Seasonal flight and resource collection patterns of colonies of the stingless bee *Melipona bicolor schencki* Gribodo (Apidae, Meliponini) in an Araucaria forest area in southern Brazil

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ABSTRACT. Seasonal flight and resource collection patterns of colonies of the stingless bee *Melipona bicolor schencki* Gribodo (Apidae, Meliponini) in Araucaria forest area in southern Brazil. *Melipona bicolor schencki* occurs in southern Brazil and at high elevations in southeastern Brazil. It has potential for use in meliponiculture but this stingless bee species is vulnerable to extinction and we have little knowledge about its ecology. In order to gather essential information for species conservation and management, we made a study of seasonal flight activities in its natural environment. We sampled bees entering the nests with pollen, nectar/water and resin/mud, in five colonies during each season. In parallel, we analyzed the influence of hour of the day and meteorological factors on flight activity. Flights were most intense during spring and summer, with daily mean estimates of 2,100 and 2,333 flights respectively, while in fall and winter the daily flight estimate was reduced to 612 and 1,104 flights, respectively. Nectar and water were the most frequently-collected resources, followed by pollen and building materials. This preference occurred in all seasons, but with variations in intensity. During spring, daily flight activity lasted over 14 hours; this period was reduced in the other seasons, reaching eight hours in winter. Meteorological factors were associated with 40.2% of the variation in flight and resource collection activity. Apparently, other factors that we did not measure, such as colony needs and availability of floral resources, also strongly influence the intensity of resource collection.

KEYWORDS. Endangered species; flight activities; guaraipo; meteorological factors; species conservation.

RESUMO. Padrão sazonal de vôo e coleta de recursos em colônias de *Melipona bicolor schencki* Gribodo (Apidae, Meliponini) em área de Floresta com Araucária no sul do Brasil. *Melipona bicolor schencki* ocorre no Sul e em regiões de altitude elevada no Sudeste do Brasil. Encontra-se vulnerável a extinção no Rio Grande do Sul e possui potencial para meliponicultura, entretanto o conhecimento de sua ecologia é escasso. Desenvolveu-se o estudo sazonal das atividades de vôo de colônias em ambiente natural, com vistas a subsidiar ações conservacionistas e manejo. Amostrou-se o ingresso de pólen, néctar/água e resina/barro em cinco colônias, durante o período de atividades externas, em cada estação do ano. Analisou-se também a influência do horário e de fatores meteorológicos sobre o vôo. Os vôos foram similarmente mais intensos durante a primavera e verão, com estimativa diária de 2100 e 2333, enquanto no outono e inverno reduziram-se respectivamente para 612 e 1104. O transporte de néctar/água foi maior, seguido de cargas de pólen e de materiais de construção. Esta situação ocorreu similarmente nas quatro estações, porém com variações de intensidade. A amplitude diária de vôo foi de 14 horas na primavera, reduzindo-se nas demais estações e atingindo 8 horas no inverno. Os fatores meteorológicos exerceram influência de 40,2% no vôo das abelhas. Este resultado indica que outros fatores, não mensurados neste estudo, como as necessidades das colônias determinadas por fatores fisiológicos e a disponibilidade de recursos florais, exercem forte influência sobre a intensidade de coleta de recursos.

PALAVRAS-CHAVE. Atividades de vôo; conservação de espécies; espécie ameaçada de extinção; fatores meteorológicos; guaraipo.

Melipona bicolor schencki Gribodo, 1893 is a stingless bee found in the southern region of Brazil and in cool regions at high elevations in the southeastern part of the country (Moure *et al*. 2007). In the southernmost state, Rio Grande do Sul, this species has been collected from Cambará do Sul, Osório and São Francisco de Paula (Blochtein & Harter-Marques 2003).

Generally, nests of *Melipona* Illiger, 1806 are found within forests, in tree trunk cavities (Nogueira-Neto 1970; Kerr *et al*. 1996; Michener 2000; Freitas *et al*. 2006; Roubik 2006). The bees enter and leave their nests through an opening through which only one bee can pass at a time (Nogueira-Neto 1970; Pirani & Cortopassi-Laurino 1993). They go on orientation flights, flights to discard detritus, as well as flights to collect nest material and food resources (Kerr *et al.* 1996; Pierrot & Schlindwein 2003).

