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Bee diversity (Hymenoptera, Apoidea) in Araucaria forest in southern Brazil

Diversidade de abelhas (Hymenoptera, Apoidea) em floresta de araucária no sul do Brasil

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ABSTRACT
The apifauna of an araucaria forest in southern Brazil was studied during 2001 – 2003, using entomological nets on flowering plants. A total of 2,749 individuals were sampled from five subfamilies and 93 species of bees. A total of 82 species with up to 10 individuals were sampled and 29 species had no distribution for Santa Catarina. Non-corbiculate Apidae and Halictidae species predominated as well as individuals of corbiculate Apidae and Halictidae. There was a decrease in species richness in cold seasons, being then sampled only *Augochloropsis* sp. 01, *Augochloropsis* sp. 10, *Exomalopsis tomentosa*, *Neocorynura aenigma*, *Paroxystoglossa brachycera*, *Trigona spinipes* and *Apis mellifera*. A bivoltine pattern was noticed, with a peak in May and in September-November, for richness and abundance. Ecological indexes over the months were different with and without *A. mellifera*. The bee accumulation curve remained in elevation until the end of sampling. The richness estimators indicated values of 142 and 175 species. The bee species were sampled on 125 species of plants of 40 famillies and the most visited were Asteraceae, Fabaceae/Solanaceae, Euphorbiaceae/Lamiaceae, Malvaceae/Rosaceae and Commelinaceae/Cucurbitaceae/ Liliaceae/Verbenaceae. A total of 48 species of plants characteristics of araucaria forests were sampled.
Keywords: Apifauna; biodiversity; community study; Santa Catarina; species richness; survey.

RESUMO
A apifauna de uma floresta de araucária no sul do Brasil foi estudada no período 2001 – 2003, por meio de redes de varredura em plantas floridas. Foram amostrados 2.749 indivíduos de cinco subfamílias e 93 espécies de abelhas. Foram amostradas 82 espécies com até dez indivíduos e 29 não têm distribuição descrita para Santa Catarina. Espécies de Apidae não corbiculadas e Halictidae predominaram, bem como indivíduos de Apidae corbiculados e Halictidae. Houve diminuição na riqueza de espécies em épocas frias, quando foram amostrados apenas *Augochloropsis* sp. 01, *Augochloropsis* sp. 10, *Exomalopsis tomentosa*, *Neocorynura aenigma*, *Paroxystoglossa brachycera*, *Trigona spinipes* e *Apis mellifera*. Houve um padrão bivoltino, com um pico em maio e outro em setembro-novembro, para riqueza e abundância. Os índices ecológicos ao longo dos meses foram diferentes com e sem *A. mellifera*. A curva de acumulação de abelhas permaneceu em ascensão até o fim da amostragem. Os estimadores de riqueza indicaram valores de 142 e 175 espécies. As espécies de abelhas foram amostradas sobre 125 espécies de plantas de 40 famílias botânicas, sendo as mais visitadas Asteraceae, Fabaceae/Solanaceae, Euphorbiaceae/Lamiaceae, Malvaceae/Rosaceae e Commelinaceae/Cucurbitaceae/Liliaceae/Verbenaceae. Foram amostradas 48 espécies de plantas características da floresta de araucária.
Palavras-chave: Apifauna; biodiversidade; estudo de comunidades; levantamento; riqueza de espécies; Santa Catarina.

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INTRODUCTION

The araucaria forest is a characteristic south Brazilian (figure 1) and featured an original range between 200,000 and 250,000 square kilometers, which spread over the southern states (40% in Paraná, 40% in Santa Catarina and 20% in Rio Grande do Sul) and as discontinuous patches in the higher parts of the *Serra do Mar, Paranapiacaba, Bocaina* and *Mantiqueira* mountain ranges (in the States of São Paulo, Rio de Janeiro and Minas Gerais) and in Argentina (SCHAEFFER & PROCHNOW, 2002) (figure 2). It is an ecosystem of the Atlantic Forest domain, characterized by the dominant presence of the Brazilian pine (*Araucaria angustifolia*), a conifer with a straight cylindrical trunk and cup-shaped treetop that gives a peculiar aspect to the landscape along with the maritime pine (*Podocarpus lambertii*) and, in the understory, Lauraceae (*Ocotea porous, Ocotea odorifera, Ocotea pulchella*) and Aquifoliaceae (*Ilex paraguariensis, Ilex theezans*) (KLEIN, 1978). Those forests occur in the cooler areas of Brazil, where there is a strong occurrence of fog and frost (three to more than 30 episodes per year) and snow (at least one episode per year in the highest areas) (NIMER, 1990).

Figure 1 – Araucaria forest in Mafra, Santa Catarina state, southern Brazil.

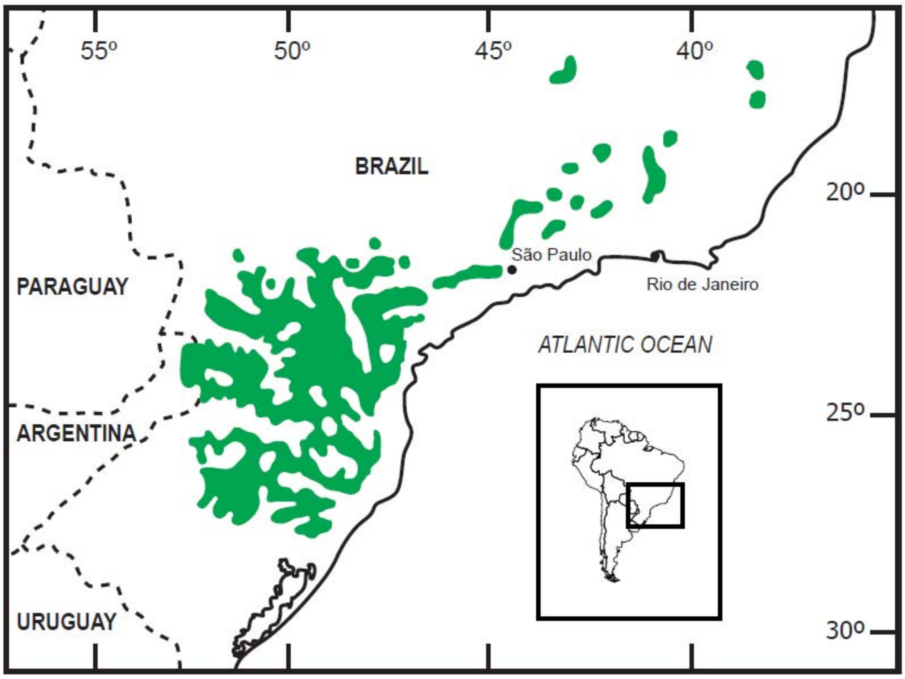


Figure 2 – Distribution of Araucaria angustifolia in southeastern South America. Adapted from Veblen et al. (1995).

