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Occupation and Emergence of Solitary Bees in Different Types of Trap Nests

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Abstract

The study investigated the occupation and emergence of bees that nest in trap-nests and assessed aspects of the structure of such nests, sex ratio, parasitism and mortality of bees in four areas of Baturité Massif, State of Ceará. Samples were taken using three types of trap-nests: dried bamboo internodes, cardboard tubes and rational boxes. In the four studied sites, a total of 185 artificial nests were offered monthly and 34 of them were occupied by bees. Six species of bees, distributed in five genera (*Centris*, *Mesocheira*, *Euglossa*, *Megachile* and *Coelioxys*) occupied the 34 trap-nests, but of this total nests, 24 presented emergence of individuals. In the rest of the nests there was mortality of the occupants. Considering the total of nests with emergence, it was obtained 139 individuals: 131 bees (28 kleptoparasite bees) and 8 coleopterans. In 34 bee nests obtained, there were constructed 162 brood cells, the number of cells per trap-nest varied from 1 to 13 brood cells and the length of these nests varied from 2.4 to 14cm. Thirteen nests were parasitized by hymenopterans (Apidae and Megachilidae) and coleopterans (Meloidae), resulting in a parasitism rate of 38.2% of the total of nests founded. In addition, mortality occurred from unknown causes in 29.4% (n=10) of individuals before reaching adult stage. This work identified the bee species that use pre-existing cavities in the Baturite Massif, determined their nesting requirements and constrains for their reproduction. This information may contribute to conservation efforts of these bee species as well as their potential use for pollination services.

Introduction

The ecological (Tscharntke et al., 1998; Willcox et al., 2017; Hung et al., 2018) and economic (Potts et al., 2010; Freitas & Nunes-Silva, 2012; IPBES, 2016) importance of bees make evident the need of studies identifying key species to natural and cultivated ecosystems, as well as their potential use in conservation and/or crop pollination programmes. In this sense, knowledge of the nesting habits of solitary species, such as the substrates used and nest attributes, may be important to guide new management practices. Although most species of bees are solitary and play key roles within ecosystems, most studies are targeted at social species (Schüepp et al., 2011; Garófalo et al., 2012).

The lack of bionomic knowledge of social or parasocial bees stems from the complexity of finding these bees on flowers and, mainly, from the difficulty in locating and accessing the nests of these insects with the habit to nest in places such as soil, logs, stumps or branches of trees and sometimes prefer to build their nests in preexisting cavities, which makes it difficult to locate them, to manage the nests and to collect pollen material (Krombein, 1967; Silva et al., 2012). The behavior of nesting in preexisting cavities causes females of these species to be attracted to artificial man-made cavities, called trap-nests (Krombein, 1967; Garófalo et al., 2012). Through the use of these artificial cavities, nests can be observed and studied in the field and in the laboratory.

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This makes possible to obtain information on the diversity and abundance of nesting solitary species, mortality of the immature, sex ratio of emerging bees, nesting behavior, architecture and materials used to construct nests, resources provided to larvae, and occurrence of parasites, predators and pathogens (Dórea et al., 2010; Seidelmann et al., 2016; Araujo et al., 2018).

Studies have shown that some of the species of solitary bees that occupy trap-nests may be reared, rationally managed and potentially used in pollination programs (Oliveira Filho & Freitas, 2003; Magalhães & Freitas, 2013; Junqueira & Augusto, 2017). However, much research is still needed to supoort the use of these bees at a commercial scale. Thus, the possibility of obtaining artificial nests of these species and studying the aspects of their biology is the first step for rearing these insects on a large scale (Garófalo et al., 2012).

Thus, this study aimed to investgate the occupation and emergence of bees nesting in trap-nests, as well as to evaluate aspects of nest structure, sex ratio, mortality and the presence of natural enemies of these insects in an area of Atlantic Forest located in the semi-arid region.

Material and Methods

Study areas

The study was conducted in the Environmental Preservation Area (APA) of the Baturité Massif, State of Ceará, Brazil, also known as the Baturité mountain range (Fig 1). This mountain range stands out from the rest of the State of Ceará because it is one of the highest, humid and biologically richest, being considered important for the maintenance of plant and animal diversity, thus representing a true genetic bank of biodiversity (Pinheiro & Sousa-Silva, 2017). The local climate is hot and humid, with the greatest abundance of rainfall in the months of March to April, while in the months from September to November there is less rainfall (INMET, 2015). The vegetation that occurs in the studied areas is classified as Ombrophylous Montane Forest (remnants of Atlantic Forest), located on the windward slope, at altitudes above 600 m. These areas are located in an isolated massif forming true islands of moisture in the middle of the semi-arid depressions of the caatinga domain (Veloso et al., 1991 Fernandes, 1998).

