ECOSYSTEM SERVICES PROVIDED BY BEES: THEORETICAL BASIS AND PRACTICAL APPLICATIONS

SERVIÇOS ECOSSISTÊMICOS PRESTADOS PELAS ABELHAS: EMBASAMENTO TEÓRICO E APLICAÇÕES PRÁTICAS

SERVICIOS ECOSISTÉMICOS PROPORCIONADOS POR LAS ABEJAS: BASE TEÓRICA Y APLICACIONES PRÁCTICAS

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ABSTRACT

This chapter addresses the ecosystem services provided by bees, with a special focus on pollination and its importance for biodiversity conservation, especially in environments such as the Brazilian Cerrado. It initially introduces the concept of environmental services and highlights the essential role of bees as pollinators of agricultural crops and native plant species. The distinction between effective pollinators and thieving or robbing floral visitors is discussed, based on morphology and behavior. The main floral attractants and pollination syndromes are also discussed, as well as experimental methods for assessing pollination efficiency. The text emphasizes the importance of stingless bees (meliponines) as key pollinators in tropical biomes and proposes a management plan aimed at conserving these species, including practical actions to stimulate meliponiculture and protect floral resources and nesting sites. The chapter concludes with a description of the biology of meliponines, their ecological needs, and threats to their survival. The work is proposed as a theoretical and practical tool for students, researchers and professionals interested in pollinator conservation and the sustainable use of biodiversity.

Keywords: Biodiversity. Sustainable Management. Meliponines. Floral Syndromes.

RESUMO

Este capítulo aborda os serviços ecossistêmicos prestados pelas abelhas, com foco especial na polinização e sua importância para a conservação da biodiversidade, sobretudo em ambientes como o Cerrado brasileiro. Inicialmente, apresenta o conceito de serviços ambientais e destaca o papel essencial das abelhas como polinizadoras de culturas agrícolas e espécies vegetais nativas. Discute-se a diferenciação entre polinizadores efetivos e visitantes florais furtadores ou pilhadores, com base em morfologia e comportamento. Também são abordados os principais atrativos florais e as síndromes de polinização, além de métodos experimentais para avaliação da eficiência polinizadora. O texto enfatiza a importância das abelhas sem ferrão (meliponíneos) como polinizadores-

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chave em biomas tropicais e propõe um plano de manejo voltado à conservação dessas espécies, incluindo ações práticas para o estímulo da meliponicultura e proteção dos recursos florais e locais de nidificação. O capítulo finaliza com uma descrição da biologia dos meliponíneos, suas necessidades ecológicas e ameaças à sua sobrevivência. A obra se propõe como uma ferramenta teórica e prática para estudantes, pesquisadores e profissionais interessados na conservação de polinizadores e no uso sustentável da biodiversidade.

Palavras-chave: Biodiversidade. Manejo Sustentável. Meliponíneos. Síndromes Florais.

RESUMEN

Este capítulo aborda los servicios ecosistémicos que prestan las abejas, con especial atención a la polinización y su importancia para la conservación de la biodiversidad, especialmente en entornos como el Cerrado brasileño. Inicialmente, presenta el concepto de servicios ambientales y destaca el papel esencial de las abejas como polinizadores de cultivos agrícolas y especies vegetales nativas. En este artículo se analiza la diferenciación entre polinizadores efectivos y visitantes ladrones o saqueadores de flores, basándose en la morfología y el comportamiento. También se abordan los principales atractivos florales y síndromes de polinización, además de métodos experimentales para evaluar la eficiencia de la polinización. El texto enfatiza la importancia de las abejas sin aguijón (meliponinas) como polinizadores clave en biomas tropicales y propone un plan de manejo orientado a la conservación de estas especies, incluyendo acciones prácticas para estimular la meliponicultura y proteger los recursos florales y sitios de nidificación. El capítulo concluye con una descripción de la biología de las meliponinas, sus necesidades ecológicas y las amenazas a su supervivencia. El trabajo se propone como una herramienta teórica y práctica para estudiantes, investigadores y profesionales interesados en la conservación de polinizadores y el uso sostenible de la biodiversidad.

Palabras clave: Biodiversidad. Gestión Sostenible. Meliponinas. Síndromes Florales.

1 INTRODUCTION

The term environmental services (or ecosystem services) refers to the conditions and processes in which natural ecosystems contribute, directly or indirectly, to the maintenance of human life (De GROOT, 1992; DAILY *et al.*, 1996; DAILY, 1997). According to the Millennium Ecosystem Assessment (2003), ecosystems provide a variety of benefits to people, including production services (goods that are obtained from ecosystems, such as food, fuel, fiber, drinking water and genetic resources), regulation (benefits that are obtained from regulating ecosystem processes, including the maintenance of air quality, climate regulation, erosion control, regulation of human diseases, and water purification), cultural (non-material benefits that people derive from ecosystems through spiritual enrichment, cognitive development, and experiences of reflection, recreation, and aesthetics), and support (those necessary for the production of all other ecosystem services, such as primary production, oxygen production, and soil formation).

The Convention on Biological Diversity and the Millennium Institute consider the environmental services provided by pollinators, including bees, as a priority research (MILLENNIUM ECOSYSTEM ASSESSMENT, 2003). Kearns *et al.* (1998) also argue that the interaction between bees and plants in their natural environments should be a key issue in biodiversity conservation projects. First, pollination services in natural ecosystems have been classified as regulatory and support services (FAO, 2006; FITTER *et al.,* 2010), thus, the loss of pollination is as destructive to the natural ecosystem as the physical changes that occur in it. Second, bees are the dominant pollen vectors in tropical forests (BAWA, 1990; RENNER & FEIL, 1993; ROUBIK, 1993) and probably in many other terrestrial biomes, including agricultural systems. In fact, Raven *et al.* (1996) report that bees are the group of floral visitors responsible for pollinating more plant species than any other animal group.

