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Benoît Geslin[1], Sophie Gachet[1], Magali Deschamps-Cottin[2], Floriane Flacher[1], Benjamin Ignace[1], Corentin Knoploch[1], Éric Meineri[1], Christine Robles[2], Lise Ropars[1], Lucie Schurr[1] & Violette Le Féon[3]

[1]: IMBE, Aix Marseille Univ, Avignon Université, CNRS, IRD, Marseille, France

[2]: Laboratoire Population Environnement Développement (LPED), Marseille

[3]: Observatoire des Abeilles, 68 rue du Onze Novembre, 59148 Flines-lez-Raches

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*

INTRODUCTION

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

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

Quaranta et al. (2014) suggested the use of trap-nests (i.e., bee hotels) to monitor the expansion of *M. sculpturalis*. The trap-nests used in that study were composed of giant reeds and dead trunks previously drilled to create holes. Such trap-nests are widely used and study in the literature either to sample local bee diversity (e.g. Tscharntke et al. 1998, Loyola & Martins 2008; Westphal et al. 2008: Nielsen et al. 2011; Fabian et al. 2014; da Rocha-Filho et al. 2017), to improve pollination service for crops (e.g. Sheffield et al. 2008, Dainese et al. 2018), to study host-parasitoides relationships (e.g. Tscharntke et al. 1998; Pitts-Singer & Cane, 2011; Groulx & Forrest, 2018; Happe et al. 2018), food preferences of bees (e.g. Jauker et al. 2012; MacIvor et al. 2014), or even in a context of biological invasions (Barthell et al. 1998). Trap-nests also called “bee hotels” (hereafter) are also increasingly set up by land managers in public parks to promote wild bee populations. The body of literature regarding the usefulness of bee hotels to enhance or protect bee populations within cities and urban parks has starting to grow past few years (e.g. Gaston et al. 2005; Pereira-Peixoto et al. 2014; von Königslöw et al. 2019). As an example, in France (Lyon), Fortel et al. (2016) collected 21 species in a two-year survey of complex bee hotels composed of multiples substrates for below-ground nesting bees and several nesting materials for above-ground nesting bees (logs of several tree species drilled with holes, hollow or pithy stems). All species were native except *M. sculpturalis* (16 out of 3102 bees in total). In Canada, in Toronto, a city known to harbour many exotic bee species (Sheffield et al. 2011), MacIvor & Packer (2015) found 31 species in a three years survey of 600 bee hotels in Toronto (Canada), with 47% of individuals being non-native bees.

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

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

METHODS

Study sites

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

Bee hotels

In February 2016, we installed the 96 bee hotels in the twelve public parks (8 per parks). Bee hotels were homogeneously distributed throughout the parks. Each hotel was placed at a minimum of 1.5 m from the ground, carefully tied to a tree and oriented southwards. Each bee hotel measured 45 × 35 × 30 cm and was composed of two substrates: trunk and bamboo or reed stems. Trunks (*Pinus* spp.) were drilled with holes of 6, 8, 10 and 12 mm on a single end (8-10 holes per trunk) with a depth of 0.2 m. The diameter of the holes are representative of the bee's preferences for nesting sites (Quaranta et al. 2014; Fortel et al. 2016). Then, hotels were entirely filled with reed or bamboo stems (Fig. 2). The diameter of stems ranged from 3 to 20 mm (mean 7.5 mm; sd = 3.5).

Bee sampling

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

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

Statistical analysis

The link between the presence of the native bees and the abundance *M. sculpturalis* was assessed using the two-step Hurdle modelling process. This approach combines logistic models with log-linear zero-truncated models in order to analyse account zero-inflated Poisson data (Zuur et al., 2009). Firstly, we fitted a binomial generalized linear mixed model to test whether the presence (or absence) of native bees was influenced by the abundance of *M. sculpturalis* in each bee hotels. Secondly, we fitted a Poisson generalized linear mixed model linking the abundance of native bees as a response variable and the abundance of *M. sculpturalis* as explanatory variable (see Meineri et al., 2013 for examples of similar analyses). The two models described above included the park as a random effect to account for repeated measurement within each of the height parks. The abundance of *M. sculpturalis* was log transformed in both models to obtain a variable closer to a normal distribution. Size of nest entrances were compared between emerging adults of *M. sculpturalis* and emerging native bees using mixed effect linear models nested on both parks and hotels. The size of nest entrances of *M. sculpturalis* males and females such as the size of emerging adult males and females were compared using mixed effect linear models nested on parks.