Pollen is the main protein source of bees, essentially for feeding the brood, while nectar is the carbohydrate source for both brood and adults (Michener 1974; Nogueira-Neto 1970; Nogueira-Neto 1997; Roubik 1989). The mutualism established between bees and plants allows for both the sustenance of bee populations and sexual reproduction of the plants through pollination (Heard & Exley 1994; Alves-dos-Santos 1999; Cortopassi-Laurino *et al.* 2006; Souza *et al.* 2007; Freitas *et al*. 2009). Plant resins are used for construction and hygienization of bee nests (Michener 1974; Nogueira-Neto 1997; Roubik 1989, 2006). The mixture of propolis with wax, secreted by the workers from their abdominal glands, forms cerumen, the material that they use to build brood combs, food pots and the envelope that protects the combs (Nogueira-Neto 1997). The resins can also be mixed with mud collected by the bees, forming batumen or geopropolis, which is applied to seal cracks (Ihering 1930 *apud* Nogueira-Neto 1997), giving greater protection to the nests. Water is another resource collected by the bees; it is important for regulating the humidity levels within the nest (Bego 1989; Silva *et al.* 1972). However, generally speaking, stingless bees are rarely seen collecting water, perhaps because their honey has high water content (Nogueira-Neto 1970).

Studies of flight activity and resource collection help understand the ecological niche of species, given that bees respond to meteorological factors (Iwama 1977; Fowler 1978; Kleinert-Giovanini & Imperatriz-Fonseca 1986; Heard & Hendriz 1993; Hilário *et al.* 2000; Hilário *et al.* 2001; Pick & Blochtein 2002; Borges & Blochtein 2005). Temperature, relative humidity, light intensity, wind and atmospheric pressure can influence the flight activity of social insects. Seasonal foraging patterns can vary in response to biological factors, such as flowering (Winston 2003). Most regions where bees are found have defined seasons, with predictable climatic variation; however, variable weather conditions can impact strongly on bee activity.

Flight activity and resource collection has been studied in two species of Meliponini in Rio Grande do Sul: *Plebeia saiqui* (Friese, 1900) (Pick & Blochtein 2002) and *Melipona marginata obscurior* Moure, 1971 (Borges & Blochtein 2005). Considering that *M. b. schencki* is considered vulnerable to extinction in Rio Grande do Sul, that it has potential for use in meliponiculture and that little is known about this species (Blochtein & Harter-Marques 2003; Freitas *et al.* 2006), we examined the flight activity of colonies of this species in a natural habitat. We also looked at the ingress of material that the bees transport to the nest and how flight activity and resource collection are affected by meteorological factors, in order to provide information necessary for the management and conservation of this species.

MATERIAL AND METHODS

Study Area

The study area is within the confluence of three phytoecological regions, including araucaria forest and Atlantic rainforest (*senso stricto*) and a herbaceous-bushy formation, regionally known as hill-top fields. The study was conducted at the Centro de Pesquisas e Conservação da Natureza Pró-Mata of PUCRS, in São Francisco de Paula, RS (29°27'S/29°35'S and 50°08'W/50°15'W). Most of this Pró-Mata reserve, which has an altitude of 900 m, consists of Araucaria forest. The climate is very humid to humid, with 1,750 – 2,500 mm annual rainfall (Bertoletti & Teixeira 1995).

Colony maintenance

Five colonies of *M. b. schencki*, from northeast Rio Grande do Sul state, were maintained in 26 x 28 x 37 cm nest boxes constructed of 2.5 cm thick wood. The nest was covered with a transparent glass pane, protected with Styrofoam and a wood cover. These nests were kept in a climate-controlled room maintained at 25 ± 4°C. The colonies were similar in number of combs (6 to 8 over the year) and stored food. The bees had access to the outside environment through a 15 mm diameter plastic tube that went through the wall of the room. The colony entrances were identified individually with colored boards. Artificial feeding was used when necessary (1:1 sucrose / water), using the method proposed by Nogueira-Neto (1997); they were not fed during the days preceding and during data collection.

