The availability of Piperaceae and the search for this resource by *Carollia perspicillata* (Linnaeus) (Chiroptera, Phyllostomidae, Carolliinae) in Parque Municipal Arthur Thomas, Londrina, Paraná, Brazil

Isaac Passos de Lima & Nélio Roberto dos Reis

Departamento de Biologia Animal e Vegetal, Universidade Estadual de Londrina. 86051-990 Londrina, Paraná, Brasil. E-mail: lima_isaac@ig.com.br

ABSTRACT. A study about the species of Piperaceae that are consumed by a colony of *Carollia perspicillata* (Linnaeus, 1758) in Parque Municipal Arthur Thomas (82,72 ha) was carried out. Five available species of Piperaceae were found in the park: *Piper aduncum* Linnaeus, *Piper amalago* (Jacq.) Yuncker, *Piper crassinervium* H.B.K., *Piper gaudichaudianum* Kunth and *Piper* sp. *C. perspicillata* fed on all of these species. During the spring, the most abundant item was *P. amalago*, but the consumption of *P. aduncum* was the highest. At the beginning of the summer, *P. crassinervium* was the most abundant and most consumed item. At the end of the summer and during the fall, *P. gaudichaudianum* was the most abundant and consumed item, even in May, when *P. amalago* was the most abundant item. During the winter, the most highly available items were *P. aduncum*, *Piper* sp. and *P. amalago*, and the ones that were consumed the most were *Piper* sp., *P. gaudichaudianum* and *P. aduncum*. The results have shown that the preferences of *C. perspicillata* in the park are related to the greater abundance or the higher energetic value of the available Piperaceae. The greater search for the most energetic and least abundant species, which happened in the spring and winter, is related to the energy gain, that is, the species searches for food that will provide a greater quantity of energy per unit of consumption; and the greater search for the most abundant item, which occurred in the summer and fall, is related to saving the energy used in the search for food.
KEY WORDS. Bats, frugivory, *Piper*, plant-animal interaction, seed dispersion.

RESUMO. Estudou-se quais espécies de piperáceas são consumidas por uma colônia de *Carollia perspicillata* (Linnaeus, 1758) localizada do Parque Municipal Arthur Thomas (82,72ha). Foram encontradas no parque: *Piper aduncum* Linnaeus, *Piper amalago* (Jacq.) Yuncker, *Piper crassinervium* H.B.K., *Piper gaudichaudianum* Kunth e *Piper* sp. *C. perspicillata* alimentou-se de todas essas espécies. Durante a primavera, o item mais abundante foi *P. amalago*, porém o mais consumido foi *P. aduncum*. No início do verão, *P. crassinervium* foi o mais abundante e o mais consumido. No final do verão e no outono, *P. gaudichaudianum* foi o mais abundante e o mais consumido, mesmo em maio, quando *P. amalago* foi o mais abundante. No inverno, os itens mais disponíveis foram *P. aduncum*, *Piper* sp. e *P. amalago*, e os mais consumidos, *Piper* sp., *P. gaudichaudianum* e *P. aduncum*. Os resultados mostraram que o maior consumo de *C. perspicillata* por infrutescências de *Piper*, no parque, está relacionado à maior abundância ou ao maior valor energético das infrutescências disponíveis: na primavera e no inverno, a maior procura pelas espécies mais energéticas e menos abundantes está relacionada ao ganho energético, ou seja, a espécie procura alimentos que lhe rendam maior quantidade de energia por unidade de consumo; no verão e no outono, a maior procura pela mais abundante está relacionada à economia da energia gasta na procura do alimento.
PALAVRAS CHAVE. Dispersão de sementes, frugivoria, interação planta-animal, morcegos, *Piper*.

Some bat species, including *Carollia perspicillata* (Linnaeus, 1758), are considered possible indicators of deteriorated areas (Schulze *et al*. 2000, Wilson *et al*. 1996). According to several authors (Dinerstein 1986, Charles-Dominique 1991, Marinho-Filho 1991, Müller & Reis 1992, Bizerril & Raw 1998, Thies *et al*. 1998, Tavares 1999), *C. perspicillata* has a special preference for *Piper* Linnaeus, 1737 species, and Reis *et al*. (2003) have suggested that its presence in a certain area would be associated to its preference for Piperaceae, whether the area is deteriorated or not. In a study about the behavior of *C. perspicillata,* Thies *et al*. (1998) observed that this species uses echolocation as well as smell to find ripe *Piper* species infrutescences. *Piper* plants are pioneers, with shrub, and more rarely arboreal or herbal, characteristics. They have great importance for ecological succession and are typical of dry, humid forests and disturbed areas (Figueiredo & Sazima 2000, Fleming 1986).

