Bats of the Beanka Forest, a limestone karstic zone near Maintirano, central western Madagascar

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Abstract

Fieldwork was undertaken between October and November 2009 in the Beanka Forest, a limestone karstic zone in central western Madagascar characterized by dry forest, to document the local bat fauna. Animals were captured using mist nets and harp traps, or were removed directly from cave roosts with a butterfly net. On the basis of this rapid survey, 12 species of bat belonging to six families were captured in the Beanka Forest and surrounding areas. This work demonstrates an important level of local species richness, as is found in other limestone karst areas of central western Madagascar. This is at least in part associated with numerous and variable day roosting sites available within these zones. A biogeographical analysis demonstrates a notable homogeneity in the species present at western limestone sites, as well as a more depauperate bat fauna in the eastern lowlands. The period from late October to November coincided with the reproductive period of most bat species, with the majority of captured females being pregnant.

Key words: bat, inventory, Beanka Forest, central western Madagascar

Résumé détaillé

Un inventaire de chauves-souris a été entrepris dans la forêt de Beanka pendant le mois d'octobre et novembre 2009 en vue de connaître la richesse chiroptérologique de cette forêt située dans la partie Centre-ouest de Madagascar et d'améliorer la connaissance de la distribution des espèces malgaches. En outre, une descente d'une semaine a été faite au mois de juin 2010 en vue de compléter les données obtenues et de vérifier que la majorité des espèces de la région ont été convenablement échantillonnées.

La forêt de Beanka (centrée à 17º55,26'S, 44º59,81'E) est située dans la Province de Mahajanga, Région Melaky, à environ 75 km à l'Est de Maintirano. L'altitude des sites échantillonnés varie de 135 à 305 m au dessus de la mer. La forêt de Beanka est gérée par ''Biodiversity Conservation Madagascar'' (BCM), représenté par son bureau de liaison à Ambinda, qui s'occupe non seulement de la gestion de la forêt mais aussi des réalités socio-économiques de la population riveraine en vue de faciliter la conservation de la biodiversité de la région. Grâce à ces formations karstiques du Mésozoïque, la forêt de Beanka possède de nombreuses grottes qui peuvent servir de gîtes diurnes pour beaucoup d'espèces de chauves-souris. Pendant cette étude, les chauves-souris ont été capturées à l'aide des filets de 6 et 12 m et des pièges harpes (1 x 1 m and 2 x 1.9 m). En outre, un filet papillon a été utilisé en vue de récolter les chauves-souris dans leur gîte diurne.

Au total, 12 espèces de chauves-souris appartenant à six familles ont été documentées dont deux espèces de Pteropodidae (*Pteropus rufus* et *Rousettus madagascariensis*) ; trois espèces d'Hipposideridae (*Hipposideros commersoni*, *Triaenops menamena* et *T. furculus*) ; une espèce d'Emballonuridae (*Emballonura tiavato*) ; trois espèces de Miniopteridae (*Miniopterus aelleni*, *M. gleni* et *M. griveaudi*) ; une espèce de Vespertilionidae (*Myotis goudoti*) ; et deux espèces de Molossidae (*Mops leucostigma* et *Chaerephon leucogaster*). Cette étude montre en premier lieu l'importance des chauves-souris dans la forêt de Beanka. L'analyse biogéographique montre une forte similarité de la richesse spécifique dans les régions de l'Ouest et un appauvrissement de la diversité spécifique dans la partie orientale de basse altitude par rapport à la partie occidentale. Si cette étude a permis de apturer un individu d'*Emballonura tiavato,* l'absence de *Miniopterus brachytragos* dans la forêt de Beanka demeure inexpliquée et mérite une attention particulière. Cette espèce, récemment décrite, devrait être présente le long de cette formation karstique de l'Ouest de Namoroka à Bemaraha.