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

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

RESULTS

Bees emerged from 41 of the 71 remaining bee hotels. No bee was found in 30 of the hotels after a single year. In total, 889 individuals emerged. *Megachile sculpturalis* was the most abundant species with 356 individuals (~40% of the total abundance). The sex-ratio of this species was highly skewed in favor of males (296 males i.e. 83% of the specimens). We only found four native bee species, all belonging to the genus *Osmia*: *Osmia niveata* (Fabricius, 1804), *O. caerulescens* L., *O. bicornis* L. and *O. cornuta* (Latreille, 1805). The most abundant native species was *O. bicornis* with 308 individuals (~34%) followed by *O. cornuta* with 143 individuals (~16%), *O. niveata*, 59 individuals (~7%) and *O. caerulescens*, 19 individuals (~2%). The remaining individuals belonged to *Osmia* but could not be determined to the species level due to their conservation state (<1%). Unfortunately, some bees chewed their way out of the plastic bags used for rearing them, as a result, we could only rely 716 of those individuals to a particular park (see Table 1) and 699 individuals to a particular bee hotel (supplementary material S1).

Link between native and exotic bees

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

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

Body and nest entrance size.

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

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

DISCUSSION

The first insight from our study concerns the limited species richness we observed in our bee hotels. Only five species were detected in a one-year survey. In comparison with the study of Fortel et al. (2016), which detected 21 species (3,102 specimens) in a comparable city in terms of population numbers (Lyon – 300 km north of Marseille), this richness appeared very weak. In 2016, we surveyed the bee populations of urban parks of Marseille (Geslin et al. unpublished data) and found 114 wild bee species. Among these, we might have expected to find some species nesting in our bee hotels such as *Megachile rotundata* (Fabricius, 1787), *Xylocopa violacea* L. or *Anthidium manicatum* L., but we did not find any. Several factors might explain this result. Firstly, our bee hotels were much simpler than those of Fortel et al. (2016). We used only two types of nesting substrates to build our hotels, bamboo/reed stems and holes drilled in trunks of *Pinus* spp. Fortel et al. (2016) used a wide diversity of logs (e.g. *Acer* sp., *Ailanthus* sp., *Fraxinus* sp., *Platanus* sp., *Populus* sp., *Prunus* sp., *Robinia* sp., *and Tilia* sp.*),* and stems (e.g. *Arundo* sp., *Phragmites* sp*, and Phyllostachys* sp.) and built larger bee hotels. Furthermore, in the latter study, the authors showed an increase in the species richness of bees that nest in man-made structures between the two years of their experiments. Here, we installed bee hotels for a single year, and we can hypothesise that the richness might be higher in the longer term. Despite this, the bee richness we did find nevertheless appeared very low in comparison to the richness of urban park we found. In addition to this low richness, we also found a very high abundance of the exotic bee *Megachile sculpturalis*. The proportion we did found is quite similar to that reported in the study of MacIvor & Packer (2015), who also found a very high proportion of exotic bees in their bee hotels (47%). The context is however slightly different, because many exotic bee species have been introduced in Canada (the study of MacIvor & Packer was carried out in Toronto, Sheffield et al. 2011) and only one (to date) in France, but it highlights that bee hotel might be widely use by exotic bee species. Barthell et al. (1998) in California, already found that some exotic bee species (two *Megachile* species) could be frequent in artificial nesting cavities. In another study relative to trap nests in Europe, the exotic wasp *Isodontia mexicana* has also been previously captured (*e.g.* Fabian et al., 2014), and Quaranta et al. (2014) have already used trap nests to capture *M. sculpturalis* in Italy. Finally, in a previous study we published relative to citizen monitoring of *M. sculpturalis*, we already mentioned several events of *M. sculpturalis* individuals nesting in bee hotels (Le Féon et al., 2018 – 26 cases among 39 reported nesting events). In the present study, *M. sculpturalis* was the most abundant species and its use of bee hotels might facilitate the extending of its geographical distribution.

