BEES AND PLANTS IN A TRANSITION AREA BETWEEN ATLANTIC RAIN FOREST AND ARAUCARIA FOREST IN SOUTHERN BRAZIL[1]

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RÉSUMÉ.— *Abeilles et plantes dans une zone de transition entre la forêt pluviale atlantique et la forêt à Araucaria dans le sud du Brésil*.— La communauté d'abeilles indigènes d'une zone de transition entre la forêt pluviale atlantique et la forêt à Araucaria, à Joinville, état de Santa Catarina, Brésil, a été étudiée en ce qui concerne la richesse en espèces, l'abondance relative, les ressources florales et les interactions avec les plantes. Les observations ont été effectuées mensuellement de 2008 à 2009, en utilisant des filets entomologiques. Ont été échantillonnés 710 individus de 88 espèces des cinq sous-familles d'abeilles existant au Brésil. Les abeilles ont été prélevées sur 62 espèces de plantes de 29 familles. Les familles végétales les plus visitées ont été les *Asteraceae* (48 %), *Lamiaceae* (10 %), *Saxifragaceae* (9 %) et *Rosaceae* (8 %). La sous-famille d'abeilles présentant la plus grande diversité d'espèces a été celle des *Halictinae* (44 %), suivie par les *Apinae* (38 %), *Andreninae* (11 %), *Megachilinae* (8 %) et *Colletinae* (1 %). La séquence en abondance d'individus, par sous-familles, a été: *Apinae* (81 %), *Halictinae* (12 %), *Andreninae* et *Megachilinae* (les deux 3 %) et *Colletinae* (moins de 1 %). *Apis mellifera* L. est l'espèce la plus abondante (42 %), suivie par *Trigona spinipes* (Fabricius) (14 %) et *Plebeia* sp. L'étude dépeint un système avec des interactions asymétriques, démontré par le groupement des espèces, avec une prédominance de relations générales, révélant l'importance relative de l´abondance pour l´imbrication des réseaux mutuels. Les mensurations de réseau évaluées dévoilent un lacis robuste et diversifié, un trait récurrent dans la structuration de la biodiversité.

SUMMARY.— The community of native bees from a transition area between Atlantic rain forest and Araucaria forest in Joinville, Santa Catarina state, Brazil, was studied regarding to species richness, relative abundance, floral resources and plant interactions. Observations were made monthly from 2008 to 2009, using entomological nets. 710 individuals of 88 species were sampled from the five bee subfamilies existing in Brazil. The bees were sampled on 62 plant species from 29 families. The most visited plant families were Asteraceae (48 %), Lamiaceae (10 %), Saxifragaceae (9 %) and Rosaceae (8 %). The bee subfamily with the highest species diversity was Halictinae (44 %), followed by Apinae (38 %), Andreninae (11 %), Megachilinae (8 %) and Colletinae (1 %). The subfamilies abundance sequence was: Apinae (81 %), Halictinae (12 %), Andreninae and Megachilinae (both 3 %) and Colletinae (less than 1 %). *Apis mellifera* L. was the most abundant species (42 %), followed by *Trigona spinipes* (Fabricius) (14 %) and *Plebeia* sp. This study depicts a system with asymmetric interactions shown by the species grouping, with a predominance of general relationships, revealing the relative importance of abundance for mutual networks nesting. The results from the network metrics evaluated reveal a robust and diverse web, in a recurrent feature of biodiversity structuring.

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[1] Presented at III CLAE – Congresso Latino-Americano de Ecologia, São Lourenço, MG, Brazil.

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Rev. Écol. (Terre Vie), vol. 67, 2012.

Bee-flower interactions that develop in a phyto-varied area with diversified melissofauna constitute one of the many webs that interweave in the community structuring of an environment. These interactions, when interpreted, reveal the functionality of pollinators acting as specialists on certain plant groups or as generalists. Plants that do not offer resources to groups of specialist pollinators can still be pollinated by generalist groups (Forup & Memmott, 2005) and even show the dependence of some plants species to pollinator species moving there.

To assess and categorize the state of the environment, given its situation of exploitation, and consequent indication of priority areas for protection, studies have been carried out that attempt, generally speaking, to detect certain parameters such as size and configuration of areas, species richness, abundance, number of species in indicator categories (endemic or endangered species) (Cullen *et al.,* 2004) that are meant as appropriate estimates of the category of preservation. Besides these parameters, the ecosystems have been studied from the point of view of the supporting ecological processes and performance, the interaction nets having been used as a measure device (Bascompte *et al*., 2003). These studies demonstrated that the approach of community structure using this tool allows perceiving the organization and complexity of the guilds, providing indices that represent the complexity of interactions (Guimarães & Guimarães*,* 2006). Studies aiming to understand the general design that prevails in interaction networks formed by plants and pollinators have recently been made, among others by Stang *et al.* (2007), Freitas *et al.* (2007) and Pigozzo & Viana (2010).

The resulting graphic ditrophic webs allow depicting the interaction that occurs between members. Their analysis leads to conjecture the various adjustments in relation to the performance of the two groups in a given biocoenotic environment for both the offered resource and the consumer (Lewinsohn *et al*., 2006). According to Biesmeijer *et al*. (2005), the study of bee communities shows that the properties presented by the network itself are more important than the identity of pollinators because the interactions are largely caused by generalist groups.

