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THE BEE COMMUNITY OF ILHA DAS FLORES, BABITONGA BAY, SANTA CATARINA STATE, BRAZIL

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ABSTRACT

This study carried out a survey of native bee species and their floral resources at Ilha das Flores, an island located in the Babitonga Bay, Santa Catarina State, Brazil. Specimens were captured with entomological nets, pantraps and aromatic baits. A total of 1,120 individual bees, representing 60 species distributed in four families and 47 plant species of 24 families, was sampled. Buzz-pollination by Centridini, Xylocopini and Bombini on Fabaceae plants, specific interaction between Emphorini and Convovulaceae and illegitimate visits were observed. Seasonal nesting was noticed. There was high diversity and equitability while dominance was low. Decrease of bees' richness and abundance in relation to the mainland, lack of Meliponini, high number of *Dialictus* sp. and the occurrence of the genus *Hylaeus* was remarked. Similarity was great with the continent, suggesting colonization from the mainland. Insularity seems to have played a role in bee assortment. The present bee community is probably due to palaeo environmental events that shaped the Babitonga Bay.

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INTRODUCTION

Studies in islands have been fundamental in the area of evolutionary biology and ecology, since they have contributed in the elucidation of concepts integrated to contemporary ecology, such as competition, adaptation, extinction, colonization, succession and dispersion. Advances in the understanding of the population fluctuations in relation to size and isolation of the insular habitat were made possible as well as the comprehension of the dynamics of the fragments of vegetation in the continent. Despite the fundamental role of the bees as pollinators in the environment, studies on bee communities on islands are scarce in Brazil. In Southern Brazil, studies about island apifaunas were carried out by Schwartz Filho and Laroca (1999) and Zanella (2005), who made comparisons between bee communities of *Ilha do Mel* and *Ilha das Cobras*, two islands in Parana State, and the bee community of Alexandra, also in Parana State, on the mainland.

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In the northern part of the Santa Catarina State, the Babitonga Bay comprises an area of approximately 160 km^2 and includes mangroves, sandy beaches and rocky banks, and more than 200 islands (Mouga *et al.,* 2018). Studies on apifauna carried out in the region include bee surveys in dense lowland rainforest, mangroves and sand dunes (Mouga *et al.,* 2015; Mouga and Nogueira-Neto, 2015; Dec and Mouga, 2014; Mouga and Dec, 2015; Warkentin and Mouga, 2016; Possamai *et al.,* 2017). However, the apifauna on the islands of Babitonga Bay was not yet object of study. In order to contribute to the knowledge about the bee fauna of the island *Ilha das Flores*, we conducted a one year study. The null hypothesis is that, due to the short distance between the island and the continent, and the size of the island, there will be great similarity between faunas of these neighboring places as well as specific and generalized interactions with the flora.

MATERIALS AND METHODS

Study area: *Ilha das Flores* (26º15'25 .63 "S and 48º41'17.91" W) (Figure 1) has an area of 9.15 ha, an irregular shape due to concave cuts, being bordered by a 7 meters wide sand strip on the north border and rocks on the other borders. It is distant 1,224 meters from the locality Vila da Gloria on the mainland and is near to other islands in the bay: 300 meters from *Ilha dos Herdeiros*, 1,700 meters from *Ilha da Rita* and 1,800 meters from *Ilha Grande*. It is located in the central portion of Babitonga Bay, that has a maximum length of 20 km and up to 5 km wide, inserted in the Quaternary Plain, formed by fluvial-marine sedimentation, a flat area that occupies a strip of approximately 35 km wide, where there are meandering rivers, deposits of rolled pebbles and sands (Knie, 2002). Climate is Cfa type (Köppen) , accumulated rainfall is about 1700-2100 mm per year with seasonal distribution, maximum altitude is of 41 meters, soil is of cambisol type, vegetation consists of sand dunes, mangroves and lowland rain forest (Mouga *et al.,* 2018).

Apifauna survey: Bees were sampled on flowering plants, during six hours per day, fortnightly, along a transect of approximately 1,500 m, in all subareas of the island, during one year, by two collectors. Specimens were captured with entomological nets, placed in ethyl acetate and each collected individual received an identification number (date, place, time of collection and number of the plant on which it was found). Pantraps and aromatic baits (containing eugenol, cineol, vanillin, benzyl acetate, methyl cinnamate and methyl salicylate essences) for Euglossini bees were used (Sofia and Suzuki, 2004). Nests were searched throughout the island all over the study. Meteorological data (temperature, luminosity index, relative humidity, wind and precipitation) were recorded (but will not be discussed). All bee specimens were prepared and identified using specific literature (Silveira *et al.,* 2002) and consulting specialists (see Acknowledgements) and are maintained in the reference collection of bees at LABEL-Laboratorio de Abelhas of UNIVILLE-University of the Region of Joinville. Bee plants were collected, herborized for the preparation of exsiccates, identified using specific literature (plant identification follows APG III (2009)) and consulting specialists (see Acknowledgements) and are maintained in the LABEL Herbarium. For quantitative analyses, the diversity (Shannon-Wienner-SW), equability (Pielou-P), dominance (Simpson-S) and the similarity (Sørensen) indexes (Krebs, 1989) were calculated with Paleontological Statistics - PAST Program. The species richness estimator (Chao 1-C1) (Chao, 2010) was also calculated in PAST. The degree of specialization of the network (H'2) was calculated with bipartite package (Dormann *et al.,* 2008) in R (Dormann *et al.,* 2009). In order to evaluate the degree of nesting of the pollination network, we used the NODF index (Nestedness metric based on Overlap and Decreasing Fill) (Almeida-Neto *et al.,* 2008), calculated in ANINHADO (Guimarães and Guimarães, 2006).

RESULTS

Bee species diversity: The species accumulation curve (Figure 2) shows that, from the eighteenth sampling on, there was stabilization, indicating sampling sufficiency, with a total of 60 species sampled. These species represent 11 tribes and four families (Apidae, Colletidae, Halictidae and Megachilidae) (Table 1) and totaled 1,120 individuals. Halictidae and Apidae had the largest numbers of species and individuals with 33 and 17 species and 394 and 686 individuals (378 corbiculate and 308 no corbiculate), respectively (Figures 3 and 4). Augochlorini presented great richness and abundance. No specimens of Andrenidae were found. One individual of Colletidae, genus *Hylaeus,* was sampled and it is a new occurrence for Santa Catarina State. A total of 11 sampled species are not mentioned in Moure *et al.* (2012) as occurring in Santa Catarina State (marked with asterisk in Table 1). The most abundant species was *Apis mellifera* (Linnaeus, 1758) with 225 specimens, followed by *Dialictus* sp. 01 (n= 219), *Epicharis (Epicharana) flava* (Friese, 1900) (n=165) and *Trigona spinipes* (Fabricius, 1793) (n=108). There was variation in abundance and in richness throughout the year (Figure 5) as the smaller values of richness and abundance were in winter, and the greatest in spring (abundance) and summer (richness). The greatest abundance and richness occurred in the period from 10 am to 1 pm (Table 2, Figure 6).

