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*Chapter 3*

**STINGLESS BEES AND HUMAN  
 DISTURBANCE: NESTING HABITS AND  
 FORAGING BEHAVIOR OF *MELIPONA  
 COLIMANA* AYALA (HYMENOPTERA:  
 MELIPONINI) IN CONSERVED AND  
 DISTURBED HABITATS: A CASE STUDY OF  
 AN ENDEMIC BEE FROM JALISCO, MEXICO**

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### ABSTRACT

*Melipona colimana* is a stingless bee endemic of pine-oak tree forests from western Mexico which has great potential for the exploitation of its nest products. However, basic information about its nesting habits and specific biology are lacking, knowledge that would allow its management and exploitation in a sustainable way. Data on characteristics of nesting sites from two areas with different degrees of human disturbance in the region of origin of *M. colimana* were generated. Additionally, the foraging behavior of the bees was studied during the course of one year to determine the season during which they are more active. It was found that this bee species has a high tendency to nest in oak trees (*Quercus laurina*). However, nesting in these trees may be detrimental for the bees because this tree species is commonly used by humans to produce oak charcoal, practice that destroys nesting sites for the bees. Regarding their foraging behavior, the period of highest activity occurred between November and February, which indicates that this is the best time to artificially reproduce colonies of these bees. General aspects of stingless bee biology as well as specific and relevant biological data of *M. colimana* are discussed in this chapter.

**Keywords:** *Melipona colimana*, nesting, human disturbance, foraging behavior, Mexico

### INTRODUCTION

Bees are insects of the order hymenoptera that display great biodiversity. There are more than 20,000 species of bees distributed throughout almost all regions of the world. Bees are economically important, particularly some

species that are managed to obtain different products such as honey, wax and pollen, or because they are used as pollinators of agricultural crops. The diversity of bees can be easily noticed because they vary in body size, color and nesting habits. For example, while some species have a short life cycle and enter diapause to survive during winter, there are others that are considered super-organisms with the ability to remain nesting in the same place indefinitely (Michener, 2000, Tautz, 2008). Mexico is a country with a great diversity of climates due to its topography; the different altitudinal gradients of its terrain result in different climates, from tropical to cold. This also results in different microclimates with habitats that favor abundant biological diversity. This is why it is possible to find many species of bees in the country, including social bees, solitary bees, bumble bees and several species of stingless bees (Ayala et al., 1996). Because bees need nectar and pollen of flowering plants as their source of food, they are important pollinating agents that contribute significantly to the conservation and restoration of ecosystems, as well as to the production of agricultural crops; they also generate economic income from the commercialization of their products (Gliesselman, 2002; Mendizabal, 2005). Among the more economically important bee species in Mexico are the western honey bees (*Apis mellifera* L.) that are managed mainly to produce honey. However, there are numerous other species with great potential for exploitation such as the so-called stingless bees. The stingless bees are social bees that are characterized by missing a functional stinger, so they cannot sting to defend themselves or their colonies. Paleontological, biogeographic and more recently molecular data, point towards an African origin for stingless bees. Today, they are widely distributed in the Afrotropical, Neotropical, Australasian and Indomalayan regions of the world, with abundant species, particularly in the Amazon area (Camargo, 1994, Michener, 2000, Costa et al, 2003, Rassmussen and Cameron, 2007, 2009). In general, stingless bees can be distinguished from other bees by three main characteristics: reduction of wing venation, presence of penicillium and lack of stinger. In contrast with *A. mellifera*, stingless bees show great biological and morphological diversity within more than 400 species. More than 250 of these species have been described in South and Central America, and Mexico. Only about 50

species live in Southern Asia and Malaysia, 20 in Australia, Papua, New Guinea and the Philippines, and more than 40 are native to Africa (Camargo and Pedro, 1992, Nogueira-Neto, 1997, Ayala, 1999, Michener, 2000).

### MELIPONICULTURE IN MEXICO

Before the arrival of Spaniards to the Americas, natives cultured stingless bees, an activity known as meliponiculture, which specifically refers to the culture and exploitation of bees from the genus *Melipona* (Gonzalez-Acereto and Medellín-Morales, 1991, Gonzalez-Acereto and de Araujo-Freitas, 2005, Gonzalez-Acereto, 2008). Meliponiculture had its maximum development in Mexico's Yucatan peninsula, where the Mayans managed colonies of *Melipona becheeii*, which were kept in hollowed trunks called hobones (Echazarreta et al., 1997, Quezada-Euán, 1999). During pre-Hispanic times, meliponiculture had a very important and broad representation in the Mayan culture, to such an extent, that there is evidence in the Mayan codices that the Yucatan inhabitants worshiped a god called "Ah Mucen-Kab". Ah Mucen-Kab was represented as a descending god harvesting honey from a nest of stingless bees. Likewise, religious ceremonies were practiced during each annual honey harvest, by holding rites and invoking this deity to get a good harvest. Complex relationships were established between the cosmogonic vision of the Mayan world and the bees; also, the products obtained from melipona bee colonies had different uses and applications (Martínez, 2005). Empirical evidence indicates that the honey of stingless bees can be used as a food supplement to counteract problems of anemia and fertility by mixing it with pollen. Likewise, stingless bee honey has been recommended for the healing of wounds, eye infections, respiratory ailments, skin and nervous system problems. For eye ailments in particular, Mayan communities use melipona bee honey to treat conjunctivitis, ocular cataract and fleshiness. It has been claimed that doctors from the Mexican Social Security Institute controlled an epidemic of eye infections in the Yucatan peninsula with honey of *M. becheeii* (Gonzalez-Acereto, personal communication). Moreover, the

