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Catherine Fernandez, Amélie Saunier, Henri Wortham, Elena Ormeño, Magali Proffit, Caroline Lecareux, Stephane Greff, Dao van Tan, Mai Sy Tuan, Huynh Duc Hoan, et al.

### ► To cite this version:

Catherine Fernandez, Amélie Saunier, Henri Wortham, Elena Ormeño, Magali Proffit, et al.. Mangrove's species are weak isoprenoid emitters. *Estuarine, Coastal and Shelf Science*, 2023, 283, pp.108256. 10.1016/j.ecss.2023.108256 . hal-04062555

**HAL Id: hal-04062555**

**<https://amu.hal.science/hal-04062555v1>**

Submitted on 13 Apr 2023

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1 **Mangrove's species are weak isoprenoid emitters.**

2

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17

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20

21 **Abstract**

22 Mangroves are ecosystems interfacing terrestrial and marine environments submitted to extreme  
23 abiotic factors (e.g. anoxia, flooding, salinity) producing stress on vegetation. Due to these stresses, we  
24 hypothesized that mangroves potentially emit biogenic volatile organic compound (BVOC),  
25 particularly isoprenoids as they are defense compounds. Despite mangroves cover only about 5% of  
26 the forest areas of the world, their emissions could impact air quality at the continental-ocean  
27 interface. As a result, it is important to fill the gap in the knowledge about BVOC emissions from the  
28 canopy of the major mangrove trees. The aim of this study was thus to screen isoprenoid emissions of  
29 the mangrove species. In this study, we sampled isoprenoid emissions of 15 species foliage among the  
30 38 core species existing in the Indo-West Pacific (IWP) and the Atlantic Est Pacific (AEP) regions.  
31 Sampling was performed using a branch-bag dynamic enclosure system and analyzed with gas  
32 chromatography coupled to mass spectrometry. Our analysis showed that mangrove tree species are  
33 very low emitters suggesting that mangrove ecosystems would not strongly influence atmospheric  
34 chemistry and air quality.