Bee-plant interactions: The composition of the melithous flora sampled in *Ilha das Flores* is represented by 47 plant species representing 24 botanical families (Table 3). The families that attracted the highest number of bees were Asteraceae (260 visits), Fabaceae (134 visits), Myrtaceae (79 visits) and Malvaceae (54 visits). Among the most visited plant species are *Coreopsis lanceolata* L. (93 visits), *Senna macranthera* (DC. ex Collad.) H. S. Irwin & Barneby (86 visits) and *Sphagneticola trilobata* (L.)Pruski (63 visits). The bee species *Melitoma segmentaria* (Fabricius, 1804) was sampled only on *Ipomoea* species (Convovulaceae). Bee species of *Megachile* shared the same resource, since all were sampled on *Stylosanthes viscosa* (L.) Sw. (Fabaceae). Bee species of *Bombus morio* (Swederus, 1787), *Epicharis flava*, *Centris* (*Trachina*) *similis* (Fabricius, 1804), *Centris* (*Melacentris*) *obsolete* Lepeletier, 1841, *Xylocopa brasilianorum* (Linnaeus, 1767) and *Xylocopa frontalis* (Olivier, 1789) were observed extracting pollen from anthers of *Senna pendula* (Humb. & Bonpl.ex Willd.) H. S. Irwin & Barneby (Fabaceae) and *Senna macranthera* (Fabaceae) by buzz-pollination. Illegitimate visits of the bee species *Xylocopa brasilianorum* and *Pseudaugochlora graminea* (Fabricius, 1804) were observed when these visitors accessed the floral resource through the perforation of the flower base of *Malvaviscus arboreus* specimens (Malvaceae).

Nests: Nests aggregations of Centridini were identified as about 75 to 90 entries of ephemeral nests, whose individuals were identified as of *Epicharis flava*. The nesting area was located in the coastal zone of the island, near the beach, from December 2016 until the end of January 2017. *Epicharis flava* maintained flight activities from December 2016 to the end of April 2017. Individuals were observed collecting pollen from *Coreopsis lanceolate* (Asteraceae), *Hibiscus rosa-sinensis* L. (Malvaceae), *Senna pendula* and *S. macranthera* (Fabaceae). In the last two botanic species (*Senna),* buzzing was observed.

Ecological indexes: The indexes of dominance (S), diversity (SW), equitability (P) and the species richness estimator (C1) varied over months (Table 4 and Figure 7). From December to April (summer), the diversity and the equitability were greater. The highest values attained by the indexes were: diversity (SW) H '= 2.77, equitability (P) J = 0.88, dominance (S) 1-D = 0.91 and the richness estimator indicates that there may be an amount of 79 bee species (there were 60 observed). The bee and plant species sampled in this work allow the existence of 2,820 interactions between the bee flora and the melissofauna, including *Apis mellifera* (Figure 8). From out 2, 820 possible interactions, there were 2,022 observed. From this total, the bee species that established the greatest number of interactions were: *Apis mellifera* with 225 interactions with 25 plant

Table 1. Bee species sampled at *Ilha das Flores* Island, São Francisco do Sul, Santa Catarina State, Brazil. Captions: * = no signaled species in Moure *et al.* (2012) as occurring in Santa Catarina State

Subfamily	Tribe	Species	Abundance
Apidae	Apini	*Apis mellifera scutellatta* Lepeleteir, 1836	225
Apidae	Bombini	*Bombus* (Thoracobombus) *morio* (Swederus, 1787)	45
Apidae	Centridini	*Centris* (*Trachina*) *similis* (Fabricius, 1804)*	13
Apidae	Centridini	*Centris* (*Melacentris*) *obsoleta* Lepeletier, 1841*	39
Apidae	Centridini	*Epicharis* (*Epicharana*) *flava* (Friese, 1900)	166
Apidae	Emphorini	*Melitoma segmentaria* (Fabricius, 1804)*	6
Apidae	Exomalopsini	*Exomalopsis* (*Exomalopsis*) *analis* Spinola, 1853	5
Apidae	Exomalopsini	*Exomalopsis* (*Exomalopsis*) *auropilosa* Spinola, 1853*	1
Apidae	Exomalopsini	*Exomalopsis* (*Exomalopsis*) *vernoniae* Schrottky, 1909*	1
Apidae	Exomalopsini	*Exomalopsis* (*Phanomalopsis*) *trifasciata* (Brèthes, 1910)	2
Apidae	Meliponini	*Trigona spinipes* (Fabricius, 1793)	108
Apidae	Xylocopini	*Ceratina (Ceratinula)* sp. 01	4
Apidae	Xylocopini	*Ceratina (Crewella) maculifrons* Smith, 1854*	14
Apidae	Xylocopini	*Ceratina (Crewella)* sp. 14	1
Apidae	Xylocopini	*Ceratina (Crewella)* sp. 18	1
Apidae	Xylocopini	*Xylocopa (Neoxylocopa) brasilianorum* (Linnaeus, 1767)	29
Apidae	Xylocopini	*Xylocopa (Neoxylocopa) frontalis* (Olivier, 1789)*	26
Colletidae	Hylaeini	*Hylaeus (Gongyloprosopis)* sp. 01	1
Halictidae	Augochlorini	*Augochlora (Augochlora) cydippe* (Schrottky, 1910)*	1
Halictidae	Augochlorini	*Augochlora (Augochlora) dolichocephala* (Moure, 1941)*	5
Halictidae	Augochlorini	*Augochlora (Augochlora)* sp. 01	7
Halictidae	Augochlorini	*Augochlora (Augochlora)* sp. 03	1
Halictidae	Augochlorini	*Augochlora (Augochlora)* sp. 04	4
Halictidae	Augochlorini	*Augochlora (Augochlora)* sp. 07	4
Halictidae	Augochlorini	*Augochlora (Augochlora)* sp. 08	1
Halictidae	Augochlorini	*Augochlora (Augochlora)* sp. 15	2
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 01	18
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 02	2
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 04	4
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 05	3
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 07	8
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 08	3
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 09	3
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 12	2
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 13	1
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 14	1
Halictidae	Augochlorini	*Augochlora (Oxystoglossella)* sp. 16	1
Halictidae	Augochlorini	*Augochlorella ephyra* (Schrottky, 1910)	3
Halictidae	Augochlorini	*Augochlorella* sp. 02	1
Halictidae	Augochlorini	*Augochlorella urania* (Smith, 1853)	1
Halictidae	Augochlorini	*Augochloropsis imperialis* (Vachal, 1903)	2
Halictidae	Augochlorini	*Augochloropsis* sp. 01	3
Halictidae	Augochlorini	*Augochloropsis* sp. 03	58
Halictidae	Augochlorini	*Augochloropsis* sp. 05	3
Halictidae	Augochlorini	*Augochloropsis* sp. 06	1
Halictidae	Augochlorini	*Augochloropsis* sp. 07	3
Halictidae	Augochlorini	*Augochloropsis* sp. 14	3
Halictidae	Augochlorini	*Augochloropsis* sp. 19	1
Halictidae	Augochlorini	*Pseudaugochlora graminea* (Fabricius, 1804)	21
Halictidae	Halictini	*Dialictus* sp. 01	219
Halictidae	Halictini	*Pseudagapostemon* sp. 01	4
Megachilidae	Megachilini	*Coelioxys (Acrocoelioxys) aculeaticeps* Friese, 1921*	3
Megachilidae	Megachilini	*Coelioxys (Rhinocoelioxys) mesopotamica* Holmberg, 1918	1
Megachilidae	Megachilini	*Megachile (Acentron)* sp. 01	5
Megachilidae	Megachilini	*Megachile (Leptorachis) aetheria* (Mitchell, 1930)*	7
Megachilidae	Megachilini	*Megachile (Moureapis) pleuralis* Vachal, 1908	3
Megachilidae	Megachilini	*Megachile (moureapis)* sp. 01	6
Megachilidae	Megachilini	*Megachile (Pseudocentron) nudiventris* (Smith, 1853)	11
Megachilidae	Megachilini	*Megachile (Pseudocentron)* sp. 01	2
Megachilidae	Megachilini	*Megachile* sp. 02	1

