Diversity and Distributions (1998) **4**, 235–241

BIODIVERSITY RESEARCH

Diversity and distribution of spiders associated with bat guano piles in Morrinho cave (Bahia State, Brazil)

RODRIGO LOPES FERREIRA and ROGÉRIO PARENTONI MARTINS *Laboratório de Ecologia e Comportamento de Insetos- Departamento de Biologia Geral- ICB-UFMG, Caixa postal 486 CEP 30161970, Belo Horizonte-MG-Brazil.* E-mail: *drops@icb.ufmg.br*

Abstract. Five species of spiders from the families Theridiidae (*Nesticoides rufipes*), Sicariidae (*Loxosceles similis* and *Sicarius tropicus*), Oecobidae (*Oecobius annulipes*) and Corinnidae were found on bat guano piles in the Morrinho cave (Bahia state, Brazil). Species richness of spiders was positively correlated with the area of the guano piles and silverfish abundance, and negatively correlated with the distance from the cave entrance. The positive relationship found between spider richness and diversity with area of the piles is presumably because prey abundance is positively correlated with pile size. The relationship between distance from the cave entrance and spider richness may be due to different colonization abilities of each spider family. Spider diversity was positively correlated only with pile area, while pH of the piles (which may be indicative of age) did not show correlation with any other parameters.

Key words. Bat guano, distribution, diversity, spider, prey distribution, caves.

INTRODUCTION

Caves are stable environments when compared with epigean habitats, with permanent lack of light far from entrances (Poulson & White, 1969; Culver, 1982). In the absence of photoautotrophic organisms, heterotrophic organisms must rely on other resources that usually are scarce in caves. These resources are mainly organic matter imported to caves by water, gravity, or animal excreta and carcasses. In some dry caves, the main resource is guano of bats, birds or crickets which can form large piles (Poulson, 1972; Gnaspini-Netto, 1989; Herrera, 1995).

Bat fauna in the neotropics is characterized by the high richness of species and feeding habits: insectivory, carnivory, piscivory, frugivory, nectarivory, omnivory and hematophagy (Gnaspini & Trajano, 1999). This diversity of bat feeding habits allows the comparison between arthropod communities that use different types of bat guano.

Guano is a variable biotope that can be considered a mosaic of microhabitats, with animal communities in various successional stages because they show alteration in physicochemical parameters over time (Harris, 1970; Decu, 1986). For example, in caves where guano piles are not being continuously produced, because resident bat colonies migrate, fresh deposits are alkaline and gradually become acid from border to centre. Therefore, the pH can be used, sometimes, as a measure of the guano pile age (e.g. Herrera, 1995). Distinct taxa differentially use the various guano components. In tropical caves, where the guano piles come from birds or bats with different feeding habits (not necessarily at the same time nor in the same cave), the preferential consumption by certain taxa is more evident, consequently the predator fauna on guano consumers is very diverse (Gnaspini & Trajano, 1999; Decu, 1986).

The guano of hematophagous bats generally is inhabited by large numbers of fly larvae, in addition to nematodes, springtails and beetles. The guano of insectivorous bats possesses mainly mites, pseudoscorpions, beetles, thrips, moths, and flies. The guano of frugivorous bats is most diversified, containing mainly pseudoscorpions, harvestmen, spiders, mites, isopods, millipedes, centipedes, springtails, barklice, true bugs, and beetles (Gnaspini-Netto, 1989; Ferreira & Martins, 1999).

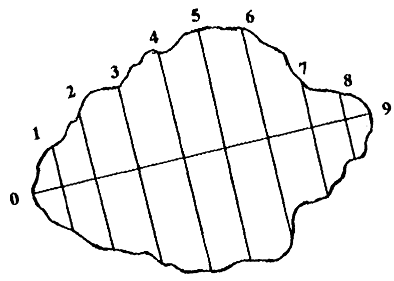
Some arthropods use the guano directly, and others can also feed on fungi that grows in it (Gnaspini-Netto, 1989). There are also predators, like most spiders, especially in dry caves (Trajano & Moreira, 1991; Ferreira & Pompeu, 1997).