The study was carried out from September 2012 to November 2013 in four areas of this massif, three located in the municipality of Guaramiranga, State of Ceará, namely: A1 in the Alto da Serra Tourist Complex (4º15'28.1" S and 38º55'39.8" W and 919 m altitude); A2 at Café Brasil Inn (4º15'20.7" S and 38º 57'57.9" W and 888 m altitude) and A3 at Remanso Hotel da Serra (4º14'33.5" S and 38º55'41.9" W and 830 m altitude). The A4 is an area in the Chalet Nosso Sítio (4º13'24.6" S and 38º55'41.5" W and 760 m altitude) that is located in the municipality of Pacoti, State of Ceará.

Sampling

For bee sampling, three types of trap-nests were produced: (1) dry bamboo internodes opened at one end and closed at the other by the node, approximately 20 cm in length

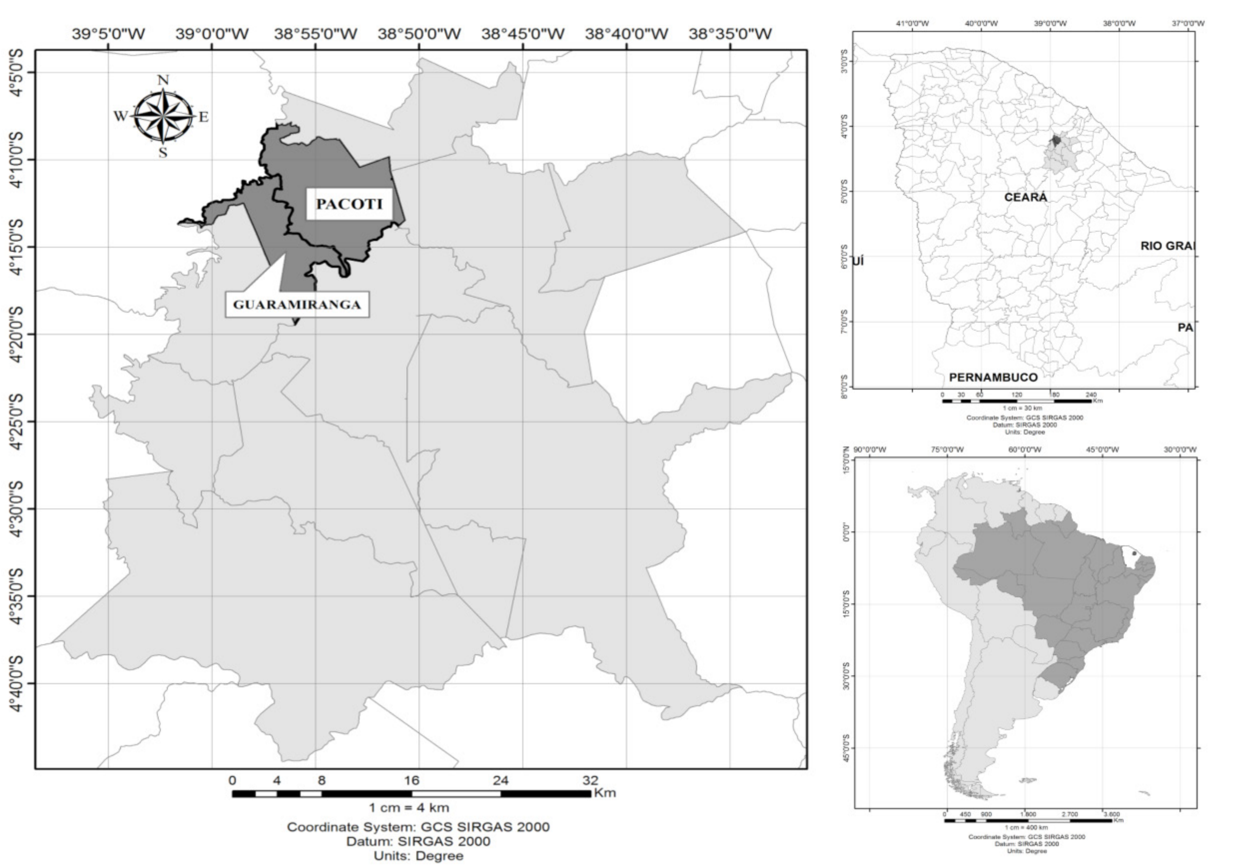

Fig 1. Location of the two study areas regarding the nesting biology of solitary bees in the region of the Baturité Massif, State of Ceará.

and diameter ranging from 0.5 cm to 3.0 cm. The bamboo internodes were placed horizontally on the shelf of each station, inside building bricks, with 18 units available; (2) tubes made of black cardboard, measuring 20 cm in length, closed at one end with the same material and inserted into blocks of wood, with 6 holes of 1 cm and 6 holes of 2 cm, totaling 12 holes per block in each station; (3) rational boxes made of wood being, four with external dimensions of 12 cm high x 12 cm wide x 10 cm long; a box with external dimensions of 15 cm high x 20 cm wide x 22 cm long; a box with external dimensions of 18 cm high x 14 cm wide x 22 cm long and a box with external dimensions of 14 cm high x 9 cm wide x 19 cm long. Boxes were 1.0 cm thick and 1.0 cm and 2.0 cm hole diameters. All the nests were arranged in collection stations, made with wooden rafters, covered by plastic tarpaulin and placed on wooden shelves fixed to the support rafters of the station at a distance of 1.3 m from the ground. All four study areas contained one collection station and the same number of trap-nests (Fig 2).