The basic instrument that provides the construction of these networks are the surveys of the involved agents, enabling to inventory, in a quantitative and qualitative manner, the bees (consumers) and the plants (trophic resources) (Lévêque, 1997). Researches involving communities of flower visitors and plants have been undertaken to this end (Pinheiro-Machado *et al.,* 2006) and, besides the purposes of understanding the components of the trophic web, aspects of pollination biology can be supported by the analysis done (Freitas *&* Sazima*,* 2006).

Studies of bee-plant networks using analytical tools for analysing metrical parameters have been conducted in Brazil in the environments of *caatinga* (xeric shrubland and thorn forest), *restinga* (dunes), *cerrado* (savanna) and rain forest (Viana & Kleinert, 2006; Rodarte *et al.,* 2008; Bezerra *et al.,* 2009; Pigozzo & Viana, 2010; Santos *et al.,* 2010, among others). In transition areas, no data is available. This paper intends to verify the interaction network within an ecotonal area. The importance of this knowledge is linked to the understanding of the structuring lattice that weaves in ecotonal environments and to the assumptions of management and conservation of biodiversity.

In this way, this study basically aimed at understanding the community organization of bees and their flowers that develop in a transition area between Atlantic rain forest and Araucaria forest (Pine forest), in Southern Brazil. The main goals were to determine the network of interactions between bees and plants and characterize its structural pattern.

MATERIAL AND METHODS

The study was performed in the northeastern region of Santa Catarina, in Caetezal Private Natural Heritage Reserve (26º18'05" S / 48º50'38" W), located in the transition area between Atlantic rain forest and Araucaria forest, and created in 1979, with a surface of 4757 hectares and an average altitude of 800 meters above sea level. It includes the original vegetation of Mountain tropical rainforest, Transition forest (rain forest to Araucaria forest) and highlands, in good state of preservation. The climate is humid mesothermal (CFa), with no dry season, with hot summers and monthly average temperatures never below 15 ^{O}C. The rainfall is abundant and evenly distributed throughout the year (1909 mm) with the most intense period of rain in the summer. The relative humidity is high (values between 84 and 86 %). It shows a quite varied topography, constituted of hills and cliffs of the Serra do Mar (the mountain chain along the seashore of Brazil), with frequent and abrupt undulations of the terrain, providing steep slopes. Soils present are shallow, well drained and sometimes rocky.

Bee were sampled monthly, between 9 a.m and 16 p.m, along a pre-established transect about 3000 m long, where flowering plants were observed, each for about 5 minutes, on sunny days, in alternate routes on every collection day (Sakagami *et al*., 1967). All native bees on flowers were collected with entomological nets by two collectors. The individuals of *Apis mellifera* L., an exotic species, completely adapted in Brazil, were just accounted and recorded. Samples of plants visited by bees were also collected.

The study was conducted from March 2008 to February 2009. At the end of captures, the sampled area had been given 84 hours of sampling effort.

Bee and botanical taxa sampled were prepared and identified by specialists and literature guidelines (classification system APG II for plants; Melo & Gonçalves, 2005 for bees). The information was grouped into a database. Vouchers are stored in the reference collection of Label – Laboratory of Bees of Univille, Joinville, Santa Catarina, Brazil.

Data regarding bees and their associations with plants were tooled into spreadsheet MS Excel and R programs (Dormann *et al.,* 2008), starting from the adjacent matrix, with presence and absence data of interaction between plants and bees species, resulting in a bipartite graphic that expresses the interaction network. In the interaction network, species are represented in lines and their thickness indicates the interaction strength between the species.

Among all the available metrics to describe a network of quantitative interactions, the following were calculated, according to Dorman *et al*. (2009): the number of interactions, the network size, the connectance, the measure of network´s specialization level, the average degree for plants and animals species and the distribution of degrees.

The number of observed interactions (E) is considered as the lines that are present in the network, after its construction. The network size is expressed by M = B. P (B and P are the number of interacting bees and plants in the habitat, respectively) and represent the number of possible interactions in the network.

The connectance (C), which measures the proportion of connections that are actually observed, is the ratio between the number of observed interactions (E) and the number of possible interactions which, in turn, is given by the product of the number of bees (B) and plants (P) from the network: C = E/ B. P. For percentage values, the value of C was multiplied by 100.

The measurement of the networks specialization level (H2) ranges from 0 to 1, revealing perfect specialization (1) or no specialization (0).

Plants average degree was obtained through the arithmetic average from all plant species degrees, as degree is the number of interactions in which each species was involved. The same was done for bees.

Degrees distribution was done graphically, in vertical bars representation, where x-axis represents the number of interactions established (degrees) and y-axis, the number of species that showed a certain degree, whether it is plant or animal.

The nesting degree of the network was measured by the NODF index and calculated with the help of the program ANINHADO (Guimarães & Guimarães, 2006), using as a model of randomization (null model) the NODF (Coe), with 1000 randomizations (Almeida Neto & Ulrich, 2011).

RESULTS

Bees

A total of 710 bees specimens of 88 species from the five subfamilies represented in Brazil were sampled, listed in Table I, as well as the plant species on which these bees were captured.

In terms of subfamilies representativeness, the greatest numbers for species diversity and individuals abundance were presented by Halictinae and Apinae, followed by Andreninae and Megachilinae (Tab. II).

In this study, regarding the species preponderance, it was observed that *Apis mellifera* has proved to be the most abundant species (42 %), followed by *Trigona spinipes* (14 %).

Among the bee species sampled, we found *Plebeia* sp. but no species of the genera *Partamona, Tetragonisca, Paratrigona, Frieseomellita* and *Nannotrigona,* taxa of relative occurrence.

