ECOTROPICA 13: 67–74, 2007

BAT DIVERSITY IN THREE CAVES IN A MONTANE FOREST OF BOLIVIA

Lizette Siles[1], Arturo Muñoz[2] & Luis F. Aguirre[1,3]

[1]Centro de Estudios en Biología Teórica y Aplicada (BIOTA), Programa para la Conservación de Murciélagos de Bolivia (PCMB). P.O. Box 994, La Paz, Bolivia.
[2]Museo de Historia Natural Alcide d'Orbigny. P.O. Box 4324, Cochabamba, Bolivia.
[3]Centro de Biodiversidad y Genética, Universidad Mayor de San Simón. P.O. Box 538, Cochabamba, Bolivia.

Key words: Anoura caudifer, Carollia, *Carrasco National Park*, *Bolivia*, *conservation*, *natural history*, Phyllostomus hastatus, *Repechón Caves*, *vampire bats*.

INTRODUCTION

Bats spend over half their lives subjected to the selective pressures of their roost environment (Kunz & Fenton 2003), therefore it is critical to understand roost requirements in order to comprehend the natural history of a species (Humphrey 1975), as well as for the development of conservation plans (Graham 1988). In contrast to Nearctic cave bats, very little is known about the patterns of cave use by bats in the tropics (Kunz 1982, Arita & Vargas 1995). In Bolivia there is no published information on cave bats. The information presented here should be very useful in establishing proper use of these caves for tourism and proper protection from the people living in the area.

The Repechón caves (Fig. 1) are located near the northwestern border of Carrasco National Park in Cochabamba Department, Bolivia (17°03'S, 65°28'W) at 500 m a.s.l. Biogeographically they are in the Andean foothills and the Chapare Amazonian district (Navarro & Maldonado 2002). The climate is hot and humid (mean annual temperature 25°C and rainfall 5852 mm), with dry and rainy seasons (April to September and October to March respectively – Sandoval 1998). The vegetation is secondary and riparian forest (Killeen *et al.* 1993, Navarro 1997), and due to agricultural land conversion and timber exploitation this ecosystem is highly endangered (Navarro 1997). The caves were formed by hydraulic erosion, and are made of calcareous and gritty rock; streams run through the floors (CGL 2002). These caves are frequently visited by tourists, and, although they are located in a protected area, very little is known about the biology and ecology of their inhabitants.

Due to their location, we predicted that these caves would be an important roosting site for bats and thus of high conservation value. To test this we determined species composition and relative abundance in the caves and how these varied between seasons. We also explored the relationship between diversity and position of bats inside the caves.

METHODS

Sampling was conducted in three caves during the wet (February and March 2001) and dry season (July and September 2001), each month for a period of two weeks; nights with a full moon were avoided. Bats were captured for three nights at each cave, each month, using a custom-made harp trap (1.2 x 1.0 m; Palmeirim & Rodrigues 1993) that was placed at the entrance and left operating all night (bats did not