Table 2. Values of temperature (°C), relative humidity of the air (%), luminosity (lux), wind (m/s), abundance and richness of bees, during the hours of sampling, at Ilha das Flores, São Francisco do Sul, Santa Catarina State, Brazil

Time	Temperature (°C)	Relative umidity of the air (%)	Luminosity (lux)	Wind (m/s)	Abundance	Richness
09:00 -09:59	24,1	87,1	0,5	184,8	87	21
10:00 - 10:59	24,9	82,7	1,3	190,9	198	27
11:00- 11:59	25,3	79,9	1,5	204,5	178	28
12:00 -12:59	26,8	78,7	1,8	203,0	195	30
13:00 -13:59	27,4	76,0	3,1	210,8	98	24
14:00 - 14:59	28,0	78,0	3,3	204,0	59	18
15:00 - 16:00	26,6	74,0	3,8	201,7	60	15

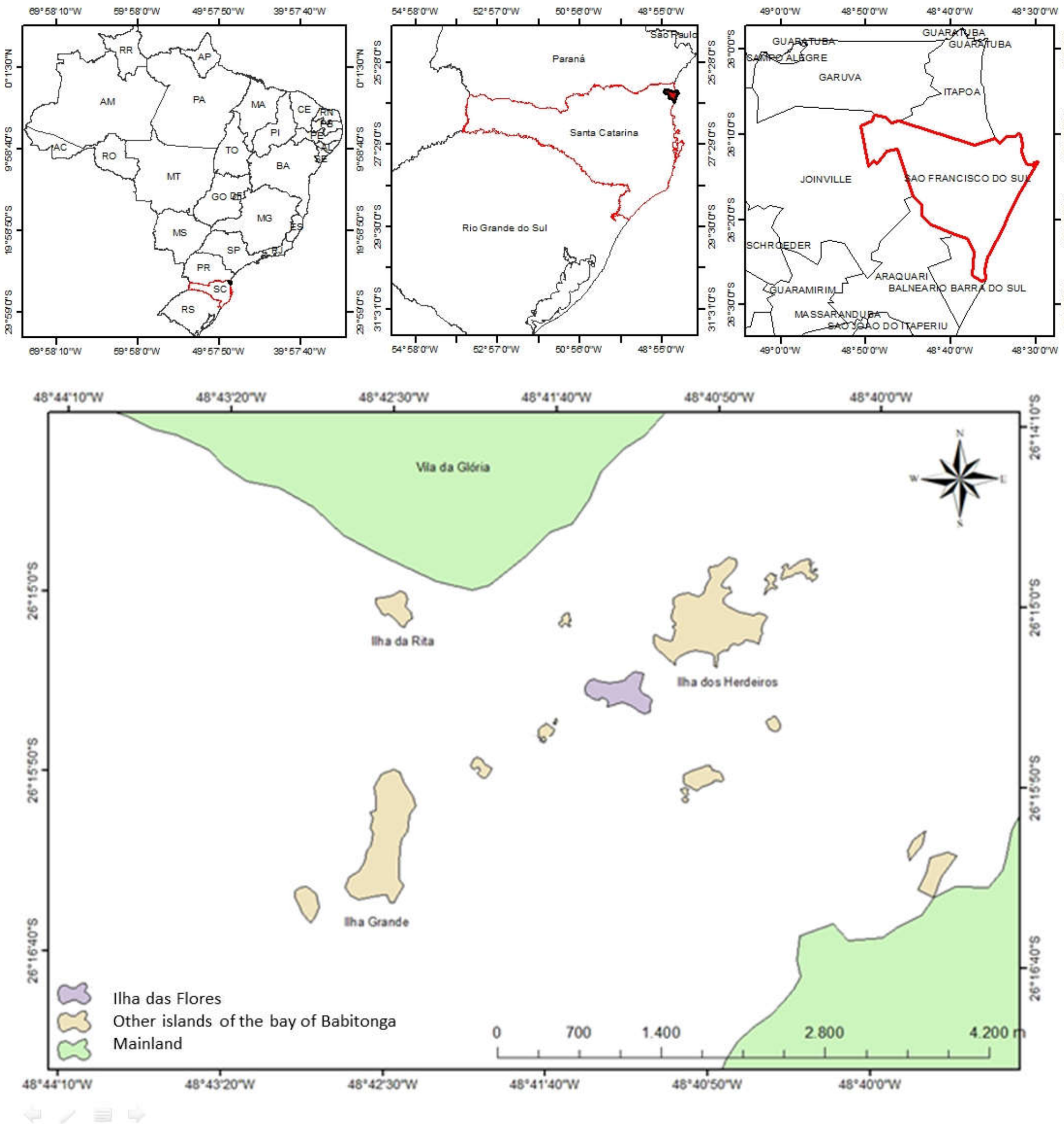

Figure 1. Map of the emplacement of *Ilha das Flores,* in the municipality of São Francisco do Sul, Santa Catarina State, Brazil. From Epagri Ciram

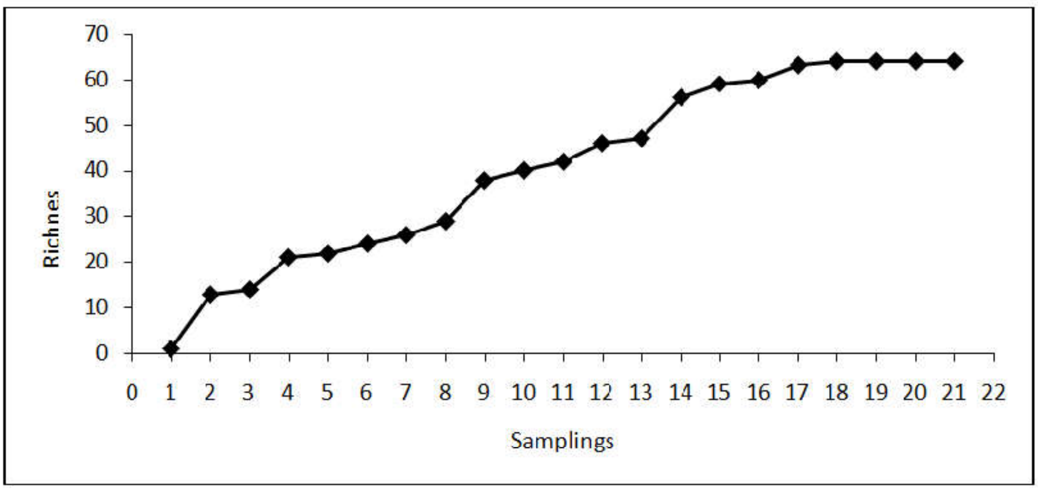

Figure 2. Bee species acumulation curve for the period August 2016 to July 2017 at *Ilha das Flores*, Santa Catarina State, Brazil