Studies about bee communities were held in Araucaria forest in Parana state by Laroca (1974), Bortoli & Laroca (1990), Bazílio (1997) and Jamhour (1998); in Rio Grande do Sul state by Wittmann & Hoffmann (1990), Wilms *et al.* (1997) and Harter (1999) and in Santa Catarina state by Orth (1983), Ortolan & Laroca (1996), Krug (2007) and Krug (2010). However, in the northeastern part of Santa Catarina state, a sedimentary *plateau* region, the araucaria forest apifauna is not known.

To fill this knowledge gap, and define the characteristic bee species of the araucaria forest ecosystem, a survey of bee species and their floral resources was conducted. The hypotheses of this work were: 1 - bee families and species follow a pattern related to geographical distribution; 2 - bee species richness and abundance follow a distribution model linked to seasons; 3 - bee species found have a known distribution for Santa Catarina; 4 - *Apis mellifera* species have an influence on the bee community; 5 - plant species characteristic of araucaria forest are foraged by bees; 6 - ecological indexes show high values; 7 - there are bee species characteristic of araucaria forest formation.

MATERIAL AND METHODS

Study area

The study was conducted in Santa Catarina state, southern Brazil, at the locality of Areal in the municipality of Mafra, (26º07’25”S 49º16’39”W (Greenwich) (SECGP, 1990). The regional climate is characterized by mild summers, with temperatures of the coldest month below 18ºC, with numerous strong frosts, well distributed rainfall during the year, average annual rainfall of 1250-1500 mm, relative humidity around 85% (http://cidades.ibge.gov.br/painel/historico.php?codmun=421010 accessed on Oct 28, 2015). The area is on a wavy to slightly wavy *plateau*, with small altimetric variations and mean altitude of 850 m (IBGE, 1990). The region is in the *Iguaçu* River Basin, by the border between the states of Santa Catarina and Paraná (PRATES *et al.*, 1986). The current local vegetation is composed of large fragments of araucaria forest, interspersed among with crops fields (IBGE, 1995).

Methodology

Daily sampling period was of six hours, in the warmest hours of sunshine days. Observations were independent of daylight saving time. Thirty samplings were conducted, from January 2001 to December 2003, resulting in a 360 hours sampling effort. Data were obtained using the method employed by Sakagami *et al.* (1967): bees were collected on flowers in an area of approximately 30 ha., over a fixed route of approximately 3000 m, including trails and abandoned roads. Bees were captured with entomological nets, prepared and identified to *genus* with the aid of literature (MICHENER *et al.*, 1994; SILVEIRA *et al.*, 2002; MICHENER, 2007; MOURE *et al.*, 2013) and to species with the collaboration of experts (see Acknowledgements). Foraging specimens of *Apis mellifera* Linnaeus, 1758, were recorded in the field not collected. Plants on which bees were captured were recorded, photographed, collected, herbalized and identified with the aid of the literature and the collaboration of experts (see Acknowledgements). All sampled material is deposited in the Bee Laboratory of UNIVILLE (LABEL). Temperature and relative humidity were recorded.

Bees and plants assemblages were characterized qualitatively and quantitatively, considering the numbers of individuals (abundance) and of species (richness). Data collected in different sampling days in the same month were pooled in a single monthly sample. The following ecological indices were computed and calculated on Excel program: the diversity index of Shannon-Wiener (KREBS, 1989), evenness (PIELOU, 1977), dominance (SIMPSON, 1949), species accumulation curve (COLWELL & CODDINGTON, 1994) and the jackknife 1 and jackknife 2 richness estimators (PALMER, 1991). The indices calculated for the study area were compared with the same *ratios,* calculated to other study sites with Araucaria forest that could enable the comparison, that is, that were performed with the Sakagami *et al.* (1967) methodology. The Sørensen Similarity Quotient (QS or SI) was calculated (SOUTHWOOD, 1971) in order to compare data from this study with those of other surveys performed in similar environments.

RESULTS AND DISCUSSION

A total of 2,749 bees were sampled, belonging to 93 species of the five families of Apoidea present in Brazil (table 1). Some *taxa* could not be identified to species because of lack of identification keys including Brazilian species (MARQUES & LAMAS, 2006). Those species were separated into morphospecies for analysis, following morphological descriptives of CRABEU (LABEL's collection of bees) (SILVEIRA *et al.*, 2006).

Table 1 – List de bee species sampled in Mafra, Santa Catarina, Brazil, from January 2001 to December 2003. Legend: nc = non corbiculate; c = corbiculate; * = not signaled for Santa Catarina State according to Moure *et al.* (2013).

Subfamília	Species	J	F	M	A	M	J	J	A	S	O	N	D	Total
Colletidae	*Belopria* sp. Moure, 1956										3			3
	Colletes rugicollis Friese, 1900		2											2
	* *Hexantheda missionica* Ogloblin, 1948			2						1	5	2	1	11
	* *Perditomorpha brunerii* Ashmead, 1899		3											3
	* *Tetraglossula anthracina* (Michener, 1989)	2	3											5
Andrenidae	*Anthrenoides meridionalis* (Schrottky, 1906)		1											1
	* *Anthrenoides ornatus* Urban, 2005											1		1
	* *Anthrenoides paolae* Urban 2005									2				2
	* *Anthrenoides petuniae* Urban, 2005										5	4	1	10
	* *Anthrenoides politus* Urban, 2005											1		1
	* *Anthrenoides rodrigoi* Urban, 2005											1		1
	Callonychium petuniae Cure & Wittmann, 1990			1	1						6	7	1	16
	* *Cephalurgus anomalus* Moure & Lucas de Oliveira, 1962		10	1										11
	* *Psaenythia annulata* Gerstaecker, 1868											1		1
	* *Psaenythia bergii* Holmberg, 1884		2	2									2	6
	* *Rhophitulus holostictus* (Schlindwein & Moure, 1998)										1			1
	* *Rhophitulus politus* (Schlindwein & Moure, 1998)											7		7
	Rhophitulus sp. 01		1											1
	Rhophitulus sp.											1		1
Halictidae	* *Augochlora (A.) foxiana* Cockerell, 1900												1	1
	Augochlora (A.) sp. 02	2	1							2	10	3	7	25
	Augochlora (A.) sp. 04			1						1	2	1		5
	Augochlora (A.) sp. 05			2						2				4
	Augochlora (A.) sp. 11				1									1
	Augochlora (A.) sp. 12				1									1
	* *Augochlorella acarinata* Coelho, 2004										1			1
	Augochlorella ephyra (Schrottky, 1910)											1		1
	Augochlorella urania (Smith, 1853)		1								1			2