e-mail: liz_siles@yahoo.com

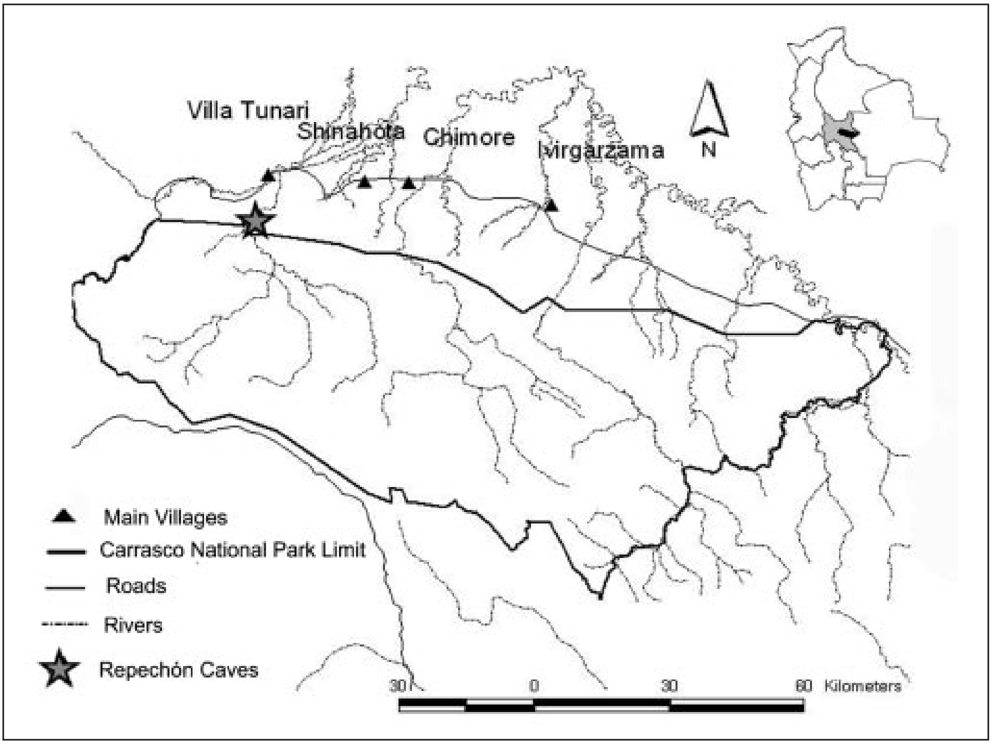

FIG. 1. Location of Repechón caves in the Carrasco National Park in relation to the main roads, villages, and rivers.

harm each other). Some bats were hand-captured or observed in detail inside the cave. Captured bats were identified (Anderson 1997, Emmons & Feer 1999), measured (body mass and forearm length), sexed, marked, and released. A punch-marking device (Bonaccorso & Smythe 1972) was used to make alphanumerical markings in the plagiopatagium, which allowed us to identify individuals and the cave of capture. These marks do not harm bats or affect their behavior. Specimens were collected only in cases of difficult field identification or uncertain taxonomy (glossophagines and vespertilionids).

Each cave was mapped using a compass (Swiss Recta, Mod. DO 315, Switzerland) to measure changes in orientation. Widths, heights, and changes in floor level were measured using a metric fabric tape (Stanley, USA). These measurements allowed us to obtain an outline of the cave from a lateral view. Some particular bat roosts (such as solution cavities) could not be measured, but we took into account their location and characteristics.

Species' positions in caves during daytime, specific roosting sites, and interspecific interactions were observed on days the cave wasn't sampled with the harp trap or measured. Population size during daytime was estimated depending on the number of bats: when it was small (< 30) we were able to count all individuals directly; for larger colonies we took photos and later counted the individuals on the print. We did not attempt a calculation of absolute population sizes using harp-trapping data; rather, we used this information to corroborate species identification and to estimate relative abundance.

A binomial test using a Generalized Linear Models algorithm (SAS program, ver. 6.11) was used to determine the influence of the cave and season and their interaction (fixed effects) on the qualitative species composition. This test was also used to determine the effects of the cave and season on species abundance. Species composition between caves, taking both seasons into account, was analyzed using the Sørenson Index (C_s) based on the formula $C_s = 2j$ /

(*a*+*b*), where *j* is the number of species found in both caves, *a* is the number of species in cave 1, and *b* is the number of species in cave 2 (Magurran 1988). Species diversity between caves was plotted with rank-abundance curves (Feinsinger 2001) using the abundance data (log-transformed) provided by the harp trap. These curves were also used to compare diversity between seasons for each cave.

RESULTS AND DISCUSSION

Species composition. During 33 nights of sampling in all caves, we recorded the presence of seven phyllostomid species (*Anoura caudifer*, *Carollia perspicillata*, *C. brevicauda*, *C. castanea*, *Desmodus rotundus*, *Diphylla ecaudata*, and *Phyllostomus hastatus*) and one vespertilionid (*Myotis nigricans*) (Fig. 2). One species (*P. hastatus*) was recorded only in one cave (Cave B), all other species were found in more than one cave. A high Sørenson index (Fig. 2) indicates that species composition was very similar between caves; there was no significant difference (x^2 = 0.1720, P = 0.9176). Species richness in Repechón was high compared with other Neotropical caves in Mexico (Arita & Vargas 1995, Arita 1996, Avila 2000), Costa Rica (Williams 1986), and Venezuela (Bonaccorso *et al.* 1992), where 80% of the caves harbored only four species or less. There were no significant differences in the presence or absence of species in the caves between wet and dry seasons (x^2 = 0.38, P = 0.5395), although we observed some species roost in the caves irregularly. A colony of *P. hastatus* (± 250 individuals) was observed only in February, and two individuals of *Diphylla ecaudata* were observed in March and September. It is difficult to determine what caused these fluctuations. Perturbation due to tourism could have affected the bats in caves A and B, and perhaps this was the reason for the disappearance of *P. hastatus*.