External activities

Flight activity of the bees was observed at the entrance of each colony, using the methodology described by Oliveira (1973), during the four seasons of the year. The number of bees returning to their nests and the material they carried were registered during five minutes per hour from sunrise to sunset, using manual counters. The materials collected by the bees were identified by direct observation. Pollen was characterized by its granular appearance, resin by its glassy aspect and mud was identified as opaque and humid. Resin and mud collection observations were grouped, as suggested by Hilário *et al.* (2003). Bees without apparent material loads were registered as nectar/water collectors, as in Carvalho-Zilse *et al*. (2007). During some days, observations were interrupted because bee flight activity had ceased (probably due to adverse meteorological conditions); they were reinitiated on subsequent days when activity at the entrance was observed, beginning at the time of day when they had initially been interrupted. Observations were made during spring/2006 (5 days in November-December), and summer (7 days in February-March), fall (6 days in May) and winter/2007 (7 days in July to September).

To determine how meteorological conditions affect flight activity, data on temperature, relative humidity, wind speed, light intensity and atmospheric pressure were collected before recording flight information, using a digital thermometer / hygrometer (Oregon Scientific® THG312), a digital anemometer (TFA®), a digital lux meter (Extech®) and a mercury column barometer (Incoterm®). These instruments were maintained outside on a table, six meters from the colony entrances.

Analyses

To determine the influence of season on flight activity, the data from the five colonies were analyzed together. Based on the number of flights recorded during each observation period, an estimate of the daily total flight activity was made for each colony calculating the results of the samples (5min) x 12 (60min). For the statistical analyses, the data were log-transformed and analyzed with the Kolmogorov-Smirnov (for normality) and Levene (for homoscedasticity) tests. As the data were normal, we were able to use analysis of variance and the Tukey test, with a 95% confidence interval.

In order to determine the influence of meteorological factors and time of day on flight activity, the colonies were

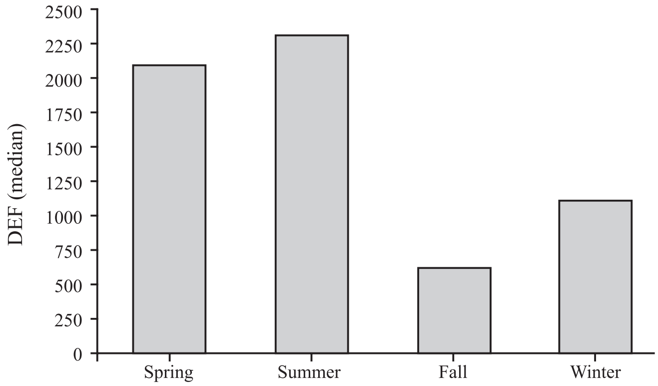

Fig. 1. Estimate of the number of daily flights made by workers of five colonies of *Melipona bicolor schencki*, during four seasons, from November 2006 to October 2007, in São Francisco de Paula, RS. Number of observations: spring = 441; summer = 628; fall = 253 and winter = 421. Daily estimative of flights (DEF).

analyzed together, without considering resources collected. The data were log converted to normalize them for analysis. A stepwise regression was used to determine the factors that most affected flight, in order of importance.

The hours of the day were grouped by similarity in terms of their influence on flight activity, using the Chi-square test with a confidence interval of 95%. The data on temperature, relative humidity, wind speed, light intensity and atmospheric pressure were grouped in quartile intervals to determine how these factors affected flight activity.

The data were analyzed using the statistical package SPSS, version 11.5 for MS Windows.

RESULTS

Influence of season on flight activity

Based on the register of external activity made at the entrances of colonies of *M. b. schencki*, there was intense flight activity during all four seasons. The most intense flight activity was during summer, followed by spring, fall and winter (Fig. 1). Spring and summer flight activity did not differ significantly. Fall and winter activity also did not differ significantly. Spring/summer flight activity was significantly greater ($p<0.01$) than fall/winter activity.