honey of melipona bees has been used in the Yucatan peninsula since ancient times for the preparation of a ceremonial Mayan drink called "Balche". Balche results from the fermentation of a mixture of honey, water and the bark of the balche tree (*Lonchocarpus longystilus*), and is used in ceremonies to thank for the harvest of honey and for ritual healing (Gonzalez-Acereto, 2008).

The practice of meliponiculture has the incentive and competitive advantage of the high price that melipona bee honey can reach. The amount of money that can be generated from selling this product rises considerably compared to honey bee honey. Usually, the honey of *A. mellifera* is used to sweeten and flavor drinks and desserts. However, the added value of melipona bee honey does not solely lie in its use as a sweetener, but also as an ingredient in alternative medicine, which considerably increases its value, to more than 20 times the price of honey bee honey (Gonzalez-Acereto, 2008; Guzmán and Vandame, 2015). Another product from melipona bees that has practical applications is the wax they produce and use for the construction of cells in their nests, a product known as "Cera de Campeche" or "cerumen". This wax is of great utility to seal plant or tree tissue that is grafted for the improvement of crop production in agriculture. Cerumen acts effectively as a sealant, protecting the grafted plant against various pests and diseases that can affect the wound that is caused to the plants as a result of this technique (Medellín, 1992; Franco, 2014; Osuna et al., 2017). Although the use of stingless bees in Mexico had its peak during the colonial period, there have been events that caused its collapse. It is thought that meliponiculture in the Yucatan peninsula began to decline by mainly two factors. The first, was the introduction of sugarcane (by the end of the 18th century), which although did not reach a high level of production in this territory, quickly replaced the traditional use of melipona bee honey as a sweetener. After the introduction of sugar cane, the second major factor that affected meliponiculture was the deforestation of extensive jungle areas to plant henequen (*Agave fourcroydes*) by the end of the 19th century. Henequen was intensively planted and cultured throughout the peninsula, practice that effectively reduced native flora upon which melipona bees depended for the development of their colonies. Henequen-related

deforestation also decreased the number of thicker trees that were used by the bees as nesting sites (Quezada-Euán et al., 2001, González-Acereto, 2008). Despite the fact that 46 species of stingless bees have been identified in Mexico (Ayala, 1999), at the present time, only in certain regions of the country does the culture and use of some stingless bee species continues. In the Yucatan peninsula, the most representative stingless bee species is *M. becheeii*. The colonies of this stingless bee are kept in traditional style "hobones", but also, colonies of this species are kept in more technical and modern hives made up of wooden boxes of specific dimensions that are known as rational boxes. Another native species that is also cultured in rational wooden boxes in certain regions of the State of Guerrero, Mexico, is *Scaptotrigona hellwegerii*, a bee that is popularly known as "Alazana", due to its light yellow color. Finally, one of the places where stingless bees are better and more rationally exploited is a region in the State of Puebla, specifically in the Sierra Norte, where remnants of the Nahuatl and Totonaca culture keep the species *Scaptotrigona mexicana* in clay pots that are known as "dumbbells." This system involves the use of two pots of similar size, in which one of them is positioned inverted over the other; the first acts as a nesting site, and the second as a space to store food resources (González-Acereto, 2008; Guzmán and Vandame, 2015). Despite the fact that the culture and exploitation of stingless bees has great potential in Mexico, there are not many incentives to develop this activity. For example, meliponiculture is not officially recognized by the Mexican government as an animal husbandry activity that qualifies to receive public financial support. Also, the characteristics of melipona bee honey are not internationally recognized by the Codex Alimentarius, which otherwise would allow their classification for commercialization in the international market (Souza et al., 2006a, Vit et al., 2006). There is evidence that the number of cultured stingless bee colonies in Mexico is decreasing drastically (Villanueva et al., 2005). In addition to this problem, the biology and culture of new stingless bee species with productive potential is poorly known. Hence, the importance of studying new species of stingless bees such as *Melipona colimana*. We aimed at studying this species biology, nesting

habits and the effect that human disturbance might have on them, all of it, critical information to develop strategies for their sustainable exploitation.

## THE CULTURE OF MELIPONA BEES IN JALISCO, MEXICO

There is no evidence of any historical record about the culture of stingless bees in the State of Jalisco. However, in other places of Mexico, peoples from the Nahuatl culture have managed several species of stingless bees. Therefore, it is possible that in the State of Jalisco, ancient peoples had kept stingless bees in the past, because in some places of the state, there are still pockets of populations from this culture. Up to 11 meliponine bee species have been reported to exist in Jalisco. They are mainly distributed in the tropical zones of the state (Ayala, 1999), which can be potentially useful. Unfortunately, the level of knowledge of local people about their technical management is very poor, limited only to the looting of nests to use their honey as a sweetener. Additionally, nine other different meliponine bee species were reported to exist in the Sierra de Manantlan (Cuzalapa and Zenzontla), of which three of them (*S. hellwegeri*, *Trigona nigra* and *Nannotrigona perilampoides*) are suitable for human culture (Contreras-Escareño, 1999).