Parque Municipal Arthur Thomas (PMAT) has been widely used as a place for bat studies. Müller & Reis (1992) studied the sharing of resources among frugivorous species in different fragmented areas; Reis & Müller (1995) and Reis *et al*. (2000) compared the diversity of bat species from the park to others from distinct forest fragments of the region; Reis *et al*. (1998) updated the list of species found in the park and in the region, and Félix *et al*. (2001) analyzed the park capacity concerning the maintenance of feasible bat populations.

According to Garcia *et al*. (2000), the presence of pioneering plant seeds and plants of late primary succession in bat feces reinforces the idea that bats contribute significantly to the increase of diversity in these altered areas. A better knowledge of the phenology of the species utilized by *C. perspicillata* as well as a study of this bat's preference in these places does not only contribute to the recovery of these environments, but also to the maintenance of feasible populations of these bats.

The aim of this study was to detect the favorite *Piper* species of *C. perspicillata* among the ones they consumed in Parque Municipal Arthur Thomas, considering the species of *Piper* available and the ones being consumed by these bats. It was also to identify the infrutescences' physio-chemical properties.

MATERIALS AND METHODS

Parque Municipal Arthur Thomas presents a subtropical and humid climate, with average annual temperature of 22ºC and rain index of approximately 1.567mm (Iapar 2002). It is situated in the geographical coordinates 23º15'-23º30'S and 51º15'-51º00'W. With an area of 82,72 ha, it is located in the southern region of the city of Londrina (Fig. 1) within its urban perimeter. The park is one of the ultimate sites of significant vegetation of the city. 66 ha of its total area are composed of altered primary forest and according to Maack (2002), this formation is referred to as seasonal semi-deciduous. In spite of the urban disturbance (Murphy 1997) in its forest portion, there are large plant species such as *Aspidosperma polyneuron* Müll. Arg. (peroba-rosa – Apocynaceae), *Gallesia integrifolia* (Spreng.) Harms (pau-d'alho – Phytolaccaceae), *Cabralea canjerana* (Vell.) Mart. (canjarana – Meliaceae), *Cedrella fissilis* Vell. (cedro – Meliaceae), *Inga marginata* Willd. (ingá – Leguminosae-Mimosoideae), *Ficus* spp. (fig trees – Moraceae), *Syagrus romanzoffiana* (Cham.) Glassm. (jerivá – Arecaceae), *Euterpe edulis* Mart. (palm tree – Arecaceae) e *Ocotea puberula* (Rich.) Ness. (canela-gosmenta – Lauraceae) (Félix *et al*. 2001). Five species of Piperaceae consumed by *C. perspicillata* are found in the park: *Piper aduncum* Linnaeus; *Piper amalago* (Jacq.) Yuncker; *Piper crassinervium* H.B. K.; *Piper gaudichaudianum* Kunth and *Piper* sp.

The identification of the *Piper* species utilized by the bats was done according to Gardner (1977) and Marinho-Filho (1991), through a comparison between the seeds found in the feces and the seeds from identified botanical material contained in the herbarium of Universidade Estadual de Londrina (Herbarium FUEL). The botanical material of *Piper* species collected from the park in this study is in the herbarium mentioned, with the collection, under the following registry number: FUEL 31763 to FUEL 31771.