Subfamília	Species	J	F	M	A	M	J	J	A	S	O	N	D	Total
	Augochloropsis sp. 01		2	1		1					2		1	7
	Augochloropsis sp. 02			1										1
	Augochloropsis sp. 03		1											1
	Augochloropsis sp. 04	1	3	2	1						1	2		10
	Augochloropsis sp. 05									1				1
	Augochloropsis sp. 07	1			1									2
	Augochloropsis sp. 09		2	2										4
	Augochloropsis sp. 10	2	2	1			1							6
	Augochlora (Oxystoglossella) sp. 03	1											1	2
	* *Neocorynura aenigma* (Gribodo, 1894)								2	1				3
	* *Paroxystoglossa brachycera* Moure, 1960								1					1
	Pseudagapostemo (Neagapostemon) cyanomelas Cure, 1989		1											1
	Pseudagapostemon (P.) arenarius (Schrottky, 1902)				1									1
	Pseudagapostemon (P.) cyaneus Moure & Sakagami, 1984											1		1
	Pseudagapostemon pruinosus Moure & Sakagami, 1984		1								3			4
	Temnosoma sp				1									1
	Caenohalictus sp											1		1
	Dialictus sp		4	1	1						9	7		22
Megachilidae	*Megachile (Chrysosarus) affabilis* Mitchell, 1930		1									1		2
	Megachile (Moureapis) maculata Smith, 1853	1	2	4	2					3				12
	Megachile (Moureapis) pleuralis Vachal, 1909		1									3		4
	Megachile (Moureapis) sp. 02											1		1
	Megachile (Pseudocentron) nudiventris Smith, 1853			1										1
	Dicranthidium arenarium (Ducke, 1907)		1											1
Apidae nc	* *Centris (Hemisiella) tarsata* Smith, 1874		1											1
	* *Centris (Trachina) fuscata* Lepeletier, 1841	1												1
	Centris sp.	1									2		1	4
	* *Gaesischia (G.) nigra* Moure, 1968		1											1
	* *Melissoptila cnecomala* (Moure, 1944)		4											4
	Melissoptila larocai Urban, 1998											3		3
	* *Melissoptila richardiae* Bertoni & Schrottky, 1910											2		2
	* *Melissoptila setigera* Urban, 1998		1	1										2
	Melissoptila thoracica (Smith, 1854)				4									4
	Thygater (T.) paranaensis Urban, 1967												1	1

Subfamília	Species	J	F	M	A	M	J	J	A	S	O	N	D	Total
	* Exomalopsis (Diomalopsis) bicellularis Michener & Moure, 1957									1				1
	Exomalopsis (E.) analis Spinola, 1853	1												1
	Exomalopsis (E.) tomentosa Friese, 1899					1								1
	Exomalopsis (Phanomalopsis) aureosericea Friese, 1899				1									1
	Exomalopsis (Phanomalopsis) trifasciata Brèthes, 1910		6										3	9
	Lanthanomelissa betinae Urban, 1995										1	3		4
	Lophopedia nigrispinis (Vachal, 1909)		1									1		2
	Monoeca sp.	1	1	1										3
	Paratetrapedia fervida (Smith, 1879)		1											1
	* *Tapinotaspoides serraticornis* (Friese, 1899)		1											1
	Coelyoxoides waltheriae Ducke, 1908		1											1
	Tetrapedia diversipes Klug, 1810		1											1
	* *Ceratina (Ceratinula) muelleri* Friese, 1910										1		1	2
	Ceratina (Ceratinula) sp. 04											1		1
	Ceratina (Ceratinula) sp. 05										1			1
	Ceratina (Ceratinula) sp. 07		1											1
	Ceratina (Crewella) sp. 02		1											1
	Ceratina (Crewella) sp. 04		4	1						1	2	1		9
	* *Ceratina (Rhysoceratina) volitans* Schrottky, 1907		3									1	1	5
	* *Xylocopa (Neoxylocopa) frontalis* Olivier, 1789			2										2
	Xylocopa (Stenoxylocopa) artifex Smith, 1874				1					1	2			4
	Xylocopa sp.				1									1
Apidae c	*Bombus (Fervidobombus) morio* (Swederus, 1787)		1		2								1	4
	Bombus (Fervidobombus) pauloensis Friese, 1913	4	32	48	59					1	6		3	153
	Melipona (Eomelipona) marginata Lepeletier, 1836		1		3					3	4			11
	Melipona (Melipona) quadrifasciata quadrifasciata Lepeletier, 1836			1										1
	Plebeia emerina (Friese, 1900)	1	6							3	1	3		14
	Plebeia remota (Holmberg, 1903)		1		2						3			6
	Plebeia saiqui (Friese, 1900)										1			1
	Trigona spinipes (Fabricius, 1793)	3	1	5	17	25	101	27	26	41	24	7	56	333
	Apis mellifera Linnaeus, 1758	68	181	73	324	63	47	88	118	243	287	373	70	1935
	total	90	296	154	424	90	149	115	147	307	384	441	152	2749

Bee famillies and species pattern and geographical distribution

The decreasing sequence of numbers of bee species by family was (separating the Apidae in corbiculate and no corbiculate): no corbiculate Apidae (32 species)> Halictidae (27)> Andrenidae (14)> corbiculate Apidae (9)> Megachilidae (6)> Colletidae (5). The decreasing sequence of numbers of individuals *per* family was (separating the Apidae in corbiculate and non corbiculate): corbiculate Apidae (2458 individuals)> Halictidae (110)> non corbiculate Apidae (76)> Andrenidae (60)> Colletidae (24)> Megachilidae (21). The most abundant bee species were *Apis mellifera*, *Trigona spinipes*, *Bombus pauloensis*, *Augochlora (A.)* sp. 02, *Dialictus* sp., *Callonychium petuniae*, *Plebeia emerina*, *Megachile (Moureapis) maculata*, *Hexantheda missionica*, *Cephalurgus anomalus*, *Melipona marginata*, *Anthrenoides petuniae* and *Augochloropsis* sp. 04. Of the 93 bee species observed, 82 were represented sampled with up to 10 individuals in the sample.