## THE ENDEMISM OF MELIPONA COLIMANA

Of the *Melipona* species present in Mexico, two of them have been classified as mountain bees: *M. colimana* and *M. fasciata*, which are characterized by their distribution across elevated areas of up to 2,500 meters above sea level (masl) in a predominantly temperate climate (Ayala, 1999). This particular habitat makes them different from the majority of meliponines that live in tropical and subtropical zones of the planet (Wille, 1983, Ortiz-Mora et al., 1995, Roubik, 2006). Therefore, they are interesting models to study to determine how it is that they have survived under these

conditions, and discover the mechanisms they use to adapt to the low temperatures that can occur in these mountain areas. Mountain stingless bees live in the western zone of Mexico, particularly in the south of the State of Jalisco. There, *M. colimana* is reported as an endemic species of pine and oak forests located at and above 1,000 masl (Ayala, 1999). The endemism of this species is geographically marked between the zones of Mazamitla (Sierra del Tigre, 19° 54' 34" N and 103° 17' 46" W), the Nevado de Colima national park (19° 33' 47" N and 103° 36' 31" W) and the Manantlan mountain range (19° 35' 10" N and 104° 16' 28" W), with an estimated potential distribution in the mountain areas of the State of Michoacan (Ayala and Ortega, 2008, Figure 1).

*M. colimana* bees are 9.5 mm long, have black integument, yellow markings and orange pubescence. *M. colimana* is a species closely related and similar in appearance to *M. fasciata*, with the difference that *M. colimana* has black tergi with yellow apical bands (Ayala, 1999). For our study, nests of *M. colimana* were found in the town of San Isidro, municipality of Tecalitlan, Jalisco (19° 19' 16" N and 103° 15' 51" W), an area of pine and oak forests. The majority of the inhabitants of this region are peasants whom own forest vegetation; others are dedicated to livestock and agriculture and very few of them have colonies of honey bees. These activities allow them to obtain income for family support, however, if they were able to develop meliponiculture projects in the region, the potential economic impact would allow them to increase their income. They could keep stingless bees to produce and market their products (honey, pollen, cerumen, and geopropolis) as well as to rent colonies as alternative pollinators of agricultural crops (Guzmán et al., 2004, González-Acereto and De Araujo-Freitas, 2005; Quezada-Euán, 2005, Slaa et al., 2006, González-Acereto, 2008). The inhabitants of this place know *M. colimana* bees as "real bees" and occasionally steal honey from their nests. However, they do not know about their biological characteristics, nor about their possible culture and commercial use. This area of Jalisco is also dedicated to intensive forest harvesting, where, as in other regions, inadequate forestry practices, clandestine logging and firewood consumption, are causing negative effects on the local flora and fauna (Toledo et al., 2006; Granados et al., 2007). For

these reasons, it is important to study the biology of this species of temperate climate bee. It is also important to learn about its relationship with the environment, since in addition to being endemic to the region; it can contribute to the conservation of the biodiversity of local flora through the pollination of wild plants (Kleinn et al., 2007; Keitt, 2009; Mitchell et al., 2009). Additionally, the study of stingless bee species from temperate climates can be biologically interesting, for example, to evaluate hypotheses concerning their nesting habits, habitat alteration and foraging behavior.

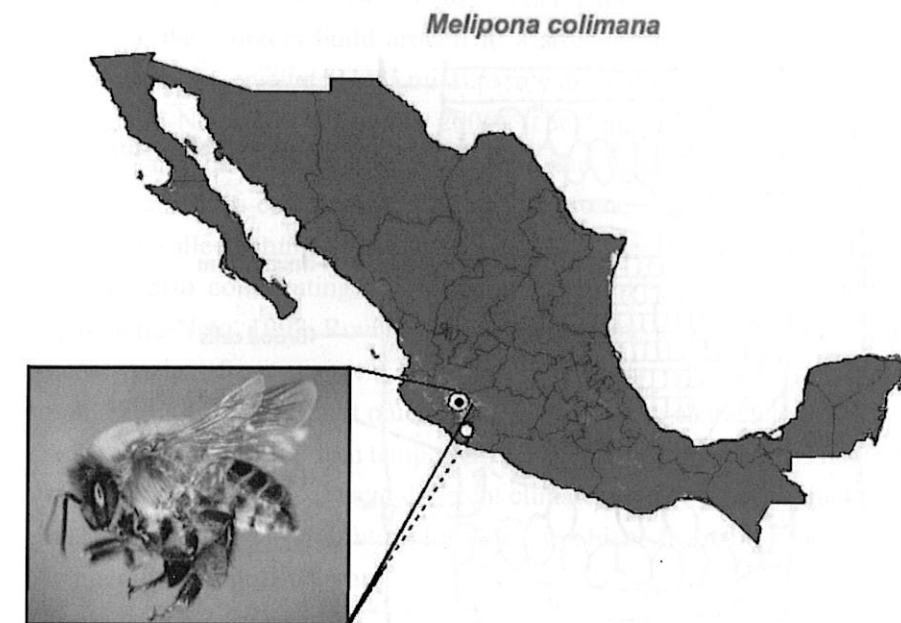


Figure 1. Actual (⊙) and potential (○) distribution of *M. colimana* in Mexico according to Ayala and Ortega (2008). Photograph and image courtesy of Ricardo Ayala.