In several countries, governmental and non-governmental organizations have been created (e.g. IPI, 2025), which prioritize the need to implement action plans that promote the conservation and sustainable use of bees in agriculture and in ecosystems associated with crops. However, according to Palmer *et al.* (2004), due to the scarcity of knowledge about the benefits of such services disclosed to society, there are few natural areas managed for ecological and/or economic purposes. It is still essential to build more knowledge about the benefits produced by bees in the maintenance of natural ecosystems and agroecosystems (IMPERATRIZ-FONSECA & NUNES-SILVA, 2010). In the case of research involving the pollination of crops by bees, it is essential that the results reflect, in addition to the scientific community, the target audience: small farmers. Successful management of the ecosystem, even if it is for agricultural purposes, requires that it be partially available to support the diverse community of bees and the pollination service provided by them.

2 IMPORTANCE OF BEES FOR BIODIVERSITY CONSERVATION

Pollination by animals, especially bees, represents one of the best examples of ecosystem services. About 35% of global agricultural production depends on animal pollination, or when analyzed by the number of species, 76% of the most important global crops depend on animal pollination (KLEIN *et al*., 2007). This is because the bee community represents "the pollinators par excellence", since it constitutes the only group of animals that obtain their diet exclusively from flowers, both in the larval stage (pollen, as a source of protein; and honey, obtained by the transformation and dehydration of nectar, as a source of carbohydrate) and in the adult stage, when they feed only on honey for energy replacement (ROUBIK, 1989). For these reasons, bees are considered key groups in almost all terrestrial habitats, since they are indispensable for plant reproduction and form the basis of a rich flow of food energy (KEARNS *et al*., 1998).

Unmanaged native bee populations are known to provide important pollination services to various groups of agricultural crops and are generally more diverse and abundant in their natural habitats (KREMEN *et al.*, 2002; RICKETTS, 2004). In Brazil, a very diverse group of high importance in the pollination of various agricultural and forest species are the meliponines or simply "indigenous stingless bees" due to the fact that they have atrophied stingers (VENTURIERI, 2003; MAUÉS, 2001).

The consistency of the previous data is reported by Kerr (1979) when he informs that for about 30% of the species in the Caatinga and Pantanal and up to 90% in some patches of the Atlantic Forest and the Amazon there is a need for meliponines for pollination. In the Cerrado, bees are once again the main pollinators of native plants (OLIVEIRA & GIBBS, 2000). However, the Cerrado suffers from: (1) local impacts such as deforestation, fires, introduction of exotic species and rampant insertion of apiaries, agricultural mechanization and its biotechnologies, agricultural pesticides, etc.; and (2) global-level impacts (global warming, air pollution, climate change). If the solitary bee or the colony to which it belongs can momentarily survive an impact, it becomes vulnerable to diseases and parasites because of the stressful environment. The end result is a drastic population reduction, with some local bee extinctions.

Another service provided by bees and widely exploited by man, through the installation of apiaries and/or meliponaries, is the use of their derivatives, such as honey, propolis, royal jelly, pollen and wax. Rational beekeeping, including meliponiculture, is an activity of great importance, as it presents an alternative of occupation and income to the countryside, mainly because it is easy to maintain and requires low initial investment in relation to other agricultural activities (FREITAS *et al*., 2004).

So, it is reflected how important the preservation of bees is, both for the maintenance of food production and for vegetation preservation because they represent the base of the food chain (for example, birds feed on fruits formed from the pollination of flowers, ants and other insects feed on seeds, reptiles and amphibians feed on insects that feed on fruits and leaves, etc.).

3 DEFINITION OF A POLLINATOR VERSUS RESOURCE STEALER/PILLAVER

Pollination in angiosperms is characterized by the transfer of pollen grains, housed in anthers, to the stigma of flowers of the same species (RAVEN *et al*., 1996; Table 1). However, these authors report that in order for the fruit to form, the pollen grains deposited on the stigma need to germinate, and this occurs through the absorption of water available on the surface of the stigma when it is receptive, modifying the pollen grains in pollen tubes that grow along the stylet until they reach the ovule and penetrate the oospheres (egg cells). fertilizing them. It is thus noted that the fertilization process involves exclusively intrinsic mechanisms, while pollination, excluding autogamous species, is totally dependent on animals or abiotic agents (wind or water) for its consummation.

Any animal that frequently touches the reproductive structures of flowers – that is, comes into contact with the anthers and the stigma – is considered a potential pollinator (RAVEN *et al*., 1996). A pollinator can also be called a "pollen vector" because it carries pollen from the male structures to the female structure of the flower. For bee species defined as pollinators of a given vegetable, Delfino (1868, 1874 *apud* ENDRESS, 1994) distinguishes three regions of the bee body responsible for pollen transport: (1) nototribic (dorsal region of the body, usually in the thoracic region between the wings), (2) sternotestribic (lower body region, especially in the abdomen) and (3) pleurotribic (the main form of pollen deposition on the stigma of flowers in most angiosperms, in which bees use their legs; especially the posterior leg that is the corbicula – a modification of the tibia, in the shape of a basket, specialized in the transport of pollen, found only in some groups of bees).

Species defined as excellent pollinators, appropriately named as effective pollinators, are those that visit flowers of several plants of the same species because it favors cross-pollination, the result of which is gene flow between plants (RICHARDS, 1997). According to the same author, many plant species are self-incompatible. In this case, fruit will only form if the pollen comes from other plants of the same species.

For a floral visitor to be an effective pollinator, there must first be a perfect fit between the morphometry of that visitor and the foraged flowers. Bees of large body size (e.g., bees of the genus *Bombus*) that use the natural opening of the gullet-like flowers to suck nectar (Figure 1A) tend to touch their thorax in both the male and female reproductive structures of the flower (POLATTO & ALVES-JUNIOR, 2008). In figure 1B it is possible to see that the thorax of the bee *Bombus* sp. was filled with pollen (whitish powder), after successive foraging on the flowers of *Sparattosperma leucanthum* (Bignoniaceae). When foraging flowers on other plants of the same species, there is a possibility that pollen adhered to the body of this bee will be deposited on the stigma of the flower, promoting cross-pollination.