The sequence of family predominance did not follow the pattern usually reported for the temperate and subtropical portions of the Neotropical region whereby Halictidae, non corbiculate Apidae, corbiculate Apidae and Megachilidae have the highest proportion of species and Andrenidae and Colletidae are little abundant groups (between 1% and 10% of the total number of species) (MARTINS, 1994). On the other hand, according to Steiner *et al.* (2006), in terms of species richness for bee families in the southern region of Brazil, faunistic inventories can be distinguished in two main groups: those in which corbiculate Apidae and non corbiculate Apidae prevail (the case of the southern Brazilian coastal zone, associated to the Atlantic Rain Forest; and inventories in which Halictidae prevail (the case of inner regions of Santa Catarina). Data from the present study do not exactly conform to this pattern because Halictidae was second place in number of species as well as in number of sampled individuals.

In terms of community structure, the bee's species association found have many rare species and few abundant ones, in a pattern that Alves-dos-Santos (2007) mentions similar to what happens in other biological communities in southern Brazil.

Bee species richness and abundance distribution and seasonality

Except for *Apis mellifera* and *Trigona spinipes* which were present throughout the year in relatively stable numbers, a decrease in species richness was observed during the cold seasons (figure 3a), from May to August, when only *Augochloropsis* sp. 01, *Augochloropsis* sp. 10, *Exomalopsis tomentosa*, *Neocorynura aenigma* and *Paroxystoglossa brachycera* were sampled. In July, no bees were sampled but *Trigona spinipes* and *Apis mellifera.* No species were observed exclusively during the winter. Many species were sampled only one ou two times.

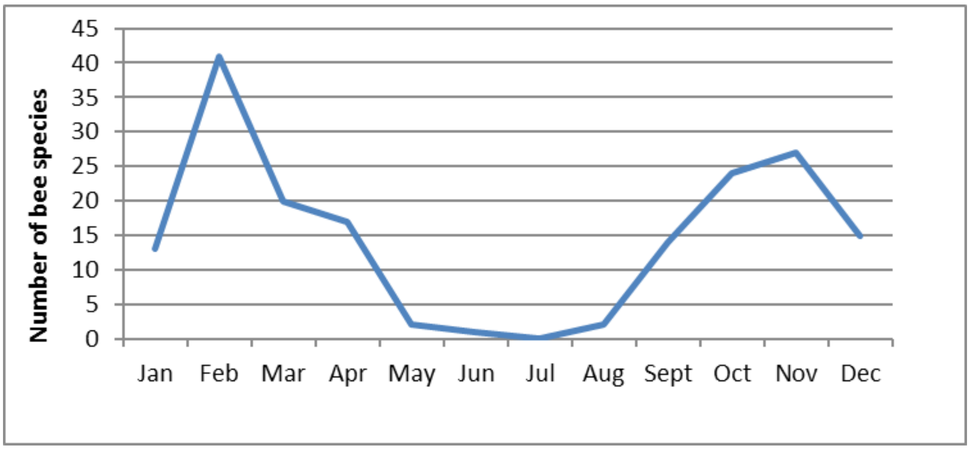


Figure 3a – Number of bee species along the months, during the sampling period (excepting *Apis mellifera* and *Trigona spinipes*).

A bivoltine pattern, with peaks in May and September-November, was observed, for both species richness and abundance (figures 3b and 3c). The bivoltine plan of species richness and individuals abundance correspond, respectively, to the *Indian summer* (that occurs in May when it´s autumn) (MONTEIRO, 2001) and to spring, in a southern shape of bee diversity (ALVES-DOS-SANTOS, 2007).

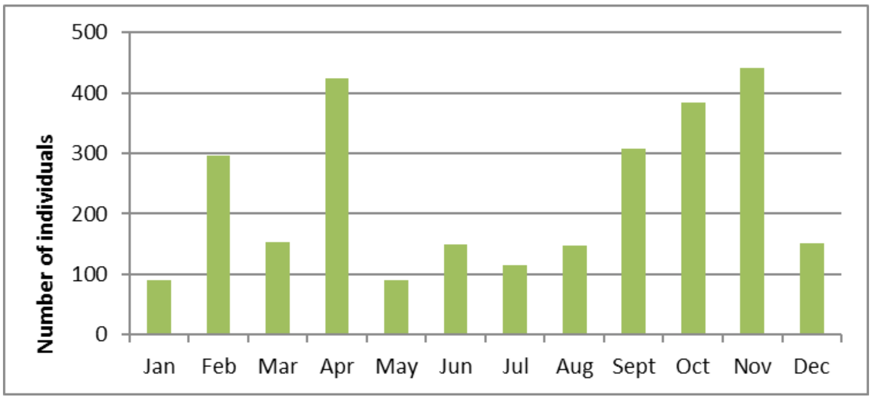


Figure 3b – Number of individuals sampled per month, during the sampling period (with *A. mellifera*).

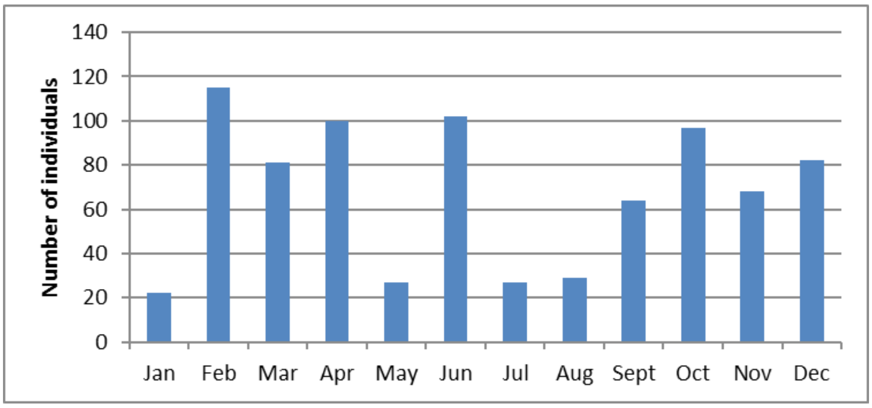


Figure 3c – Number of individuals sampled per month, during the sampling period (without *A. mellifera*).

Bee species distribution in Santa Catarina state

Among the bee species sampled in this work (93), 29 species (31.18%) (marked with an asterisk in table 1), were nor recorded before in Santa Catarina, according to Moure *et al.* (2013). Most of these species were known to occur in neighboring regions (Paraná and Rio Grande do Sul states in Brazil; Santa Fé, Mendoza and Misiones provinces in Argentina; Paraguay and Uruguay). These new records refer to species belonging to Colletidae (3 species), Andrenidae (10), Halictidae (4), Megachilidae (1) and non corbiculate Apidae (11).

Apis mellifera species in the bee community

The monthly species diversities considering and not considering *A. mellifera* were different. Without *A. mellifera*, the highest diversity was reached in February (3,08), the highest eveness in January (0,94) and the highest dominance in July (1,0). The lowest diversity was recorded in the winter (June, July and August).