### CHARACTERIZATION OF STINGLESS BEES' NESTS

The nests of stingless bees have been studied and characterized mainly for species that live in tropical climates; their architecture have similarities between the different species that inhabit the same altitude gradient (Van

Veen and Arce, 1999; Batista et al., 2001; Martins et al., 2004). However, being a diverse group, stingless bee species vary in some nest characteristics and nesting sites. Nests can be found in various lodgings, ranging from underground nests, to exposed nests; others are housed in hollowed live or dead trees, in poles of electrical power, under the roofs of houses and in abandoned nests of termites and wasps (Nogueira-Neto, 1997, Roubik, 2006). The general architecture of a stingless bee nest consists of the following structures: batumen plate, honey and pollen pots, involucrum, brood cells, gallery, and entrance (Figure 2).

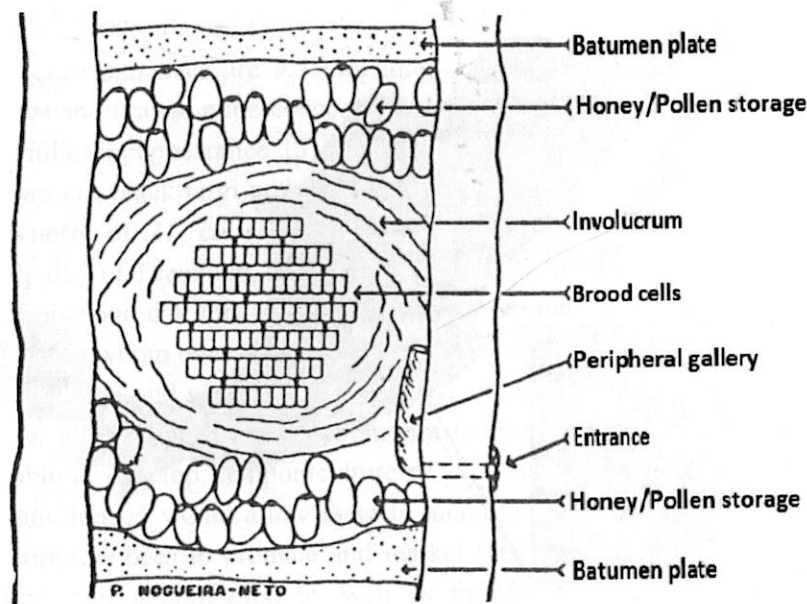


Figure 2. General architecture of a stingless bees' nest. Obtained from Nogueira-Neto (1997).

The diameter of the nest entrance is variable depending on the species; in the species of the genus *Melipona*, the entrance is designed to allow the passage of one bee at a time, while in *Trigona* species, the diameter allows the passage of several individuals continuously (Nogueira-Neto, 1997, Kinnell, 1999). When the bees enter the colony they move through a tunnel that leads them to the brood nest, which is composed of several combs where

the progeny of the queen develops. In *Melipona* species, these combs are horizontally arranged, one above the other, whereas cells are arranged as clusters or in helical structures in *Trigona* species (Sakagami, 1982, Wille, 1983). The brood nest combs contain cells with bees in different stages of development (egg, larva, pupa) as well as the queen in its reproductive functions (physiogastric). There are also workers performing different tasks to maintain and develop the colony (construction of cells, cleaning, brood provisioning, and capping of cells) (Velthuis, 1997, Nogueira-neto, 1997). To protect the brood area and to maintain the temperature of the nest ( $>26^{\circ}\text{C}$ ), the workers build around it, a structure called involucrum. The involucrum is constituted by a mixture of wax and resins known as cerumen (Nogueira-Neto, 1997; Roubik, 2006). The food resources of the colony (honey and pollen) are located around the brood nest and are stored independently in containers called pots. In some species, the nests have a structure called batumen plate, which has as its function, the isolation of the colony, also contributing to the maintenance of internal nest conditions (Nogueira-Neto, 1997, Roubik, 2006). The nesting architecture of stingless bee species from tropical climates has been described in several publications, however, not much is known about the characteristics of wild nests of stingless bees from temperate climates. This knowledge is necessary to compare nests of bees from different climates, and to obtain valuable data that will be useful in the future for designing hives that can be used in low temperature mountain areas.

## DENSITY AND SPATIAL DISTRIBUTION OF STINGLESS BEES

Generally, the density of stingless bee nests in an area is reported as the number of nests found in one hectare of land ( $\text{ha}^{-1}$ ), and the number of them that can be found in different regions is very variable. In general, it is estimated that the number of nests per ha ranges between 0.15 and 15 (Samejima et al., 2004, Kajobe and Roubik, 2006). However, the most usual number of detectable nests varies from 2 to 6 nests per ha (Roubik, 2006).