The plant species used in the example has flowers that fit into the specialized pollination system, that is, flowers adapted for pollination by a specific group of animals; in this case represented by bees of large body size (see floral specializations below). Specialist flowering plants are effective at being pollinated when the environment is conserved, since it is understood that there are pollinators. On the other hand, in degraded environments there is a predominance of plants with generalist flowers, considering that in these places there is a lower diversity of pollinators (WASER *et al.*, 1996). Any floral visitor would have a low capacity to transfer pollen to the stigmas of generalist flowers, but the presence of an inefficient animal is preferable to the absence of a highly specialized pollinator, locally extinct.

However, the flowers of a plant species rarely receive visits exclusively from pollinating animals (Table 1). Commonly, other non-pollinating animals are able to obtain floral resources (usually nectar and pollen, but sometimes oil or flower essences) without touching the anthers and stigmas (INOUYE, 1980). The animal's body size may be incompatible with the position of the reproductive structures of the flowers, or the strategy of collecting the floral resource is not compatible to enable contact with the reproductive parts of the flower. Animals are called: (1) resource stealers, when they collect nectar or pollen through the natural opening of the flower, but do not touch the reproductive structures; or (2) resource plunderers, when they produce perforations or damage to flowers to obtain pollen or nectar.

Roubik (1989) points out that the connotation of the terms 'pollinator' and 'poacher' is confusing, since it has been reported that many of the visits of effective pollinating bees to flowers do not result in pollination. But this same author emphasizes that if the pollination rate by poferers is relatively lower than that of pollinators, poferers are indeed parasites. Resource stealers can be important only in extreme situations, such as the decline of pollinator species in certain habitats, and can confer resilience to disturbances through accidental pollination (FONTAINE *et al*., 2006; POLATTO & ALVES-JUNIOR, 2008). Figure 1C shows morphological mismatches between *Apis mellifera* (Apidae) and the flower of *S. leucanthum*. *Apis mellifera*, because it has a smaller body size than the corollar cone of the flower, enters through the natural opening of the flower without contacting the reproductive organs, being a typical example of nectar theft.

Table 1

Types of floral foraging: definition of pollination and resource gathering behaviors without effective pollination (adapted from Inouye, 1980)

Type of foraging	Description
Pollination	Process in which the floral visitor transfers pollen grains from the anthers of flowers to the stigma of the same flower (self-pollination) or of another flower of the same plant (geitonogamy) or of another plant of the same species (xenogamy or cross-pollination).
Primary Nectar Looting	Characteristic behavior in deep flowers, in which the floral visitor makes a perforation on the outer face of the corolla at the level of the nectary to obtain nectar, ignoring the floral opening used by pollinators (illegitimate visit).

Secondary Nectar Looting	The floral visitor obtains the nectar from an existing perforation on the outer face of the corolla initially made by a primary nectar looter (illegitimate visit).
Nectar theft	No perforation is made in the flower; The poferfernaut uses the same opening used by the pollinator (legitimate visit), but mismatches in morphologies between the visitor and the flower make pollination impossible. However, through this type of behavior, the nectar stealer can accidentally pollinate the flower if parts of his body that are impregnated with pollen grains come into contact with the stigma of the flower.
Base foraging	Characteristic behavior in deep polypetal flowers (petals are not fused into a single structure – the corolla). No holes are made, although the opening used by the pollinator is also not used; The technique consists of obtaining nectar by inserting the mouthparts between the petals, at the level of the nectary.
Pollen looting	The floral visitor collects pollen in a way that makes pollination impossible (usually not touching the stigma), in addition to damaging the floral tissues, especially the anthers.
Pollen theft	The floral visitor collects pollen in a way that makes pollination impossible (usually by not touching the stigma), but does not damage the floral tissues.