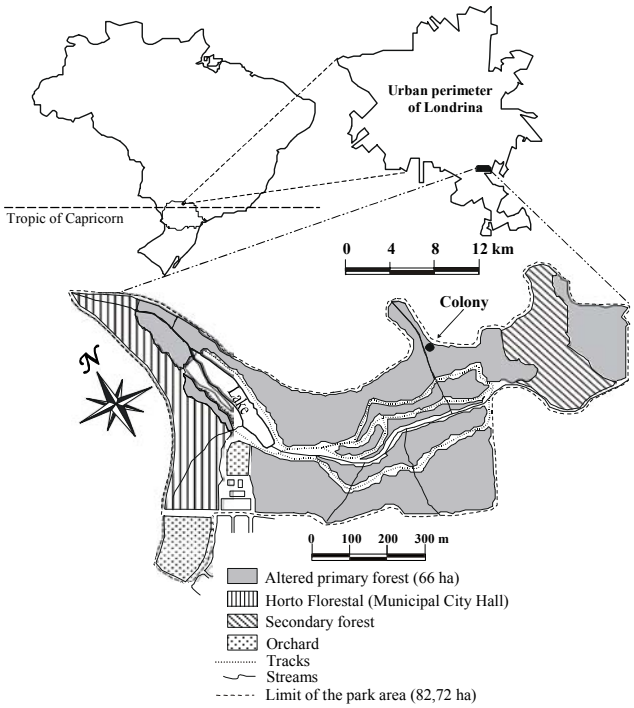


Figure 1. Location of Parque Municipal Arthur Thomas within the urban perimeter of Londrina and in detail, the location of the colony of *Carollia perspicillata* studied and the tracks where *Piper* infrutescences were collected.

In order to estimate the quantity of monthly available food in the tracks of the park, from October 2001 to September 2002, all the ripe infrutescences found along four transects measuring 100m2 were counted, modified from Dinerstein (1986). The dimension of each transect was determined with the help of a 100m nylon string in order to mark the edge of the track to be observed. All the *Piper* species which were located more than 1m from the edge towards the interior of the forest were not taken into consideration. The total sampled area measured 0,04 ha. The transects were determined in different areas of several tracks of PMAT so that there would be a reliable sample of the availability of *Piper* species in the park. Another reason for marking the area was that in its search for food *C. perspicillata* may travel long distances in only one night (280-3.000m) (Charles–Dominique 1991), making all the tracks in the park possible sites for the species to find food.

In order to obtain the average quantity of pulp mass (QPM) of ripe infrutescences of each species, the infrutescence mass (InfM), stem mass (StM) and seed mass (SeM) were determined. Therefore, through the equation QP = InfM – (StM +

SeM), the quantity of pulp mass in each infrutescence was obtained (QP). The average quantity of pulp mass (QPM) and the average seed mass (ASeM) of each species of *Piper* were obtained through the arithmetical average of the analysed infrutescences.

If the number of ripe infrutescences found in the transects and the amount of average pulp mass of each species are known, it is possible to find the amount of infrutescence mass available, and this is how the average of available mass was determined in each unit of sampled area, through the equation $Available\ mass = QPMInf \times NRInf$, where: (QPMInf) average quantity of mass pulp per infrutescence, and (NRInf) number of ripe infrutescence taken per 0,04 ha.

The feces samples containing *Piper* seeds taken from a colony of *C. perspicillata*, in which the number of individuals during the period of this study varied between 25 and 30, were located in a pluvial pipe in the northern area of PMAT. This pipe, whose length and diameter are 210m and 1.5 m, respectively, flows into the *Pica Pau* stream. In the internal part of the pipes the bats occupied several positions, establishing perches between the joints of the concrete ducts that are used to drain rainwater into the stream.

The feces samples were taken from one of these perches, located 100 m away from the entrance of the pipe. A newspaper was placed under the pipe, and a framework made of wood and nylon strings, measuring 1 square meter, was built to function as a basis for the newspaper. This structure was placed 70 cm away from the lower surface of the pipe, in order to avoid contact with humidity. During the period of collection, the newspaper was changed every day for new samples to be collected. Four monthly collections were carried out during October 2001 and September 2002. The samples were taken to a laboratory, put through nylon sieves measuring 0,3 mm and 0,1 mm under running water. The seeds were separated with the help of a stereoscopic microscope and were then dried. After being dried, their mass was determined with the use of a semi-analytic scale. Based on the average seed mass of each *Piper* species obtained, it was possible to estimate the average quantity of mass consumed by the bats through the seed mass found in the feces. The following formula was used

$$Ingested\ mass = \frac{SeMF}{ASeMInf} \times QPMInf$$

, where: (SeMF) mass of seeds found in the feces, (AseMInf) average seed mass per infrutescence, and (QPMInf) average quantity of pulp mass per infrutescence.