Bat abundance. The markings on the bats proved to be non-permanent, remaining visible for three months. Therefore the abundance data provided by the harp trap is independent for each season. Species captured

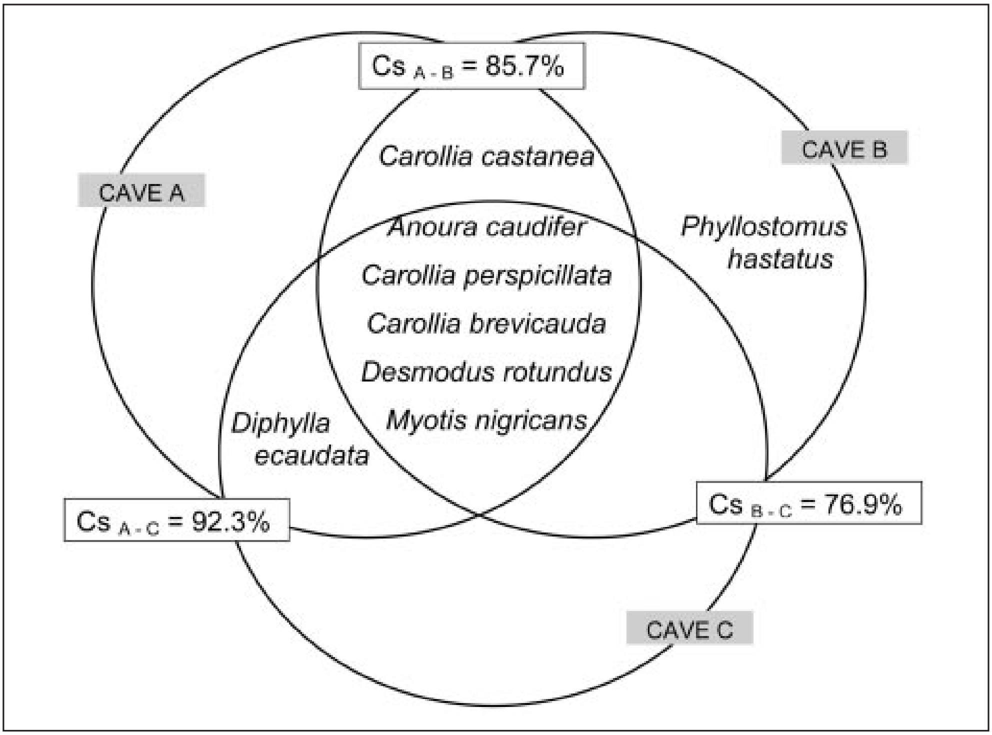

FIG. 2. Species composition in caves A, B, and C with observational and capture methods. Cs = Sørenson index for each pair of caves.