The inspections to verify the occupation of the substrates were performed fortnightly. When occupied and completed, trap-nests founded on bamboo internodes and cardboard tubes were collected, identified and taken to the laboratory. Nests founded in rational boxes, when finalized, had their entry connected to a test tube, until the individuals began to emerge. When the bees emerged, the box was transported to the laboratory. After removed from the field, all trap-nests were replaced by new ones, of similar diameter and size, in order to keep the same number of nests at the station.

The nests transferred to the laboratory had their entries individually coupled to the entrance of transparent PET plastic bottles and sealed with adhesive tape. They were kept at room temperature and inspected daily until individuals began to emerge. When all the individuals of the nest founded in rational box were emerged, the same box was taken to the collection station again. All specimens collected were sent to taxonomists at the University of São Paulo.

After the emergence of the individuals, trap-nests were opened, photographed and described in relation to the number of brood cells, length of the nest built, diameter of the trap-nest, materials used in the construction of nests (sand, plant leaves or resin), number of cells and mortality register. Nests without emergence were also opened and analyzed for the aforementioned aspects. The data of attack by natural enemies were obtained through the emergence of parasites of the nests.

Climatic data on temperature and rainfall collected during the study period were obtained through the National Institute of Meteorology (INMET, 2015).

Statistical Analysis

Chi-square test (χ^2) (Zar, 1996) was applied to test whether sex ratio was significantly different from one male for each female (1: 1). The parasitism rate was calculated by the ratio: (Total nests founded by bees/Total parasitized nests) x 100. In order to evaluate if the population parameters (occupation of trap-nests, emergence, emergence time, nest size, mortality and parasitism) differ between rainy and dry periods, the Mann-Whitney Test (U) (Zar, 1996) was used. The statistical analyses were run using the PAST software version 2.17c (Hammer et al., 2001).

Results

Occupation of trap-nests the study areas

Six species of nesting bees were sampled, distributed in five genera (*Centris, Mesocheira, Euglossa, Megachile* and *Coelioxys*) and two families (Apidae and Megachilidae). Of the species considered founders, *Centris* (*Hemisiella*) *tarsata* was the most frequently observed, occupying 45.0% of the trap-nests used in the studied areas, followed by *Centris* (*Heterocentris*) sp. (30.0%), *Megachile* (*Austromegachile*) aff. *Susurrans* (15.0%) and *Euglossa pleosticta*, which occupied 10.0% of the available nests. In addition to the founder bees, two kleptoparasite species occupied the nests: *Coelioxys* (*Cyrtocoelioxys*) sp. And *Mesocheira bicolor*. A species of Coleoptera (*Tetraonyx* sp.) was also registered, whose individuals occupied four nests (Fig 3).

Fig 2. a) Front part of a collection station, showing dry bamboo internodes inside the holes of bricks and different types of rational boxes used as trap-nests. b) Back of a collection station showing the black cardboard tubes inside wooden blocks and rational wooden boxes of different sizes. Baturité Massif, State of Ceará, Brazil.

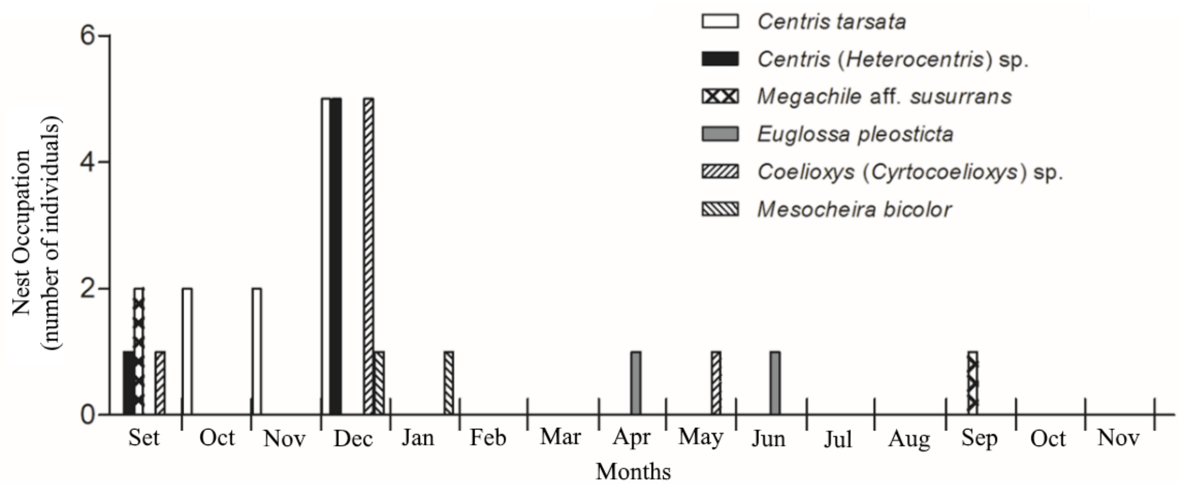

Fig 3. Number of trap-nests occupied in the four study areas, between September 2012 and November 2013, in the Baturité Massif, State of Ceará, Brazil.