35

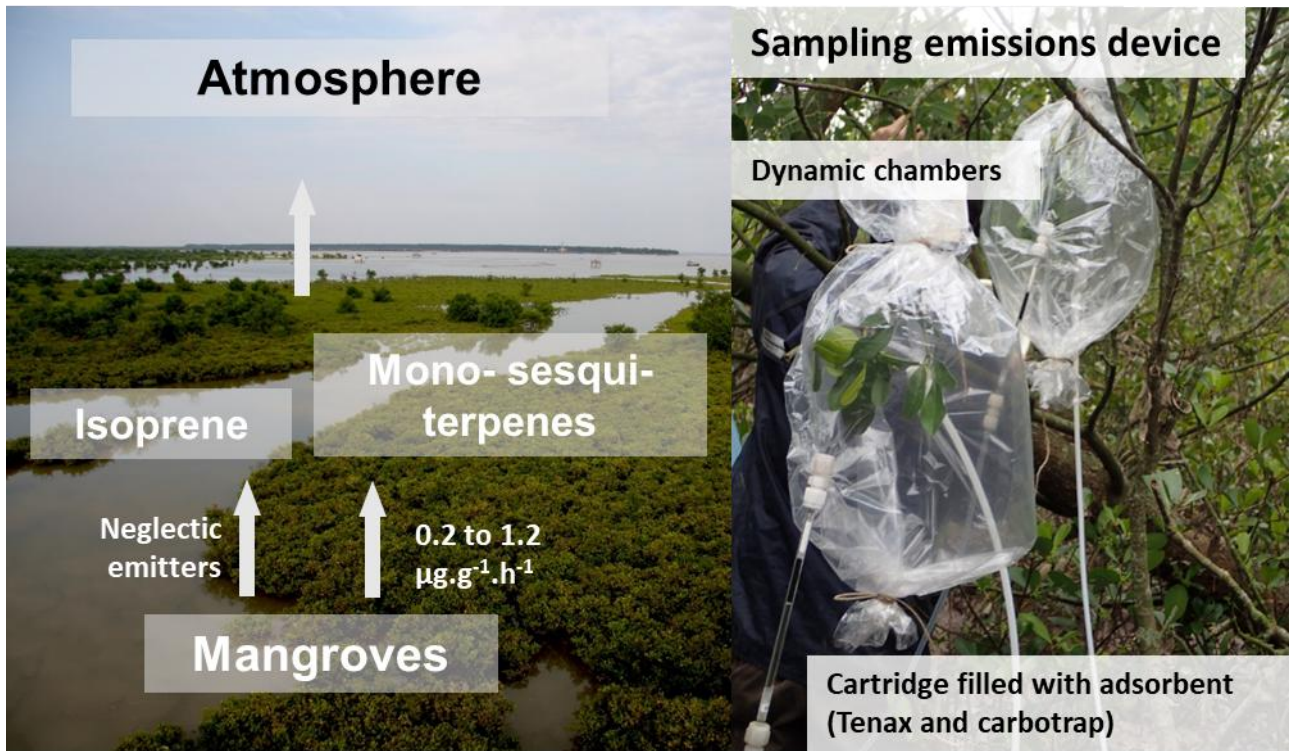
36 **Keywords**

37 BVOC emissions; Isoprenoids; Mangroves; Flooded ecosystems; extreme environments

38

39 **Highlights**

- 40
- 41 • Isoprenoid emissions of 15 mangrove species were investigated.
  - 42 • Mangrove species studied are very low isoprenoid emitters.
  - 43 • Mangrove forest weakly contribute to biosphere-atmosphere exchanges through BVOC.
- 44
- 45
- 46
- 47



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## 51 **1. Introduction**

52 Vegetation (croplands, shrublands, woodlands etc) is the most important source of volatile organic  
53 compound (VOC) as it accounts for 1015 TgC.yr<sup>-1</sup>, about 90% of total biogenic emissions (Guenther  
54 *et al.* 1995). VOCs gather a wide variety of chemical compounds having a high vapor pressure (at  
55 least 0.01 KPa) at ambient temperature. Among them, isoprenoids (including isoprene but also  
56 monoterpenes and, to a lesser extent, sesquiterpenes), as well as highly volatile compounds such as  
57 methanol, acetaldehyde, or formaldehyde, are mainly emitted (e.g. Saunier *et al.*, 2017a). These  
58 compounds play a major environmental role on air quality and indirectly modulate climate conditions.  
59 Indeed, in the presence of sunlight and nitrogen oxides (NO<sub>x</sub>), biogenic VOCs (BVOCs) contribute to  
60 the formation of tropospheric ozone (Fehsenfeld *et al.* 1992) and secondary organic aerosols (Claeys  
61 *et al.* 2004; Ng *et al.* 2006), which in turn act on cloud formation and albedo (Makkonen *et al.* 2012).  
62 Among BVOCs, isoprenoids are therefore key compounds for chemistry-model-transport and climate-  
63 change models that aim to forecast photo-chemical pollution episodes and their contribution in the  
64 future climate change (Makkonen *et al.* 2012). These two types of models rely on thousands of  
65 publications that describe, since the 1980s, BVOCs emissions from plant species (Keenan *et al.* 2009),  
66 their dependence on environmental factors such as light and temperature (Guenther *et al.* 1993). Since  
67 isoprenoid emissions are species-specific, it is crucial to investigate isoprenoid emissions from the  
68 main vegetal formations at the global scale. For this purpose, temperate environments (e.g.  
69 Mediterranean, continental, oceanic) have been widely studied in terms of BVOCs emissions (Owen *et al.*  
70 *et al.* 2001; Ormeno *et al.* 2007; Saunier *et al.* 2017b), but plant species from extreme environments such  
71 as mangroves have been clearly neglected (Rinnan *et al.* 2014; Exton *et al.* 2015).

72 Mangroves are extreme ecosystems interfacing terrestrial and marine environments. These forests are  
73 key elements of tropical coastal ecosystems as they provide many ecosystem services such as limiting  
74 erosion (e.g. cyclone, wave) and saline intrusion (Brander *et al.* 2012, Hilmi *et al.*, 2017), providing  
75 raw materials, food and habitat for fauna (e.g. migration, breeding, spawning), or being important  
76 carbon (C) sinks (Jakovac *et al.* 2020). They are found in two distinct regions: the Atlantic Est  
77 Pacific (AEP) and the Indo-West Pacific (IWP) (Spalding 2010) and account for 147,359 km<sup>2</sup>