More worryingly, we found a strong negative correlation between the presence of *M. sculpturalis* individuals and the presence of native bee species in our bee hotels. In other words, the probability of an *Osmia* to emerge from an hotel also occupied by *M. sculpturalis* is light. At this stage, it might be too straightforward to directly explain this negative correlation by the reported aggressive behaviour of *M. sculpturalis* toward other bee species (aggressive nest eviction – Laport & Minckley 2012, Roulston & Malfi 2012, Le Féon & Geslin, 2018) for several reasons. Firstly, as we have shown, *M. sculpturalis* and native *Osmia* seemed not to share the same nesting preferences, and *M. sculpturalis* tends to nest in larger cavities than the native fauna. Competition for nesting sites is therefore unlikely. Such competition might however occur with the larger bee species we previously sampled in Marseille urban parks (Geslin et al., unpublished data) such as *Xylocopa* spp. or *Anthidium* spp. Secondly, the two most abundant *Osmia* species we found (*O. bicornis* and *O. cornuta*) and *M. sculpturalis* do not share the same phenology. These two *Osmia* species are spring species whereas *M. sculpturalis* is active in summer (Le Féon et al., 2018). Direct competition (aggression or eviction) similar to aggressive events reported by Roulson & Malfi (2012) between active adults is therefore unlikely. Furthermore, we cannot exclude that the negative correlation we found between the presence of *Osmia* and that of *M. sculpturalis* in bee hotels could be due to other environmental factors and that environmental conditions (feeding resources, proximity to suitable habitats) could be highly favourable for *M. sculpturalis* and not for native bee species. However, we believe that the most likely hypothesis to explain the negative correlation we observed is probably linked to the territorial behaviour of *M. sculpturalis* toward the native fauna. Our main explanation lies in an exclusion of larvae of native bees by adults of *M. sculpturalis*. This behaviour has been previously documented on occasion (see Le Féon & Geslin 2018 for an example with *Isodontia Mexicana*) and may be more widespread. If this is the case, the negative impact of *M. sculpturalis* on the wild fauna could be greater than previously thought. This might also potentially affect the large bee species of the French Fauna such as *Xylocopa* spp. and some *Anthidium* and *Megachile* spp.

Taken together and given the widespread use of insect hotels by stakeholders, landowners and by the general public, our findings raise the question of the usefulness of simple bee hotels for the conservation of native wild bee species in urban park facing high abundance of above ground nesting exotic bees. Rather, in some cases, it appears that those simple hotels might be particularly hospitable for exotic species. *M. sculpturalis* extensively use bee hotels to nest, and these hotels might help this species to extend its geographical range. This could be worrying for the native bee fauna as *M. sculpturalis* might develop aggressive behaviours towards a large diversity of above ground nesting native bees by evicting their larvae and thus preclude their emergence. This assertion needs however to be more widely explored and we advocate here future studies to investigate the value of bee hotels as a conservation tool. More complex bee hotels harbouring several nesting substrates might for example be more efficient to support urban bee biodiversity (see von Königsloöw et al. 2019 as an example).

Recommendations for land-managers

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

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Authors' contributions :

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

Violette Le Féon wrote the paper

Éric Meineri performed statistical analysis

Sophie Gachet, Benjamin Ignace, Corentin Knoploch, Magali Deschamps-Cottin, Christine Robles, and Lucie Schurr achieved the field work

Benjamin Ignace, Corentin Knoploch Floriane Flacher, Lise Ropars & Lucie Schurr performed the laboratory work and did survey bee emergence

All authors corrected and proofread the Manuscript.

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TABLE

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

			Number of specimens				
Park number	Name	Area (ha)	*Megachile sculpturalis*	*Osmia bicornis*	*Osmia caerulescens*	*Osmia cornuta*	*Osmia niveata*
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

