mangrove, whatever the snails' species and their habitat, the concentrations of  
423 Fe, Mn and Cu were the most abundant in their soft tissues (Table 2). Previous studies showed that

424 soft tissues of mollusks accumulated higher concentrations of Cu and Fe than in the shells because  
425 of specific physiological requirements (Szefer et al. 1999, Vukašinović-Pešić et al. 2017, Yap and  
426 Cheng 2009). In fact, Fe, Mn, and Cu play important roles in metabolic biomolecules like enzymes  
427 or metalloenzymes (Langston et al. 1998, Rainbow 1997). Snails also need elevated amount of Cu,  
428 being a constituent of hemocyanin (Dallinger et al. 2005). Conversely, the other elements studied  
429 can be toxic, inducing growth retardation, edema and thinning of the shell (Factor and de Chavez  
430 2012). Similar results were reported concerning snails and different mollusks in mangroves in  
431 Malaysia (Yap and Cheng 2013), in India (Palpandi and Kesavan 2012), in Costa Rica (Vargas et  
432 al. 2015), or in Senegal (Sidoumou et al. 2006).

433 We also suggest that the different amounts of trace elements in the food sources and feeding  
434 habits of individual snail affect the degree and extent accumulation of trace elemental in their  
435 tissues. The snail *C.obtusa*, a sediment eater, exhibited higher trace elements concentrations in the  
436 *Rhizophora* stand than in the *Avicennia* one, except for Mn and Co. This could result from higher  
437 concentrations of trace elements in the available fractions in sediments beneath the *Rhizophora*  
438 stand (Table SD2). We evidenced that because of the enhanced organic enriched-sediment beneath  
439 the *Rhizophora* stand, reductive dissolution of Fe-Mn oxihydroxides by bacteria during organic  
440 matter decay processes is a source of dissolved trace elements in pore-waters, these elements being  
441 more bioavailable (Thanh-Nho et al. 2019). As a consequence, concentrations of trace elements in  
442 *C.obtusa* tissues in the present study were far higher than those measured in other mangroves  
443 (Joseph and Ramesh 2016) or estuary with strong anthropogenic pressure (Kesavan et al. 2013).  
444 Concerning *L.melanostoma*, a leaf eater, we suggest that the higher concentrations of trace  
445 elements (except Mn), combined to higher BCF (Fig. 4), in snails tissues living beneath the  
446 *Rhizophora* stand compared with the *Avicennia* one (Table 2) is likely related to the higher trace

447 elements concentrations in the *Rhizophora* leaves than the *Avicennia* ones (Table 1). In addition,  
448 *L.melanostoma* presented the highest concentrations of Fe and Mn in the tissues compare to other  
449 snail species in the Can Gio mangrove. This result suggest that leaf eater is more sensitive to  
450 accumulation of trace elements or that trace elements in leaves are more bioavailable. Furthermore,  
451 *L.melanostoma* in the present study showed higher Fe and Mn concentrations than those in  
452 *L.scabra* collected from a polluted mangrove (De Wolf and Rashid 2008). *C.capucinus*, a predator  
453 of barnacles, bivalves and other mollusks (Berandah et al. 2010), presented the highest Cu  
454 concentrations, which may result from copper biomagnification via their food chains because Cu  
455 is known to be very compatible with protein binding in organisms (Jiang and Qiu 2009). Cu  
456 biomagnification in snails body is usually observed, and they are considered as  
457 “macroconcentrators” species for Cu (Nica et al. 2012). However, concerning *N.articulata*, the  
458 microalgae eater, Mn and Cu concentration in their tissues were lower than those in other species  
459 whatever the mangrove stands, and were lower than those measured in *N.articulata* living in other  
460 mangroves like in Malaysia (Yap and Cheng 2013) or Southeast coast of India (Palpandi and  
461 Kesavan 2012). This result may be related to low Mn and Cu accumulation in microalgae in the  
462 Can Gio mangrove. Unfortunately, in the present study, we were not able to measure  
463 concentrations of trace elements in microalgae. Considering the key role of microphytobenthos in  
464 mangrove trophic food chain (Lee 2008, Raw et al. 2017), we suggest that further investigation  
465 should be carried out on accumulation of trace elements in these microalgae.

466 Eventually, among non-essential elements, all snails contained high quantity of As, which can  
467 result from its availability in their diet, and snails’ ability to metabolize As and retain it (Kirby et  
468 al. 2002, Zhang et al. 2013). Arsenic also presented the highest BCF whatever the snail species  
469 (Fig. 4). In the Can Gio mangrove, dissolved As concentrations in pore-waters reached up to almost



470 20  $\mu\text{g L}^{-1}$ . In addition at the *Rhizophora* stand, characterized by higher organic content, the organic  
471 fraction, being bioavailable, represented up to 36 % of total As concentrations (Table SD2).  
472 Khokiattiwong et al. (2009) studied on two mollusks species (*C.capucinus* and *Telescopium*  
473 *telescopium*), and they showed that *C.capucinus*, as a predator, contained more As than the detritus  
474 and algae eater species, *T.telescopium*. We also observed that *C.capucinus* contained the highest  
475 As concentrations in their body (2 to 4 fold higher level tissues than other snail species) in the Can  
476 Gio mangrove, which could be related to their predator diet and magnification along food chain  
477 (Goessler et al. 1997).