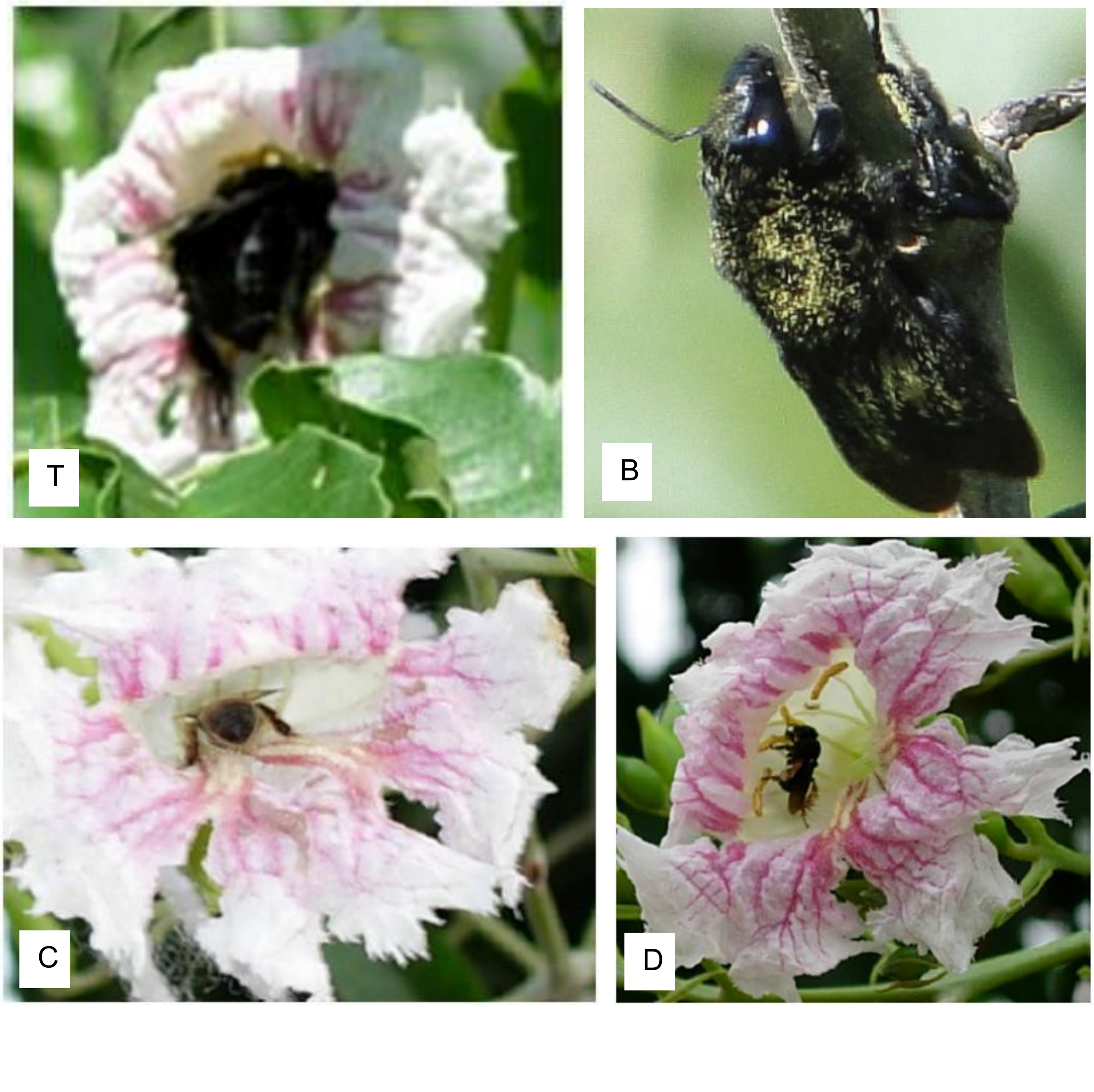
Pollen looting occurs by destroying the anthers and inserting the proboscis to remove the pollen grains (RENNER & FIEL, 1993) (Figure 1D). Pollen theft is usually carried out by small bees that collect pollen directly from the anthers of a single flower, without contacting the stigma. An important difference between pollen loss and nectar collection is that pollen is usually not replenished while nectar may be replenished (INOUYE, 1980). However, pollen pickers and looters may carry out occasional pollination if they bump into parts of their pollen-filled body in the stigma when entering or leaving the flower (INOUYE, 1980).

In turn, the behavior of primary nectar plundering varies widely among bee species (ROUBIK, 1989). Large bees, such as those of the genera *Xylocopa* (Apidae) and *Oxaea* (Andrenidae), perform the perforations quickly, inserting the proboscis through the corolla (BARROWS, 1980) (Figure 1E). Some meliponines damage the flowers slowly, such as those of the genus *Trigona* (Apidae), which use the mandibles to remove the corollar tissue and produce extremely large and damaging holes to the flower (MICHENER, 2007) (Figure 1F). Research indicates that nectar plundering has a potentially negative impact on plants, such as the damage caused to reproductive tissues (TRAVESET *et al.*, 1998), reduction of the attractiveness of pillaged flowers to pollinators (IRWIN & BRODY, 1998; TRAVESET *et al*., 1998; COTTON, 2001) and the investment of resources by the plant to replace the nectar removed (PYKE, 1991; NAVARRO, 1999).

However, different individuals of the same species, or even a single individual, can forage in more than one way in a single plant species (INOUYE, 1980). As an example, we can cite the foraging behavior of *A. mellifera* in flowers of *Pyrostegia venusta* (Bignoniaceae); Polatto *et al.* (2007) observed that the bee intensively carried out pollen theft and secondary nectar looting and, occasionally, primary nectar looting of flowers.

Figure 1

Illustration of the foraging behavior of some floral visitors in Sparattosperma leucanthum (Bignoniaceae). A – Bombus sp (Apidae) touching the dorsal region of the thorax on the anthers and the stigma during nectar suction and, consequently, performing nototribic pollination. B – Bombus sp (Apidae) with the back of the thorax full of pollen (whitish pigments) after successive foraging on the flowers. C – Apis mellifera (Apidae) sucking nectar without touching the reproductive organs of the flower, which are located in the upper region of the corolla. D – Trigona spinipes (Apidae) plundering pollen. E – Oxaea flavescens (Andrenidae) sucking nectar by primary looting – rapid removal, by insertion of the proboscis. F – Trigona spinipes (Apidae) destroying part of the floral tissues with the mandibles to perform nectar suction – this hole is usually used by ants and/or other bees to perform nectar suction by secondary looting. Personal images.



3.1 FLORAL FEATURES WITH ATTRIBUTES IN POLLINATOR ANIMAL ATTRACTION

In order for a given animal species to be classified as the ideal pollinator of a respective plant, it is expected that it presents the following characteristics in relation to the plant (FREE, 1993; FREITAS & PAXTON, 1996):

- Be attracted by the flowers;
- Present fidelity to the species and forage several individuals in the population;
- Be of adequate size and behavior to remove pollen from anthers and deposit it on the stigmas;

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- Carry a large amount of pollen in your body;
- Visit the flowers when the stigmas are receptive and the anthers are dehised.

For this reason, not all plant species are equally attractive to all pollinators, and not every floral visitor is efficient in pollinating any plant species (FREITAS, 1998).

Floral attractions are important characteristics for the perception and attraction of floral visitors, since they signal the presence of advantageous resources in a given flower (FAEGRI & van der PIJL, 1979). These attractants are usually present in the corolla, but in some cases, the petals may be small or stunted. In these situations, other floral structures assume an eye-catching role, such as sepals, stamens, modified leaves, nectaries, floral appendages (such as bracts) (Table 2; Figure 2).