species, *Trigona spinipes* with 108 interactions with 19 plant species, *Augochloropsis* sp. 03 with 58 interactions with 15 plant species and *Dialictus* sp. 01 with 58 interactions with 12 plant species, which means that 22.22% of the observed interactions (2,020) were carried out by 6.66% of the sampled bee species of the island. The NODF nesting index was 11.88530 and the degree of specialization resulted in H'2 = 0,0, showing a heterogeneous, cohesive, asymmetric network, nested and without a relevant level of specialization.

Table 3. List of botanical species visited by sampled bees in Ilha das Flores, São Francisco do Sul, Santa Catarina State, Brazil.

Family	Species	Number of visits
Anacardiaceae	*Schinus terebinthifolia* Raddi	29
Araliaceae	*Schefflera arboricola Hayata*	1
Asphodelaceae	*Aloe vera* Mill.	16
Asteraceae	*Ageratum conyzoides* L.	26
Asteraceae	*Austroeupatorium inulaefolium* (Kunth) R.M.King & H.Rob.	7
Asteraceae	*Baccharis crispa* Spreng.	8
Asteraceae	*Bidens pilosa* L.	22
Asteraceae	*Coreopsis lanceolata* L.	93
Asteraceae	*Cyrtocymura scorpioides* (Lam.) H.Rob.	17
Asteraceae	*Emilia fosbergii* Nicolson	14
Asteraceae	*Eugenia astringens* Cambess.	2
Asteraceae	*Sphagneticola trilobata* (L.) Pruski	63
Asteraceae	*Taraxacum officinale* L.	1
Asteraceae	*Vernonia vernonanthura L.*	28
Boraginaceae	*Cordia sellowiana* Cham.	10
Bromeliaceae	*Tillandsia stricta* Sol.	4
Combretaceae	*Laguncularia racemosa* (L.) C.F.Gaertn.	9
Commelinaceae	*Dichorisandra thyrsiflora*	1
Convolvulaceae	*Ipomoea cairica* (L.) Sweet	6
Convolvulaceae	*Ipomoea imperati* (Vahl) Griseb.	7
Crassulaceae	*Kalanchoe tubiflora*	1
Euphorbiaceae	*Euphorbia milii* Des Moul.	34
Fabaceae	*Indigofera suffruticosa* Mill.	4
Fabaceae	*Mimosa bimucronata* (DC.) Kuntze	1
Fabaceae	*Senna pendula* (Humb.& Bonpl.ex Willd.) H.S.Irwin & Barneby	16
Fabaceae	*Senna macranthera* (DC. ex Collad.) H.S.Irwin & Barneby	86
Fabaceae	*Stylosanthes viscosa* (L.) Sw.	25
Lamiaceae	*Plectranthus ornatus* Hochst. ex Guerke	5
Malvaceae	*Hibiscus rosa-sinensis* L.	11
Malvaceae	*Malvaviscus arboreus* Cav.	28
Malvaceae	*Sida rhombifolia* L.	4
Malvaceae	*Talipariti pernambucense* (Arruda) Bovini	12
Melastomataceae	*Pleroma granulosa*(Desr.) D. Don	16
Melastomataceae	*Pleroma heteromalla* D. Don (D.Don)	1
Melastomataceae	*Pleroma mutabilis* (Vell.) Triana	1
Musaceae	*Musa paradisiaca* L.	3
Myrtaceae	*Eugenia uniflora L.*	46
Myrtaceae	*Psidium cattleianum* Sabine	18
Myrtaceae	*Rhododendron simsii* Planch	5
Myrtaceae	*Syzygium cumini* (L.) Skeels	13
Nyctaginaceae	*Guapira opposite* (Vell.) Reitz.	5
Polygalaceae	*Polygala paniculata* L.	1
Proteanae	*Grevillea banksii* R. Br.	10
Rosaceae	*Erybotrya japonica* (Thunb.) Lindl.	24
Rutaceae	*Citrus limon* (L.) Burm. f.	39
Sapindaceae	*Cupania vernalis* Cambess.	15
Zingiberaceae	*Hedychium coronarium* J. Koenig	10

Table 4. Simpson, Shannon-Wiener, Pielou indexes and Chao1 richness estimator, calculated for the sampling of bees done at Ilha das Flores, São Francisco do Sul, Santa Catarina State, Brazil, between August/2016 and July/2017, with *Apis mellifera*

Months	Simpson (1-D)	Shannon-Wiener (H)	Equability (J)	Chao-1
January	0,75	2,07	0,67	33,2
February	0,91	2,77	0,86	38,2
March	0,90	2,56	0,84	23
April	0,91	2,62	0,86	28
May	0,52	1,05	0,65	8
June	0,62	1,16	0,83	4
July	0,66	1,22	0,88	4
August	0,66	1,44	0,56	18
September	0,65	1,57	0,57	21
October	0,69	1,35	0,65	18
November	0,80	1,92	0,75	15
December	0,61	1,71	0,56	26
Average value	0,72	1,78	0,72	19

Biogeography: We adequated our data to make comparisons between apifaunas of different places, *i.e.,* we used only data that had been obtained by the same methodologies by each pair of compared autors (for instance, we eliminated, from our samples, data from pantraps when comparing with Schwartz-Filho and Laroca (1999) and Zanella (2005) who both had not areas, covered with lowland rain forest and mangrove (35 % and 33 %, respectively *Vila da Gloria* in São Francisco do Sul/ SC and *Parque Caieira* in Joinville/ SC), than with two insular communities of the bay of Paranaguá (Table 5). *Ilha do Mel* was more similar to *Ilha das Flores* (26%) than *Ilha das Cobras* (24%), the two islands presenting a species richness of 78 and 57 species, respectively.