Plant species characteristic of araucaria and bee species

Bee species were recorded on the flowers of 125 plant species, belonging to 40 families (table 2). The most visited families were Asteraceae (40 species/32%), followed by Fabaceae/Solanaceae (8 species each/6,4%), Euphorbiaceae/Lamiaceae (5/4%), Malvaceae/Rosaceae (4/3,2%) and Commelinaceae/Cucurbitaceae/Liliaceae/Verbenaceae (3/2,4%) (figure 4). There were 48 (38,40%) plant species that are characteristic of araucaria forest (according to Gasper *et al.* (2013) and signaled with an asteristic in table 2).

Table 2 – List of plant species visited by bee species in Mafra, Santa Catarina, Brazil, from January 2001 to December 2003. Species marked with an asterisk are associated with araucaria forest according to Gasper *et al*. (2013). Legend: * = characteristic of araucaria forests according to Sevegnani et al. (2013).

Family	Species
Anacardiaceae	*Lithrea brasiliensis* March.
	Schinus polygamus (Cav.) Cabrera
Asphodelaceae	*Aloe vera* L.
Asteraceae	*Achyrocline satureoides* (Lam.) DC.
	Austroeupatorium inulaefolium (Kunth) R.M.King & H.Rob.
	Ageratum conyzoides L.
	**Baccharis anomala* DC.
	**Baccharis calvescens* DC.
	**Baccharis crispa Spreng.*
	**Baccharis dracunculifolia* DC.
	**Baccharis helichrysoides* DC.
	**Baccharis microdonta* DC.
	**Baccharis semisserrata* DC.
	**Baccharis spicata* (Lam.) Baill.
	**Baccharis trinervis* (Lam.) Pers.
	**Baccharis uncinella DC*
	Bidens pilosa L.
	Calea hispida Baker
	Campuloclinium macrocephalum (Less.) DC.
	Chrysanthemum leucanthemum L.
	**Chromolaena ascendens* (Sch.Bip. ex Baker) R.M.King & H.Rob.
	**Chromolaena laevigata* (Lam.) R.M.King & H.Rob.
	Coreopsis tinctoria Baill
	Elephantopus mollis H. B. K.
	Emilia sonchifolia (L.) DC. ex Wight)
	Eupatorium littorale Cabrera
	Galinsoga parviflora Cav.
	**Gochnatia polymorpha* (Less.)
	Jungia sellowii Less.
	Leptostelma maximus Link. & Otto
	Lessingianthus glabratus (Less.)
	Leucanthemum vulgare (Lam.)
	**Mikania cordifolia* (L. F.) Willd
	**Mikania orleanensis* Hieronymus
	**Senecio brasiliensis* (Spreng.) Less.
	**Senecio oleosus* Vellozo
	Solidago chilensis Meyen.
	Sonchus oleraceus L.
	Tagetes patula L.
	Vernonathura montevidensis H. Rob.
	Vernonanthura puberula Ekman
	Vernonanthura westiniana (Less.)
	Zinnia elegans Jacq.
Balsaminaceae	*Impatiens balsamina* L.
Bignoniaceae	*Arrabidea silloi* (Spreng.) Sandw.
Boraginaceae	*Cordia polycephala* (Lam.) I. J. Johnst.
Brassicaceae	*Raphanus raphanistrum* L.
	Raphanus sativus L.
Cannaceae	*Canna indica* Jussieu
Commelinaceae	*Commelina diffusa* Burm.
	Tradescantia fluminensis Vell.
	Tripogandra diuretica (Mart.) Handlos

Family	Species
Convolvulaceae	*Ipomoea indivisa* (Vell.) Hallier
	Jacquemontia mucronifera Hallier
Cucurbitaceae	*Cucurbita pepo* L.
	Sechium edule (Jacq.) Sw.
	Sicyos polyacanthus Cogn.
Ericaceae	*Gaylussacia brasiliensis (Spr.) Meissner*
Escalloniaceae	*Escallonia bifida Link & Otto*
Euphorbiaceae	*Croton splendidus Mart.*
	Euphorbia heterophyla L.
	Manihot esculenta Crantz
	Sapium glandulosum (L.) Morong
	**Sebastiania commensoniana* (Baill.) Smith & Downs
Fabaceae	**Collaea speciosa (Loisel.) DC.*
	Desmodium adscendens (Sw.) DC.
	**Erythrina crista-gallis* L.
	Phaseolus calcaratus Roxb
	**Mimosa per-dusenii* Burkart
	**Mimosa scabrella* Benth.
	Senna neglecta (Vogel) H.S.Irwin & Barneby
	Vicia sativa L.
Iridaceae	*Gladiolus x. hortulanus* L. H. Bailey
	Sisyrinchium vaginatum Spreng.
Lamiaceae	**Hyptis brevipes* Poit.
	**Hyptis fasciculata* Benth.
	**Hyptis mutabilis* (Rich.) Briq.
	Marsypianthes chamaedris (Vahl) Kuntze
	Stachys arvensis L.
Liliaceae	*Agapantus africanus* (L.) Hoffsgg.
	Allium sativum L.
	Lilium regale E. H. Wilson
Lythaceae	*Cuphea calophilla* Cham. & Schlecht.
	Heimia apetala (Spreng.) S.A.Graham & Gandhi.
Malvaceae	*Malvastrum coromandelianum* (L.) Garcke
	Malviscus arboreus Cav.
	**Pavonia commutata* Garcke.
	Sida rhombifolia L.
Melastomataceae	**Miconia hyemalis* A.St.-Hil. & Naudin
	**Tibouchina urbanii DC*
Myrtaceae	**Myrceugenia eosma (O.Berg) D. Legrand*
	**Myrceugenia ovalifolia (O.Berg) Landrum*
Nymphaeaceae	*Nymphaea caerulea Savigny*
Onagraceae	*Ludwigia sericea* (Cambess.) H. Hara
Oxalidaceae	*Oxalis corymbosa* DC.
Palmae	**Butia eriospatha* (Mart. ex Drude) Becc
Peraceae	*Pera glabrata* (Schott) Poepp. ex Baill.
Phytolaccaceae	*Phytolacca americana L.*
Plantaginaceae	*Veronica persica Poir.*
Poaceae	*Zea mays* L.
Polygalaceae	**Monnina tristaniana A.St.-Hil.*
Polygonaceae	*Polygonum persicarioides* L.
Primulaceae	*Lysimachia arvensis* L.
Rhamnaceae	*Rhamnus sphaerosperma* Swartz.
Rosaceae	*Fragaria vesca* L.
	**Prunus myrtifolia* (L.) Urb.
	**Prunus persica* Sieb. & Zucc.