The physio-chemical analysis of the infrutescences of each *Piper* species was carried in order to help the analysis of the food preferences of *C. perspicillata*, and with this aim 100g of ripe infrutescences were collected from the tracks. Due to the small mass of the infrutescences, several collections were necessary so that the required amount could be obtained. The infrutescences were frozen and stored until they were sent to the laboratory of the Department of Food Technology and Medication, at UEL (Universidade Estadual de Londrina). Under the responsibility of Professor Raúl J.H.C. Gómez and according to Instituto Adolfo Lutz (1976), the following characteristics were determined: carbohydrates, lipids (Soxleht), gross protein / total nitrogen (expressed in percentage) and the total calorific value (expressed in Kcal).

RESULTS

The five species of *Piper* found in Parque Municipal Arthur Thomas consumed by *C. perspicillata* are *Piper aduncum, P. amalago*, *P. crassinervium*, *P. gaudichaudianum* and *Piper* sp; they presented variation in availability throughout the year, which reflected on their consumption by bats (Fig. 2 and Tab. I). *Piper* species present, in general, infrutescences on the cob, exposed on the branch ends or directly on them, which facilitates their removal by bats during the flight (Pereira *et al*. 1995). Despite the fact that there are no significant differences in the average mass of the infrutescences (Tab. II), these present variations in shape and texture. *Piper aduncum* presents smooth infrutescences, straight when unripe and slightly curved when ripe, detaching from the leaves; *Piper amalago* presents wrinkled infrutescences, straight and slightly detaching from the leaves. *Piper crassinervium* and *Piper gaudichaudianum* infrutescences have a similar shape: they are slightly wrinkled, curved even when unripe, detaching from the leaves. The infrutescence with the greatest mass is *Piper* sp., and it is straight and wrinkled.

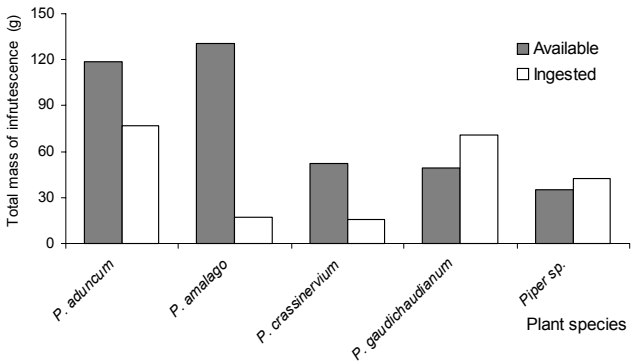


Figure 2. Total mass of *Piper* infrutescences available in the transects and quantity ingested throughout one year of collections (September 2001 to October 2002) in Parque Municipal Arthur Thomas.

During the spring (Fig. 3), in October and December, *P. amalago* and *P. aduncum* had the largest number of infrutescences available. Although *P. amalago* occurred in a larger amount, the search for *P. aduncum* by *C. perspicillata* was greater. In November *P. amalago*, *P. aduncum*, *P. gaudichaudianum* and *Piper* sp. were available, in order of abundance. Even though *P. amalago* was the most widely available species, it was the

Table I. Phenology of *Piper* species in PMAT, based on the existing species in the transections marked in the tracks, and on the newspaper placed inside the colony of *Carollia perspicillata* to collect feces between the months of October 2001 and September 2002.

Plant species	Months (2001-2002)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Piper aduncum	♣♣	♣♣	♣♣♣	♣	♣	*	*	♦	♦	*	♣	♣
Piper amalago	♦♣♣♣	♣♣♣	♣♣♣	♣	♣	♣	*	♣	*	♣	♦	♣
Piper crassinervium	–	–	♦	♣♣♣	♣♣♣	–	–	–	–	–	–	–
Piper gaudichaudianum	–	♣♣	–	♦	♦	♣♣	♣	♣	♣	♦	♣	–
Piper sp.	♣	♣	♣	♦	♣	♣	–	♦♣	*	*	♣	*

(♣) Ripe infrutescences per 0,04 ha: (♣) 1 to 6, (♣♣) 7 to 15, and (♣♣♣) 15 or more; (*) seeds found inside the colony; (♦) inflorescences; (–) absence of infrutescences and inflorescences.

third most highly consumed item while *P. aduncum and Piper* sp. were the most highly consumed species by *C. perspicillata*.