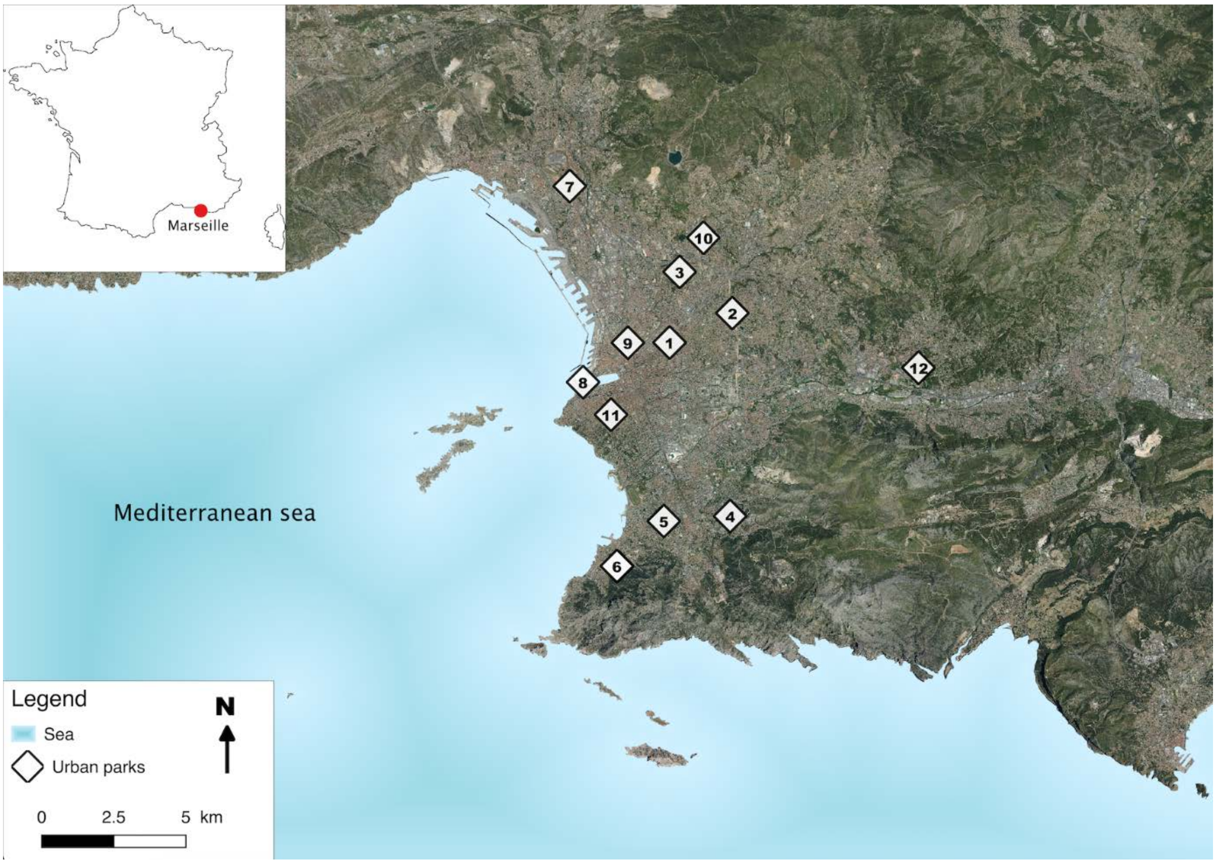
FIGURES

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

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

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

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



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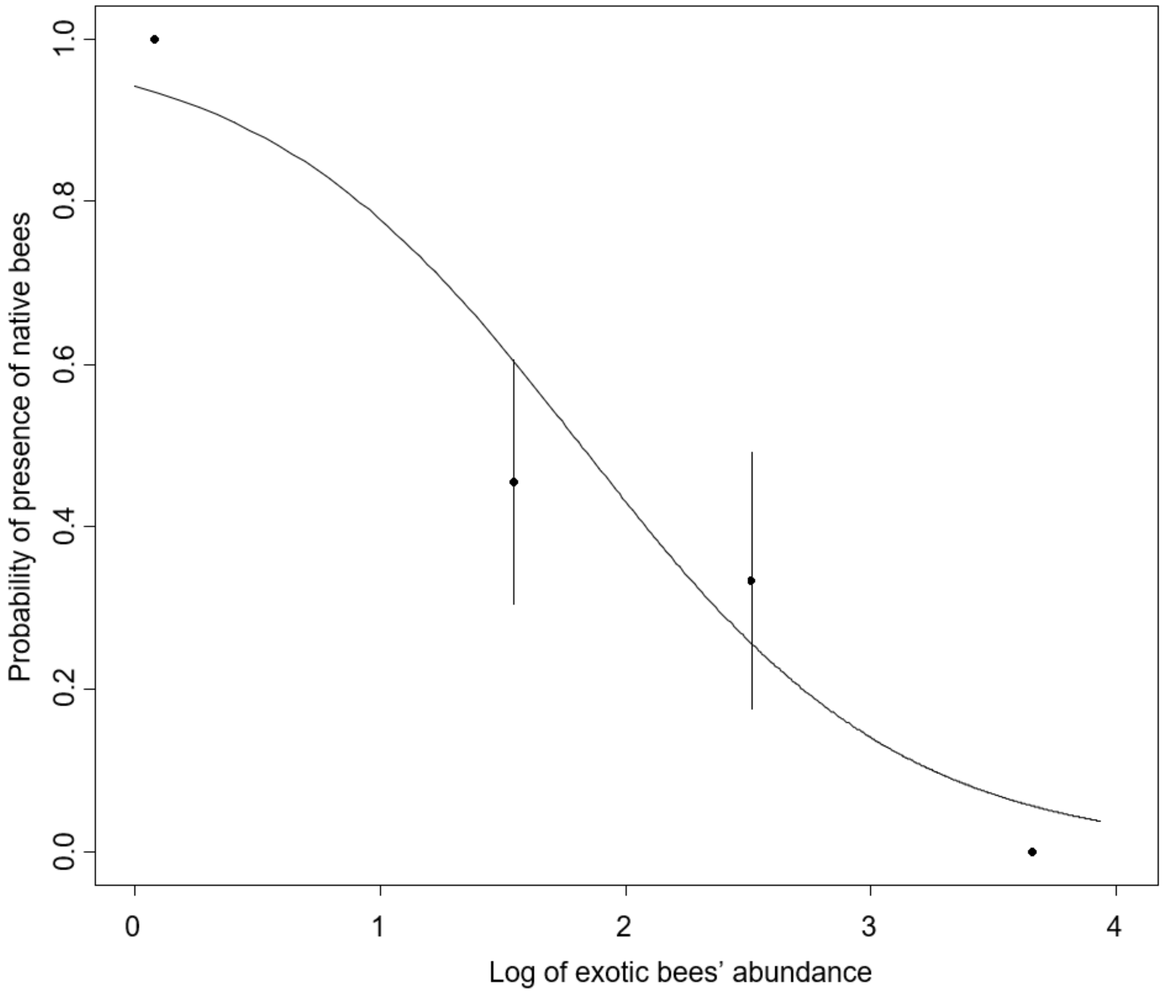