Because some meliponines nest in tree cavities, their density and spatial distribution depend on the presence and distribution of the trees that the bees use as a nesting sites. Therefore, whether the nests form aggregations or are distributed uniformly, depends on the location of these trees (Batista et al., 2001, Santos, 2006). Several studies carried out in tropical environments have shown that the density and spatial distribution of wild bee nests is affected by anthropogenic activities associated with forest use (Brown and Albrecht, 2001, Samejima et al., 2004). The results of these investigations have demonstrated the risks derived from cutting the trees where wild populations of stingless bees nest. Recommendations have been made to try to protect the trees used by stingless bees for them to have natural nesting sites (Antonini and Martins, 2003, Martins et al., 2004, Santos, 2006). This same situation could be repeated for the species of bees that inhabit mountain areas. However, studies are required to determine the effect of the use of timber resources from forests of mountain areas on the presence of wild nests of stingless bees from temperate climates; such is the case of *M. colimana*. Because this bee species has a nesting preference for some tree species and because these trees are exploited by the forest industry, this can represent a risk for the species.

### NESTING HABITS OF *M. COLIMANA* AND HUMAN DISTURBANCE

The conservation of stingless bees is important because they are part of the ecological interactions that contribute to maintaining the diversity of forests and jungles by functioning as pollinating agents of various plant species (Imperatriz-Fonseca, 2002; Slaa et al., 2006). Stingless bees can also function as indicators of disturbance in these ecosystems (Brown and Albrecht, 2001). The characteristics and nesting habits of many species of stingless bees from tropical climates have been widely studied by different authors (Wille and Michener, 1973, Batista et al., 2001, Quezada-Euán, 2005, Roubik, 2006). Conversely, to date, there are no studies that provide

specific data on the stingless bee species endemic to temperate zones. Thus, it is important to study their nesting habits and their relationship with their habitat to detect threats that may represent risks for these types of bees. The characteristics of *M. colimana* nests were determined by collecting data from 30 wild colonies and from trees that they use as nesting sites. Of the 30 colonies studied, 27 were located in oak trees that are known as “Encino chilillo” (*Quercus laurina*), the three remaining colonies were located in trees of “Laurel” (*Litsea glucesens*), “Azulillo” (*Cornus disciflora*) and “Tepehuaje” (*Lysoma apaculcensis*). All the colonies were found upright in the same position of the tree; the brood combs are arranged horizontally, one above the other, joined by cerumen structures, but with enough space for the bees to move between them. The food storage pots completely surround the brood chamber, but are separated from it by the involucrem. The entrance hole of the nests is reduced so that only one bee can enter or exit at a time, and does not have radial grooves around it. The nests present a robust appearance and the general architecture consists of: entrance, tunnel to access the brood area, brood area, involucrem, food storage pots (honey and pollen) and batumen plate (Figure 3).

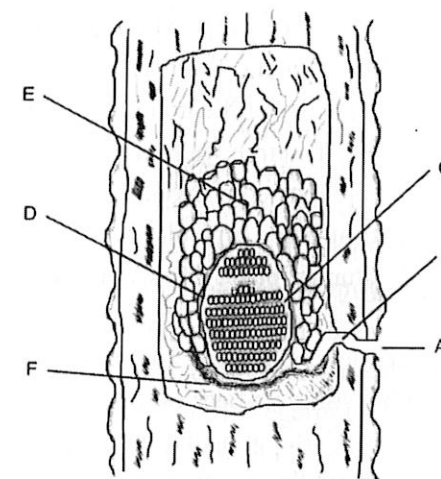


Figure 3. Architecture of a *Melipona colimana* nest in an oak (*Quercus laurina*) hollowed tree: A.- Entrance, B.- Tunnel to access the brood area, C.- Brood area, D.- Involucrem, E.- Food storage pots, F.-Batumen plate (From Macias-Macias et al., 2016).



**Table 1. Mean values ( $\pm$  standard deviation) of colony and nesting site characteristics of *M. colimana* (n = 30)**

Characteristic	Mean $\pm$ s.d.
Longitude of entrance tunnel (cm)	17.43 $\pm$ 3.71
Number of involucre coats	3.26 $\pm$ 1.08
Batumen thickness (mm)	6.17 $\pm$ 2.88
Number of combs	11.9 $\pm$ 2.50
Number of honey pots	29.56 $\pm$ 34.11
Number of pollen pots	25.73 $\pm$ 25.42
Pots size (cm)	4.39 $\pm$ 1.06 (n = 150)
Honey pots capacity (ml)	19.92 $\pm$ 4.63 (n = 150)
Pollen pots capacity (g)	18.22 $\pm$ 3.26 (n = 150)
Brood volume (l)	4.94 $\pm$ 2.61
Food volume (l)	5.75 $\pm$ 5.32
Number of worker bees	956.46 $\pm$ 328.56
Diameter at breast height (m)	1.79 $\pm$ 0.55
Wall thickness (cm)	13.82 $\pm$ 6.12
Volume of the hollow cavity (l)	30.72 $\pm$ 24.98
Diameter of nest entrance (cm)	1.32 $\pm$ 0.13
Altitude above sea level (m)	1718 $\pm$ 127.80

Most of the nests were found in the middle part of the trunks (height:  $2.53 \pm 2.85$  m) and a minority of them (four) were at heights above 4.50 m. The average volume of the brood and food areas summed amounted about 10.5 L, while the average capacity of the honey and pollen pots was almost 20 ml and 20 g, respectively. The tree walls were thick (up to 29.0 cm), and the holes where the nests were located were large, finding a tree with a cavity of 119 L. The nests were located at a high altitude ( $1718 \pm 127.80$  masl) and only seven of them had batumen plate. These and other characteristics are shown in Table 1.