Table 5. Sørensen similarity index, calculated for studies performed in the region, at continental and island environments. Legend: ETA=Estação de Tratamento de Água; PR=Parana State; SC=Santa Catarina State. Authors are listed at the References

Authors	Year	Place	Environment	Distance (Km)	Geographical coordinates	Number of species	Sørensen
Mouga *et al.*	2015	Vila da Glória, São Francisco do Sul, SC	Lowland rain forest	3	26°14'45,89"S 48°42'34,32"O	80 (24 equal)	0,35
Warkentin and Mouga	2016	Parque Caieira, Joinville, SC	Lowland rain forest/ mangrove	12	26°18'39.37"S 48°47'47.98"O	60 (20 equal)	0,33
Dec and Mouga	2014	ETA Piraí, Joinville, SC	Submontane rain forest	25	26°17'29,86"S 49°00'04,79"O	49 (11 equal)	0,28
Mouga *et al.*	2015	Praia do Ervino, São Francisco do Sul, SC	Sand dunes	18	26°23'25,46"S 48°34'57,78"O	51 (18 equal)	0,26
Zanella	2005	Ilha do Mel, Paranaguá, PR	Lowland rain forest, sand dunes	84	25°33'14,77"S 48°16'51,23" O	78 (18 equal)	0,26
Schwarz Filho and Laroca	1999	Ilha das Cobras, Paranaguá, PR	Lowland rain forest, sand dunes	85	25°29'7.58"S 48°25'54.77"O	57 (14 equal)	0,24

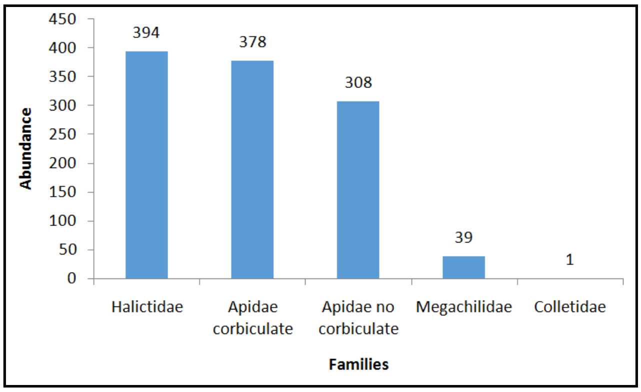

Figure 3. Abundance of bees' families at *Ilha das Flores*, Santa Catarina State, Brazil

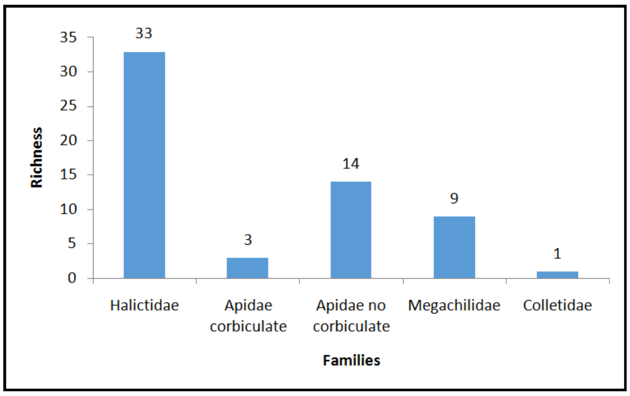

Figure 4. Richness of bees' families at *Ilha das Flores*, Santa Catarina State, Brazil

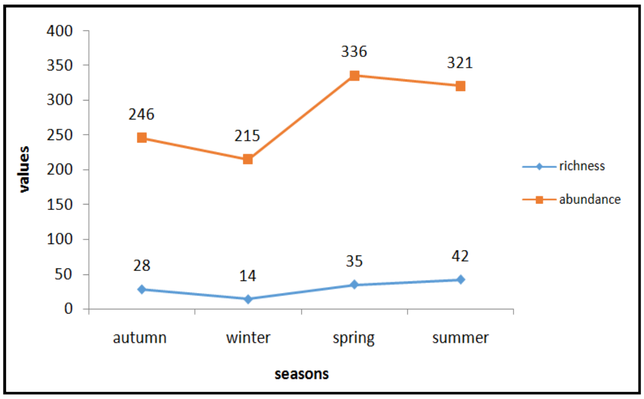

Figure 5. Variation of richness and abundance of bees along the seasons at *Ilha das Flores*, Santa Catarina State, Brazil

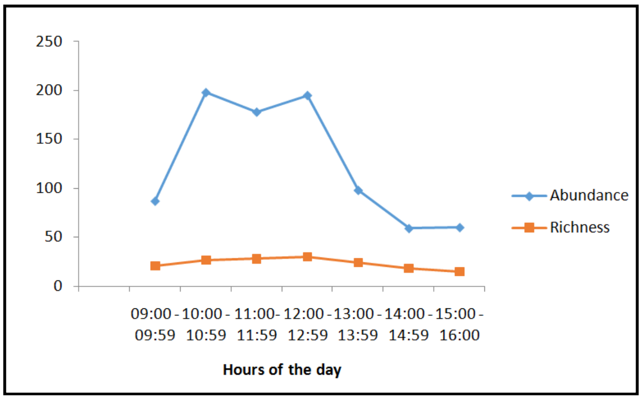

Figure 6. Variation of abundance and richness of bees during the hours of sampling at *Ilha das Flores,* Santa Catarina State, Brazil

Halictidae, a varied group, at *Ilha das Flores* and at *Vila da Gloria*, presented high richness (33 species and 36, respectively), *Augochora* and *Augochloropsis* being the genera with the largest number of species (Figures 9 and 10).

DISCUSSION

Bee species diversity: Apidae and Halictidae are, in Southern Brazil, groups with great richness and abundance (Mouga and Krug, 2010) and this was evidenced, in general terms, in former studies conducted in the region, that showed corbiculate Apidae as the most abundant group (Dec and Mouga, 2014; Warkentin and Mouga, 2016). Actually, the high abundance of corbiculate bees is expected in most ecosystems, since these bees are represented by social groups.

On the other hand, according to Martins (1994), for the temperate and subtropical Neotropical region, Halictidae, no corbiculate Apidae and Megachilidae have the highest proportion of species. However, it must be said that these groups (and regions) are not comparable. In turn, Silveira (2008) states that Halictidae would have its biogeographic origin in this area of the continent and this possibly influences the diversity of this group in the region. Andrenidae and Colletidae are groups with occurrence related to cold or xeric environments (Silveira *et al.,* 2002) and thus the low abundance or absence of these groups in the study area is probably related to the warm and humid climate prevailing in the region during a part of the year. The rareness of Andrenidae was also noticed by Mouga *et al.* (2015) who reported the seldom presence of *Acamptopoeum prinii* (Holmberg, 1884) (Andrenidae).