Spiders colonize caves mainly via the entrance, thus the distance from the entrance to the guano piles can affect their distribution. There is a defined effect of the distance from the cave entrance on the species involved in the total diversity of a cave community (Poulson & White, 1969; Peck, 1976). This effect was also verified in Taboa cave (Sete Lagoas, Minas Gerais, Brazil), where the arthropod diversity on the guano piles decreased with increasing distance from the entrance of the cave (Ferreira & Pompeu, 1997).

There are records for eleven families of Araneomorphae in caves in Bahia state, Brazil (Pinto-da-Rocha, 1995). Theridiidae, Sicariidae and Ctenidae were recorded in several caves within the state, but most families are restricted to one or two caves (Telemidae, Leptonetidae, Oecobidae, Pholcidae, Theridiosomatidae, Araneidae, Pisauridae, and Gnaphosidae). Among the eleven families listed, only Sicariidae, Oecobidae, Theridiidae, and Theridiosomatidae have been found in guano piles (Gnaspini-Netto, 1989; Ferreira & Pompeu, 1997).

There are no ecological studies of spiders that live in guano, despite the potential importance of spider predation on the structure of bat guano communities, or conversely, as in the case of this study, the influence of prey abundance and distribution on spider diversity and distribution.

The aim of this study is to verify if spider richness and abundance in guano piles decreases from the entrance to the interior of the cave. We also wanted to know if there was an effect of guano pile area in spider richness and abundance, and if the composition of spider communities would be distinct between frugivorous and hematophagous bat guano (the two types present in this cave). The effect of guano pile age in spider diversity was also tested.



A= 1/3 d (e+2i=4p)

Where:

A - Area of the guano pile;
d - Distance between each segment;
e - Extremities of the guano pile (numbers 0 and 9),
i - Sum of the length of the unpaired segments;
p - Sum of the length of the paired segments.

Fig. 1. Schematic drawing illustrating how Simpson's Index was calculated. The surrounded area illustrates a guano pile.

METHODOLOGY

Study area

Morrinho cave (40°55′5″ W, 10°12′32″ S) is located at an altitude of 600 meters in the Laje dos Negros (in Campo Formoso City), northeastern region of Bahia state, Brazil. The vegetation is composed of deciduous plant species common in drier region called 'caatinga' (Ab'Sáber, 1980). The entrance is horizontal (7 m wide and 2 m high) and the unique conduit, almost completely plain, possesses two constrictions in its 475 m. These constrictions, formed by internal collapses, partially obstruct the passage. The cave is formed in clear dolomite interspersed with thick nodules of chert (silicates) (Rubbioli & Piló, 1995). The cave is permanently dry, and the main food resource is guano from frugivorous and hematophagous bats. Frugivorous bat guano can have small undigested seeds and sometimes big seeds with some pulp attached. Hematophagous guano has a viscous consistency and reddish dark colour when fresh, but becomes black and often powdery when older (Gnaspini-Netto, 1989).

Method

Twenty-three guano piles were mapped and marked with aluminum tags. The distance from the entrance of the cave to each guano pile was taken with a tape measure. The area of each pile was calculated using Simpson's formula, which integrates the measures of the lengths of parallel segments along the longitudinal axis of each pile (Fig. 1). The perimeter of each guano pile was taken with a string (marked in mm) placed around its circumference. Except for guano pile number 23, the pH was measured with a manual pHmeter in a sample solution with deionized water, from the middle of the pile.

Spiders and other invertebrates associated with each guano pile were collected in January 1997, spending

Table 1. Measured variables for each guano pile in Morrinho cave, Bahia state, Brazil.