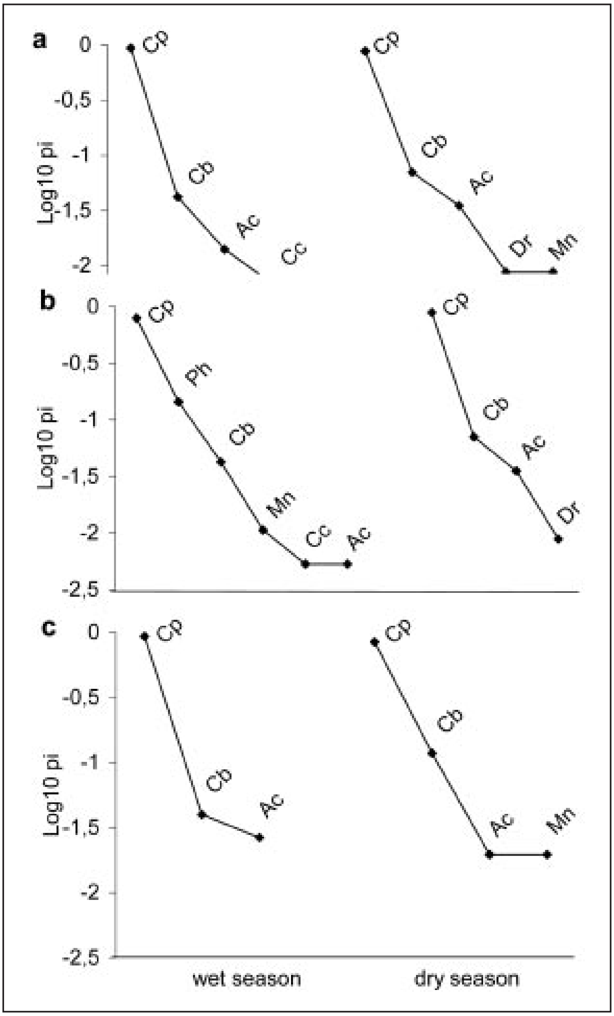

FIG. 3. Rank-abundance curves of all species captured with the harp trap in caves A, B, and C. Species: Cp = *Carollia perspicillata*, Cb = *C. brevicauda*, Cc = *C. castanea*, Ph = *Phyllostomus hastatus*, Ac = *Anoura caudifer*, Dr = *Desmodus rotundus*, and Mn = *Myotis nigricans*.

with the harp trap (*Carollia* spp., *A. caudifer*, *P. hastatus*, *D. rotundus*, and *M. nigricans*) were plotted into rank-abundance curves (Fig. 3). Bat diversity was highest in Cave B in the wet season (6 spp., 188 individuals; Fig. 3b) and lowest in Cave C, also in the wet season (3 spp., 151 individuals; Fig. 3c). We registered a higher diversity in the dry season in caves A and C (Fig. 3a,c). *C. perspicillata* and *C. brevicauda* were the most frequently captured species; this was constant in all caves and seasons, with the exception of cave B in the wet season (Fig. 3b). We recaptured marked bats in all caves and in both seasons. In cave A we recaptured 33 bats (31 *C. persipicillata* and two *C. brevicauda*; 19 from cave A, ten from cave B, and four from cave C). In cave B, 46 *C. perspicillata* individuals were recaptured (29 from cave A and 17 from cave B). In cave C, we had 12 *C. perspicillata* recaptures (three from cave A, two from B, and seven from C). These data indicate that bats share the caves and we also observed that they flew between caves A and B at dusk before they departed into the forest.

We counted all observed species in the caves (*A. caudifer*, *Carollia* spp., *Desmodus rotundus*, *Diphylla ecaudata*, and *P. hastatus* – Table 1). We were not able to differentiate visually between *C. perspicillata*, *C. brevicauda*, and *C. castanea*, but 95.1% of the *Carollia*

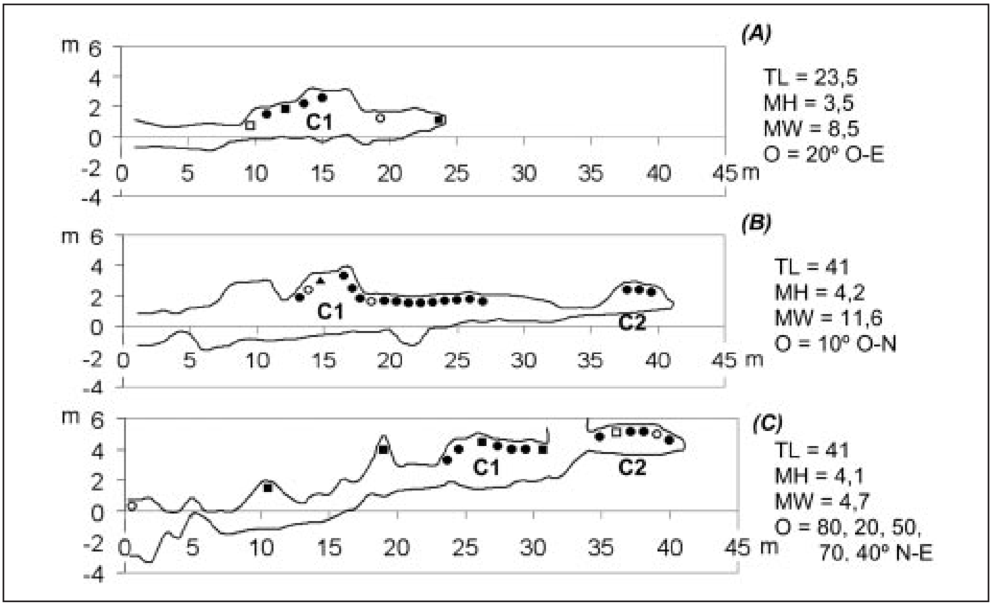

FIG. 4. Lateral view of the outline of each cave studied (A, B, and C), with the position of the species observed: ● = *Carollia* spp., **O** = *Anoura caudifer*, ▲ = *Phyllostomus hastatus*, ■ = *Desmodus rotundus*, and □ = *Diphylla ecaudata*. Cave characteristics and measurements (in meters) are also given: C1 = chamber one, C2 = chamber two, TL = total length, MH = maximum height, MW = maximum width, O = orientation.