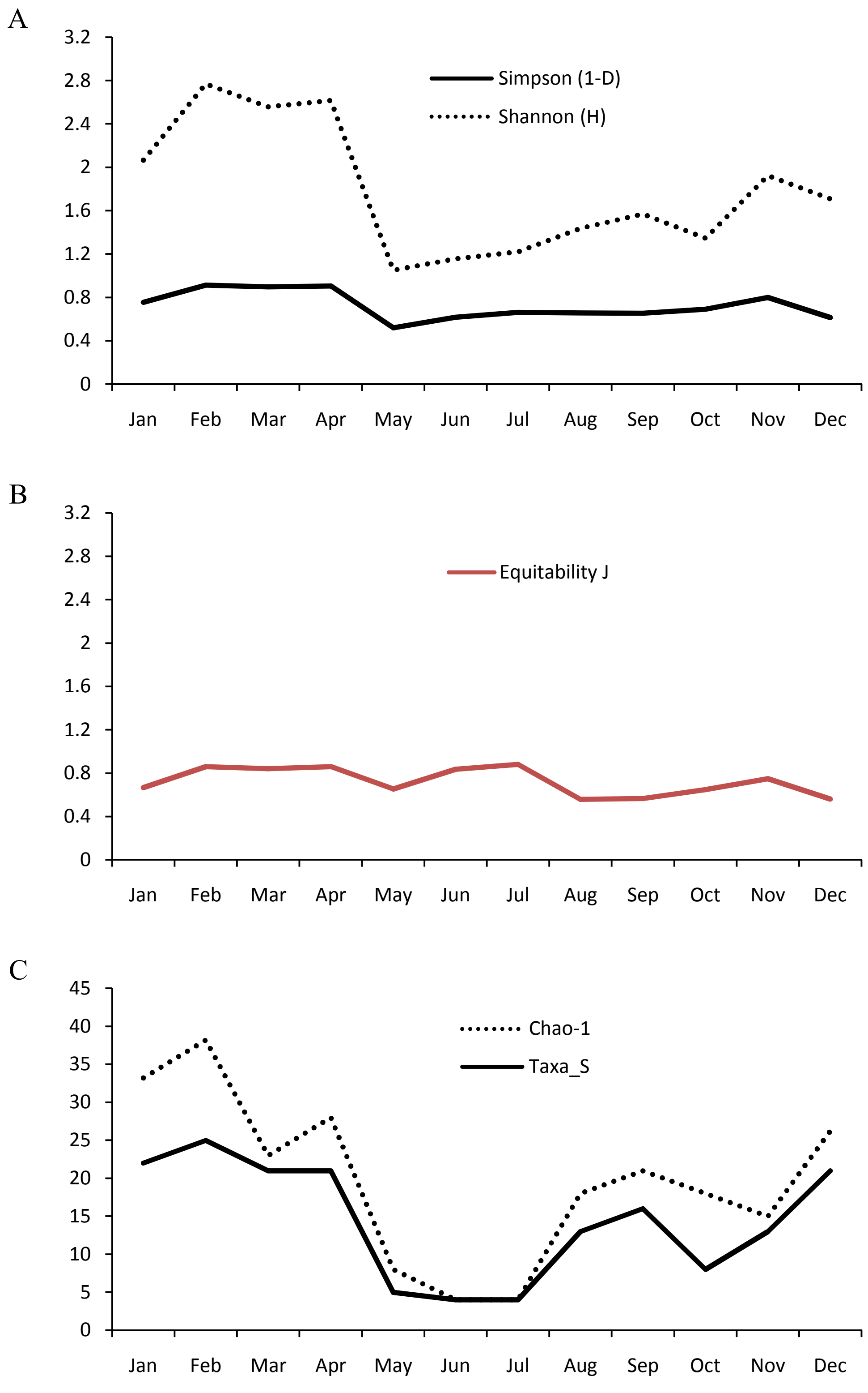

Figure 7. A – Simpson', Shannon-Wiener' indexes.B – Pielou' index. C - Chao1 richness estimator related to sampled number of species (Taxa_S). Values calculated for the sampling performed at *Ilha das Flores*, Santa Catarina State, Brazil, between August/2016 and July/2017

Hylaeus (Colletidae) is distributed in Brazil from the Amazon to the state of Parana (Moure *et al.,* 2012). Zanella (2005) rarely sampled *Hylaeus* on the mainland but in *Ilha do Mel* collected seven species with 39 individuals, representing 5.46% of the total number of individuals while Schwarz-Filho and Laroca (1999), in *Ilha das Cobras*, collected six morphospecies, with 42 individuals, representing 4.6% of the total, which suggests that this group is rare in lowland rain forest located in the mainland and more abundant in this same formation, but in islands.

Studies conducted in nearby localities in lowland rain forest and mangrove (both in mainland) have not found the *genus* (Dec and Mouga, 2014; Mouga *et al.,* 2015; Warkentin and Mouga*,* 2016). Nevertheless, an individual of this *genus* was sampled in a montane rain forest in São Bento do Sul, SC (Mouga and Krug, 2010). Regarding the abundance, the high numbers of *Apis mellifera* and *Trigona spinipes,* eusocial species*,* are explained by the large and numerous nests of these species.

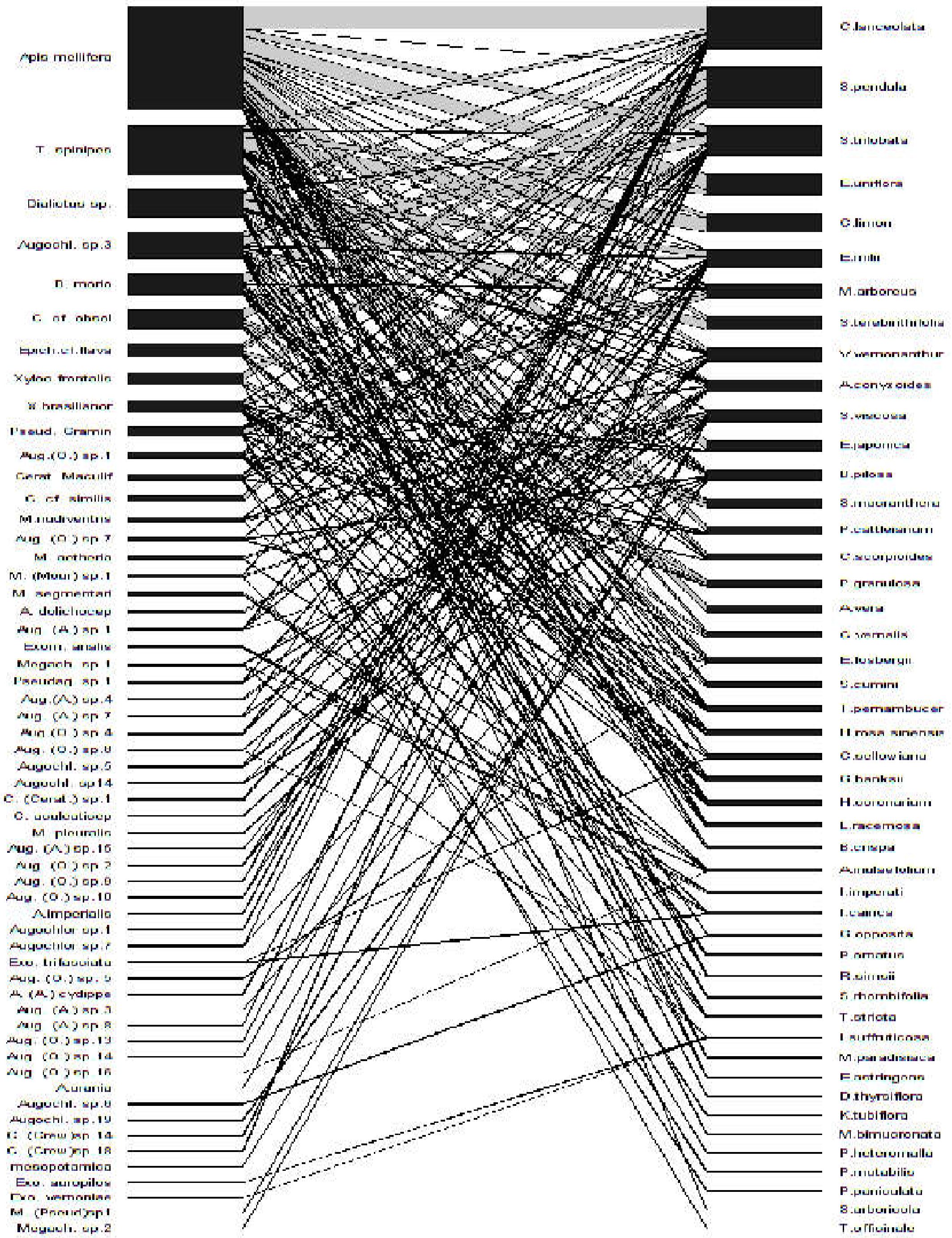

Figure 8. Bee plant interactions network, with *Apis mellifera*, at *Ilha das Flores*, Santa Catarina State, Brazil