Pile	Type	Distance (m)	Area (cm^2)	Silverfish abundance	Spider richness	Spider diversity	Spider equitability	pH
1	F	43.7	3978.0	40	1	0	0	7.50
2	H	48.6	5670.6	0	3	0.95	0.86	7.77
3	F	49.6	28155.3	1569	5	1.47	0.91	6.85
4	H	50.2	7724.5	201	2	0.64	0.92	8.37
5	H	53.3	24712.0	272	2	0.64	0.92	7.75
6	H	47.8	99602.7	1593	6	1.62	0.9	7.05
7	F	51.1	11158.8	1124	1	0	0	7.90
8	H	51.1	13650.0	417	2	0.29	0.41	7.34
9	F	52.9	14608.5	402	1	0	0	7.58
10	H	56.6	5030.7	63	1	0	0	7.45
11	F	60.3	22571.7	124	2	1.1	1	7.79
12	F	64.6	5521.6	72	1	0	0	7.09
13	H	85.8	6233.3	9	2	0.69	1	8.07
14	F	102.7	6993.0	36	2	0.56	0.81	7.67
15	F	104.4	4953.3	38	2	0.64	0.92	7.75
16	F	104.9	3369.0	71	1	0	0	9.61
17	F	108.2	5525.3	63	2	0.35	0.5	8.06
18	H	120.5	1423.3	0	1	0	0	8.09
19	H	122.7	2066.4	0	1	0	0	8.24
20	H	137.0	4136.0	0	1	0	0	8.31
21	H	137.0	3793.1	0	1	0	0	8.25
22	F	158.3	11737.7	0	2	0.64	0.92	9.55
23	H	299.1	9520.7	0	1	0	0	*

* Not measures.

30 min per pile on manual collection, with tweezers, brushes and magnifying glasses, fixing specimens in 70% alcohol. All organisms were identified and grouped in morphospecies. Voucher specimens are deposited in the laboratory of Ecologia e Comportamento de Insetos, Departamento de Biologia Geral, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil.

The area from which silverfish were collected in each guano pile was standardized at 10% of the total area of the pile, which was then divided into sub-samples of 400 cm^2, the actual number of sub-samples thus varying with pile size. Each sub-sample was removed randomly from each guano pile. The sub-samples were placed individually in trays and all silverfish were removed and fixed in 70% alcohol. The number of silverfish was divided by the volume of guano from each sub-sample, giving a measure for silverfish/ml of guano in that sub-sample. The total volume of the guano pile was then estimated using the average volume per sub-sample (i.e. per 400 cm^2) multiplied by total surface area. The average number of silverfish/ml was then multiplied by the total number of ml in the pile to give an estimate of the total number of silverfish in each pile. The diversity and equitability of spiders were calculated using the Shannon Diversity index (Magurran, 1988).

The correlations between the richness, diversity and equitability of spiders, guano pile area, and distance from the entrance of the cave were tested using the Spearman rank correlation test (Zar, 1996), mainly because of the absence of replication (impossible in this kind of study, because each guano pile has individual traits) and because some of the variables are not normally distributed. The correlation between spider richness and silverfish abundance, guano pile area, and spider richness were tested by linear regression (Zar, 1996), permissible due to the normal distribution of silverfish abundance and guano pile area.

RESULTS

The twenty-three guano piles were located between 43.7 to 299.05 m from the entrance of the cave. The