In the summer of 2002 (Fig. 4), in January, *P. crassinervium* was widely available in opposition to *P. aduncum*, but the proportion of the consumption of these items was similar. In February, *P. crassinervium* was widely available, and so was *P. amalago*. These two items were consumed proportionally to their availability, but *P. aduncum* was also consumed, despite not being amongst the items available in the transects. At the end of the summer, the most available *Piper* species was *P. gaudichaudianum*, followed by *Piper* sp. and *P. amalago*; the most highly consumed item was *P. gaudichaudianum*.

In the fall (Fig. 5), in April, only *P. gaudichaudianum* was available in the transects, and it was highly consumed. However, *P. amalago* was also consumed, but in smaller proportions. In May, in a decreasing order of abundance, *P. amalago*, *P. gaudichaudianum* and *Piper* sp. were available, *P. gaudichaudianum* being the most highly consumed species. At the end of this season, only *P. gaudichaudianum* was available in the transects, in a small amount, but its consumption was high. Yet, *P. amalago* and *Piper* sp. were also found among the ingested items.

During the winter (Fig. 6), in July, *P. amalago* and *P. gaudichaudianum* were available in the transects. However, the items that were most highly consumed were *Piper* sp. and *P. aduncum*; the consumption of *P. amalago* was considerably low. In August, *Piper* sp. and *P. aduncum* infrutescences were available in the same quantity in the transects; *P. gaudichaudianum* infrutescences were also available, but in a lower quantity. The most highly consumed species was *Piper* sp., followed by *P. gaudichaudianum*, and *P. aduncum* was nearly not consumed at all. At the end of the winter, only *P. aduncum* was available in the transects, but *P. amalago* and *Piper* sp. were found in the diet of *C. perspicillata* as well.

The quantity of infrutescences available in the transects and what was ingested by the bats of the colony throughout the year show that *P. amalago* and *P. aduncum* were the most abundant species, although *P. amalago* was among the species of lowest consumption. *P. aduncum* and *P. gaudichaudianum* were the most commonly ingested species (Figs 3-6).

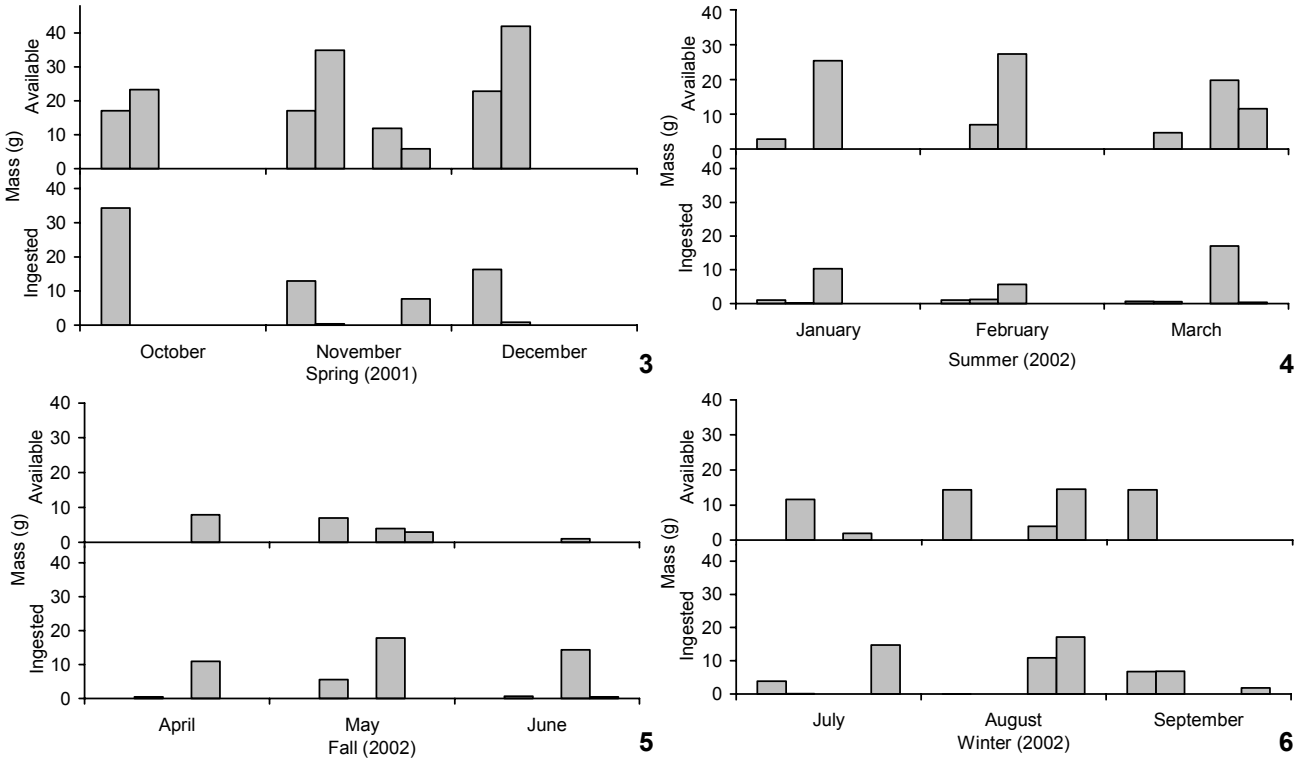
The analysis of physio-chemical values of infrutescences of the *Piper* species collected in the tracks shows only a trend of these values, due to the fact that they were collected in different periods and from different individuals (Tab. II). *P. amalago* presented the lowest percentage of lipids and the lowest total calorific value, and *Piper* sp. the highest values. It was not possible to determine the percentage of carbohydrates, proteins and total calorific value of *P. crassinervium* due to the low number of ripe infrutescences found in the transects for analysis.