78 (127,925–168,895) in 2020 (Bunting et al., 2022). In both geographical areas, there are several  
79 common genera but no common species. To handle their particular changing environmental conditions  
80 (e.g. high salinity, flooding, anoxia), mangrove species have developed several specific defense  
81 mechanisms, including physical barriers (e.g. waxes, He *et al.* 2016) or chemical protections (e.g.  
82 secondary metabolites, Naskar & Palit 2015). Indeed, specialized compounds can be produced and/or  
83 emitted by plants to cope flooding and salinity as demonstrated for other species (Copolovici &  
84 Niinemets 2016; Yang *et al.* 2018). However, to our knowledge, only a few studies have investigated  
85 BVOC emissions from mangrove despite the large distribution of this unique ecosystem over the  
86 world. For instance, Barr *et al.* (2003) focused on volatile compounds emitted by foliage of Red  
87 mangroves (*Rhizophora mangle* L.) in Florida, and found very low emissions of isoprene ( $< 0.1$   
88  $\mu\text{g}\cdot\text{g}_{\text{DW}}^{-1}\cdot\text{h}^{-1}$ ). Despite these reported low emissions, mangrove trees could have a non-negligible effect  
89 on atmospheric processes since mangroves represent one of the most biomass-productive biomes on  
90 our planet and cover about 75% of the coasts and estuaries of tropical regions (Ellison and Farnworth,  
91 2001; FAO 2007).

92 The aim of this study was to perform for the first time a screening of isoprenoid emissions from 15  
93 mangrove trees located in two geographical areas: the IWP (Vietnam) and the AEP (French Guyana)  
94 regions. We hypothesized that some mangrove species could be isoprenoid emitters in response to  
95 extreme conditions in mangrove ecosystems.

96

## 97 **2. Materials and methods**

### 98 *2.1 Species*

99 From the 73 species recognized as “true” mangroves, we investigated 15 of the dominant mangrove  
100 species among the 38 core species (Spalding 2010): *Avicennia alba* Blume, *Avicennia germinans*  
101 (L.)L., *Avicennia marina* (Forsk) Vierh (Acanthaceae), *Aegiceras corniculatum* (L.) Blanco, *Aegiceras*  
102 *floridum* Roem. & Schult. (Myrsinaceae), *Bruguiera gymnorhiza* Lam., *Ceriops zippeliana* Blume,  
103 *Rhizophora apiculata* Salvoza, *Rhizophora racemose* (Hochr.) Salvoza, *Rhizophora stylosa* Griff.  
104 (Rhizophoraceae), *Laguncularia racemose* (L.) C.F. Gaertn., *Lumnitzera littorea* (Jack) Voigt,  
105 *Lumnitzera racemosa* Wild. (Combretaceae), *Sonneratia alba* Sm. and *Sonneratia caseolaris* (L.)

106 Engl. (Lythraceae). Due to the large surface area they occupy, these species could be the most  
107 important contributors to the biosphere atmosphere relationship.

108 The 15 species were sampled in two distribution areas: 11 in the IWP (Vietnam) and 3 in the AEP  
109 (French Guyana) regions. In Vietnam, the experimental site was located in the botanical garden of Can  
110 Gio District (CGBG), Ho Chi Minh City in the South of Vietnam (10°30'N 106°51'E). The Can Gio  
111 mangrove is formed by the deltaic confluence of the Saigon, Dong Nai and Vam Co Rivers and it is  
112 the first mangrove biosphere reserve in Vietnam (UNESCO/MAB Project 2000). This estuary is  
113 subject to semi-diurnal tides, and the tidal elevation ranges from 2 to 4 m. The climate is monsoonal,  
114 with a dry season lasting from December to April and a wet season from May to November. In this  
115 site, the annual mean temperature is 27.4°C with the highest (37.6°C) occurring in October and the  
116 lowest (21.7°C) in February. The annual average rainfall ranges from 13000-14000mm with highest  
117 monthly average in September (300-400mm). To the sampling site, not directly connected to the to the  
118 main estuarine channel, the salinity ranges from 16 to 23 (Vinh et al. 2020).

119  
120 The second experimental site was located in French Guyana, along the Mahury River (04° 51.4429'N  
121 052°15.8035'W). In this site, the climate is humid equatorial climate with 2 wet seasons and 2 dry  
122 seasons. French Guiana coast is mesotidal with semi-diurnal tides (Ray et al. 2020) with a tide  
123 elevation ranged from 0.92 m and 3.06 m in this site. The average annual temperature is 26.5 °C with  
124 a thermal amplitude of 3 °C at the most between the hottest and the coldest month and the average  
125 annual rainfall ranges from 2500 to 3000 mm y<sup>-1</sup>. In the site the salinity ranges from 16 to 26  
126 (Marchand et al. 2004).