captured with the harp trap were *C. perspicillata*. The only species we did not observe roosting in any of the caves during the daytime was *M. nigricans*, probably due to its small size and low number of individuals. There are few records of this species roosting in caves, although Graham (1988) reported it in large caves in Peru. *Carollia* spp. was the most abundant genus in the caves, and its abundance increased in the wet season (Table 1). It is possible that these bats sought the protection and security that the caves offer during the heavy rainfall that occurs in this season. In this case, the caves offer a more favorable microclimate, especially for females that are expected to have litters during that period (Williams 1986). We observed two large groups of *P. hastatus* roosting in cave B during the wet season, representing 32% of all bats observed in this cave. Four *Desmodus rotundus* groups were consistently roosting during our study in cave C. In cave A this species was only observed for a few days during the dry season. Overall bat abundance was significantly higher in the wet season (x^2 = 16.3308, P = 0.0001). Although we observed a higher abundance in cave C (Table 1), the difference among caves was not significant (x^2 = 4.2530, P = 0.1193).

TABLE 1. Estimated abundance of the species observed in caves A, B, and C in wet and dry seasons; calculated by direct counts and via photographs of colonies.

species		*Carollia* spp.		*P. hastatus*		*D. rotundus*		*A. caudifer*		*D. ecaudata*	
seasons		wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
Cave	A	70	15	0	0	0	2	15	0	1	0
	B	500	300	250	0	0	0	30	15	0	0
	C	2000	1200	0	0	250	250	50	50	0	1

Interspecific association. Interactions between individuals of different species could influence use of roosting resources by those individuals (Graham 1988). Two species occupying the same roost have a null interspecific association when they use different sites (Swift & Racey 1983). In Repechón, some species always roosted separated from the rest (*Desmodus rotundus*, *Diphylla ecaudata*, and *P. hastatus*), and probably have a null association with the other species. Fleming (1988) reported that *Desmodus rotundus* protects its roost position by aggressive bites, which would be a case of negative interaction, but we did not observed this in Repechón for this or any other species. On the other hand, we observed individuals of *A. caudifer* roosting in contact with *Carollia* species in caves B and C. Similarly, Graham (1988) reported that *Glossophaga soricina* and *Carollia perspicillata* roosted in contact with each other in many Peruvian roosts, and that this provides the most visible possibility of positive interspecific interaction. In Repechón, the interaction between *A. caudifer* and *Carollia* may be simply opportunistic because we observed small *A. caudifer* groups roosting separately in two occasions in caves A and C.

Cave structure. Measurements and characteristics of the outline of the caves and sites in which bats were observed are given in Fig. 4. Caves A and B are next to each other (the entrances are two meters apart) and are frequently visited by tourists, whereas cave C is approximately 1 km away and tourists are not allowed to visit. Cave A is the smallest and simplest (Fig. 4); we observed *Carollia* spp. and *A. caudifer* roosting there regularly, and two species (*Desmodus rotundus* and *Diphylla ecaudata*) were observed occasionally (Fig. 4); overall bat abundance was lowest in this cave (Table 1). Cave B shows the highest values of maximum height and width (Fig. 4). Its chambers harbored *Carollia* spp., *A. caudifer*, and *P. hastatus*; the latter was observed only in the wet season (Fig. 4). Cave C is a complex cave; it is the only one with two entrances, its orientation changes four times, and the floor level has an inclination of 4 m (Fig.4). Within this cave we regularly observed *Carollia* spp., *A. caudifer*, *Desmodus rotundus*, whereas a hairy-legged vampire (*Diphylla ecaudata*) was observed only once (Fig. 4); overall bat abundance was highest in this cave (Table 1). Bigger caves tend to be more complex (Arita 1996) and harbor more bats, especially maternity colonies, than other simpler caves (Sherwin *et al*. 2000). In all caves, *Carollia* spp. and *A. caudifer* were observed mainly occupying the chambers, hanging from small rocks. Occasionally we observed the latter species roosting alone in protected sites (caves A and C). *P. hastatus* used two sites in cave B, one group roosting in a ceiling cavity (length 1.5 m, width 1m) located 7 m from the entrance, and the second group in a section of the cave wall located 14 m from the entrance. The common vampire (*Desmodus rotundus*) was observed using solution cavities in cave C, to which they were apparently faithful through our study. By contrast, Lewis (1995) reports that this species change roosts frequently. Other species reported to use solution cavities in caves are *Artibeus jamaicensis* (Arita & Vargas 1995, Ortega & Arita 1995), *Phyllostomus hastatus* (McCracken & Bradbury 1981), *Pteronotus parnellii*, and *Diphylla ecaudata* (Arita & Vargas 1995).