The colony characteristics and general architecture of *M. colimana* nests are similar to those of other stingless bees of the same genus (Roubik, 1983, Quezada-Euán et al., 2001, Cortopassi-Laurino et al., 2006). In this study, only one exception was found: the entrance orifices of *M. colimana* do not have radiated structures. Naturally, stingless bees usually nest in holes of living or dead trees, on the ground, in abandoned nests of termites, under

wooden roofs, in rural areas, and under concrete in urban areas, in tombs of cemeteries and in the poles of electric power (Wille and Michener, 1973; Copa-Alvaro, 2004; Roubik, 2006; Nates-Parra et al., 2006). For *M. colimana*, the fact that most of the colonies had been found in hollowed oak trees (*Q. laurina*) could be because the bees find there the right conditions to nest, since it is very common that in the thicker oak trees, humidity creates hollows in the center of their trunks (Cuevas et al., 2004). It was observed that the total average volume of the cavities in the oak trees is larger than the calculated volume of the *M. colimana* colony. Thus, it could be thought that this space would allow the nests to have numerous layers of involucre to better control the temperature of the brood nest, since involucre layers play a role in the maintenance of nest homeostasis (Roubik, 2006). However, the number of involucre layers that the nests of *M. colimana* have are similar to those reported from species that inhabit tropical climates (Moo-Valle and Quezada-Euán, 1999). The fact that the nests of this bee species do not have a higher number of involucre layers than the nests of tropical stingless bees, can be explained because the workers of *M. colimana* are able to regulate the internal temperature of the nest regardless of the external environmental temperature (tropical stingless bees are not able to do it), and also because the thickness of the oak tree walls helps maintain the internal temperature of the nests (Macías-Macías et al., 2011). With regards to the thickness of tree walls from the lodging sites, Van Veen and Arce (1999) recorded a thickness of 5 cm in natural shelters used by colonies of *M. beecheii* in Costa Rica. If we compare these results with the data recorded for *M. colimana*, the lodging sites were almost twice as thick as those from tropical environments; we even found a tree with walls that were almost 30 cm thick. These differences may be a consequence of the type of arboreal vegetation that can be found in the mountain areas where *M. colimana* lives; in these areas, it is quite common to find oak trees with even larger diameters (Cuevas et al., 2004, INIFAP, 2006). Regarding the number of workers and brood combs, the studies carried out with *M. beecheii* colonies by Van Veen and Arce (1999) found a minimum of 3 and a maximum of 12 brood combs, while in this work, more brood combs were found in average; the minimum was 6 and the maximum 16. Likewise, in the Yucatan peninsula, González-

Acereto and Medina (2001) reported the presence of 400 to 1200 individuals in the nests of *M. beecheii* they studied, whereas in *M. colimana* nests, we found a minimum of 450 and a maximum of 1620 individuals (a difference of 420 individuals in the maximum range). These differences and similarities could be a consequence of the period of the year during which the observations were made. It is known that the conditions of strength and weakness of the colonies are directly related to the seasons of presence or absence of flowering resources (Roubik, 2006; González-Acereto, 2008). It is known that the number of stingless bee nests that can be found in an area can be affected by three factors: predation, limitation of nesting sites and food availability (Hubbell and Johnson, 1977; Eltz et al., 2002). The presence and density of stingless bee nests can be affected by anthropogenic activity, which can cause a limitation of nesting sites due to the logging of trees that stingless bees use to nest (Cannon et al., 1994; Brown and Albrecht, 2001, Venturieri, 2002, Eltz et al., 2003, Samejima et al., 2004). In the State of Jalisco, 31% of its territory is dedicated to the commercial exploitation of forest trees, with pine (*Pinus spp.*) and oak (*Quercus spp.*) as main resources of wood (CONAFOR, 2010). Clearly, the area of origin of *M. colimana* is not exempt from the effects of this human activity, which could imply a threat to the species. Few studies have been carried out in Mexico to analyze the factors that affect the presence of wild nests of stingless bees in zones with different degrees of human disturbance, and about the possible impact of forest use in them. This is why we studied the populations of wild colonies of *M. colimana* in two zones with different degrees of human disturbance. One of the objectives of the study was to determine whether deforestation of the forests from southern Jalisco negatively affects the presence of this bee species and propose measures for its conservation in the temperate forests of western Mexico. The colonies found were recorded and geo-positioned, and the total study area, as well as the density of nests per ha were calculated. Additionally, in each area, the number of oak trees was counted and their diameter measured at breast height (DBH). The total area of study was 594 ha, of which 280 ha were surveyed in the search for *M. colimana* nests. Twenty-four wild nests of *M.*

