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Bee hotels host a high abundance of exotic bees in an urban context

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ABSTRACT

Bee hotels are increasingly set up by land managers in public parks to promote wild bee populations. However, we have very little evidence of the usefulness of bee hotels as tools to help the conservation of wild bees within cities. In this study, we installed 96 bee hotels in public parks of Marseille (France) for a year and followed their use as a nesting substrate by the local fauna. The most abundant species that emerged from bee hotels was the exotic bee species *Megachile sculpturalis*, representing 40% of all individuals. Moreover, we only detected four native bee species all belonging to the *Osmia* genus. More worryingly, we found a negative correlation between the occurrence of *M. sculpturalis* in bee hotels and the presence of native bees. One hypothesis to explain this result might be linked to the described territorial and aggressive behaviour of *M. sculpturalis* toward the nests built by the native fauna. This study raises the question about the usefulness of bee hotels for the conservation of native bees especially within cities harbouring high abundance of exotic bees. We provide here concrete advices to land managers to build bee hotels that can both host native bees and prevent the installation of *M. sculpturalis*.

KEYWORDS: Bee hotels; native and exotic bees; *Megachile sculpturalis*

26

27 INTRODUCTION

28 *Megachile sculpturalis* Smith, 1853 (Hymenoptera, Apoidea, Megachilidae) is the first exotic
29 bee species that has been detected in continental Europe. This large bee native to East Asia and
30 easily recognisable by its infusate wings and its orange hair on the thorax was first detected in
31 2008, near Marseille (Vereecken & Barbier, 2009). Since this first detection, *M. sculpturalis*
32 now occupies the whole southeast of France (Le Féon et al. 2018; Le Féon & Geslin 2018) and
33 has also been recorded in several other European countries: Germany (Westrich et al. 2015),
34 Hungary (Kov et al. 2016), Italy (Quaranta et al. 2014), Slovenia (Gogala & Zadravek 2018),
35 Spain (Aguado et al. 2018), and Switzerland (Amiet 2012).

36 Regarding its ecology and its interactions with the local flora and fauna, the little evidence we
37 have suggests that *M. sculpturalis* tends to seek pollen preferentially from exotic plants,
38 including *Sophora japonica* L. (= *Styphnolobium japonicum* Schott, Fabaceae; Andrieu-Ponel
39 et al. 2018) or *Ligustrum* sp. (Olaceae; Quaranta et al. 2012). This species nests in hollow stems
40 or pre-existing cavities in dead wood. More worryingly, several events of aggressive eviction
41 of wild bees from their nest by *M. sculpturalis* (mostly *Osmia* spp. and *Xylocopa* spp.) has been
42 previously documented (Laport & Minckley 2012, Roulston & Malfi 2012, Le Féon et al. 2018),
43 showing potential negative interactions between the local bee fauna and this exotic species.

44 Quaranta et al. (2014) suggested the use of trap-nests (i.e., bee hotels) to monitor the expansion
45 of *M. sculpturalis*. The trap-nests used in that study were composed of giant reeds and dead
46 trunks previously drilled to create holes. Such trap-nests are widely used and study in the
47 literature either to sample local bee diversity (e.g. Tschardt et al. 1998, Loyola & Martins
48 2008; Westphal et al. 2008; Nielsen et al. 2011; Fabian et al. 2014; da Rocha-Filho et al. 2017),
49 to improve pollination service for crops (e.g. Sheffield et al. 2008, Dainese et al. 2018), to study
50 host-parasitoid relationships (e.g. Tschardt et al. 1998; Pitts-Singer & Cane, 2011; Groulx
51 & Forrest, 2018; Happe et al. 2018), food preferences of bees (e.g. Jauker et al. 2012; MacIvor