127 Samplings were performed in the dry season during 2 field campaigns in April 2019 in Vietnam and  
128 October 2019 in French Guyana. The environmental conditions in terms of temperature (°C), relative  
129 humidity (%) occurring during the field campaigns were recorded using a HOBO device (Onset,  
130 USA). Photosynthetically Active Radiation (PAR) was measured using a quantum sensor (PAR- SA  
131 190®, LI- COR, USA) (Table 1).

132

133 *2.2 Isoprenoid sampling*

134 For each species, five mature trees (2-5m) were sampled during each field campaign and sampling site  
135 (only exception: 6 *Avicenia alba* were sampled), for a total of 76 trees sampled (see Table 2 for  
136 details). The sampling procedure was described in detail in Saunier *et al.* (2017). On each sampled  
137 tree, one branch sun-exposed and without flower and having about 6 leaves was enclosed in a  
138 polytetrafluoroethylene (PTFE) chamber of about 10 L. A continuous atmospheric air flow, filtered  
139 with VOC and ozone scrubbers, flowed through the chamber at 1 L.min<sup>-1</sup>. After a 30 min system  
140 stabilization period, air from the enclosure was collected during 30 min at 0.2 L.min<sup>-1</sup> on cartridges  
141 (two beds of adsorbants: tenax and cartotrap B), one for isoprene and one for other isoprenoids. Inlet  
142 and outlet air flows were controlled by mass flow controllers (Porter Instrument, USA). Cartridges  
143 were then stored at -20°C until analysis (portable freezer in the field and classical one in the  
144 laboratory). Samplings were performed between 10 h and 15 h (local time) on fully developed leaves.  
145 Twice a day, blanks were performed to control inlet air quality.

146 One test was performed in April 2019 to check the reliability of our protocol of transport and storage.  
147 According to this test, no significant difference was detected between an analysis right after the  
148 sampling or after a period of transport/storage (Fig. S1 in supplementary files).

149

### 150 2.3 GC-MS analyses

151 Cartridge analyses were conducted by gas chromatography (model 6890N, Agilent technologies,  
152 USA) coupled to mass spectrometry (model 5973, Agilent Technologies, USA). VOC were extracted  
153 using thermodesorption system (TDS3/CIS, Gerstel, Germany) using helium as carrier gas (50  
154 mL.min<sup>-1</sup>) at 250 °C during 10 min. The extracted compounds were concentrated on-line by cryo-  
155 trapping at -50 °C using liquid nitrogen. The sample was then injected by rapid heating to 250°C at  
156 10°C/min. Initial oven temperature was 40 degrees hold for 5 minutes and then increasing by 3  
157 degrees per minute to 250 °C maintained for 15 min.

158 Two distinct chromatographic methods were used, one to detect and quantify isoprene (C5) and  
159 another one to analyze C10-C15 compounds. Isoprene was analysed using a capillary Al/KCl column  
160 (Agilent Technologies, USA; 30 m x 0.25 mm x 5 µm) as described in Saunier *et al.* (2017b) whereas  
161 other isoprenoids were separated on a HP-5MS column (Agilent Technology, USA; 30 m x 0.25 mm x



162 0.25  $\mu\text{m}$ ) as shown in Ormeño *et al.* (2007). For both analyses helium was the carrier gas at a constant  
163 flow rate of 1  $\text{mL}\cdot\text{min}^{-1}$ . Isoprenoids were identified based on the co-injection of analytical standards  
164 (Sigma-Aldrich, Germany), the Kovàts' index calculation through the injection of alkanes ( $\text{C}_8\text{-C}_{20}$ ) as  
165 well as the comparison of mass spectra to the NIST library (2011). BVOC emission rate (ER) were  
166 calculated according to Saunier *et al.* (2017).

#### 167 2.4 Statistical analyses

168 The statistical analyses were performed with R software (version 4.2.1). After having checked the  
169 normality of the data set, one way-ANOVA or Kruskal-Wallis tests were performed for isoprene  
170 emissions and other BVOC emissions according to the species. Dunn post-hoc tests were performed to  
171 detect the species with statistical differences in their emissions.