Resource collection and seasonality

Nectar/water was the most frequently collected, followed by pollen and resin/mud. This order of frequencies was maintained during the four seasons of the year (Fig. 2).

Resource collection varied with season (Fig. 2). Pollen was most intensively collected in summer, superior to the frequency in spring, though the difference was not significant ($p=0.054$). Pollen collection frequency was statistically similar in fall and winter ($p=0.187$), though it was somewhat higher in winter (Fig. 2). The frequency in spring was similar to that in winter ($p=0.987$) and fall ($p=0.095$). Pollen collection frequency in summer was significantly different from that in fall ($p<0.001$) and winter ($p<0.050$).

Nectar collection was similar in spring and summer ($p=0.982$) and was also similar in fall and winter ($p=0.805$). The frequencies in summer and winter differed, though the difference as not quite significant ($p=0.050$).

Collection of resin/mud was significantly greater in spring, compared to the other seasons ($p<0.001$). It was similar in summer, fall and winter ($p=0.870$).

Influence of hours of day on flight activity

The hours of day during which the colonies foraged varied among the four seasons. During spring, the bees flew during 14 hours; they did so fewer hours per day in the other seasons, reaching a minimum of eight hours in winter (Fig. 3).

Pollen was preferentially collected by the bees in the morning during all four seasons, continuing till the early afternoon in summer and winter (Fig. 3). Returning flights with nectar/water increased in frequency during the day during all four seasons. This nectar/water collecting activity was intense during all of the hours that flights were recorded in spring and summer. During fall, nectar/water collecting flights were more common in the morning and during winter they were more common late in the morning and in the early afternoon (Fig. 3).

During spring and summer, resin and mud were collected during all flight activity hours, though it was most intense in spring. During fall, resin/mud collection also occurred during all flight activity hours, though at a lower intensity than in spring and summer. Winter was the season with the lowest frequency of resin/mud collection (Fig. 3).

Factors that influenced flight activity

Based on regression analysis (Table I), the abiotic factors temperature, hour of the day, atmospheric pressure and light intensity, influenced the flight activity of the five colonies of *M. b. schencki*. They explained 40.2% of the variation in flight activity. Among these factors, temperature accounted 32.3% of the variation; the influences of wind speed and of relative humidity were not significant.

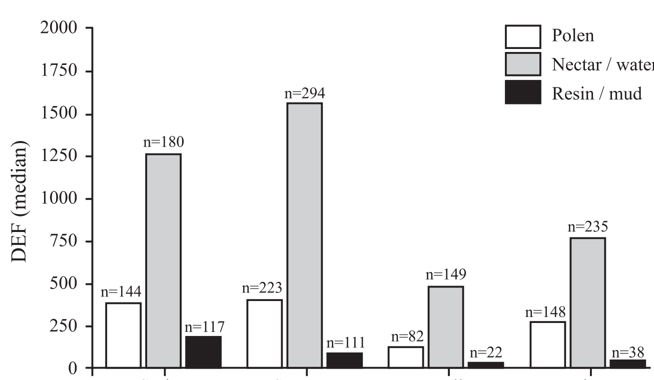

Fig. 2. Estimate of the number of daily flights and respective types of material collected made by *Melipona bicolor schencki* workers during the four seasons, from November 2006 to October 2007, in São Francisco de Paula, RS. Daily estimative of flights (DEF).