Floral features are considered primary attractants – that is, substances produced by the flower and collected by floral visitors during foraging (DAFNI, 1992). The two main floral resources are nectar (flowers with the presence of nectary) and pollen availability. Other primary attractions that are less frequent and explored by specific groups of visitors include: perfumes, oils, stigmatic exudates, floral fabrics and resins (DAFNI, 1992).

Concomitantly, the main secondary attractants – that is, those with an exclusively attractive function – include: general color of the flower, specific coloration (such as nectar guides or pollen guides), presence of odor and floral shape (DAFNI, 1992).

Table 2

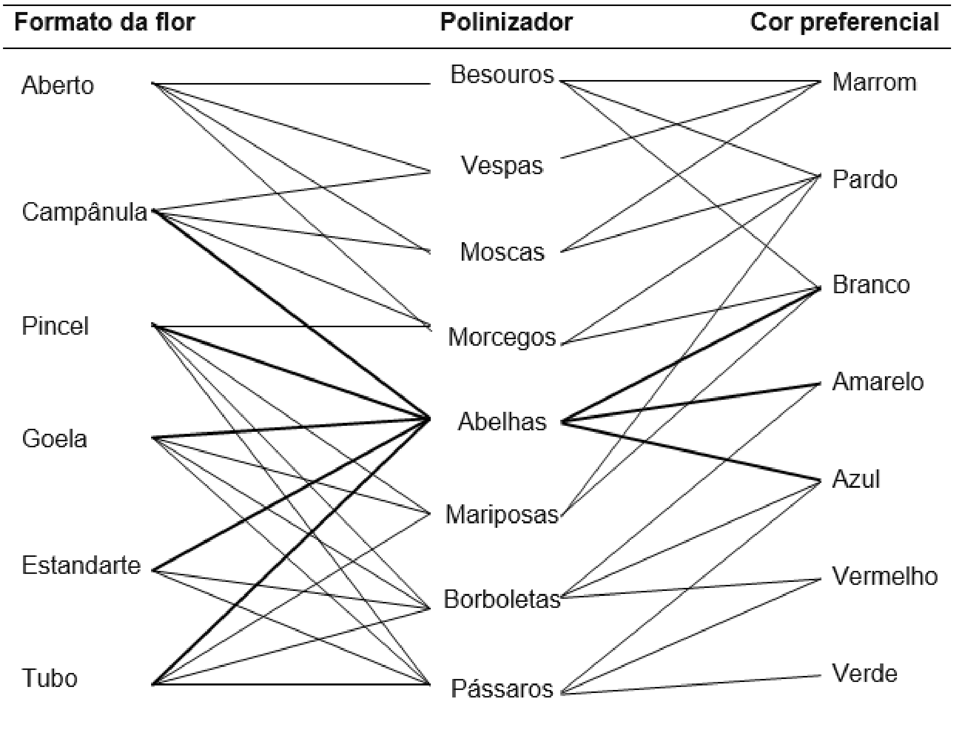
Main floral morphologies adapted to certain pollinators (adapted from Faegri & van der Pijl, 1979)

Flower Type	Description
Inconspicuous flowers	Very small and barely perceptible flowers, with no evident attractions. They are almost exclusively wind-pollinated (anemophilous).
Open flowers (plate shape)	They can be isolated flowers, but usually form inflorescences. The reproductive organs are located in the center of the flower, sometimes slightly detached. They have radial symmetry. In general, the pollinator's abdomen comes into contact with the anthers and the stigma (sternorhythmic pollination).
Campanulate or tapered flowers (bell type)	They have a narrow portion and flat edges, which function as attractants or landing platforms. They represent a transition to the tubular type. The sexual organs usually protrude from the center, through long fillets and stylets.
Brush-shaped flowers	Some species are anemophilous. The outer surface of the flower is composed exclusively of sexual organs, while the perianth is reduced or divided into filiform segments between the sexual organs. Pollinators that land on these flowers carry the pollen in the abdomen or head.
Flowers in the shape of a gullet	The sexual organs are located in the upper part of the flower, so the pollen is deposited on the back of the pollinator (nototribic pollination). These flowers feature a landing platform at the base of the corollar opening.

Flowers in the form of a banner	The sexual organs are located at the bottom of the flower, and the insects carry pollen in the abdomen (sternorhythmic pollination).
Tubular flowers	The tubular shape is not related to the arrangement of the sexual organs, but to the accessibility to the nectar, functioning as a mechanism that prevents the foraging of floral visitors with mouthparts shorter than the effective length of the floral tube.

Figure 2

The harmonic relationships between pollinator and flowers (adapted from Faegri & van der Pijl, 1979)



3.2 POLLINATION SYNDROMES

Most angiosperm species show adaptations to pollination by certain groups of pollinators, influenced by a set of floral attributes – such as color, morphology, anthesis period, presence of odor, among others – called pollination syndrome (FAEGRI & van der PIJL, 1979; WASER *et al*., 1996). According to Faegri & van der Pijl (1979), the syndromes can be classified as follows:

- **Melitophilia** – Pollination by bees (including wasps and ants). Zygomorphic (bilateral) and relatively deep flowers; strong floral structure; the lower part of the perianth functions as a landing platform; fresh and usually mild odor; presence of nectar guides; occult sexual organs, with few stamens and many eggs per ovary; Floral rewards include nectar, pollen, oil, or resin. The colors vary: brown (wasps), white, blue or yellow (bees). Floral morphologies: open or bell (wasps); bell, brush, gullet, banner or tubular (bees).