Plants

Sixty two plant species from 29 plant families were sampled. Asteraceae was the most visited family (48 %) and also the family with the largest number of plant species (34 %). The other most visited plant families by bees were: Lamiaceae (10 %), Saxifragaceae (9 %) and Rosaceae (8 %), the first one being represented by two species and the following by only one species. In decreasing number of visited plant species, there were: Solanaceae (7 %), Verbenaceae (6 %) and Melastomataceae (5 %).

TABLE I

List of bee (Apidae) and plant species on which they were observed as well as the number of individuals sampled for each plant species in the locality of Caetezal, Joinville, Santa Catarina, Brazil, in 2008-2009

Subfamily	Bee species		Plant species	Nº
Colletinae	*Colletes rugicollis* Friese, 1900			
		Lamiaceae	*Hyptis lappulacea* Mart. ex Benth	2
Andreninae	*Anthrenoides antonii* Urban, 2005			
		Araceae	*Zanthedeschia aethiopica* (L.) Spreng	1
	Anthrenoides meridionalis (Schrottky, 1906)			
		Onagraceae	*Ludwigia sericea* (Cambess.) H. Hara	1
	Anthrenoides albinoi Urban, 2005			
		Solanaceae	*Solanum bistellatum* L.B. Sm. & Downs	2
	Anthrenoides sp. 2			
		Asteraceae	*Baccharis uncinella* DC.	1
	Anthrenoides sp. 3			
		Asteraceae	*Elephantopus mollis* Kunth.	1
		Onagraceae	*Ludwigia sericea* (Cambess.) H. Hara	1
	Psaenythia bergi Holmberg, 1884			
		Asteraceae	*Baccharis trimera* (Less.) DC.	1
			Hypochoeris brasiliensis (Less.) Griseb	2
	Psaenythia sp.1			
		Asteraceae	*Barrosoa betoniciiformis* (DC.) R.M. King & H. Rob.	1
			Bidens pilosa L.	1
			Hypochoeris brasiliensis (Less.) Griseb	1
		Fabaceae	*Desmodium adscendens* (SW) DC.	1
	Psaenythia sp.2			
		Asteraceae	*Elephantopus mollis* Kunth.	1
			Erigeron maximus (D.Don.) Otto ex DC.	1
			Hypochoeris brasiliensis (Less.) Griseb	1
		Fabaceae	*Desmodium adscendens* (SW) DC.	1
	Psaenythia sp. 3			
		Asteraceae	*Solidago chilensis* Meyen	1
		Begoniaceae	*Begonia cucullata* Ruiz ex Klotzsc	1
Halictinae	*Augochloropsis aff. sparcilis* (Vachal, 1903)			
		Asteraceae	*Baccharis stenocephala* Baker	1
	Augochloropsis cognata Moure, 1944			
		Polygalaceae	*Polygala paniculata* J. Le Conte ex Torr. & A. Gray	1
		Rosaceae	*Rubus rosifolius* Stokes	1
	Augochloropsis sp.1			
		Asteraceae	*Baccharis trimera* (Less.) DC	4
			Bidens pilosa L.	1
			Erechtites valerianifolius (Link ex Spreng.) DC.	1
			Vernoanthura catarinensis (Cabrera) H. Rob.	2
	Augochloropsis sp.2			
		Asteraceae	*Austrœupatorium picturatum* (Malme) R.M. King & H. Rob.	1
	Augochloropsis sp.3			
		Asteraceae	*Baccharis trimera* (Less.) DC.	1
	Augochloropsis sp.4			
		Asteraceae	*Baccharis trimera* (Less.) DC.	1
			Hypochoeris brasiliensis (Less.) Griseb	1

Subfamily	Bee species		Plant species	Nº
		Lythraceae	*Cuphea calophylla* Cham. & Schltdl.	1
		Melastomataceae	*Tibouchina cerastifolia* Cogn.	1
		Solanaceae	*Solanum bistellatum* L.B. Sm. & Downs	1
	Augochloropsis sp.5			
		Asteraceae	*Elephantopus mollis* Kunth.	1
		Malvaceae	*Sida planicaulis* Cav.	1
		Melastomataceae	*Tibouchina cerastifolia* Cogn.	1
		Rubiaceae	*Emmeorhiza umbellata* (Spreng.) K. Schum	1
	Augochloropsis sp.6			
		Asteraceae	*Jungia floribunda* Less.	1
	Augochloropsis sp.7			
		Solanaceae	*Solanum bistellatum* L.B. Sm. & Downs	1
	Augochloropsis sp.8			
		Asteraceae	*Solidago chilensis* Meyen	1
	Augochloropsis sp.9			
		Asteraceae	*Solidago chilensis* Meyen	1
	Augochloropsis sp. 10			
		Asteraceae	*Erigeron maximus* (D.Don.) Otto ex DC.	1
	Augochlora dolichocephala (Moure, 1941)			
		Rosaceae	*Rubus rosifolius* Stokes	1
	Augochlora aff. cydippe (Schrottky, 1910)			
		Asteraceae	*Vernoanthura montevidensis* (Spreng.) H. Rob.	1
	Augochlora sp. 1			
		Asteraceae	*Austrœupatorium picturatum* (Malme) R.M. King & H. Rob.	1
			Hypochoeris brasiliensis (Less.) Griseb	1
		Melastomataceae	*Tibouchina cerastifolia* Cogn.	1
	Augochlora sp. 2			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	2
		Malvaceae	*Sida carpinifolia* L.	1
	Augochlora sp. 3			
		Iridaceae	*Sisyrinchium vaginatum* Spreng.	1
	Augochlora sp. 4			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	2
		Lamiaceae	*Cunila galioides* Benth.	1
	Augochlora sp. 5			
		Asteraceae	*Vernoanthura catharinensis* (Cabrera) H. Rob.	1
		Onagraceae	*Ludwigia sericea* (Cambess.) H. Hara	1
	Augochlora sp. 6			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
	Augochlora sp. 7			
		Asteraceae	*Austrœupatorium picturatum* (Malme) R.M. King & H. Rob.	1
		Malvaceae	*Sida carpinifolia* L.	1
		Onagraceae	*Ludwigia sericea* (Cambess.) H. Hara	1
	Augochlorella sp. 1			
		Asteraceae	*Baccharis trimera* (Less.) DC.	1
			Hypochoeris brasiliensis (Less.) Griseb	1
	Augochlorini sp 2			
		Asteraceae	*Elephantopus mollis* Kunth.	1