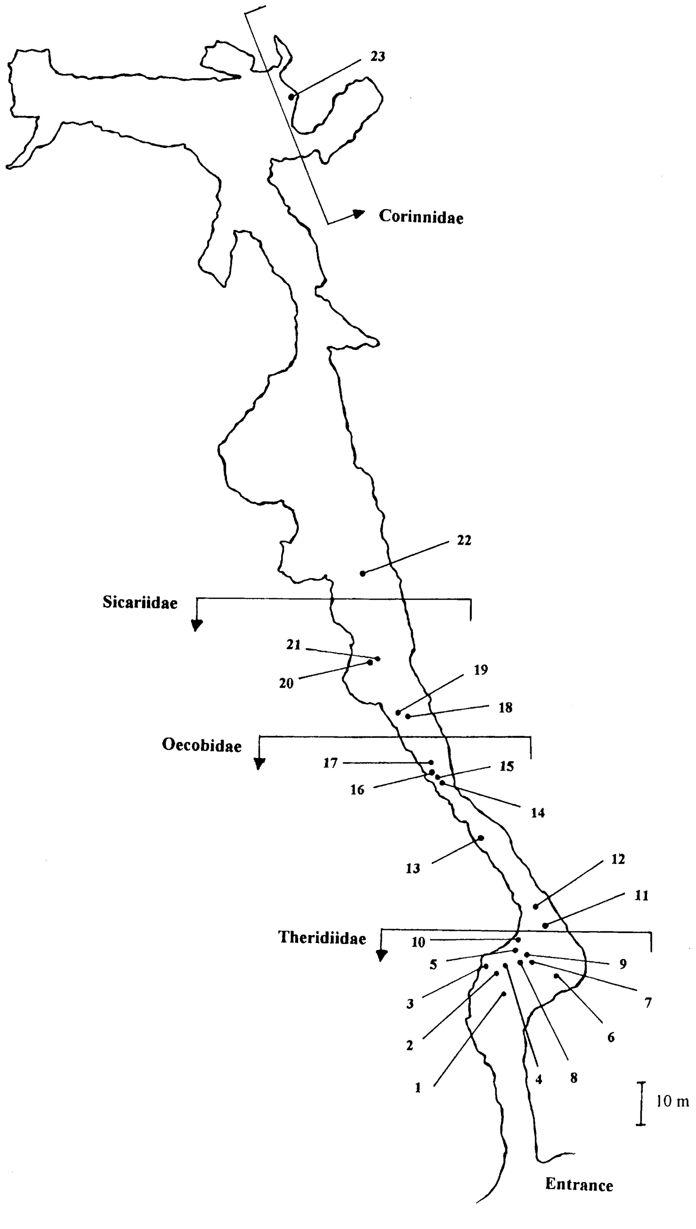


Fig. 2. Spatial distribution of the spider families in Morrinho cave (numbers correspond to guano piles).

area of the guano piles was variable, not related to the distance from the cave entrance, and did not show any pattern of distribution with respect to location in the cave. The pH ranged from 6.85 to 9.61. Spider richness, diversity and equitability and total richness were variable in the guano piles (Table 1).

A total of 120 individuals were caught belonging to five species of Theridiidae (*Nesticoides rufipes*—twenty-

Table 2. Correlations (Spearman) between all tested variables. The numbers in boldface are significant at $P<0.05$)

	Distance (m)	Area (m^2)	pH
Spider richness	**−0.420**	**0.617**	−0.292
Spider diversity	−0.395	**0.628**	−0.222
Spider equitability	−0.221	**0.547**	−0.012

seven individuals), Sicariidae (*Loxosceles similis*—thirty-five individuals, and *Sicarius tropicus*—four individuals), Oecobidae (*Oecobius annulipes*—fifty-three individuals) and Corinnidae—one individual, all probably troglophiles (Table 2).

N. rufipes were more abundant near from the cave entrance, where 89% of all individuals were collected. Those individuals stayed on the surface of the guano pile or inside small cracks in it. *O. annulipes* was collected at a maximun distance of 142.45 m, and it was regulary distributed along this length. Individuals of this species, like those of *N. rufipes*, were found on the surface of the pile or in cracks. Sicariidae showed the largest distribution, and were collected from the cave entrance up to 158.25 m into the cave. *L. similis* were found in the borders of the deposits, in small webs they made. *S. tropicus* usually buried themselves completely in the dry guano. The unique individual of Corinnidae was collected on the surface of a hematophagous pile almost 300 m from the entrance (Fig. 2), and it is the first record of this family in Brazilian caves.