Implications for conservation. A recent 40-day study searched for roosts in the Repechón area and found only two small caves harboring a few bats and one hollow tree roost harboring 15 *Saccopteryx bilineata* individuals (Barboza, pers. comm.). Therefore the caves we studied are the only ones in the area that harbor a very large bat population of around 3000 individuals, mainly frugivorous species, and thus are of a great conservation value. Frugivorous bat species play an important role in regeneration of perturbed habitats (Fleming 1988, Findley 1993, Kalko *et al*. 1999). The location of the caves within the boundaries of Carrasco National Park (Fig. 1) increases their value because the bats they harbor can play an important role in regenerating adjacent habitats.

Bat colonies that roost in caves are threatened wherever they are present (Nowak 1994), and most of these bats are vulnerable to different types of perturbation caused by humans (Culver 1986, McCracken 1989). Unintentional disturbance, such as entering a cave or shining a light on maternity colonies, often poses a threat that could result in decreased survival and possible abandonment of a roost (McCracken 1989). This is why tourism in these caves may be detrimental for the bats, especially if people's perceptions towards them do not change. During our study, we observed tourists screaming inside the caves and shining lights at bats, which could have negative consequences for female bats during the reproductive period. We recommend diminishing the tourist influence in the months in which we captured lactating and pregnant females, March and September respectively. We do not know the reasons why *P. hastatus* abandoned cave B, but perhaps it was due to disturbance caused by tourists in addition to our own study, like the case reported by McCracken & Bradbury

(1981). In recent visits we observed two large groups of this species roosting in cave C, and in one of the caves recently discovered (Siles and Muñoz, pers. obs.), so their departure was not permanent. It is noteworthy that highest bat abundance was found in cave C (Table 1) which is not open to tourism; therefore we recommend that it remains this way in order to keep bat abundances high in the area. Vandalism is often a major threat in caves (Nowak 1994), but it is not likely to occur in Repechón due to its location within a protected area. However recent feuds between the park administration and the local residents resulted in the agricultural colonization of the area. So vandalism in the future cannot be discarded and possible destruction of the surrounding forest poses an even greater threat.

ACKNOWLEDGMENTS

This work was funded by Bat Conservation International (BCI) through the Program for Conservation of Bolivian Bats. The administration of Carrasco National Park granted the permits to work in the area. We thank Sergio Siles and the Carrasco park guards for their help during the fieldwork. We thank Elisabeth Kalko, Eric Yensen, and an anonymous referee for their helpful comments on the manuscript.

REFERENCES

Anderson, S. 1997. Mammals of Bolivia, taxonomy and distribution. Bulletin of the American Museum of Natural History 231: 1–652.

Arita, H.T. 1996. The conservation of cave-roosting bats in Yucatan, Mexico. Biological Conservation 76: 177–185.

Arita, H.T., & J.A. Vargas. 1995. Natural history, interspecific association, and incidence of the cave bats of Yucatan, Mexico. The Southwestern Naturalist 40(1): 29–37.

Avila, R. 2000. Patrones de uso de cuevas en murciélagos del centro de México. Unpublished Licenciatura Thesis, Universidad Nacional Autónoma de México, México.

Bonaccorso, F.J., & N. Smythe. 1972. Punch marking bats, an alternative to banding. Journal of Mammalogy 53: 389–390.

Bonaccorso, F.J., Arends, A., Genoud, M., Cantoni, D., & T. Morton. 1992. Thermal ecology of moustached and ghost-faced bats (Mormoopidae) in Venezuela. Journal of Mammalogy 73(2): 365–378.