Subfamily	Bee species		Plant species	Nº
			Hypochoeris brasiliensis (Less.) Griseb	4
	Neocorynura aenigma (Gribodo, 1894)			
		Onagraceae	*Ludwigia sericea* (Cambess.) H. Hara	1
		Rosaceae	*Rubus rosifolius* Stokes	1
	Neocorynura oiospermi (Schrottky, 1909)			
		Asteraceae	*Solidago chilensis* Meyen	1
	Neocorynura sp. 1			
		Asteraceae	*Bidens pilosa* L.	2
			Cyrtocymura scorpioides (Lam.) H. Robinson	2
			Hypochoeris brasiliensis (Less.) Griseb	2
	Pseudaugochlora indistincta Almeida, 2008			
		Solanaceae	*Solanum bistellatum* L.B. Sm. & Downs	2
	Dialictus sp.8			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	2
	Dialictus sp.9			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
	Dialictus sp.10			
		Asteraceae	*Jungia floribunda* Less.	1
	Dialictus sp.11			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
	Dialictus sp.12			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
	Dialictus sp.13			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
	Dialictus sp.14			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
	Dialictus sp.15			
		Lamiaceae	*Cunila galioides* Benth.	1
	Dialictus sp.			
		Asteraceae	*Baccharis uncinella* DC.	1
			Hypochoeris brasiliensis (Less.) Griseb	13
		Iridaceae	*Sisyrinchium vaginatum Spreng.*	1
		Scrophulariaceae	*Agalinis communis* (Cham & Schltdl.) D´Arcy	1
	Halictini sp.1			
		Malvaceae	*Tibouchina clinopodifolia* (DC.) Cogn.	1
Megachilinae	*Megachile (Acentron)* sp.1			
		Asteraceae	*Bidens pilosa* L.	1
	Megachile (Austromegachile) sp.1			
		Asteraceae	*Chrysolaena platensis* (Spreng.) H. Rob.	1
	Megachile (Moureapis) maculata Smith, 1853			
		Asteraceae	*Vernoanthura montevidensis* (Spreng.) H. Rob.	1
		Lamiaceae	*Cunila galioides* Benth.	1
	Megachile (Pseudocentron) sp. 1			
		Asteraceae	*Erigeron maximus* (D.Don.) Otto ex DC.	3
			Hypochoeris brasiliensis (Less.) Griseb	1
		Malvaceae	*Sida carpinifolia* L.	1
		Solanaceae	*Solanum mauritianum* Scop.	1
		Tiliaceae	*Triumpheta semitriloba* Jacq.	1
		Verbenaceae	*Lantana camara* L.	1

Subfamily	Bee species		Plant species	Nº
	Megachile (Pseudocentron) sp. 2			
		Tiliaceae	*Triumpheta semitriloba* Jacq.	1
	Megachile (Trichurochile) thygaterella Schrottky, 1913			
		Asteraceae	*Jungia floribunda* Less.	1
		Begoniaceae	*Begonia cucullata* Ruiz ex Klotzsc	1
		Lamiaceae	*Cunila galioides* Benth.	3
	Coelioxys sp. 1			
		Asteraceae	*Austrœupatorium picturatum* (Malme) R.M. King & H. Rob.	1
			Bidens pilosa L.	1
			Erigeron maximus (D.Don.) Otto ex DC	1
Apinae	*Melissoptila thoracica* (Smith, 1854)			
		Asteraceae	*Bidens pilosa* L.	3
			Solidago chilensis Meyen	5
		Lamiaceae	*Cunila galioides* Benth.	2
			Hyptis lappulacea Mart. ex Benth	9
		Malvaceae	*Sida carpinifolia* L.	10
			Sida planicaulis Cav.	2
	Thygater sp. 1			
		Begoniaceae	*Begonia fischeri* Schrank.	1
	Paratetrapedia fervida (Smith, 1879)			
		Asteraceae	*Solidago chilensis* Meyen	1
		Lamiaceae	*Cunila galioides* Benth.	1
	Paratetrapedia volatilis (Smith, 1879)			
		Rosaceae	*Rubus rosifolius* Stokes	1
	Paratetrapedia sp. 1			
		Asteraceae	*Cyrtocymura scorpioides* (Lam.) H. Robinson	1
			Hypochoeris brasiliensis (Less.) Griseb	1
			Solidago chilensis Meyen	1
		Malvaceae	*Sida carpinifolia* L.	2
		Melastomataceae	*Tibouchina pilosa* Cogn.	1
		Solanaceae	*Aureliana wettsteiniana* (Witasek) Hunz. & Barboza	1
			Solanum bistellatum L.B. Sm. & Downs	4
		Verbenaceae	*Stachytarpheta cayennensis* (Rich.) Vahl.	1
	Lophopedia sp. 1			
		Asteraceae	*Jungia floribunda* Less.	1
			Solidago chilensis Meyen	4
		Fabaceae	*Desmodium adscendens* (SW) DC.	1
	Exomalopsis cf. vernoniae Schrottky, 1909			
		Lamiaceae	*Cunila galioides* Benth.	1
	Xylocopa (Ioxylocopa) chrysopoda Schrottky, 1901			
		Begoniaceae	*Begonia cucullata* Ruiz ex Klotzsc	1
		Fabaceae	*Desmodium adscendens* (SW) DC.	1
		Lamiaceae	*Cunila galioides* Benth.	2
			Hyptis lappulacea Mart. ex Benth	4
		Malvaceae	*Sida planicaulis* Cav.	1
	Xylocopa (Neoxylocopa) brasilianorum (Linnaeus, 1767)			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
		Lamiaceae	*Hyptis lappulacea* Mart. ex Benth	2
		Solanaceae	*Solanum bistellatum* L.B. Sm. & Downs	1