Perhaps because it was a small sampling, no significant association was detected between the occupation of trap-nests by the species and the mean monthly values of temperature and humidity ($p > 0.05$ for all analyses). There was also no difference in the occupation rate of trap-nests between dry and rainy periods, when all species were considered together (Mann-Whitney = 18.5, $p = 0.272$) or each species alone in each study area ($p > 0.05$ for all analyses).

Emergence of bees

Of the 24 nests registered with emergence, 139 individuals were obtained, being 131 bees (28 kleptoparasite bees) and eight coleopterans. Bee emergence started in the second month after the installation of the traps and were more intense between October 2012 and January 2013 (Fig 2). There was no significant association between bee emergence and mean monthly values of temperature and humidity for any of the species analyzed ($p > 0.05$).

Of the nests built by bees, *Centris (Hemisiella) tarsata* and *Centris* (*Heterocentris*) sp. were the most abundant founder species with 54 (52%) and 17 (16.5%) individuals respectively, emerging both in the rainy and in the dry period. *Euglossa pleosticta* and *Megachile (Austromegachile)* aff. *susurrans* were less abundant in the areas, presenting together 31% of the total emergence, with individuals emerging only in the dry period, in July, September and October (Fig 4). Among the kleptoparasite species, *Coelioxys (Cyrtocoelioxys)* sp. had 93% (n=26) of emerged individuals and *Mesocheira bicolor* 7% (n=2) (Table 1).

Euglossa pleosticta and *Megachile (Austromegachile)* aff. *susurrans* were the least abundant founder species. They did not present a common pattern and built their nests in the two areas that presented the greatest richness of bee species. The mean time elapsed from the collection of nests to the emergence of individuals varied between species and also within the species (Fig 5).

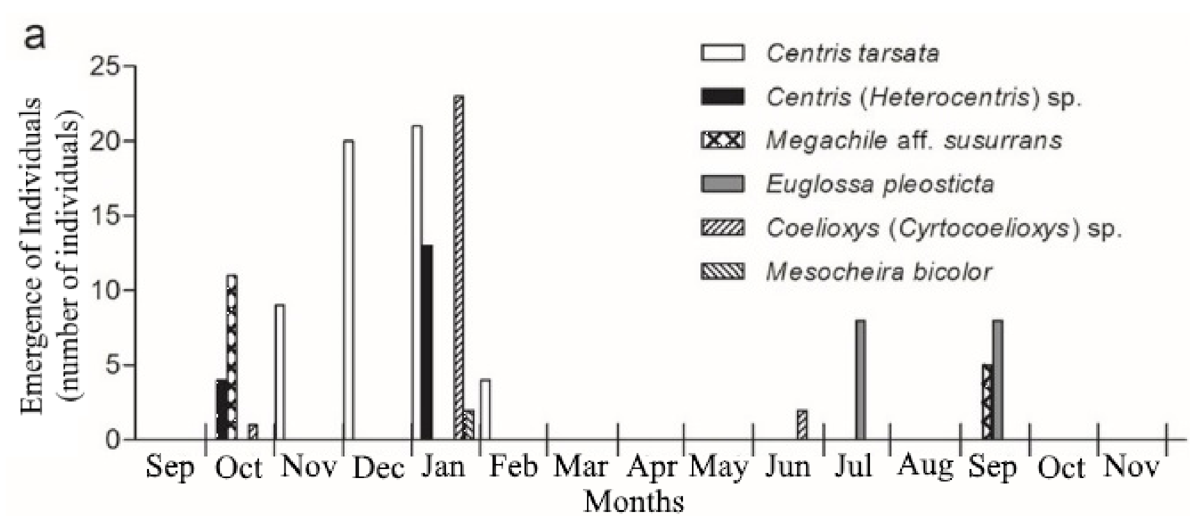

Fig 4. Individuals emerged from the nests, from September 2012 to November 2013, from the study areas, located in the Baturité Massif, State of Ceará, Brazil.

Table 1. Number of emerged individuals (EI) in artificial nests and emergence time (days) (ET), observed in the period from September 2012 to November 2013, in areas A1, A2, A3 and A4 in the Baturité Massif, State of Ceará, Brazil.