Family	Species
	Rubus urticifolius Poiret
Rubiaceae	**Borreria capitata* (Ruiz & Pav.) DC.
	**Borreria latifolia* K.Schum.
	**Palicourea australis* C.M.Taylor.
	Spermacoce latifolia Aulb.
Scrophulariaceae	*Buddleja thyrsoides Lam.*
Solanaceae	*Calibrachoa linoides (Sendltn.) Wijsman.*
	Nicotiana tabacum L.
	**Petunia integrifólia* (Hook.) Schinz & Thellung
	**Petunia scheideana Steud.*
	**Solanum aculeatissimum* Jacq.
	**Solanum grandiflorum* Ruiz & Pav.
	**Solanum lacerdae* Dusén
	**Solanum variabile* Mart.
Theaceae	*Camellia japonica* L.
Verbenaceae	*Lantana camara* L.
	**Verbena bonariensis L.*
	**Verbena littoralis* Kunth

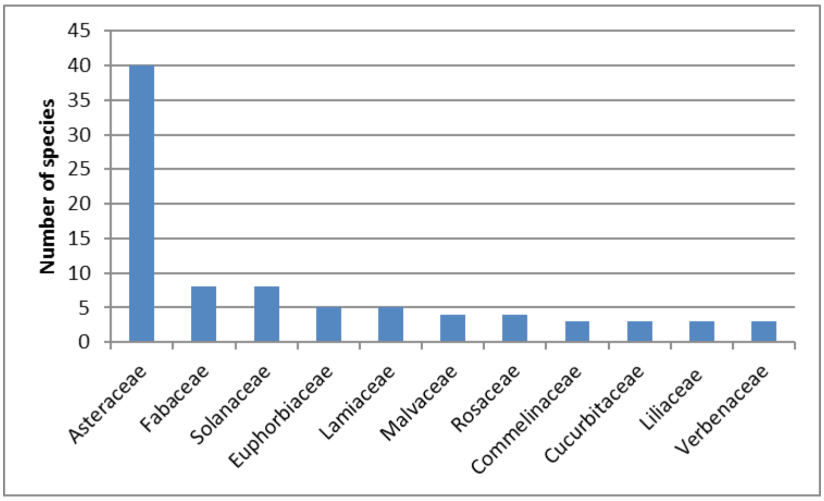


Figure 4 – Number of bee species sampled per botanic family in the municipality of Mafra, Santa Catarina.

The number of bee plants sampled in this work (125) is higher than most of the ones reported in other studies done in araucaria forests as Orth (1983) reported 69 plant species, Bortoli & Laroca (1990) 83, Ortolan & Laroca (1996) 64, Bazílio (1997) 72, Jamhour (1998) 67, Harter (1999) 188 and Krug (2007) 97.

Bees forage as well in the canopy as in the understory but in the present study were sampled on the flowers in the ground, mainly in the understory of the araucaria forest, where there is a great and complex variety of plants, including many characteristic and endemic species (LEITE & KLEIN,1990) as the araucaria forest of the *plateau* includes 1,107 spécies of trees, schrubs, herbs, vines, ephytes and, among these, 181 spécies of ferns and two Pinidae (Gymnosperms) (SEVEGNANI *et al*., 2013).

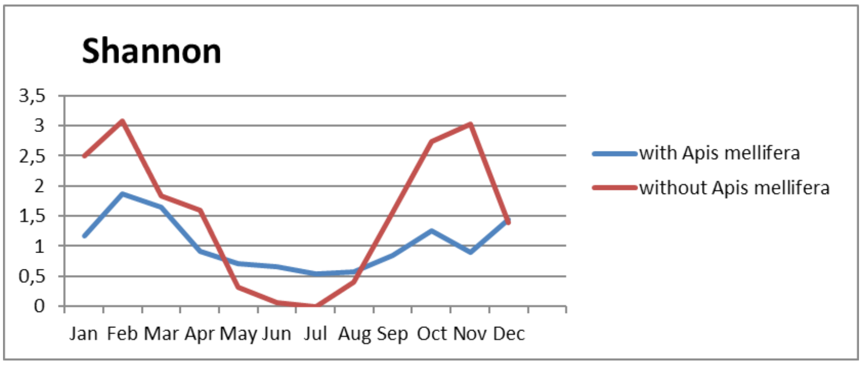
Plant species visited by the bee species and specially related to araucaria forest included, among others, *genera Baccharis, Chromolaena, Mikania, Senecio* and *Vernonanthura* (Asteraceae), *Mimosa* (Fabaceae), *Hyptis* (Lamiaceae), *Myrceugenia* (Myrtaceae), *Borreria* (Rubiaceae), *Petunia* and *Solanum* (Solanaceae), *Verbena* (Verbenaceae). Many of these *taxa* are reported as attractive to bees by the other studies mentioned, performed in araucaria forests. Because of its botanic richness, many beekeepers install their hives in this kind of ecosystem, thus increasing the presence of *Apis mellifera* in araucaria formations.

Ecological indexes and other araucaria studies

The monthly variation of the species diversity, as measured by Shannon-Wiener, Simpson and Pielou´s indices, is presented in table 3 and figures 5 and 6. Shannon-Wiener's median value was of 2.65, Pielou's median value varied from J" = 0.307 (including *A. mellifera*) to J" = 0.586 (excluding *A. mellifera*), and Simpson's median values resulted in D = 0.514 and D = 0.207 (with and without *A. mellifera*, respectively).

Table 3 – Variation of indexes (Shannon-Wiener, Pielou, Simpson), with and without *Apis mellifera*, during the sampling months.

Indexes / Months	Shannon-Wiener		Pielou		Simpson	
	with Apis mellifera	without Apis mellifera	with Apis mellifera	without Apis mellifera	with Apis mellifera	without Apis mellifera
January	1,167294	2,500138	0,431046	0,94736	0,576543	0,095041
February	1,873883	3,084908	0,495187	0,820192	0,38648	0,098841
March	1,654282	1,829909	0,535186	0,601049	0,325097	0,362902
April	0,920724	1,587778	0,312699	0,549333	0,605164	0,3818
May	0,705483	0,315396	0,508899	0,287086	0,567407	0,860082
June	0,6611	0,055099	0,601759	0,07949	0,559029	0,980584
July	0,544991	0	0,786256	0	0,640681	1
August	0,575211	0,398441	0,414927	0,362676	0,675876	0,80975
September	0,837217	1,560401	0,301962	0,576208	0,644856	0,421875
October	1,254535	2,729002	0,385052	0,847812	0,56505	0,101073
November	0,897622	3,033203	0,266571	0,910269	0,716846	0,061419
December	1,442211	1,394292	0,509037	0,502885	0,351368	0,478584