52 et al. 2014), or even in a context of biological invasions (Barthell et al. 1998). Trap-nests also
53 called “bee hotels” (hereafter) are also increasingly set up by land managers in public parks to
54 promote wild bee populations. The body of literature regarding the usefulness of bee hotels to
55 enhance or protect bee populations within cities and urban parks has starting to grow past few
56 years (e.g. Gaston et al. 2005; Pereira-Peixoto et al. 2014; von Königslöw et al. 2019). As an
57 example, in France (Lyon), Fortel et al. (2016) collected 21 species in a two-year survey of
58 complex bee hotels composed of multiples substrates for below-ground nesting bees and several
59 nesting materials for above-ground nesting bees (logs of several tree species drilled with holes,
60 hollow or pithy stems). All species were native except *M. sculpturalis* (16 out of 3102 bees in
61 total). In Canada, in Toronto, a city known to harbour many exotic bee species (Sheffield et al.
62 2011), MacIvor & Packer (2015) found 31 species in a three years survey of 600 bee hotels in
63 Toronto (Canada), with 47% of individuals being non-native bees.

64 In this study, we had two main aims. Firstly, we explored the role of bee hotels in hosting a
65 diverse community of wild bees (above-ground nesting species) in a Mediterranean city
66 (Marseille). The Mediterranean area is considered as a bee diversity hotspot at the European
67 scale (Nieto et al. 2014) and we wanted to know whether simple bee hotels could provide
68 nesting opportunities for above-ground nesting bee species. Secondly, we evaluated the use of
69 bee hotels by the exotic bee *M. sculpturalis*. As previously mentioned, this species has rapidly
70 extended its geographical distribution within a few years in Europe, and we hypothesise here
71 that *M. sculpturalis* might widely use bee hotels to nest. Moreover, as reported above, *M.*
72 *sculpturalis* may exhibit aggressive behaviour towards the local native fauna. Its presence in
73 bee hotels might therefore be detrimental for the nesting of native bees, and we also sought to
74 acquire some insight concerning the potential of native and exotic bees to coexist in the same
75 bee hotels.

76 For this purpose, we installed 96 bee hotels in 12 parks in the city of Marseille and we monitored
77 their use as a nesting substrate by the local bee fauna. We specifically wanted i) to monitor the
78 occupation of bee hotels by *M. sculpturalis* and by the local native bee fauna, ii) to estimate the
79 potential coexistence of both native and exotic bees in the same bee hotels and iii) to provide
80 information on their nesting preferences in terms of size of the nest entrance. The ultimate goal
81 of this study is to provide management recommendations to stakeholders when installing bee
82 hotels.

83

84 **METHODS**

85 *Study sites*

86 The city of Marseille is the second biggest town in France after Paris with nearly 870 000
87 inhabitants (INSEE, 2015). Marseille is located in the south of France on the Mediterranean
88 coast (43.3N, 5.4E). The climate is typical of the Mediterranean basin, with hot, dry summers,
89 a mean annual temperature of 14.6 °C and mean annual rainfall of 552 mm. In this city, we
90 selected 12 public parks of with a minimum area of 1 ha (for precise location see Fig. 1, see
91 also Table 1 for further information).

92

93 *Bee hotels*

94 In February 2016, we installed the 96 bee hotels in the twelve public parks (8 per parks). Bee
95 hotels were homogeneously distributed throughout the parks. Each hotel was placed at a
96 minimum of 1.5 m from the ground, carefully tied to a tree and oriented southwards. Each bee
97 hotel measured 45 × 35 × 30 cm and was composed of two substrates: trunk and bamboo or
98 reed stems. Trunks (*Pinus* spp.) were drilled with holes of 6, 8, 10 and 12 mm on a single end
99 (8-10 holes per trunk) with a depth of 0.2 m. The diameter of the holes are representative of the
100 bee's preferences for nesting sites (Quaranta et al. 2014; Fortel et al. 2016). Then, hotels were

101 entirely filled with reed or bamboo stems (Fig. 2). The diameter of stems ranged from 3 to 20
102 mm (mean 7.5 mm; sd = 3.5).

103

104 *Bee sampling*

105 After a year, in February 2017, 71 of the 96 bee hotels were still in place, the rest having
106 undergone severe damages. We collected each stem and trunk used by the local fauna to nest
107 (entrance filled with mud or resin). Each nesting substrate was individually placed in plastic
108 bags and stems and trunks from the same hotel were placed in the same box when possible. We
109 tried to prevent as far as possible emerging bees from escaping from the plastic bags, but some
110 individuals still managed to escape by chewing the plastic of the bags. From February 10th to
111 June 1st, each bag was monitored to look for emerging bees. Each bee was then collected and
112 frozen for further identification to species level by expert-taxonomists (David Genoud &
113 Matthieu Aubert).