Family/Species	A1		A2		A3		A4		GRAND TOTAL	
	E I	*E T	E I	*E T	E I	*E T	E I	*E T	E I	*E T
Apidae										
Centris (*Hemisiella*) *tarsata* Smith, 1874	-	-	32	36 ± **1.5**	-	-	22	34.8 ± **1.7**	54	35.5 ± **1.6**
Centris (*Heterocentris*) sp.	3	31.3 ± **0.6**	-	-	7	35 ± **7**	7	38 ± **1.9**	17	35.6 ± **5.1**
Mesocheira bicolor Fabricius, 1804	-	-	1	30 ± **0**	1	15 ± **0**	-	-	2	22.5 ± **10.6**
Euglossa pleosticta Dressler, 1982	-	-	16	82.4 ± **6.0**	-	-	-	-	16	82.4 ± **6.0**
Megachilidae										
Megachile (Austromegachile) aff. *susurrans* Haliday, 1836	5	12 ± **0**	11	20.9 ± **4**	-	-	-	-	16	18.1 ± **5.4**
Coelioxys (Cyrtocoelioxys) sp.	6	31 ± **0**	2	34.5 ± **4.9**	5	30.8 ± **0.8**	13	32.2 ± **2.0**	26	31.8 ± **2.0**
Total	14	-	62	-	13	-	42	-	131	-

* Elapsed time (in days) between nest collection in the field and adult emergence in the laboratory.

In *Centris* (*Hemisiella*) *tarsata*, the emergence time of individuals ranged from 33 to 38 days, with a mean of 35.5 ± 1.6 days. For *Centris* (*Heterocentris*) sp., the time of emergence ranged from 29 to 45 days with a mean of 35.6 ± 5.1 days. *Megachile* (*Austromegachile*) aff. *susurrans* presented an emergence time of 12 to 26 days, with a mean of 18.1 ± 5.4 days. For *Euglossa pleosticta*, the time of emergence of the bees varied between 72 and 90 days, with a mean of 82.4 ± 6.0 days. The kleptoparasite bee *Coelioxys* (*Cyrtocoelioxys*) sp. ranged from 30 to 38 days with a mean of 31.8 ± 2.0 days and *Mesocheira bicolor*, which had only two individuals emerged, ranged from 15 to 30 days with a mean of 22.5 ± 10.6 days (Table 2). There was no significant difference in the mean time of emergence of the species studied between dry and rainy periods ($p > 0.05$ for all species). There was no evidence of diapause in the species studied.

Nest structure and sex ratio

In the 34 bee nests obtained, 162 brood cells were constructed. The number of cells per trap-nest ranged from 1 to 13 brood cells and the length of these nests ranged from 2.4 to 14 cm.

Bees of the genus *Centris* built 15 nests in preexisting cavities. The material used to construct the cells consisted basically of a mixture of sand grains and an oily binder substance, whose composition was not determined. The cells were oval in shape, with the concave back, thick wall and colors ranging from light yellow to dark brown. Externally they presented a rough and irregular texture, whereas internally they had smooth, homogeneous, shiny and rigid aspect. Some nests present vestibular cell, which is characterized by an empty space located between the last cell of the nest with brood and the closing wall of the nest, the cell closest to the entrance of the nest. These cells were made of sand, but were not lined with oily substances and were filled with uncompacted sand. Cells of the nests of *Centris* (*Hemisiella*) *tarsata* were arranged horizontally, whereas cells of *Centris* (*Heterocentris*) sp. were arranged horizontally in some nests and in other nests, arranged obliquely in relation to the horizontal plane. All cells of both species were individualized in a linear series.