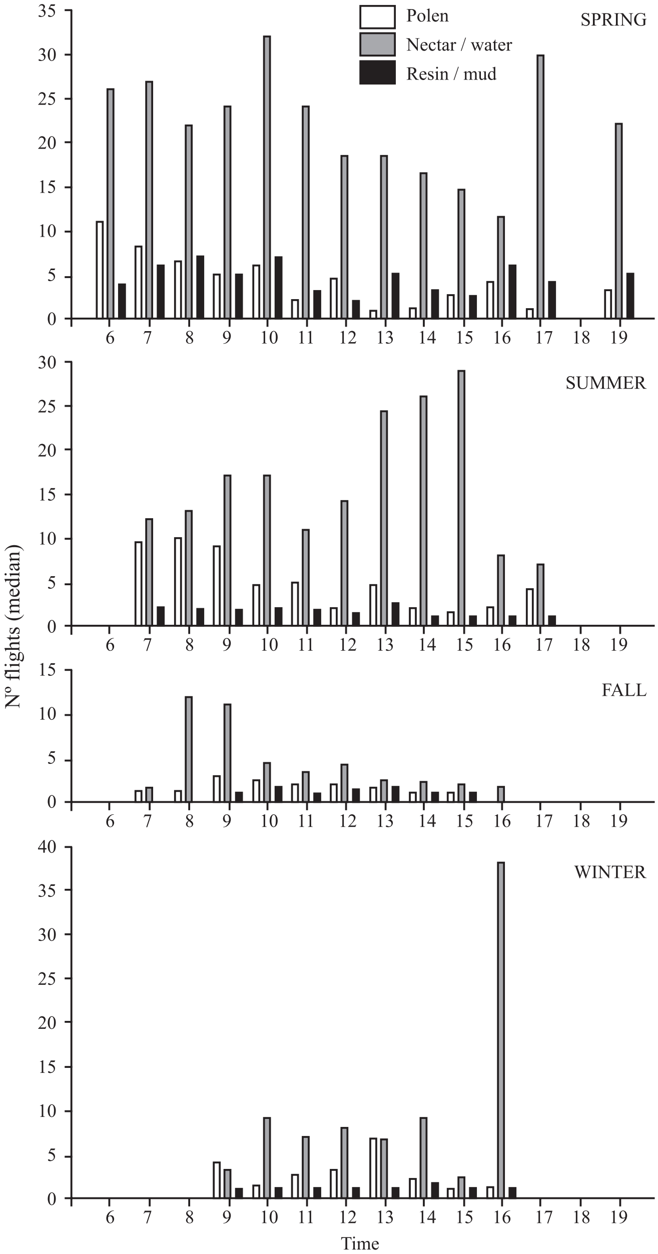

Fig. 3. Flight activity of *Melipona bicolor schencki*, during 5 min/hour, in five colonies, with the respective materials collected, during the four seasons of the year, from November 2006 to October 2007, in São Francisco de Paula, RS. Number of observations: spring = 441; summer = 628; fall = 253 and winter = 421.

Variations in atmospheric pressure did not significantly affect flight activity (p>0.05). However, when combined with other climate factors, some influence was seen (Table I). The last factor in this model, light intensity, explained 2.8% of the variation in flight activity.

Analysis of the influence of meteorological factors on flight activity, done with a quartile scale, showed the ideal ranges for external activity. In this model, the most active quartile comprised 50% of the flights that were recorded (Table II).

DISCUSSION

Influence of season on flight activity

Flight activity by *M. b. schencki* was most intense in spring and summer. Seasons are quite defined in southern Brazil and it is clear that these two seasons are favorable for bee flight, because the minimum mean temperatures, the mean solar radiation and the number of sunlight hours are higher than in fall and winter (IPAGRO 1989). These are also the seasons when there is abundant flowering (Truylio & Harter-Marques 2007). According to Roubik (1989), nectar offered by the plants influences flight activity, as a consequence of the mobilization of bees to collect these resources. Our results on flight activity of *M. b. schencki* are similar to those found for *Melipona asilvai* Moure, 1971 (Souza *et al*. 2006). In this latter study, flight activity was most intense in September, January and March, months that correspond with spring and summer, when flowering is most intense.

Hilário *et al*. (2000) reported that the flight activity of *Melipona bicolor bicolor* Lepeletier, 1836 varied daily and seasonally and could be affected by environmental changes. We found that flight activity was greater in winter than in fall (Fig. 1), however these data were not statistically significant. Possibly, resources availability, as indicated by Hilário *et al.* (2000), influenced this increase, as flowering began about a month before the end of winter in 2007.