- **Psychophilia** – Pollination by butterflies. Narrowly tubular, colorful flowers (red, blue or yellow), with a mild odor; presence of nectar guides; hidden nectar. Floral morphologies: tubular, banner, gullet or brush.
- **Phallophilia** – Pollination by moths. Narrow tubular flowers; twilight or nocturnal anthesis; light color (whitish or brown); intense and pleasant odor; high volume of nectar, higher than that of psychophilic and melithophilous flowers. Floral morphologies: tubular, throat or brush.
- **Cantharophilia** – Pollination by beetles. Flowers with few visual attractions; shallow, without nectar guides; usually large, open, resistant, with many floral elements; strong odor; accessible rewards (pollen, floral parts or nectar); exposed sexual organs. Flowers with brown, brown or white colors. Floral morphologies: open.
- **Myiophilia** – Pollination by flies (non-saprophiles). Regular, simple and shallow flowers; light colors (brown or brown); nectar guides usually present; imperceptible odor; affordable nectar; exposed sexual organs. Floral morphologies: open or bell.
- **Sapromyophilia** – Pollination by saprophilic flies. Radial, deep, trap-shaped flowers; dark colors (brown or greenish-purple); absence of nectar guides; odor similar to decaying flesh; usually without nectar or other primary attractant; Sexual organs are hidden inside the flower.
- **Ornithophily** – Pollination by birds. Tubular, resistant and colorful flowers (reddish, which can be green); odorless; wider floral tube than in psychophilia and phallenophilia; absence of nectar guides, but with abundant nectar. Floral morphologies: tubular, banner, gullet or brush.
- **Chiropterophilia** – Pollination by bats. Nighttime, whitish flowers with firm petals; strong and unpleasant odor (deteriorated or fermented); flowers positioned externally to the foliage; extremely abundant nectar. Floral morphologies: brush, bell or open.

- **Anemophilia** – Pollination by wind. Flowers usually dioecious (unisexual), exposed above the layer of leaves; insignificant, small or absent perianth; absence of floral attractions; anthers and stigmas exposed; small, light, dry pollen grains produced in large quantities.
- **Hydrophilia** – Pollination by water. It can be subdivided into:
    - Hyphidophiphilia – Pollination occurs below the surface of the water;
    - Epidrophilia - Pollination occurs on the surface of the water;
    - In humid forests, pollination by raindrops, which transfer pollen between flowers, can also occur.
- **Autogamy** – Spontaneous self-pollination (in self-compatible species), without the participation of biotic or abiotic agents. The most common mechanism is contact between anthers and stigma of the same flower, usually at the end of anthesis.

However, the publication of studies that questioned the validity of the concept of syndromes (HERRERA, 1996; WASER *et al.*, 1996) generated intense debate about the prevalence of generalist or specialist systems (JOHNSON & STEINER, 2000, 2003; GÓMEZ, 2002; WILSON *et al*., 2004). One of the issues that emerges from this scenario is the understanding of the factors that are linked to the emergence and maintenance of pollination systems with a high degree of specialization (WESTERKAMP, 1997; AIGNER, 2001, 2004; FENSTER *et al.*, 2004; CANE & SIPES, 2006).

According to Aigner (2001), natural selection often favors the specialization of plants for pollination by a particular type of animal (often at the level of order or family) and, in parallel, the specialization of the pollinator in the exploitation of the floral resources of a restricted group of plants (family, genus or species). Although specialist plant species tend to be more efficiently pollinated by their specific pollinators, they generally receive fewer floral visits.

Most entomophilous plants have a high degree of generalization, being visited by several animal groups (WASER *et al.*, 1996; JOHNSON & STEINER, 2000; FENSTER *et al*., 2004). However, even when a specific pollinator visits the flower, it does not always result in pollination. In a study with *S. leucanthum*, whose flowers are specialized for pollination by bees of large body size (especially of the genus *Bombus*), it was found that, for each fruit set, there were about 10 thousand visits to 200 flowers, among all visitors. Considering only the actual pollinators, there were more than 3 thousand visits (POLATTO & ALVES-JUNIOR, 2008).

The high rate of visits per fruit produced is common among melitophilous species (JANZEN, 1977). This is because usually the bee forages when the stigma is no longer receptive or after most of the pollen has been removed from the flowers. Thus, fruit production is usually limited by the insufficient amount of pollen received by the stigma (ROUBIK, 1989).

3.3 TECHNIQUES USED TO ESTIMATE THE IMPORTANCE OF POLLINATORS

Several methods to evaluate the role of floral visitors in the pollination of plant species have been employed for a variety of plants (KENDALL & SMITH, 1975; TEPEDINO, 1981; DAFNI *et al*., 1987; INOUYE *et al*., 1994). Many of these methods, however, have provided only indirect estimates of the importance of visitors.

A direct method was proposed by Spear (1983), in which virgin flowers are exposed to the visit of a single floral visitor and then are monitored for fruit production. The pollination efficiency index of Spear (1983) allows estimating the contribution of different pollinators to the reproductive success of the plant.

In addition, the performance of standardized reproductive tests – spontaneous self-pollination, manual self-pollination, geitonogamy, xenogamy, apomixis and natural pollination – allows the evaluation of the degree of dependence of plants on biotic pollination for fruit formation, both in cultivated and native species (SOBREVILA & ARROYO, 1982; OLIVEIRA & GIBBS, 2000; FREITAS & OLIVEIRA, 2002; POLATTO & ALVES JUNIOR, 2009). To do this, several flowers of a certain plant species must first be individually isolated at the beginning of anthesis (the moment of floral opening) and prevent their contact with floral visitors. This can be done with the use of paper or voal fabric bags, which wrap the flowers without damaging them. During the period when pollen is available and the anthers are receptive, the floral protection material against foraging by floral visitors is removed and experimental treatments are carried out; Soon after the experimental procedure, the flowers should be wrapped again with the protective bags. In all tests, except in the control group, flowers that have pollen deposition in their stigmas should be emasculated (removal of anthers) (Table 3).

Table 3

Floral handling techniques to develop floral reproduction tests

Reproductive testing	Description
Spontaneous self-pollination	Bagging of flowers in pre-anthesis; absence of further handling.
Manual self-pollination	Manual transfer, carried out by the researcher, of the pollen to the stigma of the same flower.
Geitonogamy	Manual transfer of pollen to the stigma of different flowers of the same plant.
Cross-pollination (xenogamy)	Manual transfer of pollen to the stigma of flowers of different individuals of the same species.
Apomixis	Emasculation (removal of anthers) of flowers still in the pre-anthesis phase, without pollen supply.
Control	Absence of any floral handling. Verification of the fruiting rate under natural conditions.