Subfamily	Bee species		Plant species	Nº
	Xylocopa (Stenoxylocopa) artifex Smith, 1874			
		Asteraceae	*Baccharis uncinella* DC.	1
		Convolvulaceae	*Ipomoea indivisa* (Vell.) Hallier	2
		Malvaceae	*Sida carpinifolia* L.	1
	Ceratina (Crewella) sp.8			
		Acanthaceae	*Hydrophila costata* Nees	1
	Ceratina (Crewella) sp.9			
		Asteraceae	*Senecio jurgensii* Hemsl.	1
	Ceratina (Crewella) sp.10			
		Fabaceae	*Desmodium adscendens* (SW) DC.	1
	Ceratina (Crewella) sp.11			
		Asteraceae	*Jungia floribunda* Less.	7
	Ceratina (Crewella) sp.12			
		Rosaceae	*Rubus rosifolius Stokes*	1
	Ceratina sp. 1			
		Polygalaceae	*Polygala paniculata* J. Le Conte ex Torr. & A. Gray	1
	Ceratinula sp. 1			
		Asteraceae	*Baccharis trimera* (Less.) DC.	1
	Pseudepeolus angustatus (Moure, 1954)			
		Asteraceae	*Jaegeria hirta* Lag. Less.	1
	Rhynepeolus rufiventris (Friese, 1908)			
		Asteraceae	*Bidens pilosa* L.	1
		Malvaceae	*Sida carpinifolia* L.	1
	Bombus (Fervidobombus) morio (Swederus, 1787)			
		Acanthaceae	*Hydrophila costata* Nees	1
		Commelinaceae	*Tripogandra diuretica* (Mart.) Handlos	1
		Fabaceae	*Desmodium adscendens* (SW) DC.	1
		Melastomataceae	*Tibouchina pilosa* Cogn.	2
	Bombus (Fervidobombus) pauloensis Friese, 1913			
		Acanthaceae	*Hydrophila costata* Nees	2
		Asteraceae	*Vernoanthura tweediana* (Baker) H. Rob.	2
		Lamiaceae	*Cunila galioides* Benth.	5
			Hyptis lappulacea Mart. ex Benth	3
		Malvaceae	*Sida planicaulis* Cav.	2
		Melastomataceae	*Tibouchina pilosa* Cogn.	1
		Saxifragaceae	*Escallonia bifida* Link & Otto	1
Meliponina	*Melipona (Eomelipona) bicolor schenki* Gribodo, 1893			
		Asteraceae	*Hypochoeris brasiliensis* (Less.) Griseb	1
			Solidago chilensis Meyen	1
			Vernoanthura montevidensis (Spreng.) H. Rob.	2
		Solanaceae	*Solanum bistellatum* L.B. Sm. & Downs	1
	Melipona (Eomelipona) marginata Lepeletier, 1836			
		Melastomataceae	*Tibouchina pilosa* Cogn.	1
	Melipona (Melipona) quadrifasciata anthidioides Lepeletier, 1836			
		Asteraceae	*Baccharis trimera* (Less.) DC.	1
			Solidago chilensis Meyen	2
		Cucurbitaceae	*Cucurbita pepo* L.	2
		Solanaceae	*Solanum delicatulum* L.B. Sm. & Downs	2
	cf. Schwarziana quadripuctata (Lepeletier, 1836)			
		Asteraceae	*Baccharis uncinella* DC.	2