Seasonal variation in materials collection

As seen with other species of this genus, studied by Roubik *et al.* (1995), Pierrot & Schlindwein (2003), Souza *et al*. (2006) and Fidalgo & Kleinert (2007), most flights by *M. b. schencki* involved nectar/water collection, followed by pollen and construction material. This pattern, observed during the four seasons of the year, can be explained by the need for energy, which is essential for internal and external activity by the bees of the colonies.

Pollen is needed for provisioning brood, and is also consumed to a lesser degree by adults. According to Winston (2003), pollen collection is modulated by both colony necessity and the availability of this resource. Resin/mud was less frequently collected than the other materials along the year; this category of material was most intensively collected in spring, suggesting intense nest construction activity, which is what we actually observed during our study. Collection of resin and mud during all hours and during the whole year could be a function of the permanent availability of these

Table I. Regression test of abiotic factors on flight activity of *Melipona bicolor schencki* from November 2006 to October 2007, in São Francisco de Paula, RS.

Set of factors	r²
Temperature	0.323
Temperature + Time	0.353
Temperature + Time + Atmospheric Pressure	0.374
Temperature + Time + Atmospheric Pressure + Light intensity	0.402

Table II. Interquartile distribution (%) of flights made by *Melipona bicolor schencki*, from November 2006 to October 2007, in São Francisco de Paula, RS, as a function of meteorological factors: temperature (n=888), relative humidity (n=888), luminosity (n=834), atmospheric pressure (n=888) and wind speed (n=834).

	Interquartile ranges of recorded flights		
	25%	50%	25%
Temperature (°C)	9.2 - 17.7	17.7 - 24.5	24.5 - 38.4
Relative Humidity (%)	20 - 48	48 - 74	74 - 98
Light intensity (Lux)	3-26.200	26.200-93.500	93.500-196.800
Atmospheric Pressure (mmHg)	679 - 685	685 - 691	691 - 695
Wind Speed (Km/h)	0 – 2.6	2.6 – 12.2	12.2 – 39.8

resources in the environment, which has also been seen in studies of other species of Meliponini (Hilário *et al*. 2000; Hilário *et al*. 2001; Souza *et al*. 2007).

Among the different materials foraged on by *M. b. schencki*, nectar was collected during all hours of the day, due to the prolonged availability of this resource in the flowers, though with varying intensity during the different seasons (Silva *et al*. 2007). Similar observations were made for other species of *Melipona* (Brujn & Sommeijer 1997; Hilário *et al*. 2000; Pierrot & Schlindwein 2003; Borges & Blochtein 2005). However, during winter (Fig. 3, at 16 h), nectar/water collection was more intense in the *M. b. schencki* colonies. Since the conditions during this season are less favorable for the bees, both in terms of food resource availability and meteorological factors, the large number of workers returning during this time period could be due to bees that have spent a long time looking for this resource and then all return at the end of the day.

Pollen collection was most intense in the morning and the early afternoon during all four seasons. This was also found in other studies (Brujn & Sommeijer 1997; Hilário *et al*. 2000; Pierrot & Schlindwein 2003); this could be attributed to the period of dehiscence of the anthers (Buchmann 1983) and the consequent liberation of pollen in numerous plant species. Usurpation by competitors could also explain the timing of pollen availability (Roubik 1989).