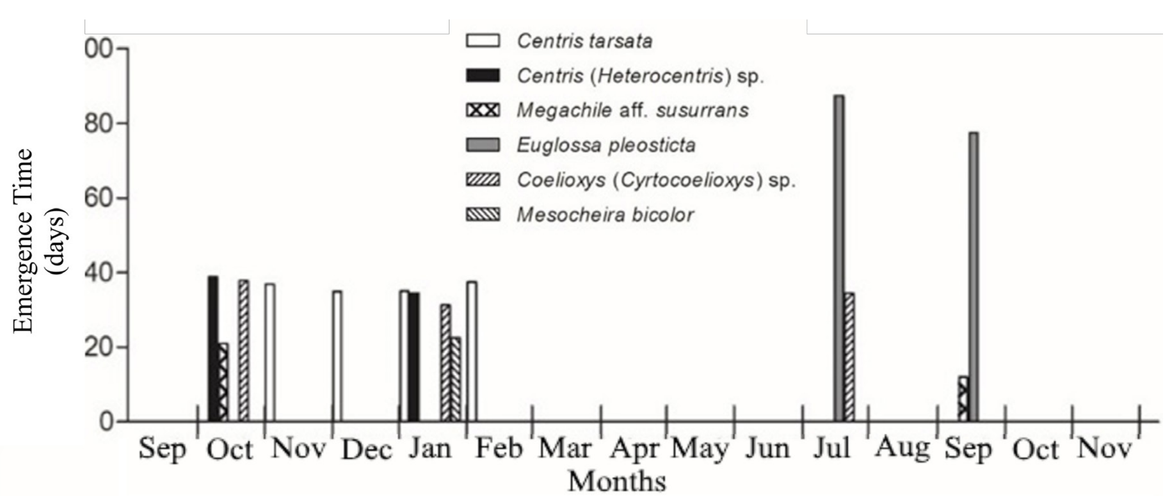

Fig 5. Emergence time of individuals emerged from occupied nests, in the period between September 2012 and November 2013, in the study areas located in the Baturité Massif, State of Ceará, Brazil.

Table 2. Number of nests founded, nest size and number of males and females of emergent species in artificial nests in areas A1, A2, A3 and A4, between September 2012 and November 2013, in the Baturité Massif, State of Ceará, Brazil.

Family/Species	Number of nests founded	Number of individuals emerged	Number of males (♂)	Number of females (♀)	Sex ratio (♂/♀)	Nest size cm (**$\bar{X}$±SD**)
Apidae						
Centris (*Hemisiella*) *tarsata*	9	54	12	42	1:3.5	9.5 ± **3.9**
Centris (*Heterocentris*) sp.	6	17	10	7	1:0.7	8.3 ± **3.8**
Euglossa pleosticta	2	16	7	9	1:1.28	*
Megachilidae						
Megachile (Austromegachile) aff. *susurrans*	3	16	8	8	1:1	11 ± **2.0**
Total	20	103	37	66		

* Nests founded on rational wooden boxes. Because the cells were not in linear arrangement, nest size was not calculated.

Centris (Hemisiella) tarsata used both bamboo internodes and cardboard tubes to build their nests, founding nine nests with 69 cells. The number of cells per nest ranged from 2 to 13 and the nest size ranged from 5.5 to 14 cm with a mean of (9.5 ± 3.9) cm. *Centris* (*Heterocentris*) sp. constructed six nests and 37 cells in bamboo internodes. The size of the nests ranged from 2.4 to 14 cm, with a mean of (8.3 ± 3.8) cm, with maximum and minimum number of brood cells observed inside nests ranging from 2 to 11.

The three nests of *Megachile* (*Austromegachile*) aff. *susurrans* were constructed on bamboo internodes, in a linear series of cells, arranged horizontally in the cavity and separated by walls. The material used for the construction consisted basically of leaves with cuts in elliptical format. All *Megachile susurrans* cells had a similar architecture, being elongated, cylindrical in appearance, slightly rounded at the bottom, with smooth inner surface of the cells. At the entrance of the nests, there were observed several layers of leaves cut in a rounded shape and loose, arranged in order to prevent the entry of natural enemies. For nests of this species, the number of brood cells ranged from 5 to 7. The nests had a length ranging from 9 to 13 cm, with a mean of (11 ± 2.0 cm) (Table 3). There was no significant association between mean nest length and mean monthly temperature and humidity ($p > 0.05$ for all species). There was also no significant difference in mean nest length between dry and rainy periods ($p > 0.05$ for all species).

The two nests of *Euglossa pleosticta* were built in rational wooden boxes. Females built their nests on the wall and the bottom of the box. Each nest was formed by a set of nine cells, constructed with resin, of elliptic shape that after closed presented a structure at the apex similar to a nipple. One nest was constructed with yellow resin, whereas the other one was produced with dark brown resin.

Except for the species Centris *(Hemisiella) tarsata*, in which the proportion of females was higher than that of males, in all other species the proportion of males and females was similar. This difference in *C. tarsata* was significantly different ($\chi^2 = 16.67$, $p < 0.0001$). For the other species, the sex ratio among the emerged bees did not differ statistically from 1: 1, being: *Centris* (*Heterocentris*) sp. ($\chi^2 = 0.53$; $p = 0.467$); *Megachile (Austromegachile)* aff. *Susurrans* ($\chi 2 = 0$; $p = 1$) and *Euglossa pleosticta* ($\chi^2 = 0.62$; $p = 0.803$) (Table 2).

Table 3. Parasite species and their respective host species in trap-nests founded in the four studied areas, between September 2012 and November 2013, in the Baturité Massif, State of Ceará, Brazil.

Order Family	**Parasite species**	**Emerged individuals**	**Sex ratio**	**Host species**	**Nests parasitized by the species**	**Site of occurrence**
Hymenoptera Apidae	*Mesocheira Bicolor*	1	1:1	*Centris* (*Hemisiella*) *tarsata*	2	A2 A3
		1		*		
Megachilidae	*Coelioxys* (*Cyrtocoelioxys*) sp.	12	1:1	*Centris* (*Heterocentris*) sp.	7	A1 A2 A3 A4
		14		*		
Coleoptera Meloidae	*Tetraonyx* sp.	8		*Centris* (*Hemisiella*) *tarsata*	4	A2 A4
Total		36			13	

* Host unknown, only the species kleptoparasite emerged.