CGL. 2002. Actividades Ecoturísticas en el Santuario de Vida Silvestre Cavernas del Repechón. Informe Final Borrador Vol. I. Consultores Galindo Ltda. Prefectura del Departamento de Cochabamba, Unidad de Turismo.

Culver, D.C. 1986. Cave faunas. Pp. 427–443 *in* Soulé, M.E. (ed.). Conservation Biology, the science of scarcity and diversity. Sinauer Associates, Inc., Sunderland, Massachusetts.

Emmons, L.H., & F. Feer. 1999. Mamíferos de los bosques húmedos de América tropical. Una guía de campo. Editorial F.A.N., Bolivia.

Feinsinger, P. 2001. Designing field studies for biodiversity conservation. Island Press, Washington DC, USA.

Findley, J.S. 1993. Bats: a community perspective. Cambridge University Press, Cambridge.

Fleming, T.H. 1988. The short–tailed fruit bat. A study in plant–animal interactions. The University of Chicago Press, Chicago and London.

Graham, G.L. 1988. Interspecific associations among Peruvian bats at diurnal roosts and roost sites. Journal of Mammalogy 69(4): 711–720.

Humphrey, S.R. 1975. Nursery roosts and community diversity of Nearctic bats. Journal of Mammalogy 59(2): 321–346.

Kalko, E.K.V., Friemel, D., Handley Jr., C.O., & H.U. Schnitzler. 1999. Roosting and foraging behavior of two neotropical gleaning bats, *Tonatia silvicola* and *Trachops cirrhosus* (Phyllostomidae). Biotropica 31(2): 344–353.

Killeen, T.J., García, E., & S.G. Beck. 1993. Guía de árboles de Bolivia. Herbario Nacional de Bolivia – Missouri Botanical Garden. Editorial Instituto de Ecología, Bolivia.

Kunz, T.H. 1982. Roosting ecology. Pp. 1–56 *in* Kunz, T.H. (ed.). Ecology of bats. Plenum Press, New York and London.

Kunz, T.H., & M.B. Fenton (eds.). 2003. Bat Ecology. The University of Chicago Press, Chicago and London.

Lewis, S.E. 1995. Roost fidelity of bats: a review. Journal of Mammalogy 76(2): 481–496.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey.

McCracken, G.F. 1989. Cave conservation: special problems of bats. The National Speleological Society Bulletin 51: 49–51.

McCracken, G.F., & J.W. Bradbury. 1981. Social organization and kinship in the polygynous bat, *Phyllostomus hastatus*. Behavioral Ecology and Sociobiology 8: 11–34.

Navarro, G. 1997. Contribución a la clasificación ecológica y florística de los bosques de Bolivia. Revista Boliviana de Ecología y Conservación Ambiental 2: 3–37.

Navarro, G., & M. Maldonado. 2002. Geografía ecológica de Bolivia: Vegetación y ambientes acuáticos. Centro de Ecología Simón I. Patiño – Departamento de Difusión, Cochabamba, Bolivia.

Nowak, R.M. 1994. Walker's bats of the world. The Johns Hopkins University Press, Baltimore.

Ortega, J. & H.T. Arita. 1999. Structure and social dynamics of harem groups in *Artibeus jamaicensis* (Chiroptera: Phyllostomidae). Journal of Mammalogy 80(4): 1173–1185.

Palmeirim, J.M., & L. Rodrigues. 1993. The 2-minute harp trap for bats. Bat Research News 34(2, 3): 60–64.

Sandoval, M. 1998. Estructura y diversidad del bosque tropical en el Parque Nacional Carrasco, comunidad San Rafael. Unpublished Licenciatura Thesis, Universidad Mayor de San Simón, Bolivia.

Sherwin, R.E., Stricklan, D., & D.S. Rogers. 2000. Roosting affinities of Townsend's big-eared bat (*Corynorhinus townsendii*) in northern Utah. Journal of Mammalogy 81(4): 939–947.

Swift, S.M., & P.A. Racey. 1983. Resource partitioning in two species of Vespertiolionid bats (Chiroptera) occupying the same roost. Journal of the Zoological Society of London. 200: 249–259.

Williams, C.F. 1986. Social organization of the bat, *Carollia perspicillata* (Chiroptera: Phyllostomidae). Ethology 71: 265–282.

Accepted 30 January 2007