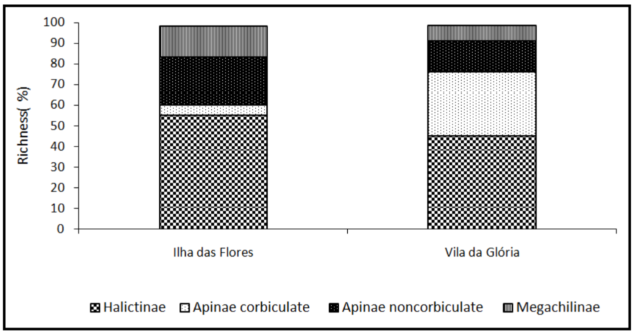

Figure 9. Richness of bees' taxa at *Ilha das Flores* and *Vila da Glória* in Santa Catarina State, Brazil (relative frequency).

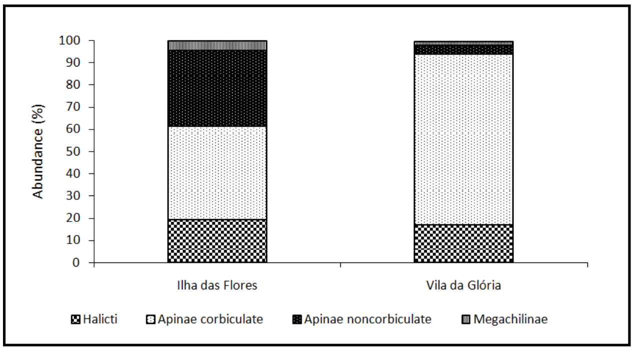

Figure 10. Abundance of bees' taxa at *Ilha das Flores* and *Vila da Glória* in Santa Catarina State, Brazil (relative frequency).

In the case of *Dialictus* sp. 01, totals are due to the type of sampling methodology (pantraps) that is selective to some *taxa. Epicharis flava* was sampled during its reproductive period and this may have overestimated its population, due to its gregarious nesting habit. Seasonality was observed in terms of abundance. According to Krug and Alves-Dos-Santos (2008), for Suthern Brazil, situated in the subtropical climate, spring represents the time of activity of many periodic species. On the other hand, in terms of sampling time, the observed results are possibly related to the climatic conditions at these moments, as bees initiate, increase or decrease the rate of foraging activities in accordance with climatic conditions, mainly temperature, and meteorological factors that directly influence bees' foraging, determining the energy expended to regulate body temperature during the flight periods (Roubik, 1989). Some of the species found, that are not mentioned in Moure *et al.* (2012) as occurring in Santa Catarina State, had already been cited in studies by Mouga and Krug (2010), Dec and Mouga (2014), Mouga *et al.* (2015) and Warkentin and Mouga (2016). Elseways, the species *Centris (Melacentris) obsoleta*, *Exomalopsis (Exomalopsis) auropilosa* Spinola, 1853, *Exomalopsis (Exomalopsis) vernoniae* Schrottky, 1909, *Coelioxys (Acrocoelioxys) aculeaticeps* Friese, 1921 and *Megachile (Leptorachis) aetheria* (Mitchell, 1930) were sampled only at *Ilha das Flores* and not in other studies on apifauna carried out in the region.

Bee-plants interactions: The results obtained in this study show a relationship between oligolectic bees of Emphorini and Convolvulaceae flowers, especially in *Ipomoea* as pointed out Zanella (2000). Pick and Schlindwein (2011) also report that the most efficient pollinator of *Ipomoea cairica* (L.) Sweet was *Melitoma segmentaria* (Fabricius, 1804), due to the length of the its glossa that can reach the nectar in the flowers. The different species of *Megachile* Latreille, 1802 shared the same resource (*Stylosanthes viscosa)* (L.) Sw. (Fabaceae), a fact noticed also by Ramalho and Rosa (2010). About the buzzing pollination performed by some bee's species on *Senna* species (Fabaceae), Pinheiro and Sazima (2007) verified that the main pollinators of *Senna multijuga* and *Senna macantrera* (Fabaceae) were large bees. In the present study, buzzing was performed by the more robust bees (1.5 to 4 cm) (*Bombus morio, Epicharis flava*, *Centris* (*T.*) *similis*, *Centris* (*M.*) *obsoleta*, *Xylocopa brasilianorum*, *Xylocopa frontalis).* However, Nunes-Silva *et al.* (2010) showed that the vibrations produced by bees of different sizes have similar vibration velocity and frequency, stating that the efficiency of this pollen collection behavior is independent of the bee's body size. In the present work, illegitimate visits by *Xylocopa brasilianorum* and *Pseudaugochlora graminea,* who perforate flowers, were recorded as well as in the study of Alves-Dos-Santos *et al.* (2016) who describe bees of *Xylocopa* Latreille, 1802 performing illegitimate visits, by tearing the base of the flower. In the present work, this perforation allowed other smaller bees, such as *Pseudaugochlora graminea,* to use the hole and extract the resource, without contacting the reproductive organs. The presence of Centridini (collectors of oils), sampled in *Ilha das Flores*, was also recorded on *Ilha das Cobras*. These bees have modified structures in the legs and sternum (mainly the specialization of pilosity) for collecting and handling the floral material (oils) and these lipids are used to cover the nests and to feed the larvae as they have a higher nutritional value (Alves-Dos-Santos *et al*., 2007).

Nests: The situation how *Epicharis flava* was found confirms what is known about the *genus, i.e., Epicharis* species are active mainly in the summer months, characterized by high temperatures and high humidity and all bees of this group nest in the soil, mainly with sandy characteristics, being able to form aggregations (Camargo *et al.,* 1975). After the nests are constructed, the founding females die before the pups emerge, males emerging from the nests in first place and seeking the newly emerged females for copulation (Alves-Dos-Santos *et al.,* 2007). Although suggestive, the possible correlations between environmental factors with the seasonality of bees were not formally tested.