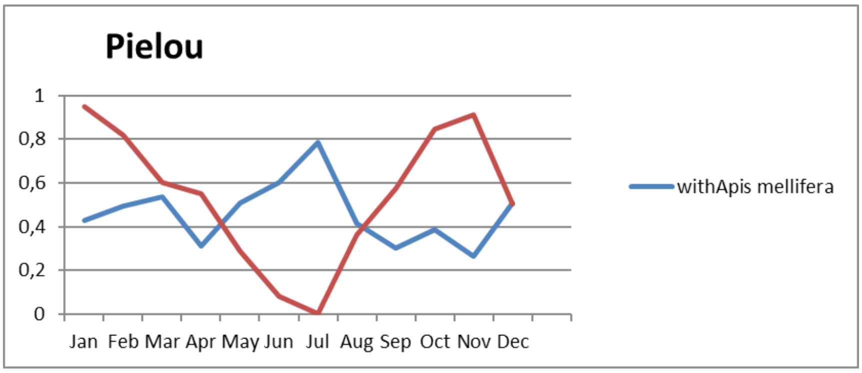


Figure 5 – Variation of Shannon-Wiener diversity index and Pielou equability index, during the sampling months, with and without *Apis mellifera*.

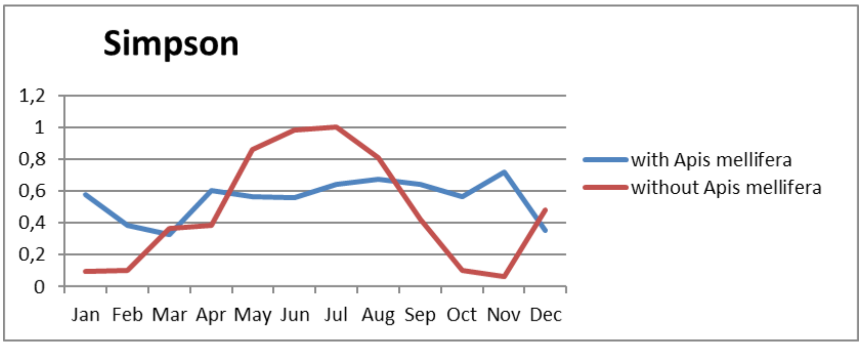


Figure 6 – Variation of Simpson's dominance index during the sampling months, with and without *Apis mellifera.*

It is observed that the Shannon-Wiener (SW) diversity index obtained in this study (2.65) is a median value, lower than those calculated for the other studied araucaria formations (table 4), except for the work of Orth (1983). The fact that SW index have not been very high compared to other studies conducted in similar formations can be explained by the fact that its calculation takes into account also the abundance of each species, which ultimately influence the outcome of actual diversity of the place (MAGURRAN, 2004). When analyzed month by month, one observes that the SW shows a big drop in winter and another, smaller, in the summer peak, in a seasonal pattern, which Pinheiro-Machado (2002) reports, for bee surveys in South Brazil, as a model of temperate activity. SW showed litlle fluctuation when it took into account *A. mellifera* in the calculations. Excluding this species, the diversity plummeted during the winter.

Table 4 – Diversity index of Shannon-Wiener (SW), equability of Pielou (P) and dominance of Simpson (S), calculated for studies done in araucaria forest in southern region of Brazil. The distance refers to the municipality of Mafra (this study).

Studies	Altitude (m)	Study duration (months)	Number of species	Indices			Distance (km)	Municipalities
				SW	P	S		
Orth, 1983	950	13	142	2,488	0,493	0,756	196	Caçador (SC)
Bazílio, 1997	1120	12	127	3,567	0,736	0,932	259	Guarapuava (PR)
Jamhour, 1998	760	14	151	3,768	0,751	0,949	361	Pato Branco (PR)
Harter, 1999	600-960	38	187	3,902	0,747	0,960	507	São Francisco de Paula (RS)
Krug, 2007	794	13	164	4,413	0,866	0,979	147	Porto União (SC)
Krug, 2010	550	26	110	3,576	0,780	0,944	321	Concórdia (SC)
This study	850	35	93	2,650	0,586	0,793		Mafra (SC)

Regarding evenness, Pielou's index obtained in this study (0.586 excluding *A. mellifera*) indicates no great dominance, among native species, of one or a few species, as it´s an intermediate value, setting that a little more than half of the species are equally abundant with each other. In the other araucaria sites studied, the values were higher, denoting that there were more also abundant species. The evenness ranged from 0.79 in November to 0.27 in July, possibly due to, in late winter, plenty of individuals being concentrated in a few species, which are those that remain active in the cold season. The variation of the values of Pielou´s index has not been addressed in studies of bee communities, although it is possibly linked to effects of interspecific interactions.

Simpson's index (indirect or 1-D) obtained in this study (0.793) expresses a context of little dominance, which is most evident in other studied araucaria sites. The index was relatively stable when it took into account *A. mellifera*. Excluding this species, the dominance soared during the winter. *A. mellifera* was the most dominant species throughout the period and, in its absence, few species dominated during winter. *A. mellifera* is an exotic species to Brazil, often reared in countryside, and, in several regions of secondary vegetation, has overcome in number of individuals all the others species of wild bees (LAROCA, 1974).

The bee species accumulation curve (figure 7) remained in ascension till the end of the sampling, indicating that there are still more species to be sampled in the area.

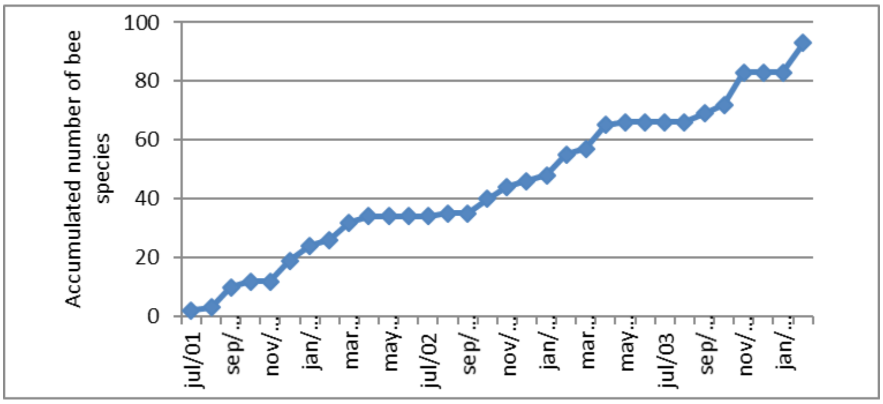


Figure 7 – Bee species accumulation curve during the sampling period.