Parasitism and mortality of bees

Of the 34 bee nests occupied in the four studied areas, 13 were parasitized by hymenopterans (Apidae and Megachilidae) and coleopterans (Meloidae), resulting in a parasitism rate of 38.2% of the total nests founded. The number of emerged parasites represented 25.9% (n = 36) of the total. In all, three parasite species were recorded parasitizing only nests of bees of the genus *Centris*, being: *Coelioxys (Cyrtocoelioxys)* sp., *Mesocheira bicolor* and *Tetraonyx* sp. (Table 3). *Euglossa pleosticta* and *Megachile (Austromegachile)* aff. *susurrans* did not have natural enemies associated with their nests during the study period.

Coelioxys (Cyrtocoelioxys) sp. was the most frequent kleptoparasite species attacking exclusively nests of *Centris* (*Heterocentris*) sp. in three of the studied areas: A1, A3 and A4. Fourteen individuals of *Coelioxys* (*Cyrtocoelioxys*) sp. emerged from three distinct nests, from which the hosts were not born. Of the seven nests parasitized by this species, 14 females and 12 males emerged and the sex ratio among them did not differ from 1: 1 ($\chi^2 = 0.15$; p = 0.695).

Nests of *Centris* (*Hemisiella*) *tarsata* were attacked by *Mesocheira bicolor* and *Tetraonyx* sp., the latter being the most frequent species parasitizing 44.4% of the nests. The sex ratio of individuals emerged from *Mesocheira bicolor* was 1: 1, with 1 female and 1 male emerged ($\chi^2 = 0$; p = 1). An individual of *Mesocheira bicolor* emerged from a nest in which the host was not known. Among the three parasite species of the genus *Centris*, *Coelioxys* (*Cyrtocoelioxys*) sp. was the most abundant species, presenting an important negative effect on the population of *Centris* (*Heterocentris*) sp., parasitizing 67% of the nests of this species.

Of the total number of bee nests founded, mortality from unknown causes occurred in 29.4% (n = 10) of the total number of individuals before reaching adult stage. In four nests (11.8%), only kleptoparasite species emerged, of which it was not possible to know the founder species. However, there is strong evidence that such nests belonged to the genera *Centris* and *Megachile* because of the material used in the construction, size and shape of the nest cells.

In the nests with emergence of founder bees, the mortality rate of the individuals was considered low, when compared to the number of bees emerged, representing 1.42% (n = 2) of the total of constructed cells. The mortality of the individuals was recorded only in two nests of the species *Centris* (*Heterocentris*) sp. where it was verified the death of one individual in the adult phase and another one in the larval phase, both caused by unknown causes.

Discussion

The pattern of occupation of trap-nests founded by bees in this study was characterized by the occurrence of few nesting species and few nests built. Nevertheless, even with variables that may impede the nesting of bees in the artificial cavities, some species, especially those of the genus *Centris*, were dominant in the occupation of the nests offered, mainly *Centris* (*Hemisiella*) *tarsata*, which also occur with higher density in some sites in the Brazilian Northeast (Aguiar et al., 2005; Melo & Zanela, 2012; Aguiar et al., 2013; Vivallo & Zanella, 2012). Some authors suggest that this species has a preference in nesting in warm and sunny areas (Aguiar & Garófalo, 2004), in open spaces of secondary vegetation (Pérez-Maluf, 1993), in a dune environment (Viana et al., 2001), caatinga (Vivallo & Zanella, 2012), as well as in forest fragments in Northeast Brazil (Aguiar & Garófalo, 2004). The Baturité Massif, being an area that has fragments of secondary Atlantic forest, receives solar incidence mainly in the dry period favoring the nesting of this species, which had more intense emergence between October and January. These can be important and favorable characteristics for the management of this species in the programs of pollination of agricultural crops (Aguiar et al., 2013).

During the dry period, it was observed the exclusiveness in the emergence of *Euglossa pleosticta* and *Megachile* (*Austromegachile*) aff. *susurrans*, suggesting bee preferences for the dry period. This is probably due to the fact that solitary bees are more sensitive to environmental conditions and therefore have the time development easily affected by climate (Klein, 2017).

The developmental period of the founder species is consistent with the patterns evaluated in other studies for the species of the genus *Centris* (Mendes & Rêgo, 2007), *Euglossa* (Aguiar & Garófalo, 2004) and *Megachile* (Teixeira et al., 2011). However, the average time of emergence of the species *Megachile* (*Austromegachile*) aff. *susurrans* was relatively short when compared to studies on species of the same genus (Sabino & Antonini, 2017). This result may be associated with relatively constant temperatures in the months of development and emergence of these individuals in the study areas. Kemp and Bosch (2000) experimentally proved that temperature has a considerable influence on the development of immature bees of the genus *Megachile* and that, in general, development rates increase with increasing temperature, with mean temperatures between 22 °C and 29 °C being the most efficient for the rapid development, the low mortality rate and the rapid emergence of these individuals, being able to provide larger populations. These factors are important when intending to use insects of this genus in pollination programs.