Ecological indexes and interaction network: The mean value of diversity in this study (H = 1.78) was lower than that obtained by works conducted in nearby areas as Mouga *et al.* (2015) cite in lowland rain forest H '= 2.31, Warkentin and Mouga (2016) in mangrove area H' = 2.64 and Dec and Mouga (2014) in submontane rain forest H '= 2.84. This is consistent with the insular proportionality that states that the diversity of an island is directly proportional to its size (MacArthur and Wilson, 1967) and on islands, pollination is more generalized than on mainland (Armbruster, 2006). Actually, these indices are directly affected by the number of individuals collected *per* species and thus, for any conclusion, they must be closely checked: the abundance/ diversity should be looked to rawly and methods should be comparable among each other. The stabilized accumulation curve at 18 samples and 60 bee species confort this point of view, although, on the other hand, the estimated richness (79 species, that is, an increase of 31.6 %) suggests more sampling efforts to best settle the trend. Regarding the interaction network, in the present study, the basic characteristics of a nested web were observed: a nucleus of generalists interacting with each other, specialists interacting with generalists and the absence of interactions between specialists (Guimarães and Guimarães, 2006), that is, an asymmetric network. The asymmetry of interactions is one of the properties of a network of nested interactions, expected for the ditrophic networks of mutualist interactions (Pigozzo and Viana, 2010).

Biogeography: About the similarity between environments, the composition of the bees' groups at *Ilha das Flores* presented peculiarities in relation to apifauna sampled in *Vila da Glória* on mainland, especially in relation to the relative abundance of the families collected. In *Vila da Glória*, 1,519 individuals from 80 species were sampled while and, in the present study, 1,120 individuals from 60 species were surveyed. The corbiculate Apidae showed a significant decrease in the number of species and individuals since, in *Vila da Glória*, 25 species (1,175 individuals) were collected from this group and in the present study only three species (abundance of 378 individuals, that belong to Apini, Bombini and Meliponini). This contrast was due to the scarcity of Meliponini on the island, where only one species (*Trigona spinipes*) was identified while eight species were sampled on the continent. Meliponini's scarcity had already been recorded in the studies of Schwarz Filho and Laroca (1999) and Zanella (2005), both in southern positions. This last author suggests that Meliponini is replaced by Halictidae, a predominant group in tropical island communities, due to the absence of competitors and, consequently, to an increase in food resources, a process defined by MacArthur (1972) as compensation of density. On the other hand, Lorenzon *et al.* (2006), in *Ilha Grande* (area of 19,300 ha) located in Rio de

Janeiro/ RJ, a northern place, reported a great occurrence of Meliponini, with 12 species and 1,860 individuals. Gonçalves and Brandão (2008), in their turn, through analyzes of latitudinal gradient, corroborate the high richness of this group (Meliponini) in the Atlantic Forest, in areas ranging from the state of Rio de Janeiro to Paraiba. However, caution should be exercised since the Meliponini species that currently occur on islands may have been introduced by man. *Ilha das Flores* showed an apifauna more similar to that of close lowland rain forest environments than to that of distant islands. The geographical proximity of *Vila da Glória* (mainland), which is 3 km away from the study area, may indicate a gradient of insularity, as proposed by Schwarz Filho and Laroca (1999) for *Ilha do Mel, Ilha das Cobras* (both islands) and Alexandra/ PR (continental area), where the latter would represent the source area of species (Zanella, 2005). In the present study, the community of bees of Vila da Glória would represent the source area, where the richness (80 species) is larger and *Ilha das Flores* represents the derived area, where the richness (60 species) is smaller. Still regarding similarity between islands, seemingly *Dialictus opacus* (Moure, 1940) was the *taxon* that presented the greater abundance on the islands of Paranaguá, state of Parana. Despite the methodology (pantraps) used in the present study favor the capture bees of this *genus* and due to the taxonomic impediment already mentioned, it is not possible to rule out the possibility of the *genus* found in both locations be of the same epithet.

Babitonga Bay: Insularity seems to have played a role in the bee species assortment of *Ilha das Flores* and the present apifauna is probably due to palaeoenvironmental events that shaped the Babitonga Bay. When studying the composition of different communities of the same biological group, the first question is about the factors that determine the occurrence or not of some taxonomic groups (Zanella, 2005). The colonization of the bees´ groups on *Ilha das Flores* may be related to the palaeoenvironmental variation of the estuary complex of Babitonga Bay. In the last glacial maximum of the Pleistocene period (37,500 to 14,500 BC), during which large areas of Southern South America and the Andes were glaciated, the sea level retreated at least 100 km east of Itapoá/ SC (a municipality 10 km from the site of the present study). Coastal tropical vegetation was replaced by grasslands *taxa* (Eriocaulaceae, *Eryngium* sp. (Apiaceae) and *Moritzia* sp. (Boraginaceae)) and by cold adapted forest patches (Behling and Negrelle, 2001). These *taxa* currently occur in high areas of the State of Santa Catarina, indicating that the last glacial vegetation in the plain was similar to the vegetation of high grasslands (Ziffer-Berger and Dos Santos Ribas, 2007). From this point of view, it can be understood that the apifauna of adjacent continental coastal environments may have been favored in the colonization of Babitonga Bay´s islands, by the formation of bridges (MacArthur, 1972) constituted of herbaceous vegetation, due to the regression of the sea level. The process of colonization of an island is related to the behavior of dispersion and migration of the organisms. According to Martin *et al.* (1988), the relative sea level in Santa Catarina coast has surpassed the current level in the Holocene for about 6,500 years BP, rising to the post-glacial maximum of 3.5 m at 5,100 BP. This maximum of the Santos Transgression (formerly called Flandrian Transgression) has invaded the Palmital Canal of Babitonga Bay, which still maintains this landscape heritage in the form of a ria (partially submerged valley) (Oliveira and Horn Filho, 2001). Santos Transgression reached its maximum around six thousand years ago and, after that, the sea underwent minor eustatic changes but with a general tendency towards a small decrease to the present (Vieira, 1981). Souza *et al.* (2001) studied the paleogeographic evolution of Itapoa region and concluded that the maximum transgression was possibly greater than 2.5 ± 1.0 m in the period of 4200 ± 70 years BP. In brief, during the glacial periods, the retention of waters in the glaciers exposed continental shelves, promoting a floristic and faunistic homogenization of the environments (Schwarz Filho and Laroca, 1999).

We suggest that fluctuations in the relative sea level influenced the differentiation of the bees' community on *Ilha das Flores*, since the island may have been partially submerged in periods of transgression. Meliponini (highly social bees) may have suffered from the probable destruction of nests and fertile individuals of the populations, being eventually not able to recover from the disturbances caused by relative sea level variation over the period. This might be true for species that nest in the soil but not so severe for those that nest in pre-existing wood cavities and other issues need to be taken into account. In solitary bees (Centridini, Emphorini, Exomalopsini, Halictinae, Megachilinae, and Xylocopini), all females are fertile, so each one is an independent reproductive unit, which increases the probability of reestablishing the populations of these species. The apifauna of the present *Ilha das Flores* can represent a relic of the time of connection of the island with the continent. However, it must be said that the distances are small between the focused island and the continent, as well as the size and the proximity of the studied area with the neighboring islands and the mainland. These elements are of the fundamental importance for the comprehension of organisms' dynamics on the insular biogeography. The existing short distances would confirm our null hypothesis, i.e., due to this, there is a great similarity between the apifaunas of these neighboring places as well as specific and generalized interactions with the flora. It is noteworthy the importance of preserving the community of plants and bees of Babitonga Bay islands, so that ecological interactions in these environments, which are remnants of the natural history of the region, are not restricted.

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