Silverfish (Zygentoma: Lepismatidae), the main prey of the spiders, were common throughout the guano piles and their abundance is directly related both to the area of the piles ($\beta=0.726$, $P=0.00009$, Fig. 3a), and to spider richness ($\beta=0.530$, $P=0.035$, Fig. 3b). The silverfish exhibted no preference for frugivorous versus haematophagous guano piles, being found in approximately the same proportions in both (Table 1). Probably because of this, the spiders likewise demonstrated no preference for foraging in the two kinds of guano: four species and sixty-three individuals were found in frugivorous guano piles (eleven deposits) versus five species and fifty-seven individuals in hematophagous guano piles (twelve deposits).

Except for the corinnid, predation on silverfish was observed by individuals of all spider species only in guano piles. Other potential prey of comparable size (mainly beetles and moth larvae) were observed in

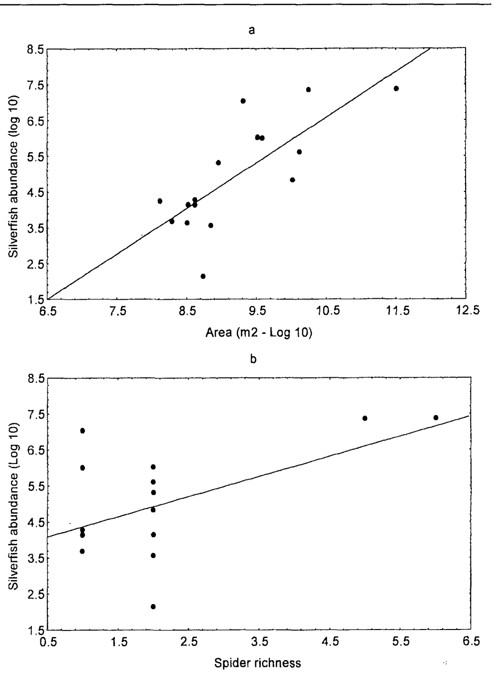


Fig. 3. a) Silverfish abundance (logarithmic scale) versus area of the guano piles (logarithmic scale); (b) Silverfish abundance (logarithmic scale) versus spider richness.

small number in few piles (beetles: piles 3, 6, 7, 11; moth larvae: piles 6, 8, 14, 16, 18, 19, 21, 23).

Analyses of distance versus diversity ($R=-0.395$) and distance versus equitability ($R=-0.221$) demonstrated no significant correlations, while the spider richness was positively correlated to the area of the guano piles ($R=0.620$, $P=0.002$, Fig 4a) and negatively correlated to the distance from the cave entrance ($R=-0.420$, $P=0.046$, Fig. 4b). The diversity and equitability were positively correlated only to pile area ($R=0.628$, $P=0.002$ and $R=0.547$, $P=0.007$ respectively, Fig. 4c), and pH did not show correlation with any other parameter (Table 2, Fig. 4).

DISCUSSION

This is the first ecological study of spider distribution and diversity associated with bat guano piles in caves. Spiders always prey upon other arthropods in caves, but they are not always associated with bat guano piles. The distribution of spiders depends largely on prey occurrence, thus in caves where other sources of