172

### 173 3. Results

174 The 15 studied mangrove species are low isoprenoid emitters ( $< 1.200 \text{ ng}\cdot\text{gDW}^{-1}\cdot\text{h}^{-1}$ , Table 2). In  
175 details, species from the IWP region are the lower isoprene emitters with emissions rates ranging  
176 between 0.3 and 1.6  $\text{ng}\cdot\text{gDW}^{-1}\cdot\text{h}^{-1}$  while species from the AEP region present a larger range of  
177 isoprene emission rate with values ranging between 0.1 and 2.1  $\text{ng}\cdot\text{gDW}^{-1}\cdot\text{h}^{-1}$ . Isoprene emissions  
178 represent 0.3, 0.5 and 2.1% of total emissions for *A. germinans*, *L. racemosa* and *R. racemosa*,  
179 respectively.

180 Besides, those species are also low emitters of other BVOC ( $200 - 1.2 \text{ ng}\cdot\text{g}^{-1}\text{DW}\cdot\text{h}^{-1}$ , Table 2 and 3)  
181 and the main BVOC detected are monoterpenes but also benzenoids as well as methyl salicylate.  
182 Sesquiterpene emissions are very low, closed to the detection limit of the analyzers.

183 Other BVOC such as benzaldehyde, benzeneacetaldehyde, acetophenone or methyl salicylate  
184 contribute (Table 3) significantly to the total BVOC emission specifically for *A. germinans* and *L.*  
185 *racemosa* with 76 and 82% of the total emissions, respectively.

186 *Rhizophora racemosa* is the highest emitter of the mangrove species with an average emission rate of  
187 about 1200  $\text{ng}\cdot\text{g}^{-1}\text{DW}\cdot\text{h}^{-1}$ . Contrary to the two other species from AEP region, *R. racemosa* emissions  
188 are dominated by monoterpenes which represent about 93% of its total emissions. The three dominant  
189 emitted monoterpenes of *R. racemosa* are  $\alpha$ -pinene, sabinene and  $\beta$ -pinene.

190

#### 191 **4. Discussion**

192 The low isoprenoids emissions observed for the 15 mangrove species sampled in the two geographical  
193 regions (IWP and AEP) are in agreement with previous findings (Barr *et al.* 2003). In addition,  
194 Guenther *et al.* (1994) reported values below  $100 \text{ ngC.g}^{-1}\text{h}^{-1}$  for emissions from the genera *Avicennia*,  
195 *Laguncularia* and *Rhizophora* in the United States of America, referring to the works of Zimmernan  
196 (1979) and Evans *et al.* (1982). Moreover, the dominant monoterpenes  $\alpha$ -pinene and  $\beta$ -pinene detected  
197 here are also present in the study of Barr *et al.* (2003). Sabinene was detected in the essential oil of  
198 *Melaleuca cajuputi*, a species not directly related to the mangrove but often found in the back of  
199 mangroves (Sharif *et al.* 2009). The presence of monoterpenes but also benzenoids as well as methyl  
200 salicylate in emissions from mangrove species is not surprising as they are observed in many other  
201 biogenic emissions (Rodriguez-Saona *et al.* 2011; Gentner *et al.* 2014).

202 The two geographic areas of mangroves have no species in common but share *Avicennia* L. and  
203 *Rhizophora* L., the most characteristic genera of mangrove systems worldwide (Robert *et al.*, 2009). In  
204 our study, several species belonging to these two genera were sampled and show qualitatively  
205 different but always small emissions. These results agree with those of Lorto (2002) who showed that  
206 within the genus *Quercus*, that have a wide geographical distribution, non-emitting species and  
207 emitting species of isoprenoids (isoprene and/or terpenes) can be found.

208 Although they share a common ecological niche and must adapt to similar environmental conditions,  
209 mangroves are nonetheless a genetically diverse group of flowering plants (Duke, 2002). This may  
210 explain the observed differences in their emission spectra, which are also driven by internal factors  
211 such as genetics (Peñuelas and Llusia, 2001).