114 To assess the relationship between the adult body size and the nest entrances (holes), we first
115 measured this entrance with a digital calliper (Digit-Cal MK IV, Brown & Sharpe). The inter-
116 tegular distance (ITD) of a subset of individuals was then measured (238 individuals were
117 measured, 129 *Megachile sculpturalis* and 109 native *Osmia*). For this purpose, we used a
118 binocular magnifier, a digital camera (Motic – 1.3 MP) and an image processing software
119 (Motic Images Plus 2.0 ML).

120

121 *Statistical analysis*

122 The link between the presence of the native bees and the abundance *M. sculpturalis* was
123 assessed using the two-step Hurdle modelling process. This approach combines logistic models
124 with log-linear zero-truncated models in order to analyse account zero-inflated Poisson data
125 (Zuur et al., 2009). Firstly, we fitted a binomial generalized linear mixed model to test whether

126 the presence (or absence) of native bees was influenced by the abundance of *M. sculpturalis* in
127 each bee hotels. Secondly, we fitted a Poisson generalized linear mixed model linking the
128 abundance of native bees as a response variable and the abundance of *M. sculpturalis* as
129 explanatory variable (see Meineri et al., 2013 for examples of similar analyses). The two models
130 described above included the park as a random effect to account for repeated measurement
131 within each of the height parks. The abundance of *M. sculpturalis* was log transformed in both
132 models to obtain a variable closer to a normal distribution. Size of nest entrances were compared
133 between emerging adults of *M. sculpturalis* and emerging native bees using mixed effect linear
134 models nested on both parks and hotels. The size of nest entrances of *M. sculpturalis* males and
135 females such as the size of emerging adult males and females were compared using mixed effect
136 linear models nested on parks.

137 Finally, to explore potential competitive interactions between native and exotic bees, we linked
138 the body size of mature individuals of native bees with the presence/absence of *M. sculpturalis*
139 individuals using linear mixed model using parc as random effect.

140 All statistical analyses were performed with R 3.5.2 (R Core Team, 2018). Mixed effect models
141 were run within the libraries lme4 (Bates et al., 2015). The library lmerTest was used for the
142 estimations of P-values for the coefficients (Kuznetsova et al., 2017).

143

144 **RESULTS**

145 Bees emerged from 41 of the 71 remaining bee hotels. No bee was found in 30 of the hotels
146 after a single year. In total, 889 individuals emerged. *Megachile sculpturalis* was the most
147 abundant species with 356 individuals (~40% of the total abundance). The sex-ratio of this
148 species was highly skewed in favor of males (296 males i.e. 83% of the specimens). We only
149 found four native bee species, all belonging to the genus *Osmia*: *Osmia niveata* (Fabricius,
150 1804), *O. caerulea* L., *O. bicornis* L. and *O. cornuta* (Latreille, 1805). The most abundant

151 native species was *O. bicornis* with 308 individuals (~34%) followed by *O. cornuta* with 143
152 individuals (~16%), *O. niveata*, 59 individuals (~7%) and *O. caerulescens*, 19 individuals
153 (~2%). The remaining individuals belonged to *Osmia* but could not be determined to the species
154 level due to their conservation state (<1%). Unfortunately, some bees chewed their way out of
155 the plastic bags used for rearing them, as a result, we could only rely 716 of those individuals
156 to a particular park (see Table 1) and 699 individuals to a particular bee hotel (supplementary
157 material S1).

158

159 *Link between native and exotic bees*

160 The probability of presence of a native bee within a bee hotel significantly decreased as the
161 abundance of *M. sculpturalis* increased ($P=0.002$). According to the model, the probability of
162 finding native bees drop by 51% (from 0.51 to 0.25) after a single individual of *M. sculpturalis*
163 was observed (Fig. 3). Only ten hotels harbour both native and exotic bees.

164 The abundance of *M. sculpturalis* had however not significantly affected the abundance of
165 native bees when focussing only on the hotels that were colonised by both exotic and native
166 bees.