DISCUSSION

The methodology used does not offer conditions to determine the quantity of food consumed by *Carollia perspicillata* during the whole night because, according to Fleming (1988), it can cover long distances in its search for food, use temporary night roosts near the feeding area for short breaks and eat the ripe *Piper* plants found. Moreover, it may remain in the same area for a long period, returning to the day roost only at the end of the night. However, this methodology allows us to identify and quantify the items utilized in its diet in the moment that precedes the return of the animals to its roost through the feces found.

During the spring, *C. perspicillata* ingested a larger quantity of one of the least available species in the transects, *Piper aduncum*, and not the most abundant one, *P. amalago*. This higher consumption of *P. aduncum* may be related to the nutritional differences of the infrutescences, once the comparison of the physio-chemical composition of the two species revealed that *P. aduncum* had a larger quantity of lipids and a higher calorific value than *P. amalago*. This reinforces Pianka (1982), who claims that any consumer prefers to save energy by finding food that is worth a higher quantity of energy per unit of consumption.

During the summer, there was a greater search for more abundant species, such as *P. crassinervium* in January and February and *P. gaudichaudianum* in March, which could be justified, in the first case, by the fact that in addition to its abundance, *P. crassinervium* presented a quantity of lipids higher than all the other *Piper* species available in the transects. According to Wendeln *et al*. (2000), the consumption of abun-



Figures 3-6. Quantity of Piperaceae mass found in the sample transects (0,04 ha/month) and quantity ingested by the colony of *Carollia perspicillata* studied during the: (3) spring, (4) summer , (5) fall , and (6) winter in the Parque Municipal Arthur Thomas.

Table II. Physio-chemical analysis and average of total mass of *Piper* infrutescences consumed by *Carollia perspicillata* in Parque Municipal Arthur Thomas from October 2001 to September 2002.

Plant species	Physio-chemical characteristics				Total mass of infrutescence				
	N_1	Carbohydrates (%)	Lipids (%)	Gross protein total N_2 (%)	Calorific value (Kcal/100 g)	N_2	Average (g)	SD	VC
P. aduncum	35	18.59	1.46	3.25	100.50	10	3.47	0.46	13.25
P. amalago	40	18.12	0.53	3.65	91.85	21	3.02	0.70	23.17
P. crassinervium	12	ND	1.68	ND	ND	12	2.41	0.47	19.54
P. gaudichaudianum	45	18.14	1.29	4.79	103.33	12	2.39	0.46	19.24
Piper sp.	30	21.66	2.41	5.56	130.57	10	3.52	0.73	20.73

(N1) number of ripe infrutescences collected for the determination of their physio-chemical characteristics; (N2) number of ripe infrutescences collected for the determination of the mass average; (ND) not determined; (SD) standard deviation; (VC)= variation coefficient.

dant items with a higher calorific value provides the bat with a higher energetic return. In March, although *Piper* sp. was available in the transects and presented a high calorific value and the highest quantity of lipids of all *Piper* species, it was not highly consumed, which may be explained by the average mass of infrutescences available, as *P. gaudichaudianum* was 32% lighter than *Piper* sp. The fact that *C. perspicillata* consumed the lightest and most abundant item may indicate energy saving concerning the search for and transport of this plant species, even in the presence of a potentially more energetic one. According to Delorme & Thomas (1999), in places where food is abundant, the individuals can be more selective and limit their diet to the best food types.