Subfamily	Bee species		Plant species	Nº
	Scaptotrigona cf. bipunctata (Lepeletier, 1836)			
		Asteraceae	*Baccharis uncinella* DC.	2
	Plebeia saiqui (Friese, 1900)			
		Acanthaceae	*Hydrophila costata* Nees	2
		Araceae	*Zanthedeschia aethiopica* (L.) Spreng	9
		Asteraceae	*Baccharis anomala* DC.	3
			Baccharis trimera (Less.) DC.	7
			Baccharis uncinella DC.	2
			Hypochoeris brasiliensis (Less.) Griseb	9
		Balsaminaceae	*Impatiens walleriana* Hook.	1
		Brassicaceae	*Rhaphanus sativus* L.	3
		Malvaceae	*Sida carpinifolia* L.	1
			Sida planicaulis Cav.	1
		Rosaceae	*Rubus rosifolius* Stokes	8
		Solanaceae	*Solanum bistellatum* L.B. Sm. & Downs	1
		Verbenaceae	*Vitex megapotamica* (Spreng.) Moldenke	2
	Trigona spinipes (Fabricius, 1793)			
		Araceae	*Zanthedeschia aethiopica* (L.) Spreng	12
		Asteraceae	*Baccharis dentata* (Vell.) G.M. Barroso	40
			Baccharis uncinella DC.	1
			Hypochoeris brasiliensis (Less.) Griseb	1
			Vernoanthura montevidensis (Spreng.) H. Rob.	2
		Iridaceae	*Sysirinchium vaginatum* Spreng	2
		Loganiaceae	*Buddleja stachyoides* Cham & Schltdl.	1
		Plantaginaceae	*Plantago tomentosa* Lam.	4
		Rosaceae	*Rubus rosifolius* Stokes	37
		Rutaceae	*Citrus sinensis* (L.) Osbeck.	3
Apina	*Apis mellifera* Linnaeus, 1758			
		Apiaceae	*Eryngium eburneum* Decne.	12
		Araceae	*Zanthedeschia aethiopica* (L.) Spreng	6
		Asteraceae	*Baccharis trimera* (Less.) DC.	33
			Baccharis uncinella DC.	18
			Cyrtocymura scorpioides (Lam.) H. Robinson	13
			Erigeron maximus (D.Don.) Otto ex DC.	3
			Hypochoeris brasiliensis (Less.) Griseb	77
			Jaegeria hirta Lag. Less.	1
			Symphypappus itatiayensis (Hicron) R.M. King & H. Rob	12
			Vernoanthura montevidensis (Spreng.) H. Rob.	10
		Bignoniaceae	*Podranea ricasoliana* (Tanfani) Sprague	8
		Brassicaceae	*Rhaphanus sativus* L.	1
		Fabaceae	*Trifolium repens* Walter	1
			Desmodium adscendens (SW) DC.	1
		Lamiaceae	*Cunila galioides* Benth.	18
			Hyptis lappulacea Mart. ex Benth	15
		Plantaginaceae	*Plantago tomentosa* Lam.	2
		Rosaceae	*Rubus rosifolius* Stokes	5
		Rutaceae	*Citrus sinensis* (L.) Osbeck.	1
		Saxyfragaceae	*Escallonia bifida* Link & Otto	64
Total				710

BEE – FLOWER INTERACTIONS

The total number of species x species interactions observed was 210, while the number of possible interactions of this network is 5368; therefore, approximately 3.91 % of the possible interactions were actually registered. The connectance which indicates the proportion of possible interactions that are actually observed in the network is of the order value of 0.0391. The value of the measure of the network specialization (H2 ’) was 0.516.

In terms of the interactions observed for the bees, 43 (20 %) focused on three social species, representing only 3.4 % of the bee fauna: *Apis mellifera* Linnaeus, 1758 (20 plant taxa – 10 %), *Plebeia* sp. (13 plant taxa – 6 %) and *Trigona spinipes* Fabricius, 1793 (10 plant taxa – 5 %) (Fig. 1). Many species were sampled only once. The degree of bees varied from 1 to 20, where the average degree for the bee community was equal to 2.39. It is noteworthy that 24 (27 %) bee species used more plants species than average and 54 (60,5 %) visited only one plant species (Fig. 2).

The plant species that had the largest number of connections in the network was *Hypochoeris brasiliensis* (Less) Griseb (Fig. 1), interacting with 24 species of native bees and also with the exotic species *Apis mellifera*, which represented 60 % of all visits to this plant. In descending order, the three plant species that had the highest interaction concentration were: *Hypochoeris brasiliensis* (25 – 12 %), *Cunila galioides* Benth (10 – 5 %) and *Baccharis trimera* (Less.) DC. (9 – 4 %), all of the Asteraceae family. The degree of the plants ranged from 1 to 25, with the average degree for the plant community of 3.39. Twenty one of 84 species of plants (25 %) received a number of species visitors above the average, while 29 (34 %) received only one bee species visit (Fig. 3).

The asymmetry of the interactions was observed in this network through the species grouping. In the bipartite graph (Fig. 1), which represents the bee-flower associations in the study area, it was observed that many plant species are visited by a few species of bees, while a few bee species visit many plant species, showing a system with asymmetric interactions, shown by the value of nesting NODF = 6.22 ($P < 0.00$) that was significant.

DISCUSSION

Different bee species richnesses have been detected in other studies in the State, realized with the same methodology (Ortolan & Laroca, 1996; Krug & Alves-dos-Santos, 2008; Mouga & Krug, 2010) as well as in a neighbourhood state (Alves-dos-Santos, 1999). On the other hand, the data of subfamilies representativeness partly deviate from the pattern noticed for the State (Mouga, 2009).

Among the bee species found, there were rare taxa not assigned to the state of Santa Catarina but only to neighbouring or distant ones: *Augochlropsis cognata* Moure, 1944, *Augochlora dolichocephala* (Moure, 1941), *Neocorynura aenigma* (Gribodo, 1894) (Moure *et al*., 2007) as well as species indicative of well-preserved environments or recently described (e.g. *Anthrenoides antonii* Urban 2005, *Megachile (Trichurochile) thygaterella* Schrottky, 1913 and *Melipona (E.) bicolor shencki* (Gribodo, 1893).

The great number of interactions displayed by *Apis mellifera* in the network was already noticed before (Santos *et al.,* 2010, among others) and notifies about the place this species occupies in the environment. As this species is, in many places in Brazil nowadays, very common, its inclusion in the analysis is unavoidable but realistic of the structure of the bee communities.