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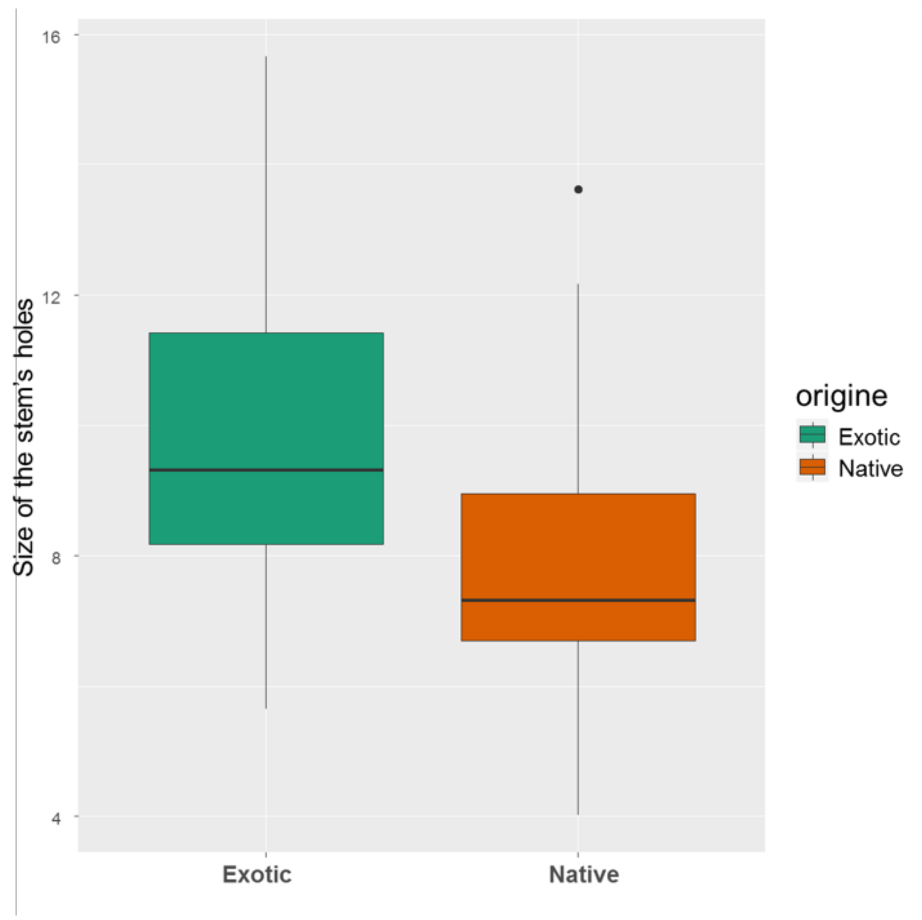

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