167

168 *Body and nest entrance size.*

169 As expected, individuals of *M. sculpturalis* were significantly larger than native bees ($P < 0.001$;
170 *M. sculpturalis* mean ITD = 0.42 mm, native bees mean ITD = 0.30 mm) and nested in larger
171 cavities ($P = 0.032$; *M. sculpturalis* mean nest entrance's size = 9.57 mm, native bees mean nest
172 entrance's size = 7.76, Fig. 4). Emerging males of *M. sculpturalis* were smaller than emerging
173 females ($P < 0.001$; males mean ITD = 0.41 mm, female mean ITD = 0.55), and emerged from
174 smaller stems ($P < 0.001$, males mean stem's size = 9.46 mm; female mean stem's size = 12.03
175 mm).

176 We also asked whether native bees tended to nest in larger cavities in the absence of *M.*
177 *sculpturalis*. However, we did not find any effect of the presence/absence of *M. sculpturalis* on
178 the mean size of nest entrance of native bees.

179

180 **DISCUSSION**

181 The first insight from our study concerns the limited species richness we observed in our bee
182 hotels. Only five species were detected in a one-year survey. In comparison with the study of
183 Fortel et al. (2016), which detected 21 species (3,102 specimens) in a comparable city in terms
184 of population numbers (Lyon – 300 km north of Marseille), this richness appeared very weak.
185 In 2016, we surveyed the bee populations of urban parks of Marseille (Geslin et al. unpublished
186 data) and found 114 wild bee species. Among these, we might have expected to find some
187 species nesting in our bee hotels such as *Megachile rotundata* (Fabricius, 1787), *Xylocopa*
188 *violacea* L. or *Anthidium manicatum* L., but we did not find any. Several factors might explain
189 this result. Firstly, our bee hotels were much simpler than those of Fortel et al. (2016). We used
190 only two types of nesting substrates to build our hotels, bamboo/reed stems and holes drilled in
191 trunks of *Pinus* spp. Fortel et al. (2016) used a wide diversity of logs (e.g. *Acer* sp., *Ailanthus*
192 sp., *Fraxinus* sp., *Platanus* sp., *Populus* sp., *Prunus* sp., *Robinia* sp., and *Tilia* sp.), and stems
193 (e.g. *Arundo* sp., *Phragmites* sp, and *Phyllostachys* sp.) and built larger bee hotels. Furthermore,
194 in the latter study, the authors showed an increase in the species richness of bees that nest in
195 man-made structures between the two years of their experiments. Here, we installed bee hotels
196 for a single year, and we can hypothesise that the richness might be higher in the longer term.
197 Despite this, the bee richness we did find nevertheless appeared very low in comparison to the
198 richness of urban park we found. In addition to this low richness, we also found a very high
199 abundance of the exotic bee *Megachile sculpturalis*. The proportion we did find is quite
200 similar to that reported in the study of MacIvor & Packer (2015), who also found a very high

201 proportion of exotic bees in their bee hotels (47%). The context is however slightly different,
202 because many exotic bee species have been introduced in Canada (the study of MacIvor &
203 Packer was carried out in Toronto, Sheffield et al. 2011) and only one (to date) in France, but
204 it highlights that bee hotel might be widely use by exotic bee species. Barthell et al. (1998) in
205 California, already found that some exotic bee species (two *Megachile* species) could be
206 frequent in artificial nesting cavities. In another study relative to trap nests in Europe, the exotic
207 wasp *Isodontia mexicana* has also been previously captured (e.g. Fabian et al., 2014), and
208 Quaranta et al. (2014) have already used trap nests to capture *M. sculpturalis* in Italy. Finally,
209 in a previous study we published relative to citizen monitoring of *M. sculpturalis*, we already
210 mentioned several events of *M. sculpturalis* individuals nesting in bee hotels (Le Féon et al.,
211 2018 – 26 cases among 39 reported nesting events). In the present study, *M. sculpturalis* was
212 the most abundant species and its use of bee hotels might facilitate the extending of its
213 geographical distribution.