*colimana* were located in the conserved area (C) and six in the disturbed area (D). The density of nests in area C was 0.17/ha<sup>-1</sup> and 0.04/ha<sup>-1</sup> in area D. The number of nests per ha found in the two study areas was considerably lower than what has been reported by other authors for tropical stingless bee species. Roubik (2006) estimated that the usual number of colonies per ha ranges from 2 to 6, while in areas of fragmented and rain forest, the density of wild bee nests was 8.4 and 6.8 per ha, respectively (Batista et al., 2001; Eltz et al., 2003). This study on *M. colimana* nest density is the first report of its kind for meliponines of temperate climates. Therefore, it is unknown if the low nest density found is common among other stingless bee species of temperate climates. In the case of *M. colimana*, the results suggest that the wild populations of this species might be threatened by the forestry activity in the areas of study. Many species of stingless bees are opportunistic and take advantage of the cavities of various tree species to nest (Hubbell and Johnson, 1977; Roubik, 1989). For *M. colimana*, the results of the study suggest that the nesting sites are mostly conditioned by the cavities of *Q. laurina*, since in this region it is one of the predominant tree species and it is very common for old trees of this species to naturally be hollowed due to the carving effect of water (Cuevas et al., 2004). This bee-tree relationship also occurs in other meliponine species, among which, there is a natural tendency for the bees to take advantage of the predominant tree species in the area. These are the cases of *M. subnitida* and *M. asilvae*, which in Brazil, nest in trees of *Commiphora leptophoeos* and *Cesalpineae pyramidalis* (Martins et al., 2001). Also, *M. quadrifasciata* associates with *Caryocar brasiliense* trees for nesting sites (Antonini and Martins, 2003). This close relationship of the bees with a predominant type of tree in their distribution zone predisposes them to a situation of imminent danger, since the disappearance or decrease in numbers of such trees would directly affect the bees due to the lack of nesting sites. This could probably be the situation threatening *M. colimana*, because oak trees are used in the production of oak charcoal (Reyes, 2007), which could be decreasing the number of nesting sites for the bees. Analyzing the two study areas, in area C, the number of nests found was greater than in area D, as was the DBH. It is likely that these

differences were due to the fact that area D had been recently disturbed with forestry practices, and although in area D, the number of oak trees was greater than in area C, the diameter of the trees in area C was much greater than in area D. These findings are important because in other places like in Malaysia, it has been found that stingless bees build their nests in trees with a diameter greater than 60 cm (Eltz et al., 2003). Therefore, it is possible that a higher DBH and a larger number of hollowed trees (old) could have been determinant so that a greater number of nests had been found in area C compared to area D. The greater diameter of oak trees found in area C can be explained as a consequence of the conservation efforts of tick trees carried out in this area (INIFAP, 2006).

### FORAGING BEHAVIOR OF STINGLESS BEES

Some species of stingless bees are endemic to certain regions, so they have co-evolved with their natural habitat, adapting to the climatic conditions that influence their foraging activity and the development of their nests (Roubik, 1989). From the time that worker bees begin their activities outside the colony, they perform several tasks. In addition to collecting nectar and pollen, they also collect resins and mud to seal the openings of their lodges; they bring microorganisms that ferment their pollen stores so that it becomes more digestible and nourishing for the brood. They also remove remains of cocoons and waste material from the interior of the colony (Sakagami, 1982; Wille, 1983; Rubio, 2006). The foraging behavior of stingless bees is influenced by external environmental factors such as temperature, humidity, wind speed and light intensity (Kleinert-Giovannini, 1982). In tropical climates, where most of the research on stingless bees has been conducted, it has been found that the collection of resources starts early in the morning and decreases throughout the day. Bees tend to collect pollen in the morning and nectar in the afternoon (Roubik and Buchmann, 1984). Unfortunately, the foraging behavior of stingless bees and the factors that affect it have only been studied in tropical climates. Therefore, it is not

known if the foraging behavior and the collection of resources by stingless bees in temperate climates is similar to what occurs in tropical climates, and how environmental factors affect the activities that bees perform outside the colony. It is known that stingless bees, like honey bees, perform different activities according to their age (age polyethism). But they also possess great plasticity and can adapt to different environmental conditions, so that in changing environments, bees could start collecting nectar in the morning and pollen in the afternoon or vice-versa (Monteiro and Schindwein, 2003). In addition to the above, there is no information available on how and when nests of stingless bees develop in geographic zones of transition where the climate is predominantly temperate. This is important to know since in order for colonies of stingless bees to increase in numbers, the main requirement is that the colony from which another colony is going to be obtained, is strongly populated. Therefore, it is critical to know the period of the year when stingless bee colonies in temperate environments perform greater foraging activity, because this will be reflected in an increase in bee population and food stores (Guzmán et al., 2004). It is also important to know the time of the year when there is less foraging activity, to artificially induce the development of colonies by providing artificial feeding to the bees (González-Acereto and De Araujo-Freitas, 2005).