212

213 This emission rate from mangroves is low compared to the emission rates of most other tropical plant  
214 species. For instance, Geron *et al.* (2002) performed a screening of BVOC from twenty species in a  
215 lowland wet forest located in Costa Rica. Half of these common species emitted isoprene at a rate  
216 ranging from 10 to  $126 \mu\text{g.gDW}^{-1}\text{.h}^{-1}$  or about 100 times higher than the isoprene emissions of the 15  
217 mangrove species under study. The same trend is observed for the other BVOCs that are generally

218 emitted by tropical species at higher rates than mangrove species (Singh *et al.* 2011; Bracho-Nunez *et*  
219 *al.* 2013).

220

221 We can confirm that mangroves invest in isoprenoid emissions as chemical defences against the  
222 extreme environmental conditions that typically occur in their environment (e.g. flooding, salinity) but  
223 to a small extent. Indeed, mangroves have other strategies that ensure very good adaptation to these  
224 extreme conditions. They possess strategies such as osmolyte production which absorb salt as  
225 previously observed in *Avicennia* genus and other halophytes (Khan *et al.* 2016) (Slama *et al.* 2015).  
226 However, samplings were performed only on a short time. As a result, it cannot be excluded that we  
227 missed plant response to salinity and or flooding that could have caused emission puffs. For example,  
228 *Eucalyptus globulus*, a non-halophyte plant, exhibits puffs of isoprene only when salt stress is relieved  
229 (Loreto & Delfine 2000). Velikova *et al.* (2012) also observed important emissions of volatile  
230 isoprenoids from *Citrus* leaves, mainly limonene, during flooding with saline water.

231

232 Moreover, it would be worth investigating the emission of highly volatile organic compounds such as  
233 acetaldehyde and methanol since mangroves face anoxic conditions that could lead to alcoholic  
234 fermentation processes and, as a result, ethanol could be produced and transformed to acetaldehyde  
235 and to a lesser extent to acetic acid (Oikawa & Lerdau 2013). More generally, plants can also emit  
236 methanol through growth process (Hüve *et al.* 2007) and acetone through acetoacetate decarboxylation  
237 (Fall 2003). Acetaldehyde and acetic acid impact air quality by contributing to the atmospheric  
238 oxidative capacity and forming toxic secondary pollutants such as formaldehyde (Oikawa & Lerdau  
239 2013). In addition, other halophytes have been shown to be a source of methyl halides and  
240 dimethylsulphoniopropionate (DMSP) (Otte *et al.* 2004; Rhew & Mazéas 2010). One experimental  
241 study conducted under greenhouse conditions also demonstrated that mangrove trees emit methyl  
242 halides with possible atmospheric impact (Manley *et al.* 2007). However, this study emphasizes the  
243 need for field experiments to check for the occurrence of these emissions from mangroves. Further  
244 investigations are thus required to explore if mangroves are a source of halide VOC.

245

#### 246 **4. Conclusion**

247 Our results show that mangrove trees are very low isoprenoid emitters. Only *R. racemosa* can be  
248 regarded as a non-negligible source though monoterpene emissions still low ( $\sim 1000 \text{ ng.gDW.h}^{-1}$ ).  
249 Such results suggest that mangrove does not strongly affect local or regional atmospheric chemistry  
250 through BVOC emissions despite the large distribution of this ecosystem over the globe. However,  
251 despite the low-rate emission, the data from this study can be used in atmospheric chemistry models to  
252 study the impact of biogenic VOC emissions on air quality in areas where mangroves are present.

253 It is still worthy to note that we only made punctual samplings and that continuous monitoring of  
254 isoprenoid emissions should be carried out to check for potential seasonal variations. Moreover, as far  
255 as our results showed important differences between plant species, it could be interesting to broaden  
256 the sampling design including other sites (African west coast and Caribbean Islands) as they include  
257 mangrove species that have not been investigated.

258 It could be also interesting to focus on other compounds than isoprenoids such as highly volatile or  
259 halogenated compounds which might be tackled in future studies focused on BVOC emissions from  
260 mangroves.

261

#### 262 **5. Acknowledgements**

263 We thank Sylvie Dupouyet (IMBE), Mr. Le Van Sinh, from Can Gio Mangrove Protection Forest  
264 Management Board of Ho Chi Minh City, Vietnam for help with sampling emissions. This study was  
265 funded by the ECCOREV research Federation, by the CNRS through the French National program  
266 EC2CO (Ecosphère Continentale et Côtière), PEPS (Projets Exploratoires Premier Soutien) and the  
267 IRP-CNRS France-Vietnam (Tropical Ecology Laboratory) 2018-2021. This work was also supported  
268 by the Pépinière Interdisciplinaire de Guyane and the Foundation “Ecologie d’Avenir” from  
269 “Académie des Sciences”.