The structure of the nests founded by *Centris* bees reveals a great similarity to the nests described in the literature for species of this genus, mainly, as to the type of material used, arrangement and number of cells (Aguiar & Garófalo, 2004; Mendes & Rêgo, 2007; Mesquita et al., 2009). The presence of an oily binder substance for the construction of cells and the presence of a vestibular cell in the nests is discussed by some authors as a protection strategy against parasitism (Jesus & Garófalo, 2000; Couto & Camillo, 2014).

According to Mesquita et al. (2009) as well as Magalhães and Freitas (2013), the fact that these species accept nesting in artificial nests and use oil to build their nests may be a good strategy to use these species in pollination programs applied in orchards of plants secreting oil, such as acerola tree (*Malpighia emarginata* DC), proving effective both for the multiplication of populations of the genus *Centris* and to provide considerable gains in the productivity of acerola (Sazan et al., 2014).

Megachile susurrans nests were constructed with only cut leaves in a linear series of cells, with a similar structure to the nests described by Sabino and Antonini (2017) for *Megachile* (*Moureapis*) *anthidioides* and Cardoso and Silveira (2012) for *Megachile* (*Moureapis*) *benign* and *Megachile* (*Moureapis*) *maculata*.

Euglossa pleosticta, the only species that nested in a rational wooden box, built its nests on the wall and bottom of the box. Garófalo et al. (1998) reported a similar result on the structure of *Euglossa annectans* nests when testing small rational boxes of wood and bamboo internodes of different diameters and lengths as trap-nests for this bee species. The authors reported that the cells were constructed on the floor of the box with structure and arrangement similar to those described in this study. The similarity in the architecture of the nests founded by the species of bees in this study with those of other researches indicates that, regardless of the type of environment, the characteristics of the nesting biology of these species are preserved.

According to some authors, the variation in the sex ratio is associated with the abundance of resources available in the environment for females. The similar proportion of males and females may be related to a stable availability of trophic resources preferred by these species in nature. However, in times of greater availability of resources, there is a greater production of females that require a greater amount of food for their development (Pérez-Maluf, 1993; Mendes; Rêgo, 2007). These factors may be related to the sex ratio of *Centris tarsata*, which in this study had a significantly different proportion of males and females, with a deviant sex ratio for females of (1♂: 3.5♀), which may be related to high availability of preferred resources by this species during the study period. In addition, the size of the trap-nests (such as the length of the bamboo internodes and cardboard tubes used in this study) may also influence the sex ratio of bees, as observed by Gruber et al. (2011) for *Osmia bicornis* and Alonso et al. (2012) for *Centris* (*Heterocentris*) *analis*. Increased numbers of females in trap-nests can contribute positively to the use of these species in pollinating services, since females have a greater pollinator effect than males by collecting resources such as pollen and nectar for their brood (Bosch & Blas, 1994; Cane et al., 2011).

The association of the parasites *Coelioxys* (*Cyrtocoelioxys*) sp., *Mesocheira bicolor* and *Tetraonyx* sp. with bees of the genus *Centris* has been documented in several studies carried out in Brazil as the most frequent parasites of this genus (Aguiar & Garófalo, 2004; Aguiar et al., 2006; Drummont et al., 2008; Gazola & Garófalo, 2009). The high value in the parasitism rate of *Coelioxys* (*Cyrtocoelioxys*) sp. attacking bees of the genus *Centris* may be related to the number of cells observed in the parasitized nests. According to Aguiar and Gaglianone (2003), nests with a higher number of cells may be more susceptible to parasite attack. In this study, *Coelioxys* (*Cyrtocoelioxys*) sp. attacked only the nests with the largest number of cells. Moreover, the proximity and density of trap-nests may influence the attractiveness of these parasites (Wcislo & Cane, 1996).

The mortality rates attributed to unknown causes (Couto & Camillo, 2007) and fungal proliferation (Camarottide-Lima & Martins, 2005) have been diagnosed as the main causes of mortality of immature individuals of various bee species nesting in trap-nests.

Conclusions

Our study concludes that the species *Centris* (*Heterocentris*) sp. and *C.* (*Hemisiella*) *tarsata* have important and potential characteristics to be reared and multiplied through the use of trap-nests. On the other hand, species such as *Euglossa pleosticta* and *Megachile (Austromegachile)* aff. *susurrans* present limitations for mass rearing throughout the year, since they have a preference for nesting during the hottest periods of the year. The high rate of kleptoparasitism may also be a problem for population growth in trap-nests and should be controlled. These peculiarities may be relevant for the use of these species in crop pollination programs.

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