Factors that influence flight activity

As with other social insects, bee behavior is strongly influenced by meteorological conditions, mainly because they are "cold-blooded" (Silveira Neto *et al*. 1976). During daily flight activities, meteorological factors oscillate and associate in different ways. Movement of masses of air and of clouds are examples of phenomena that affect weather (Sonnemaker 2005). Another relevant factor is the movement of the rotation of the earth, so that the sun progressively illuminates the different meridians of the globe, constantly altering luminosity, temperature, humidity, wind speed, atmospheric pressure, and many other variables, both biotic and abiotic. Together, the factors temperature, hour of day, atmospheric pressure and luminosity explained 40.2% of the variation in flight activity of *M. b. schencki*. Temperature alone accounted for 32.3% of this variation, being the factor that most influenced flight activity. Corbet *et al.* (1993) also found that temperature was the most important factor influencing flight activity of social insects. Other studies also reported on the influence of temperature on flight activity of Meliponini (Hilário *et al*. 2000; Hilário *et al*. 2001; Borges & Blochtein 2005; Souza *et al*. 2006). The temperature range considered ideal for *M. b. schencki* flight (17.7 – 24.5°C) in Rio Grande do Sul state was similar to that reported by Hilário *et al*. (2000) for *M. b. bicolor* (16–26°C) in São Paulo state. However, the minimum temperature for flights by *M. b. schencki* was 9.2°C (Table II), inferior to that reported for *M. b. bicolor,* which was 11°C (Hilário *et al.* 2000). According to Teixeira & Campos (2005), there is a relationship between body size and minimum temperature for initiating flight activity; the larger the bee, the lower the temperature at which it begins to fly. In this case, the two species, *M. b. schencki* and *M. b. bicolor*, have similar body sizes. Apparently factors other than body size also have an influence (Hilário *et al*. 2001).

Though the optimum relative humidity range for flight by these bees was found to be 48 - 74%, we found that variations in humidity did not significantly influence flight activity by *M. b. schencki.* The same was reported for *M. asilvai* (Souza *et al.* 2006). However, in studies made with colonies of *Melipona quadrifasciata quadrifasciata* Lepeletier, 1836 (Guibu & Imperatriz-Fonseca 1984) and *M. b. bicolor* (Hilário *et al.* 2000) there was a positive correlation between relative humidity and flight activity. The opposite was found for some other species of stingless bees, in which flight activity was inversely correlated with relative humidity: *Tetragonisca angustula* (Latreille, 1811) (Iwama 1977), *Plebeia droryana* (Friese, 1900) (Oliveira 1973), *Plebeia emerina* (Friese, 1900) (Kleinert-Giovanini 1982), *Plebeia saiqui* (Oliveira 1973; Pick & Blochtein 2002) and *Melipona marginata* Lepeletier, 1836 (Kleinert-Giovannini & Imperatriz-Fonseca 1986).

We found that changes in luminosity explained 2.8% of the variation in flight activity in *M. b. schencki*. Luminosity is as important as temperature for flight. However, the bees do not appear to respond as intensively to variations in luminosity as they do to temperature, even though light is essential for flight. A luminosity of 3 Lux was found to be sufficient for flight activity. Though the influence of this factor was low based on the regression model, based on the statistical models developed by Iwama (1977) and Hilário *et al*. (2001) suggested that luminosity is the factor that determines the initiation and termination of external activities, as also concluded by Heard & Hendriz (1993) in a study of *Trigona carbonaria* Smith, 1854.

Atmospheric pressure also has some influence on flight (2.1%). Alone, it does not determine flight activity, but phenomena associated with its variation, such as temperature and rainfall, do directly affect flight. High pressure indicates good weather and low temperature, while low pressure occurs during warm days and when rain clouds are present or are approaching (Sonnemaker 2005).

We found that *M. b. schencki* flew in winds up to 39.8 Km/h. Though wind can make foraging more difficult (Fidalgo & Kleinert 2007), a significant effect of wind on flight activity was not found, as also reported by Borges & Blochtein (2005) for *M. m. obscurior* in the same geographic region.

Bee flight activity can also be influenced by biotic factors, such as availability of flower resources, rate of emission of volatiles by certain plants and the activity of predators. All of the biotic and abiotic factors that we did not measure accounted for 59.8% of the variation in flight activity of *M. b. schencki*. The most important of these factors is probably flower-resource availability. However, the resource collection patterns and the general flight activity patterns of *M. b. schencki* influenced by the well defined seasons that occurred in southern Brazil. During spring and summer, flight activity is intense and similar, when compared to fall and winter. Given the current scenario of climate changes, monitoring species such as *M. b. schencki* could help us to detect alterations in ecological patterns and to plan policies focused on conserving biodiversity.

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