#### 270 **6. Author contributions:**

271 **Catherine Fernandez:** Conceptualization, Investigation, Methodology, Visualization, Writing –  
272 review & editing **Amélie Saunier:** Investigation, Methodology, Formal analysis, Data curation,

273 Writing – original draft **Henri Wortham:** Conceptualization, Investigation, Methodology,  
274 Visualization, Writing – review & editing **Elena Ormeño:** Conceptualization, Methodology, Writing  
275 – review & editing **Magali Proffit:** Conceptualization, Methodology, Writing – review & editing  
276 **Caroline Lecareux:** Resources, Methodology, Writing – review & editing **Stéphane Greff:**  
277 Resources, Methodology, Writing – review & editing **Dao Van Tan:** Investigation, Resources,  
278 Methodology **Mai Sy Tuan:** Resources, **Huynh Duc Hoan:** Resources, **Bui Nguyen The Kiet:**  
279 Resources **Dounia Dhaou:** Investigation, Methodology **Virginie Baldy:** Investigation, Methodology,  
280 Writing – review & editing **Anne Bousquet-Mélou:** Funding acquisition, Project administration,  
281 Supervision, Conceptualization, Investigation, Methodology, Visualization, Writing – review &  
282 editing  
283

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421 **Table 1:** Means ( $\pm$  SE) of temperatures (T, °C), relative humidity (RH, %) and Photosynthetic Active  
422 Radiation (PAR,  $\mu\text{mol.m}^{-2}.\text{s}^{-1}$ ) between 10 h and 15 h (sampling time for BVOC, local time) during  
423 each field campaign. PAR in March 2019 could not be calculated due to technical problems with the  
424 HOBO sensor.

<b>Site</b>	<b>Sampling</b>	<b>T</b>	<b>RH</b>	<b>PAR</b>
<b>Vietnam</b>	<b>April 2019</b>	$33.0 \pm 0.2$	$66.0 \pm 0.5$	$301 \pm 23$
<b>French Guyana</b>	<b>October 2019</b>	$35.0 \pm 0.3$	$60.0 \pm 0.6$	$603 \pm 55$

425 **Table 2:** Emission rates (ER, ng.gDW<sup>-1</sup>.h<sup>-1</sup>) of 15 mangrove species in terms of isoprene and other  
 426 BVOC (see Table 3 for details) detected with GC-MS, n.d.: no compound detected. Values are means  
 427 ± SE. Statistical test are presented for each BVOC type and site. Lower case letters denote post-hoc  
 428 test differences at 95% confidence level (Due to a problem during the analysis, we lost a series of  
 429 samples from French Guyana and therefore only have 4 samples with results)

Sites	Species	ER isoprene* C <sub>5</sub>	n	ER other BVOC (C <sub>10</sub> – C <sub>15</sub> )	n
Vietnam	<i>Aegiceras corniculatum</i>	1.5 ± 1.0 <sup>a</sup>	5	n.d.	5
	<i>Aegiceras floridum</i>	1.0 ± 0.4 <sup>a</sup>	5	n.d.	5
	<i>Avicennia alba</i>	0.3 ± 0.1 <sup>a</sup>	6	n.d.	6
	<i>Avicennia marina</i>	0.2 ± 0.1 <sup>a</sup>	5	n.d.	5
	<i>Bruguiera gymnorrhiza</i>	n.d.	5	n.d.	5
	<i>Ceriops zippeliana</i>	0.8 ± 0.5 <sup>a</sup>	5	n.d.	5
	<i>Lumnitzera racemosa</i>	1.6 ± 0.8 <sup>b</sup>	5	n.d.	5
	<i>Lumnitzera littorea</i>	0.1 ± 0.1 <sup>a</sup>	5	n.d.	5
	<i>Rhizophora apiculata</i>	0.3 ± 0.2 <sup>a</sup>	5	n.d.	5
	<i>Rhizophora stylosa</i>	0.7 ± 0.4 <sup>a</sup>	5	n.d.	5
	<i>Sonneratia alba</i>	0.3 ± 0.2 <sup>a</sup>	5	n.d.	5
	<i>Sonneratia caseolaris</i>	1.3 ± 0.4 <sup>a</sup>	5	n.d.	5
	Kruskall-Wallis test p=0.02				
French Guyana	<i>Avicennia germinans</i>	0.5 ± 0.3 <sup>a</sup>	5	212 ± 38	4
	<i>Laguncularia racemosa</i>	0.3 ± 0.3 <sup>a</sup>	5	222 ± 97	4
	<i>Rhizophora racemosa</i>	2.1 ± 0.8 <sup>b</sup>	4	1176 ± 626	4
Kruskall-Wallis test p=0.04      Anova test p=0.09					