According to the methodology of Sobrevila & Arroyo (1982), from the results obtained in the manual pollination tests, it is possible to calculate the indices of:

- **Spontaneous self-pollination (ISA)** – Percentage of fruiting formed by spontaneous self-pollination divided by the percentage of fruits formed by manual self-pollination);
- **Self-incompatibility (ISI)** – Percentage of fruiting resulting from manual self-pollination divided by the percentage of fruits from cross-pollination);
- **Reproductive efficacy (RE)** – Percentage of fruiting from natural pollination divided by the percentage of fruits formed by cross-pollination).

Values lower than 0.25 in each of these indices indicate that the plant species does not present that specific qualification: spontaneous self-pollination, self-incompatibility or reproductive efficacy.

The classification of Gallai & Vaissière (2009) can also be applied to establish the level of dependence on pollinators by plant species, according to the following criteria:

- **Essential** – When the average value of production reduction is between 100% and 90% without pollinating animals;
- **Large** – When the reduction range is between 40 and < 90%;
- **Modest** – When the reduction range is between 10 and < 40%;
- **Little** – When the reduction range is between > 0 and < 10%.

To complement the evaluation of the ecosystem services provided by floral visitors, it is essential to record the type of visit to the flower, according to the classification of Inouye (1980), allowing to distinguish between effective pollinators and resource stealers/looters.

Estimates of the relevance of pollination in the aggregation of economic value of agricultural products have been discussed in several forums (e.g. SOUTHWICK & SOUTHWICK Jr., 1992; MORSE & CALDERONE, 2000; GALLAI *et al*., 2009; WINFREE *et al*., 2011). However, estimates of the economic value of pollination services have varied widely (e.g. RICHARDS, 1993; COSTANZA *et al.*, 1997) due to the absence of standardized evaluation methods and lack of consolidated experiences in analyzing the economic valuation of this ecological service.

4 MANAGEMENT PLAN FOR THE MAINTENANCE OF BEES, WITH EMPHASIS ON MELIPONINES

The maintenance of floral visitors in a plant ecosystem is vital for its functionality. There are at least three strategies that ensure their maintenance:

1. To explore floral resources of different species of plants (PLEASANTS, 1980);
2. Seek resources at different times of the day or different periods of a season (GINSBERG, 1983; KOPTUR *et al*., 1988);
3. Foraging on different resource spots or at different densities on the spots (JOHNSON & HUBBELL, 1974; GINSBERG, 1983).

Regarding the analysis of faunal abundance of floral visitors, it is common to find a predominance of *A. mellifera* and *T. spinipes*, bees with a eusocial way of life. This can be attributed to the large number of individuals in the colonies, the efficiency in recruitment, and the generalist habit, which commonly forage together for the most abundant sources of resources (KERR *et al*., 1981; WILMS *et al*., 1996; JOHNSON & STEINER, 2000).

However, in a fragment of secondary forest with characteristics of Atlantic Forest and Cerradão (an ecotone), Polatto & Chaud-Netto (2013) reported that the high abundance of foraging of the exotic bee *A. mellifera* in the flowers of several native plant species was influenced by:

- The occupation of the forest fragment predominantly by lianas and shrubs, to the detriment of vegetation with arboreal characteristics, which favored the finding of flowering plants by *A. mellifera*;
- The development of rational beekeeping, making the number of natural swarms that originate annually from colonies of commercial hives and colonies previously established in the environment very high, thus leading to an increase in the population size of this species of bee at the study site.

The authors also pointed out that the frequent occurrence of human fires and deforestation within the forest fragment may also have reduced the size and diversity of the native bee population, including *that of A. mellifera*. As populations of *A. mellifera* had the ability to rapidly occupy the environment, this species eventually became dominant after successive disturbances made to the fragment. It is, therefore, a classic example of an environment apparently favorable to the maintenance of bees, but which, under detailed analysis, proves to be unfavorable to the diversity of species.

After the theoretical descriptions on the ecology of pollination, a management plan aimed at the conservation of pollinating bees is proposed, prioritizing meliponines, to be implemented in altered environments (Table 4). The management plan must analyze the environmental characteristics necessary to allow the establishment and lasting fixation of bees in the place, in addition to including important requirements to enable a balanced interaction between the species involved.

Based on these perspectives, some recommendations for the management of bees were elaborated, aiming to maintain the integrity of the interactions between them. The implementation of a meliponines management plan also involves raising awareness among the local community – especially rural landowners in the surrounding area – about the need for the correct use of agricultural techniques that enable the on-site maintenance of bees. For the success of the project, the active participation of the community will again be essential.

5 BIOLOGY OF MELIPONINES

Meliponines (Apidae, Meliponinae) occur in South and Central America, Asia, the Pacific Islands, Australia, New Guinea, and Africa. Taxonomically, they are divided into two tribes: Meliponini, formed only by the genus *Melipona* and found exclusively in the Neotropical region, and Trigonini, which groups a large number of genera and is distributed throughout the distribution area of the subfamily (MICHENER, 2007).

It is estimated that there are about 500 species of meliponines, all with eusocial organization, with colonies ranging from a few hundred to thousands of individuals, depending on the species (KERR *et al*., 1996). The workers perform the tasks of building and maintaining the physical structure of the colony, collecting and processing food, and a queen (in a few species up to five are found) is responsible for laying eggs, which give rise to females (queens and workers) and part of the males (in several species, a portion of the males are descendants of the workers). These males are produced in large numbers at certain times of the year and can sporadically perform some tasks within the colony, in addition to fertilizing the queens during the nuptial flight.