The observed richness (93 species) was used for calculating the richness estimators jackknife 1 and 2, which indicated of the total bee assemblage in the area to be composed by 142 and 175 species, respectively. Species appearing only in one only one (singletons) or two (doubletons) samples were used as parameters to prevent the results from being affected by the high number of individuals of some species (COLWELL & CODDINGTON, 1994).

The number of species reached by the accumulation curve is 65.5% and 53.14% of the jackknife 1 and 2 estimators, respectively. These numbers indicate that alternative strategies must be implemented on the study site in order to obtain a closer estimate of the apifauna (KRUG & ALVES-DOS-SANTOS, 2008). The complete sample of local species is virtually impossible as one can not collect all the bee species occupying a particular area since all favorable climatic variations to the activity of all kind of species are unlikely to occur, mainly because of the fact that optimal conditions for some are unfit for others and therefore there is always a rising curve while sampling remains (SANTOS, 2003).

Bee species characteristic of araucaria forest formation

According to table 5, the number of bee species sampled in this work (93) is lower than the ones reported in other studies done in araucaria forest as Orth (1983) reported 142 bee species, Bortoli & Laroca (1990) 167, Ortolan & Laroca (1996) 127, Bazílio (1997) 127, Jamhour (1998) 151, Harter (1999) 187 and Krug (2007) 164. This situation may be due, among other possible explanations, to the degree of human interference on near restricted areas (culture exploitation, urbanisation processes) that alters the bee abundance and richness (ORTH, 1983). The numbers obtained by Soerensen index were not very high but offer the possibility of comparison of the values, that is interesting by the parallelism it can show. The highest similarity was that of the apifauna of *Porto União* and *Caçador*, municipalities 147 and 196 km away respectively. Geographical proximity did not always explained similarity as neighboring localities such as São José dos Pinhais and Boa Vista (the nearest ones) showed low similarity with the study site of this work. According to Heithaus (1979) and others, nearby environments, but with different vegetation types, involve quite distinct apifaunas while geographically distant plant communities, if physiognomically similar, have more analogous melissofaunas.

Table 5 – Similarity of apifauna (Soerensen index) sampled in this study with others performed in araucaria forests in southern areas of Brazil. The mentioned authors are listed in References.

Authors	Year	Place	Distance (Km)	Altitude (m)	Geographic coordinates	Soerensen´s similarity index	Number of species of the study	Number of species in common
Krug	2007	Porto União, SC	147	794	26°14'34'' S 51°4'28'' W	0,327	164	42
Orth	1983	Caçador, SC	196	950	26º46'31" S 51º00'54" W	0,249	156	31
Figueiredo & Alves-dos-Santos	2003	Aparados da Serra, RS	416		29°11'30" S 50°5'51" W	0,222	24	13
Harter	1999	São Francisco de Paula, RS	507	960	29°26'49" S 50°34'45" W	0,214	187	30
Bazílio	1997	Guarapuava, PR	259	1120	25º23'26" S 51º27'15" W	0,209	127	23
Laroca	1974	Boa Vista, Curitiba, PR	116	945	25º25'40" S 49º16'23" W	0,197	146	25
Jamhour	1998	Pato Branco, PR	361	765	26°13'46'' S 52°40'18'' W	0,189	151	23
Laroca	1974	São José dos Pinhais, PR	115	900	25°31'51" S 49°11'45" W	0,162	123	21
Ortolan	1989	Lages, SC	195	930	27°49'0" S 50°19'35" W	0,158	135	18
Bortoli & Laroca	1990	São José dos Pinhais, PR	115	900	25°31'51" S 49°11'45" W	0,1462	167	19
Wilms *et al.*	1997	São Francisco de Paula, RS	507	960	29°26'49" S 50°34'45" W	0,085	48	6
This work	2016	Mafra, SC		850	26°6'42'' S 49°48'25'' W		93	

The number of bee species in other araucaria forest sites in southern Brazil (table 5) is high, indicating that the apifauna of this plant formation is quite rich. The verification of the apifauna sampled in other works show some bee species in common (species appeared in at least three studies), that could be characterisitic of the araucaria forest, since their distribution is restricted to southern Brazil, in this type of plant formation or to neighboring countries, according to Moure *et al.* (2013). These are: Colletidae with one species (*Chilicola dalmeidai*), Andrenidae with three (*Psaenythia bergi*, *P. colaris*, *P. quadrifasciata*), Halictidae with eight (*Augochlora semiramis*, *Caenohalictus implexus*, *Dialictus phleboleucus*, *Paroxystoglossa brachycera*, *Pseudagapostemon cyaneus*, *P. cyanomelas*, *Rhectomia pumilla*), Megachilidae with three (*Megachile apicipennis*, *M. nigropilosa*, *M. pleuralis*), non corbiculate Apidae with three (*Ceratina asuncionis*, *Lanthanomelissa betinae*, *Melissoptila larocai*) and corbiculate Apidae with one (*Plebeia emerina*).

Pinheiro-Machado (2002) pointed out a regional fauna to southern Brazil, a fact exemplified by Orth (1983), who mentionned that the occurrence, in *Caçador/* Santa Catarina, of many *genera* and species present bees in the Parana *plateau* (located approximately 300 km away) previews the existence of a common basic structure to the whole araucaria forest region in southern Brazil. The pattern of the apifauna sampled in this study stays at an intermediate standard between studies in Parana and Santa Catarina. According to Silveira *et al.* (2002), it seems to exist an association between the bee species richness and the botanic formation, beyond the latitudinal gradient of species diversity, although the factors that determine this association are not apparent. Krug (2010), in turn, found high similarity between some bee communities and attributed this fact to a latitudinal pattern of richness.

The interactions observed between the plant species characterisitic of the araucaria forest and the apifauna permit a discern of the representation of this vegetation type along the time as it is known that the apifauna develops close relations, including co-evolutionary, with the plant resources that it explores (MOLDENKE, 1994). Accordind to Behling (2002), at the beginning of the last glacial period, araucaria forests were confined to gallery forests along the river courses; when temperatures got milder, these woods began to expand upwards the mountains and so, around 3,000 B.P., there were large areas of grasslands with scattered araucarias in the landscape, a vegetation which would have supported minimum temperatures down to -10°C. A significant expansion of montane araucaria forests upwards the high regions of southern Brazil is mostly found in records of Rio Grande do Sul and Santa Catarina States after 1,000 years B.P., and of Paraná State (Serra dos Campos Gerais) after 1,500 years B.P. (BEHLING & Lichte, 1997). The fact that there are still many bee species foraging on characteristic flora of araucaria forest is an evidence of the importance of this ecosystem. Nowadays, the araucaria forest is a very threatened environment. The knowledge about extant bee communities can help to understand its structure and evolution and support its maintenance.

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