### FORAGING BEHAVIOR OF *M. COLIMANA*

The foraging behavior of *M. colimana* bees was monitored in their place of origin during one year. Every 15 days and throughout the day, the number of bees leaving and entering their nests was recorded. Bees returning from foraging trips were classified as bees that were not carrying visible resources or carrying pollen or resins. The relative humidity, temperature, light intensity and wind speed were recorded every hour of each observation day. The period of maximum foraging activity during the year was observed from November to February, with a small rebound in the month of April. Conversely, the period of least activity was recorded between the months of

June and September. Most of the environmental factors recorded had a positive and significant correlation with foraging behavior. Only humidity showed a negative and significant correlation with the foraging activities of the bees. The start and end times of the foraging activity of *M. colimana* differed from those reported in other studies conducted with stingless bees of the same genus in tropical climates (Monteiro and Schlindwein, 2003, Von and Blochtein, 2005, Fidalgo and Kleinert, 2007; Nates-Parra and Rodriguez, 2011). Tropical stingless bees start and end foraging between two and three hours earlier than *M. colimana* bees. However, the total amount of time that bees forage in tropical and temperate climates is similar (between 11 and 12 hours/day). The gathering of pollen and resins by *M. colimana* bees occurred during the course of the day for 9 to 10 hours, peaking towards noon. By comparison, stingless bees of tropical climates, such as *M. beecheii* and *M. fasciata*, collect pollen mainly early in the mornings (Roubik and Buchmann, 1984, de Bruijn and Sommeijer, 1997), a behavioral difference with stingless bees from a temperate climate. An explanation for this difference in pollen foraging times between tropical and temperate stingless bees could be due to the fact that in temperate climates, plants release pollen later in the day, when the environment is warmer and less humid. The foraging activity of *M. colimana* varied between the seasons studied, with the highest activity being observed during autumn and winter, and with a sharp decrease during summer, when the rainy season occurs. The months of greatest activity of the bees coincides with the season of highest blooming of different plant species, which suggests that these bees, like other species, have a higher foraging activity related to the presence of flowers (Waddington, 1983; Heard and Hendrikz, 1993, Nates-Parra and Rodríguez, 2011, Macías-Macías et al., 2017). Regarding environmental parameters, it was found that all of the ones measured, were related to the different foraging activities of the bees, which indicates that these factors may affect their ability to gather resources, especially humidity, which showed a negative correlation with foraging behavior. The temperature ranges that affected the foraging behavior of *M. colimana* coincide with those reported for other bee species of the same genus in tropical

environments (Hilario et al., 2000, Borges and Blochtein, 2005, Souza et al., 2006b).

## CONCLUSION

The results from our study strongly indicate that oak trees of the species *Q. laurina* play a critical role in the existence, conservation and distribution of *M. colimana*. Thus, the protection of these trees should be emphasized and regulated. Several strategies to achieve the protection of these trees that *M. colimana* bees use as nesting sites could be suggested. These would include issuing and implementing federal laws, like in Brazil, where regulations were established for the protection of *Caryocar brasiliense* (Antonini and Martins, 2003). Additional measures could include the marking of trees that contain stingless bee nests to prevent their logging, and the conservation of older trees in the context of commercial seed production (Eltz et al., 2003) since oak trees reproduce by this means (INIFAP, 2006). Likewise, if *M. colimana* nests are harvested without cutting the trees where they occur, this practice could be beneficial for the conservation of the nesting sites, leaving two positive effects simultaneously, because there would not harm the natural dynamics and development of the forest with a potential nesting site left for another colony. This system has been used successfully in Brazil where it has been used to exploit wild nests of stingless bees that nest in *Persea americana* and *Piranhea trifoliata* trees (Colleto-Silva, 2005). This harvesting technique could also have a great impact in the future for the conservation and sustainable management of *M. colimana* because at the same time that the trees are not cut, a genetic resource is maintained *in situ* by not extracting the entire nest, but by periodically obtaining new colonies through artificial division (González-Acereto and De Araujo-Freitas, 2005). Moreover, it can be concluded that environmental factors influence the foraging activity of *M. colimana*, and that the best time for the division and multiplication of colonies is during the season that spans from November to February, whereas the critical period occurs during the rainy season (in the summer), a time of the year when artificial feeding

should be provided to the colonies to stimulate their continuous development. Similarly, the results generated on the nesting habits of wild *M. colimana* colonies, could serve to propose housing colonies of *M. colimana* bees in wooden lodges with a volume of 10.5 L and evaluate them, which could contribute to the future management of these bees, as well as to their conservation and sustainable use in the mountain areas of western Mexico.

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#### Chapter 4

## MONOGYNY AND POLYGYNY: PLASTICITY IN THE NUMBER OF QUEENS IN COLONIES OF ARBOREAL ANT SPECIES

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#### ABSTRACT

In ant societies, the number of queens in a colony varies among different species or among different colonies within a particular species. In cases of monogyny, a new mated queen looks for nest space, where she then lays eggs, rears the brood and founds the nest with initial adult workers. After such colony founding, the mature monogynous colony produces gynes that disperse from the colony via mating flights. In some species, several new mated queens aggregate and found a nest cooperatively. When the nest founded by multiple queens produces initial adult workers, the founding queens compete with each until only one remains, which results in a secondary monogynous colony (pleometrosis).

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