Meliponines seek nectar, pollen and resin in a set of plant species, which is different for each bee species (ABSY *et al*., 1984). Therefore, the organization of the meliponines community is minutely adjusted with various habitat characteristics, including floral diversity, floral abundance (BANASZAK, 1995), the availability of floral resources (PETANIDOU & VOKOU, 1990), and suitable nesting sites (POTTS *et al*., 2003).

The importance of foraging sources (pollen and nectar) for the maintenance of the bee community is clearly demonstrated in several studies. However, according to Potts *et al.* (2005), the places that bees use for nesting are little studied and receive relatively little importance in research. In one study, it was found that 5% to 10% of the organization of the bee community is influenced by the availability of nesting resources (POTTS *et al*., 2003). Thus, it is believed that for the organization and maintenance of the meliponinean community in the habitat, the availability of nesting sites plays an even more important role compared to other groups of bees, mainly due to the specificity of the substrate to be used for nesting that this group of bees has.

These bees have been severely affected, mainly by the destruction of forests, as a result of the following factors (KERR, 1997:

- **Deforestation** – Several species of meliponines nest in tree hollows, which are destroyed with deforestation.
- **Removal of old trees** – The largest trees are those that usually have adequate hollows to be occupied by new swarms.
- **Large fires** – Fertilized queens have a very voluminous abdomen, but their wings are the same size as the wings of workers, so they cannot fly and the entire colony is killed in the fires. For the few species that manage to survive the fires by building underground nests, they are killed in the first plow of the soil, as a result of most building their nests close to the surface of the ground.
- **Destruction by honeydew** – Destruction of abandoned chicks, which are later attacked by ants.
- **Inadequate legal reserves** – The legal reserve areas of rural properties are generally smaller than those required for bee reproduction and maintenance of genetic variability. These bees need a minimum area of forest that houses at least 44 colonies of the same species (Kerr & Vencovsky, 1982), or else, the reserves could not be separated from other fragments by a distance of more than 6 km, ensuring a normal gene flow (AIDAR, 1996).
- **Insecticides** – The application of insecticides to crops affects colonies of meliponines in nearby forests, especially if the insecticides reach the flowers foraged by them.

Table 4

Logical Matrix on the conservation of meliponines (Apidae: Meliponinae)

Obj. General	Obj. Specific	Goals	Actions	Goods
Determine the conservation status of meliponines in the area	Inventory the species and nests of meliponines occurring in the area	Obtaining the identity of the species and the number of nests housed in the area	Collect some individuals of meliponines in the flowers of various plants and make the respective identification of these bees	Entomologic al reference collection
			Reference the nests found in the area	Mapping the nests
	Investigatin g the sustainabilit y of meliponines	Maintenance of all species and colonies found in the area	Diagnose the loss of occurring species and mapped colonies over time (annually)	Reports linked to the entomologic al collection and mapping of nests
Conserve the meliponines in the area	Increasing the abundance and	Presence of at least 10 different cultures that	Plant sustainable crops (fruits, vegetables,	Increased diversity and abundance of floral

	biological diversity of meliponines	exert great attraction to the meliponines	tubers, etc.) with rational use of agrochemicals	resources in the area, as well as nesting sites
		Establishment of at least one swarm (colony) in the area annually	Manufacture of several models of trap nests and distribution throughout the area	Predominance of suitable nesting sites
	Ensuring genetic viability of meliponine populations	Displacement of colonies from other regions to the area or exchange between other beekeepers, covering at least 50% of the species occurring in the area in 5 years	Transfer to the area the colonies housed in regions unfavorable to their survival, or exchange hives with beekeepers from other regions	Sufficiently large populations, and mainly with great genetic variability
		Presence of at least 44 colonies within a radius of 6	Encourage the breeding of these bees in the	Presence of meliponaries or non-profit colonies in the vicinity

		km for most species	surroundings of the area	

Obj. General	Obj. Specific	Goals	Actions	Goods
Reduce negative impacts on meliponines	Reducing anthropogenic impacts on meliponines	No removal of plant matter	Avoid the exploitation of plant biomass, especially large trees	Preservation of nesting sites and food sources
		Absence of exotic plants in the area that will compete with native plants or that are harmful to meliponines	Eliminate exotic invasive plants in the area that compete with attractive native ones	Greater availability of floral resources to meliponines
		Absence of apiaries in the area	Request beekeepers to relocate apiaries housed in the area	
	Reducing natural impacts on meliponines	Prevent colony mortality due to winter food shortages	Supplement colony feeding with syrup in severe winter conditions	Colonies with strong populations throughout the year
		Keeping colonies free from the presence of natural enemies	Inspect the colonies annually, eliminating phorids, ants and lemon bees (*Lestrimelitta limao*)	

Raising awareness in society for the conservation of meliponines	Encourage landowners about the importance of conservation of meliponines and the need to create such a management plan	Buy-in of landowners located in the area	Develop educational resources to raise awareness among owners	Target population involved
		Their adhesion in the implementation of cultures attractive to the meliponines	Development of the actions listed above that require the support of the owners	Successful development of the plan in question
		Their adherence to the creation of at least two bee colonies, even if it is non-profit		

Note:

The natural multiplication of colonies occurs through swarming. Initially, a group of workers leaves the mother nest looking for a place to install a new nest. Finding the appropriate place, they clean, build the first food pots and start collecting pollen, in addition to bringing cerumen and a mixture of honey and pollen from the mother nest. Subsequently, a larger group of workers accompanied by one or more virgin queens arrive at the new nest, and soon after the queen is fertilized. Contacts between nest-child and nest-mother can remain for a long period, usually until the birth of the first chicks in the nest-child (OLIVEIRA *et al*., 2009).

Therefore, to attract the swarms, wooden boxes or other material are used and a little cerumen and resin are placed inside, which can be taken from other colonies. These boxes must be well closed and have an opening through which the bees can enter, in addition to being placed in protected places, preferably near a colony that can swarm. They must be periodically inspected, removing colonies of ants and/or other animals that may have settled there (KERR *et al*., 1996).

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