478 According to Dallinger (1993), snail tissues can be classified in macroconcentrators (BCF >  
479 2), microconcentrators ( $1 < \text{BCF} < 2$ ) or deconcentrators (BCF < 1). Thus, in the present study, the  
480 *L.melanostoma* and *C.obtusa* can be classified as macroconcentrators for Cu. The *L.melanostoma*  
481 was macroconcentrators for As, Co and Ni. Conversely, all snails were deconcentrators to  
482 microconcentrators for Mn and Fe. Due to negative effects of toxic trace elements on community  
483 structure, gender, size of snails (Amin et al. 2009, Yap and Cheng 2013), the obtained results in  
484 the present study provided a further claim that these snails can be used as good biomonitors for  
485 environmental quality (Samsi et al. 2017).

## 486 5. Conclusions

487 Trace elements accumulation in the tissues of mangrove plants and snails studied in the Can  
488 Gio mangrove reflected their concentrations in the sediment, their bioavailability, and specific  
489 adaptation strategies or physiological processes of the biota. Clear differences between the two  
490 stands were evidenced, notably because of different sediment geochemistry. The main conclusions  
491 concerning mangrove trees can be summarized as follow:

- 492 - Fe and As were characterized by low translocation to the leaves of the *Avicennia* and  
493 *Rhizophora* trees. We suggest that the formation of iron plaque on roots by oxygen release  
494 in the rhizosphere may be a key factor preventing this translocation. Consequently,  
495 mangroves roots can be considered as “phytostabilizers”, immobilizing trace elements  
496 and limiting their transfer in the environment.
- 497 - Co exhibited higher concentrations in roots and leaves of the Can Gio mangrove trees than  
498 the world average. However, this element was characterized by low BCF and TF, which  
499 may be related to its high concentrations in available forms in the sediment
- 500 - High translocation factors for Mn and Cu may possibly result from physiological  
501 requirements, both elements being useful in photosynthetic processes, but also from  
502 elevated bioavailability in the sediment. We also suggest that the *Rhizophora* trees have a  
503 high potential for Mn “phytoextraction”.
- 504 - Ni and Cr were characterized by low BCF and TF whatever the mangrove plants, which  
505 may result from their low bioavailability in the sediment and from the limited physiological  
506 roles of those elements.
- 507 - Consequently, we suggest that the mangrove trees species studied can act as sinks when  
508 elements are stored in their root systems, or sources for the trophic chain when they  
509 accumulate in the leaves. Therefore, studies regarding the turnover of trace elements from  
510 decomposing of leaf litter should be developed to get a better understanding of the cycling  
511 of trace elements in mangroves ecosystem.

512 The main conclusions concerning mangrove snails can be summarized as follow:

- 513 - The great variability in concentrations of studied trace elements in the various snails  
514 indicated that bioaccumulation of trace elements depended not only on characteristics of

515 trace elements (i.e. physiological properties and biological functions), and metabolic  
516 requirements of each species but also on available concentrations of these trace elements  
517 in their feeding sources.

518 - Fe, Mn and Cu, which are essential elements, presented higher concentrations in all snails  
519 tissues than As, Ni, Cr and Co, which can be toxic.

520 - Most of the snails living in the *Rhizophora* stand presented higher levels of trace elements  
521 concentrations (except Mn and Co) than those living in the *Avicennia* stand, specifically  
522 for *L.melanostoma* and *C.obtusa*, due to higher concentrations of trace elements in the  
523 leaves or in the bioavailable fractions in the sediment.

524 - Concerning the predators, *C.capucinus*, possible biomagnification of Cu via the food chain  
525 induced elevated Cu concentrations in their tissues.

526 - In this study, we also measured that all snails contained high amount of As, most probably  
527 because it is highly bioavailable in mangrove sediments.

528 - Eventually, most snails can be classified as “maroconcentrators” of some trace elements  
529 such as Cu, As, Co and Ni. Because of their potential toxic effects, a further study should  
530 be performed to assess the possibility of using snails as bioindicators of environmental  
531 quality. In addition, it would be relevant to compare trace elements dynamics between  
532 seasons. We suggest that during the dry season, lower elements inputs and lower sediment  
533 reactivity may induce lower accumulation in mangrove plants and snails tissues.

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537

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