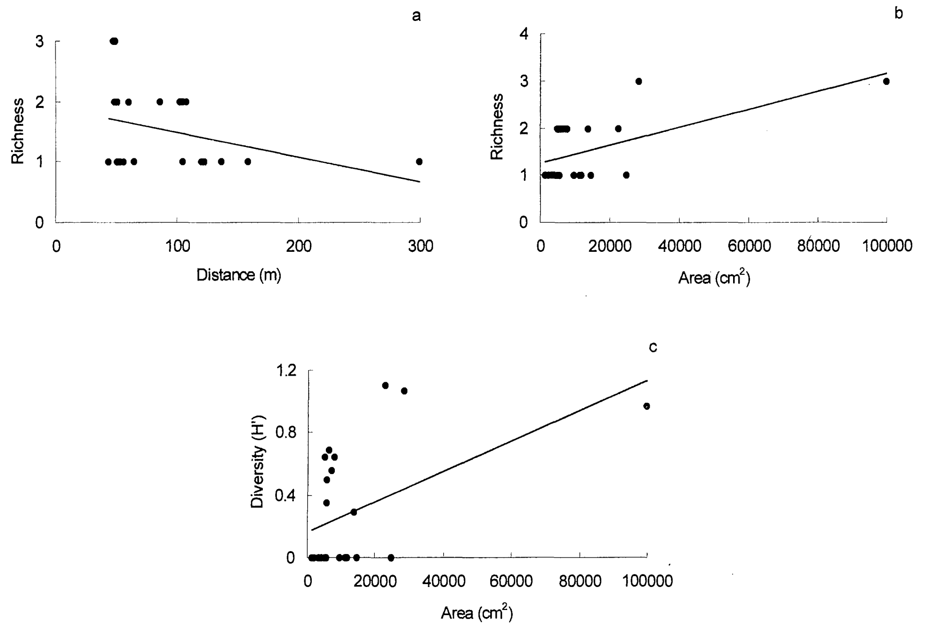


Fig. 4. a) Spider richness versus distance from the cave entrance; (b) Spider richness versus area of the guano piles; (c) Spider diversity versus area of the guano piles.

organic matter exist (particulate or dissolved organic matter entering by streams), spiders can be found preying upon organisms that feed on these alternative sources (e.g. vegetable debris). In permanently dry caves, where the main resource is guano, spiders will naturally be associated with these deposits, as observed in several Brazilian caves (Ferreira & Martins, 1999). Extant information about spider families found in caves of Bahia state is from limited faunistic surveys, without data on species biology (Pinto-da-Rocha, 1995). Thus, some of the spider families in caves of Bahia state are not recorded from guano piles probably because of limited study, and not because they cannot live in this substrate.

Both prey abundance and dispersal ability, among other factors, may help to explain the high richness and the distribution of the spiders in this cave. The absence of *N. rufipes* in piles placed far from the entrance can be due to the extreme climatic conditions in deeper portions of this cave, that might be selective against this family (Decu, 1986), since this species is unlikely to be a trogloxene. Conversely, *S. tropicus*, *O. annulipes*, and *L. similis* were relatively widespread in the cave, and individuals were collected as far as 90, 120 and 150 m from the cave entrance, respectively. This wide distribution is probably due to the high motility and colonization ability of members of these species. However, the distance from the entrance to the deepest guano pile in the cave where individuals of these species were collected was less than half the total length of the cave, all of which contained guano piles. The distribution of these species can be ruled by the same factors discussed for *N. rufipes*. However, silverfish (Lepismatidae), the main prey of these spiders in this cave, are distributed only until approximately 150 m, as well. It is most likely that the presence of those spiders is directly related to the presence of silverfish. The one individual of Corinnidae was found some 300 m from the cave entrance, on a guano pile with a unique and large isopod population (*Trichorhina troglophila*), but we did not see the spider eating them.

The sizes of populations in guano piles are usually proportional to the amount of available resource (Decu, 1986). Guano piles with large areas probably embrace a higher diversity of microhabitats, which can support a higher number of associated taxa (or individuals) in these biotopes, as in other ephemeral ones (Doube, 1986). As pointed out by Poulson & White (1969), the number of species in a cave is a result of a balance between extinction and colonization, which can also occur in isolated guano piles. Thus large piles have higher probabilities of being colonized than small ones, as was shown by Ferreira & Pompeu (1997). The higher richness and diversity of spiders associated with large guano piles observed in this study is probably due to the higher abundance of prey in larger piles as observed in this work.

Guano is the main food resource in Morrinho cave, with the entire biota directly or indirectly dependent upon it. All the prey items used by the spiders were always observed in guano piles.

Silverfish were especially abundant in several guano piles (Table 1), whereas the populations of coleopterans (larval and adult Dermestidae) and lepidopterans (mainly larvae) were very small. The silverfish are the main prey of the spiders in this cave, thus influencing their richness and diversity. However, there are no spider preferences for either type of guano because silverfish abundances are roughly similar in both.