During the fall, in April and June, when only *P. gaudichau-*

dianum infrutescences were available in the transects, other *Piper* species were consumed in a lower quantity, indicating that the bats searched for food outside the transects and/or tracks, confirming data obtained by Courts (1988), who suggests that European frugivorous bats search for alternative food sources when they are scarce. Some species can even search for unripe fruits to supply their nutritional needs (Nelson *et al*. 2000). The greater search for *P. gaudichaudianum*, which had infrutescences available in the transects during the month of May, may be related to its better energetic quality when compared to *P. amalago*, the most abundant species as, according to Pianka (1982), when there are distinct types of food available the search is for the most calorific items. This justifies the energetic gain, since the quality of the food is as important as the quantity (Odum 1988).

During the winter, in July, *C. perspicillata* preferred to feed on *Piper* sp., indicating the search for this item outside the transects and/or tracks, a fact which could be related to the better content of energetic substances in this plant species when compared to the others available in the transects. According to Wendeln *et al*. (2000), the ingestion of more energetic food compensates for the effort made during the search for it. In August, there was a greater search for *Piper* sp. and *P. gaudichaudianum*, which supports the idea of a greater consumption of the most calorific food items when various species are in frutification, agreeing with what is suggested by Pianka (1982) and Wendeln *et al*. (2000). At the end of the winter, when food was scarcer in the transects, *C. perspicillata* also consumed *P. aduncum*, the only *Piper* available in them, and also *Piper* species outside the transects and/or tracks, even those with a lower calorific value. Some bats complemented their diet with food items available in low quantities (Ruby *et al*. 2000) and with a low calorific value (Elangovan & Marimuthu 2001). In this study, *C. perspicillata* did not discard the species available in smaller amounts.

In addition to the factors that lead bats to choose their food and the importance of the fruit mass for this choice, Fleming (1986, 1988) suggests that they are potentially influenced by extrinsic factors, like ambient light level (related to the risk of predation), the time-space abundance of the fruits, their nutritional characteristics, size and availability, and by intrinsic factors, which comprise the size of the animal, its reproductive status and social position.

It was observed that in PMAT the variation of the infrutescence abundance throughout the year and the nutritional characteristics of each species influenced *C. perspicillata* on its food choice. In addition to that, the collections were carefully carried out always in the period of new moon with the aim of minimizing the influence of the light, since this species presents lunar phobia (Fleming 1988).

According to Pereira *et al*. (1995), bats can carry the entire fruit to perches depending on the size and mass of the fruit. Bizerril & Raw (1988) have observed *C. perspicillata* biting pieces of *Piper arboreum* infrutescences because they could not carry the whole fruit. In PMAT the entire infrutescences were carried because the discarded stems were found inside the colony and on the newspaper utilized for the collection of feces, indicating that the mass of the *Piper* species had little influence on the food choice.

The PMAT, with its 66 ha of unspoiled native area, has proved to be a safe shelter for some bat species (Felix *et al*. 2001), such as *Myotis ruber*, which is threatened with extinction (Aguiar *et al*. 1998), and for other animals which depend on the food found in the park. Therefore, more effort should be made for its conservation and preservation.

In this study five species of *Piper* were found in PMAT: *P. aduncum*, *P. amalago*, *P. crassinervium*, *P. gaudichaudianum* and *Piper* sp. The results show that in the park, the preferences of *C. perspicillata* are related to the greater abundance or the higher energetic value of the available species. The greater search for the most energetic and least abundant species, which occurred in the spring and winter, is related to the energetic gain, that is, the species searches for food that is worth a higher quantity of energy per unit of consumption; and the greater search for the most abundant species, which occurred in the summer and fall, is related to the energy saved in the search for food.

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