214 More worryingly, we found a strong negative correlation between the presence of *M.*
215 *sculpturalis* individuals and the presence of native bee species in our bee hotels. In other words,
216 the probability of an *Osmia* to emerge from an hotel also occupied by *M. sculpturalis* is light.
217 At this stage, it might be too straightforward to directly explain this negative correlation by the
218 reported aggressive behaviour of *M. sculpturalis* toward other bee species (aggressive nest
219 eviction – Laport & Minckley 2012, Roulston & Malfi 2012, Le Féon & Geslin, 2018) for
220 several reasons. Firstly, as we have shown, *M. sculpturalis* and native *Osmia* seemed not to
221 share the same nesting preferences, and *M. sculpturalis* tends to nest in larger cavities than the
222 native fauna. Competition for nesting sites is therefore unlikely. Such competition might
223 however occur with the larger bee species we previously sampled in Marseille urban parks
224 (Geslin et al., unpublished data) such as *Xylocopa* spp. or *Anthidium* spp. Secondly, the two
225 most abundant *Osmia* species we found (*O. bicornis* and *O. cornuta*) and *M. sculpturalis* do not

226 share the same phenology. These two *Osmia* species are spring species whereas *M. sculpturalis*
227 is active in summer (Le Féon et al., 2018). Direct competition (aggression or eviction) similar
228 to aggressive events reported by Roulson & Malfi (2012) between active adults is therefore
229 unlikely. Furthermore, we cannot exclude that the negative correlation we found between the
230 presence of *Osmia* and that of *M. sculpturalis* in bee hotels could be due to other environmental
231 factors and that environmental conditions (feeding resources, proximity to suitable habitats)
232 could be highly favourable for *M. sculpturalis* and not for native bee species. However, we
233 believe that the most likely hypothesis to explain the negative correlation we observed is
234 probably linked to the territorial behaviour of *M. sculpturalis* toward the native fauna. Our main
235 explanation lies in an exclusion of larvae of native bees by adults of *M. sculpturalis*. This
236 behaviour has been previously documented on occasion (see Le Féon & Geslin 2018 for an
237 example with *Isodontia Mexicana*) and may be more widespread. If this is the case, the negative
238 impact of *M. sculpturalis* on the wild fauna could be greater than previously thought. This might
239 also potentially affect the large bee species of the French Fauna such as *Xylocopa* spp. and some
240 *Anthidium* and *Megachile* spp.

241 Taken together and given the widespread use of insect hotels by stakeholders, landowners and
242 by the general public, our findings raise the question of the usefulness of simple bee hotels for
243 the conservation of native wild bee species in urban park facing high abundance of above
244 ground nesting exotic bees. Rather, in some cases, it appears that those simple hotels might be
245 particularly hospitable for exotic species. *M. sculpturalis* extensively use bee hotels to nest, and
246 these hotels might help this species to extend its geographical range. This could be worrying
247 for the native bee fauna as *M. sculpturalis* might develop aggressive behaviours towards a large
248 diversity of above ground nesting native bees by evicting their larvae and thus preclude their
249 emergence. This assertion needs however to be more widely explored and we advocate here
250 future studies to investigate the value of bee hotels as a conservation tool. More complex bee

251 hotels harbouring several nesting substrates might for example be more efficient to support
252 urban bee biodiversity (see von Königsloöw et al. 2019 as an example).

253

254 *Recommendations for land-managers*

255 *Megachile sculpturalis* is a large species. As we show, this species nests in larger cavities than
256 most species of the native fauna that is commonly found in bee hotels. Female in particular are
257 laid in large cavities of about 12 mm. To discourage the spread of this species, one should bring
258 attention to the diameter of the holes of the substrate use to build the bee hotels. At this stage,
259 we advise land-managers to use nesting substrates designed to favour the reproduction of the
260 native fauna (cavities of 4 to 8 mm) and to banish larger cavities (above 8 to 10 mm) in their
261 bee hotels to prevent the installation of *M. sculpturalis*.

262

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269

270 **Authors' contributions :**

271 *Benoît Geslin* conceived the study, achieved the field work and wrote the paper.