The prey diversity in fresher guano piles (probably with higher pH) is very low, because they still had not enough time to develop a structured community, or because the high pH precludes the use of this resource by several organisms. However, this does not mean that as the pile ages, its diversity will rise indefinitely, because there may not be much change in fauna beyond a certain threshold, and the piles will eventually become unavailable as resources. This may explain the absence of correlation between pH and all of the tested parameters.

ACKNOWLEDGMENTS

We acknowledge the helpful comments of Dan Simberloff, Léo Trajano and Doug Yanega, who helped with the english. The CNPq provided financial support for both authors. We would like to thank Marcelo Gonzaga and Adalberto dos Santos for the identification of the spiders. Raquel T. Moura and Lília S. Horta helped in the field. Marcos Barbeitos helped with the graphs. The Bambuí Speleological Group and the U.S. Fish & Wildlife Service provided some logistic support. This is a contribution of the Program in Ecology and Wildlife Management of the Universidade Federal de Minas Gerais, Brazil.

REFERENCES

Ab'Sáber, A. N. (1980) O domínio morfoclimático semi-árido das caatingas brasileiras. *Geomorf.* **43**, 1–26.

Culver, D. C. (1982) *Cave life: evolution and ecology*, 189 pp. Harvard University Press. Cambridge, Mass.

Decu, V. (1986) Some considerations on the bat guano synusia. *Trav. Inst. Spéol. 'Emile Racovitza'* **25**, 41–51.

Doube, B. M. (1986) Spatial and temporal organization in communities associated with dung pads and carcasses. *Organization of communities, past and present* (ed. by J.H.R. Gee and P.S. Giller), pp. 255–280. Blackwell Scientific Publications, Oxford.

Ferreira, R.L. & Pompeu, P.S. (1997) Fatores que influenciam a riqueza e a diversidade da fauna associada a depósitos de guano na gruta Taboa, Sete Lagoas, Minas Gerais, Brasil. *O Carste* **2**, 30–33.

Ferreira, R. L. & Martins, R. P. (1999) Ecologia e evolução de invertebrados associados ao guano de morcegos em cavernas. *Ciência Hoje*.

Gnaspini-Netto, P. (1989) Análise comparativa da fauna associada a depósitos de guano de morcegos cavernícolas no Brasil. Primeira aproximação. *Revta Brasil. Entomol.* **33**, 183–192.

Gnaspini, P. & Trajano, E. (1999) Guano communities in tropical caves. Case study: Brazilian Caves. *Ecosystems of the World. Subterranean biota* (ed. by H. Wilkens, D.C. Culver and F. Humphries). Elsevier Science, Amsterdam.

Harris, J. A. (1970) Bat-Guano cave environment. *Science*, **169**, 1342–1343.

Herrera, F. F. (1995) Las comunidades de artropodos del guano del Guácharo en la cueva del Guácharo, Venezuela. *Bol. Soc. Venezoelana Espel.* **29**, 39–46.

Magurran, A. E. (1988) *Ecological diversity and its measurement*, 179 pp. Princeton University Press, Princeton, New Jersey.

Peck, S. B. (1976) The effect of cave entrances on the distribution of cave-inhabiting terrestrial arthropods. *Int. J. Speleol.* **8**, 309–321.

Pinto-da-Rocha, R. (1995) Sinopse da fauna cavernícola do Brasil (1907–1994). *Pap. Avul. de Zool.* **39**, 61–163.

Poulson, L. T. (1972) Bat Guano Ecosystems. *Bull. Nat. Speleol. Soc.* **34**, 55–59.

Poulson, T. L. & White, W. B. (1969) The cave environment. *Science*, **165**, 971.

Rubbioli, E. & Piló, L.B. (1995) Os arredores da toca da Boa Vista. *O Carste*, **1**, 15–21.

Trajano, E. & Moreira, J. R. A. (1991) Estudo da fauna de cavernas da província espeleológica arentica Altamira-Itaituba, Pará. *Revta. Bras. Biol.* **51**, 13–29.

Zar, J. H. (1996) *Biostatistical analysis*, 3rd edn. Prentice Hall, New Jersey.