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432 **Table 3:** Emissions rates (ng.gDW<sup>-1</sup>.h<sup>-1</sup>) of *Avicennia germinans*, *Laguncularia racemosa* and  
 433 *Rhizophora racemosa*. Asterisks indicate the co-injection of analytical standards to perform compound  
 434 identifications and quantifications. Means  $\pm$  SE.

<b>Compounds</b>	<b><i>A. germinans</i></b>	<b><i>L. racemosa</i></b>	<b><i>R. racemosa</i></b>
<b><i>Monoterpenes</i></b>			
$\alpha$ -pinene*	18.5 $\pm$ 3.1	3.9 $\pm$ 2.1	393.6 $\pm$ 220.0
camphene	0.1 $\pm$ 0.1	n.d.	32.8 $\pm$ 25.4
sabinene	0.6 $\pm$ 0.6	n.d.	393.3 $\pm$ 268.0
$\beta$ -pinene*	0.4 $\pm$ 0.4	0.1 $\pm$ 0.1	102.5 $\pm$ 68.2
$\beta$ -myrcene	19.9 $\pm$ 6.2	7.3 $\pm$ 4.1	13.0 $\pm$ 2.7
$\alpha$ -terpinene	n.d.	n.d.	4.9 $\pm$ 2.9
p-cymene*	3.5 $\pm$ 2.0	3.4 $\pm$ 1.1	8.4 $\pm$ 3.6
Limonene*	2.8 $\pm$ 1.7	4.7 $\pm$ 1.9	72.8 $\pm$ 43.9
$\beta$ -ocimene (Z)	n.d.	2.1 $\pm$ 1.6	n.d.
$\beta$ -ocimene (E)	n.d.	10.9 $\pm$ 4.6	0.4 $\pm$ 0.4
$\gamma$ -terpinene	n.d.	n.d.	12.3 $\pm$ 6.8
sabinene hydrate	n.d.	n.d.	0.4 $\pm$ 0.3
E-DMNT	0.5 $\pm$ 0.5	2.0 $\pm$ 1.8	n.d.
linalool	n.d.	3.4 $\pm$ 3.4	3.4 $\pm$ 2.4
allo-ocimene	n.d.	0.3 $\pm$ 0.3	0.2 $\pm$ 0.2
camphor	n.d.	n.d.	2.1 $\pm$ 1.3
pinocarvone	n.d.	n.d.	5.3 $\pm$ 3.6
borneol	0.4 $\pm$ 0.4	0.6 $\pm$ 0.6	40.1 $\pm$ 20.9
terpinen-4-ol	n.d.	n.d.	1.1 $\pm$ 0.5
myrtenal	n.d.	n.d.	4.9 $\pm$ 3.1
verbenone	n.d.	n.d.	0.9 $\pm$ 0.5
<b><i>Sesquiterpenes</i></b>			
$\beta$ -caryophyllene	3.9 $\pm$ 3.9	n.d.	n.d.
$\alpha$ -bergamotene (Z)	0.1 $\pm$ 0.1	n.d.	0.7 $\pm$ 0.7
<b><i>Other BVOC</i></b>			
benzaldehyde	73.6 $\pm$ 11.3	89.1 $\pm$ 49.3	42.2 $\pm$ 8.3
benzeneacetaldehyde	2.1 $\pm$ 0.4	1.2 $\pm$ 1.1	0.8 $\pm$ 0.2
acetophenone	83.6 $\pm$ 14.2	90.2 $\pm$ 36.0	38.1 $\pm$ 5.7
methyl salicylate	2.6 $\pm$ 2.6	2.7 $\pm$ 2.5	0.4 $\pm$ 0.4

435 n.d. = not detected, E-DMNT = (E)-4,8-Dimethyl-1,3,7-nonatriene

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