272 *Violette Le Féon* wrote the paper

273 *Éric Meineri* performed statistical analysis

274 *Sophie Gachet, Benjamin Ignace, Corentin Knoploch, Magali Deschamps-Cottin, Christine*

275 *Robles, and Lucie Schurr* achieved the field work

276 Benjamin Ignace, Corentin Knoploch Floriane Flacher, Lise Ropars & Lucie Schurr performed
277 the laboratory work and did survey bee emergence
278 All authors corrected and proofread the Manuscript.

279

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400 **TABLE**

401 Table 1: Details of public parks' names, superficies and the abundance of each bee species.

Park number	Name	Area (ha)	Number of specimens				
			<i>Megachile sculpturalis</i>	<i>Osmia bicornis</i>	<i>Osmia caerulescens</i>	<i>Osmia cornuta</i>	<i>Osmia niveata</i>
1	Parc Longchamp	7,72	39	44	0	6	16
2	Parc de la Moline	8,10	4	29	4	52	3
3	Parc de Font Obscure	11,27	112	0	0	0	0
4	Parc de la colline St Joseph	6,91	7	30	0	0	14
5	Parc central de Bonneveine	2,94	54	12	0	0	0
6	Parc Pastré	56,20	2	0	0	0	0
7	Parc Brégante	3,37	3	7	0	2	0
8	Jardin Emile Duclaux - Palais du Pharo	4,89	0	21	0	0	0
9	Faculté Saint-Charles	6,37	52	0	0	0	0
10	Faculté Saint-Jérôme	19,44	33	29	0	2	0
11	Parc de la colline du Bois sacré	2,35	0	1	0	6	0
12	Parc de la Buzine	2,63	15	69	9	16	23

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405 **FIGURES**

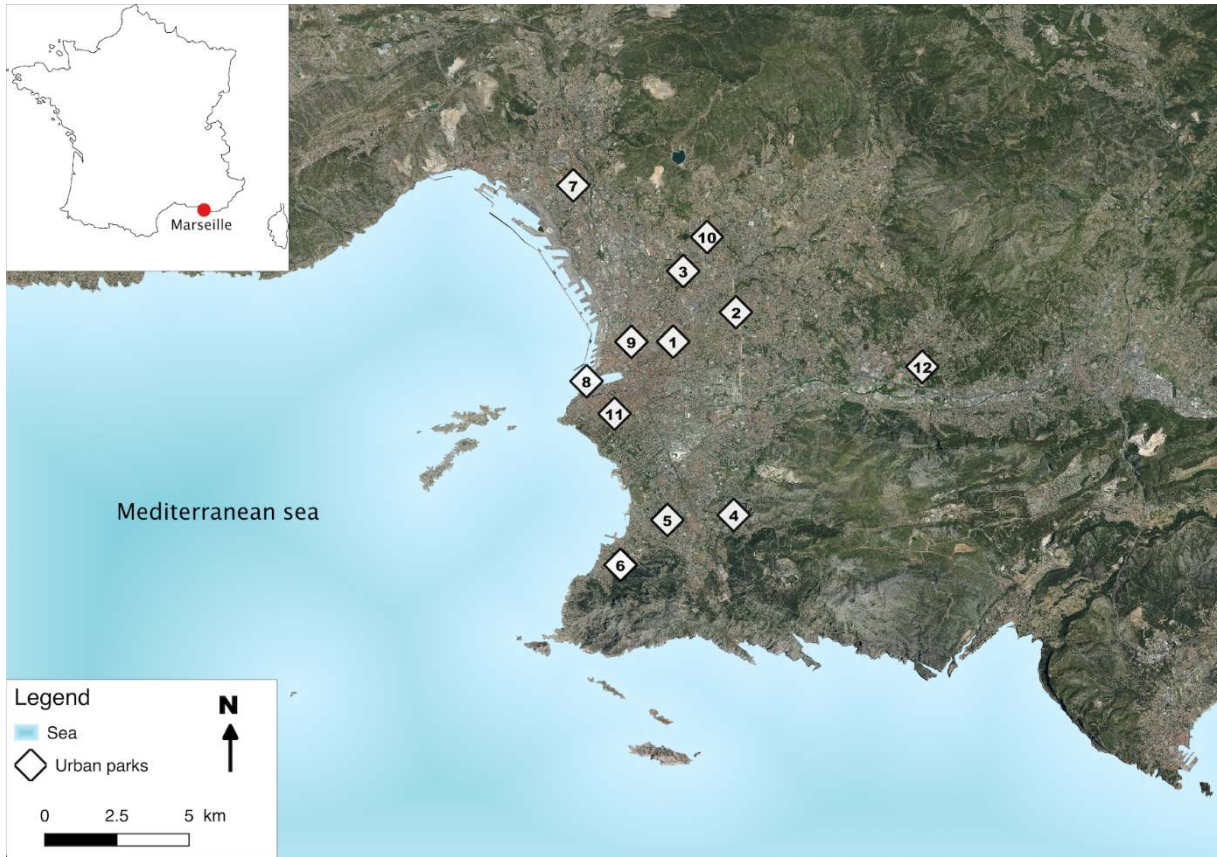
406 **Figure 1:** Location of public parks in the city of Marseille (France)