The Asteraceae family was the dominant group of mellitophilous plants in many studied areas in Brazil: grasslands and Araucaria forest (Bortoli & Laroca, 1990; Barbola *et al.,* 2000), rocky grasslands (Martins, 1995; Faria-Mucci *et al.,* 2003), “cerrado” (savanna) (Carvalho & Bego, 1997), dunes and Atlantic forest (Alves-dos-Santos, 1999) which is in part explained probably by the fact that Asteraceae flowers display characteristics that make these plants more attractive to floral visitors in comparison to plants in other families: inflorescences with a large number of gathered flowers (more attractive to floral visitors than scattered single flowers) (Faegri & Van Der Pijl, 1979); their surface serving as a landing area (Endress, 1994); the floral traits as the floral tube size with few millimetres and the secondary pollen presentation (Proctor *et al.,* 1996).

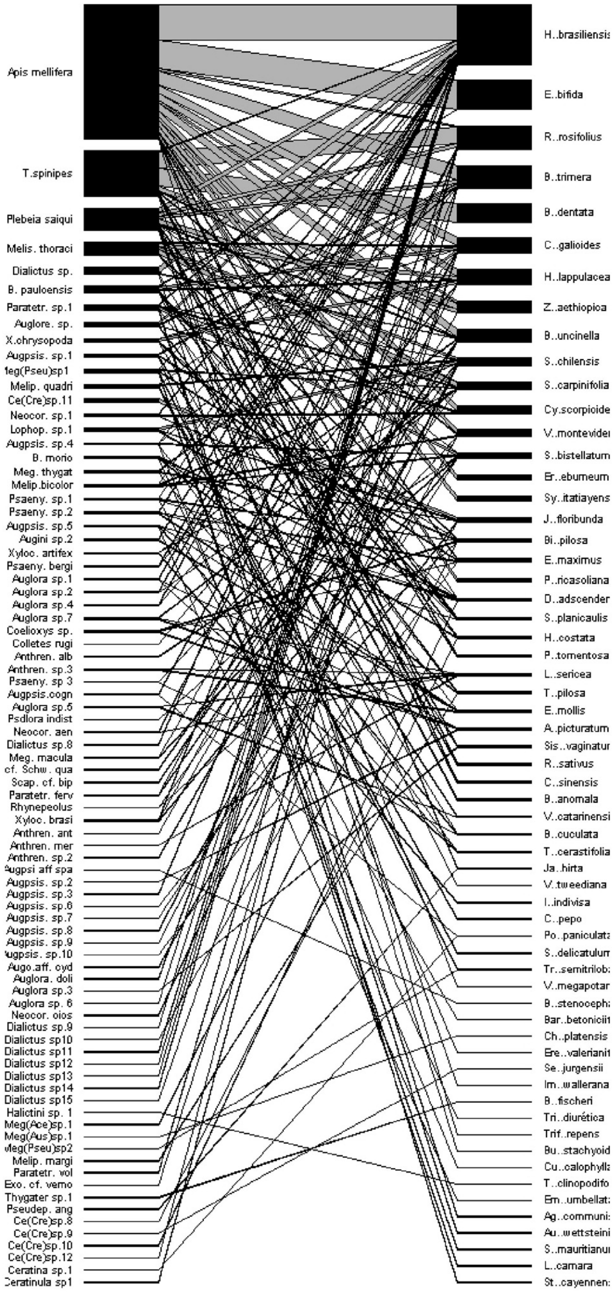

Figure 1.—Interaction network between bees and plants in the locality of Caetezal, Joinville, Santa Catarina State. On left, species of bees; on the right, species of plants. The number of lines and their thickness represent the strength of interaction between the species. Legend: Auglora = *Augchlora*; Augpsis = *Augchloropsis*; Auglore = *Augchlorella*; Augini = *Augchlorini*; Anthren = *Anthrenoides*; B = *Bombus*; Ce = *Ceratina*; Cre = *Crewella*; Lophop = *Lophopedia*; Meg = *Megachile*; Melip = *Melipona*; Melis = *Melissoptila*; Neocor = *Neocorynura*; Paratetr = *Paratetrapedia*; Psaeny = *Psaenythia*; Psdlora = *Pseudaugochlora*; Pseudep = *Pseudepeolus*; Scap = *Scaptotrigona*; Schw = *Schwarziana*; Thygat = *Thygaterella*; Xyloc = *Xylocopa*.

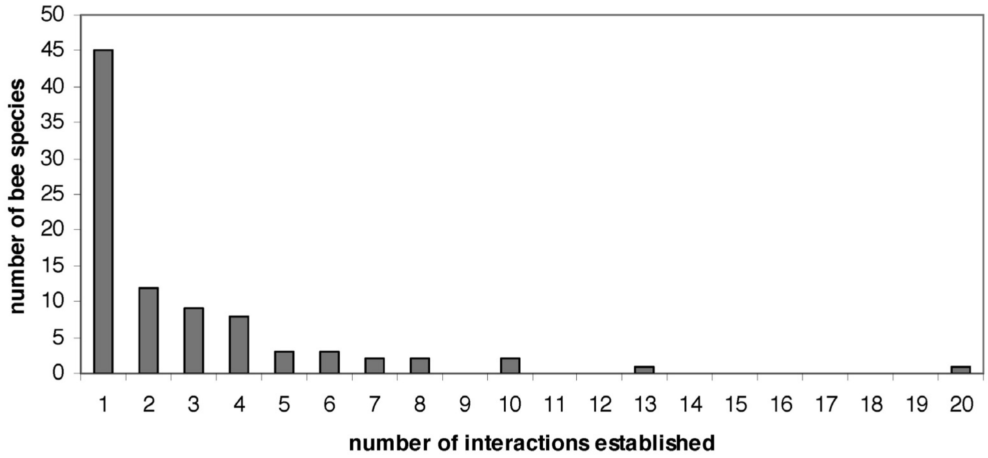

Figure 2.— Histogram of interactions frequency by number of bee species in the locality of Caetezal, Joinville, Santa Catarina State, Brazil.