407 **Figure 2:** Example of a bee hotels composed of a dead trunk of *Pinus* spp. drilled with holes
 408 of 6 to 12mm and filled with stems.

409 **Figure 3:** Probability of observing at least an individual of native bee emerging from a bee
 410 hotel as a function to the logarithm of the abundance of *M. sculpturalis*. We observed a strong
 411 significant decrease of the probability of emergence when *M. sculpturalis* were presents
 412 (P=0.002).

413 **Figure 4:** Boxplots of the mean sizes of the nest's entrances between *M. sculpturalis* and native
 414 bees. *Megachile sculpturalis* nest in significantly larger holes than native bees (P=0.032 - *M.*
 415 *sculpturalis* mean nest entrance's size = 9.57 mm, native bees mean nest entrance's size = 7.76).

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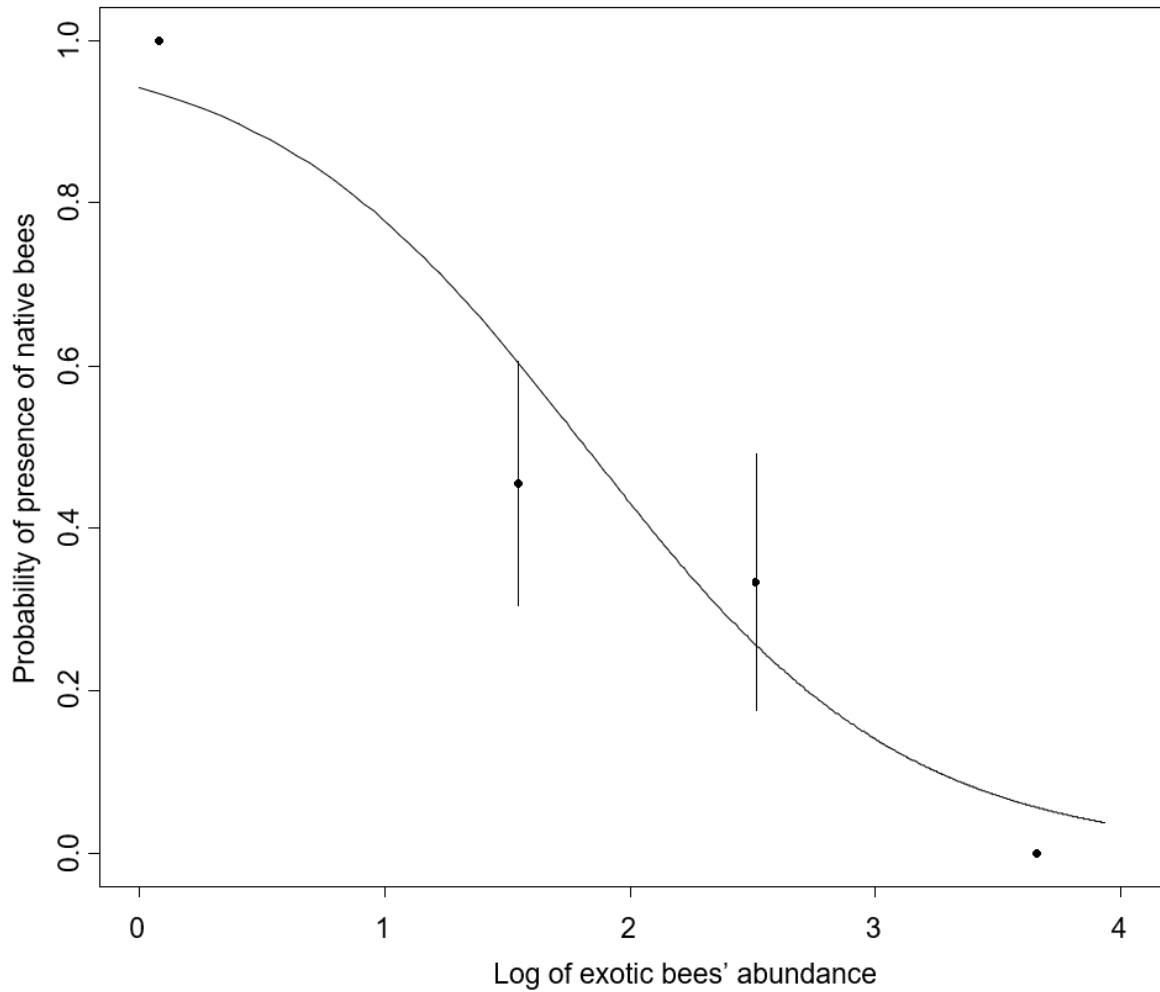
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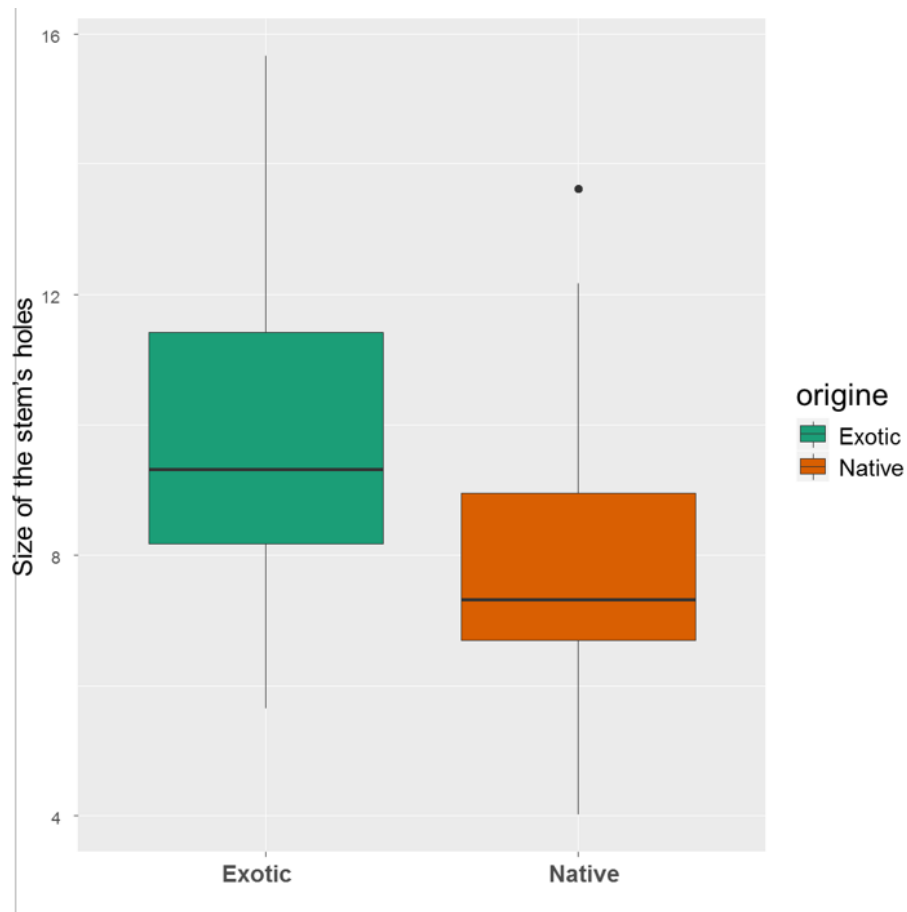
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