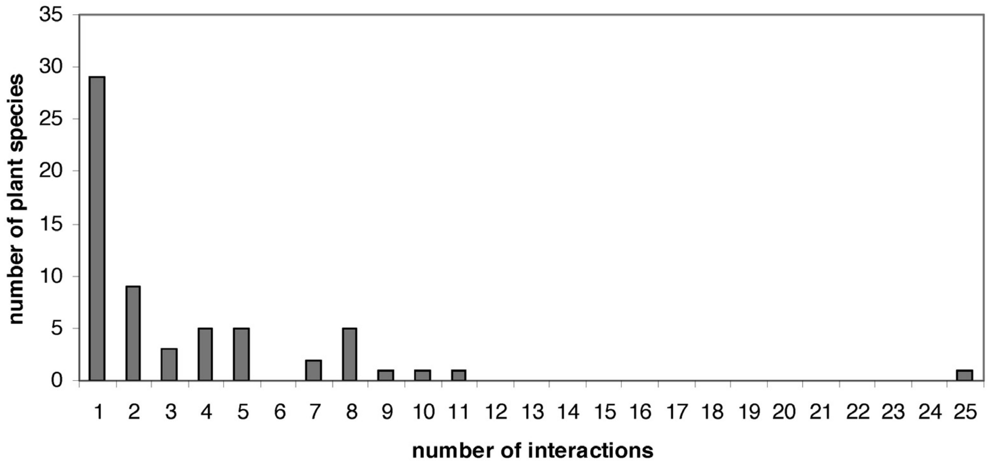

Figure 3.— Histogram of interactions frequency by number of plant species in the locality of Caetezal, Joinville, Santa Catarina State, Brazil.

In a quantitative comparison of social bee – food plant relationships retrieved from several studies performed in Brazil, Biesmeijer & Slaa (2006) report that the prevalence of social species of Apidae in the environment has influenced the interaction networks as a result of the peculiarities of behaviour, foraging and competition of these taxa.

The value of connectance confirms numbers found in other studies (Basilio *et al*., 2006; Petanidou *et al.,* 2008), amounts that often stay in the same order of values. As an alternative, Blutgen *et al*. (2006) proposed H2´, instead of the use of connectance.

Dormann *et al.* (2008) indicate that the properties of first order (abundance distribution of network participants) and second order (network connectance) are factors that, above all, allow a very large agreement between the observations and null models.

The value of the measure of the network specialization indicates a greater specialization of the studied community, in relation to a similar study conducted in England (H2' = 0.24) and close to the one in an Argentine community (H2' = 0.63) (Blüthgen *et al.,* 2006).

In this study, the relationship that transpires between the attractiveness of the plant species to bees and their demand of supplies points to a generalization of the use of resources rather than a specialization.

On the other hand, the data collected show a community structure with less social species, which may purport bee species with more specialized resources. Oligolecty relationships (Pinheiro-Machado *et al.,* 2006) and concentration of visits to a few floral species (Roubik, 1989) can be expected in the rain forest. However, in this study, several bee species that show this pattern were represented by few individuals, and are possibly rare, what requires caution in the understanding of this study, and, if possible, further surveys. Most bee species that visited only one plant species are solitary and represented by few individuals, what precludes conclusions about their diet breath (Bascompte & Jordano*,* 2007).

The found system, with asymmetric interactions, is a general pattern for this kind of interaction web, confirmed by several authors (Vazquez & Aizen, 2003; Mouga & Krug, 2010, among others).

Pigozzo & Viana (2010) suggest that there is a correlation between the abundance of certain bee species and the richness of plant species they exploit as well as the fact that plant species with more intense blooms attract the greatest number of bees. In fact, according to Blutgen *et al* (2006), the nested pattern can be generated by the random combination of sets of plants and flower visitors with different abundances.

In short, in the focused environment, the study exposed rare taxa and others not yet reported to the state. As in Biesmeijer & Slaa (2006), in their summary on the community structure of social bees in Brazil, we found, in this study, the set of bees that forage in group, of medium size, non-aggressive and the set of aggressive, group bee foragers (including *Trigona spinipes, Apis mellifera* and *Plebeia* sp.). However, species of the genera *Partamona, Tetragonisca, Paratrigona, Frieseomellita* and *Nannotrigona,* taxa of relative occurrence as commonly found across habitats and latitudes, referred by the authors mentioned before, were not sampled.

Considering that the study was performed in a transition area, a comparison with the bee fauna of the adjacent Atlantic rain forest and Araucaria forest, when the data of these two formations would be available, would be very interesting.

The organization and complexity level of the bee-plant interaction network in the area have been addressed, aiming to contribute to their conservation as well to understand the community structure in different ecosystems of Brazil, emphasizing the ecological characterization of the tool in the environmental assessment.

ACKNOWLEDGEMENTS

To UNIVILLE for funding of the project, to Joinvillea Herbarium of UNIVILLE and Botanical Municipality Museum of Curitiba for their aid with the plant identification as well as to the bee experts Danúncia Urban, Antonio Aguiar and Gabriel A. R. Melo for their help in bee identification.

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