La présente étude a coïncidé avec la saison de reproduction des chauves-souris de la forêt de Beanka

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aussi bien pour les insectivores que les frugivores étant donné que la plupart des femelles étaient enceintes. Une étape importante a été accomplie dans la connaissance de la faune chiroptérologique de la forêt de Beanka. Cependant, davantage de recherches orientées vers les aspects écologiques comme l'utilisation de l'espace, le régime alimentaire ainsi que leur habitat préférentiel par le biais des analyses ultrasoniques seraient encore indispensables afin d'assurer une meilleure conservation des chauves-souris de la région.

Introduction

During the last decade, knowledge of the bats of Madagascar has increased considerably, particularly in the fields of systematics, including phylogenetics, biogeography, and to a lesser extent ecology. Even in light of these different studies, information on bat diversity and distribution is still rather incomplete. Several endemic species new to science have been recently described (Bates *et al*., 2006; Goodman *et al*., 2008a, 2009a, 2009b), others recorded for the first time (Bates *et al*., 2006; Goodman *et al*., 2008b), and a certain number of taxa remain to be described. Continued inventory work, particularly in poorly known areas of Madagascar, allow for further sampling and the refinement of distribution patterns and associated biogeographic insights. In light of new information providing such enhancements, here we report on a bat inventory conducted in the Beanka Forest, a zone of limestone karst in central western Madagascar. This area falls approximately mid-way between the limestone areas of Bemaraha and Namoroka, both with rich bat faunas, providing interesting details on the distributional patterns of the communities occurring at these three sites.

Methodology

Study site

The Beanka Forest (centroid at 17º55.26'S, 44º59.81'E) is located in the central western part of Madagascar in the Province of Mahajanga, Melaky Region, and approximately 75 km east of Maintirano (Figure 1). The recently rehabilitated road linking Tsiroanomandidy to Maintirano passes through the southern part of the forest. The elevational range of inventoried sites varied from 135 to 305 m. Biodiversity Conservation Madagascar (BCM), with their local headquarters in Ambinda, is currently managing the conservation program associated with the Beanka Forest and social-economic development in neighboring villages.

The natural vegetation formation as defined by Moat & Smith (2007) in this portion of central western Madagascar is "western dry forest". The Beanka Forest including surrounding karstic *tsingy* formations is dominated by Mesozoic limestone (Du Puy & Moat, 1996), which contains a certain number of caves. This area is located approximately 160 km south of the southern limit of the Namoroka National Park and 20 km to the north of the northern limit of the Bemaraha National Park (Figure 1). Most sites we surveyed in the Beanka Forest were located in the southern third of the massif. Our inventories were undertaken during a three-week period from October – November 2009 and one week in June 2010. Surveyed habitats included relatively intact dry deciduous forest zones, often in the proximity of caves, as well as more anthropogenic habitats, including those close to the forest edge (Figure 1).

Bat capture, measurements, and specimens

Several different techniques were used to capture bats in the Beanka Forest and surrounding areas. Mist nets (6 and 12 m in length) were set across potential bat flyways, such as trails and streams, as well as near standing water in marshes. The nets were opened at dusk for approximately four consecutive hours. In some cases, nets were left open throughout the night and checked at regular intervals. Harp traps (1 x 1 m or 2 x 1.9 m traps) were used to capture bats as they emerge from their day roost sites, including caves and buildings, or flying along natural passages. Additionally, a butterfly net was employed to obtain bats from day roosts in caves.

Standard measurements were taken from captured bats, which include total length, tail length, hind foot (excluding the claw), tragus length for some species, ear length, and weight. All of the linear measurements (in mm) were made with a plastic ruler, while weight (in g) was obtained with a Pesola spring balance. Measurement data are segregated herein for sexually dimorphic species. In some cases, bioacoustic recordings were made and voucher specimens retained, including associated tissue samples for molecular genetic research (see Ramasindrazana *et al*., 2011 for some of these results). Morphological characteristics, including pelage coloration or tragus shape, as well as measurements were used to distinguish species, particularly members of the genus *Miniopterus*. Voucher specimens are housed in the Field Museum of Natural History, Chicago, and

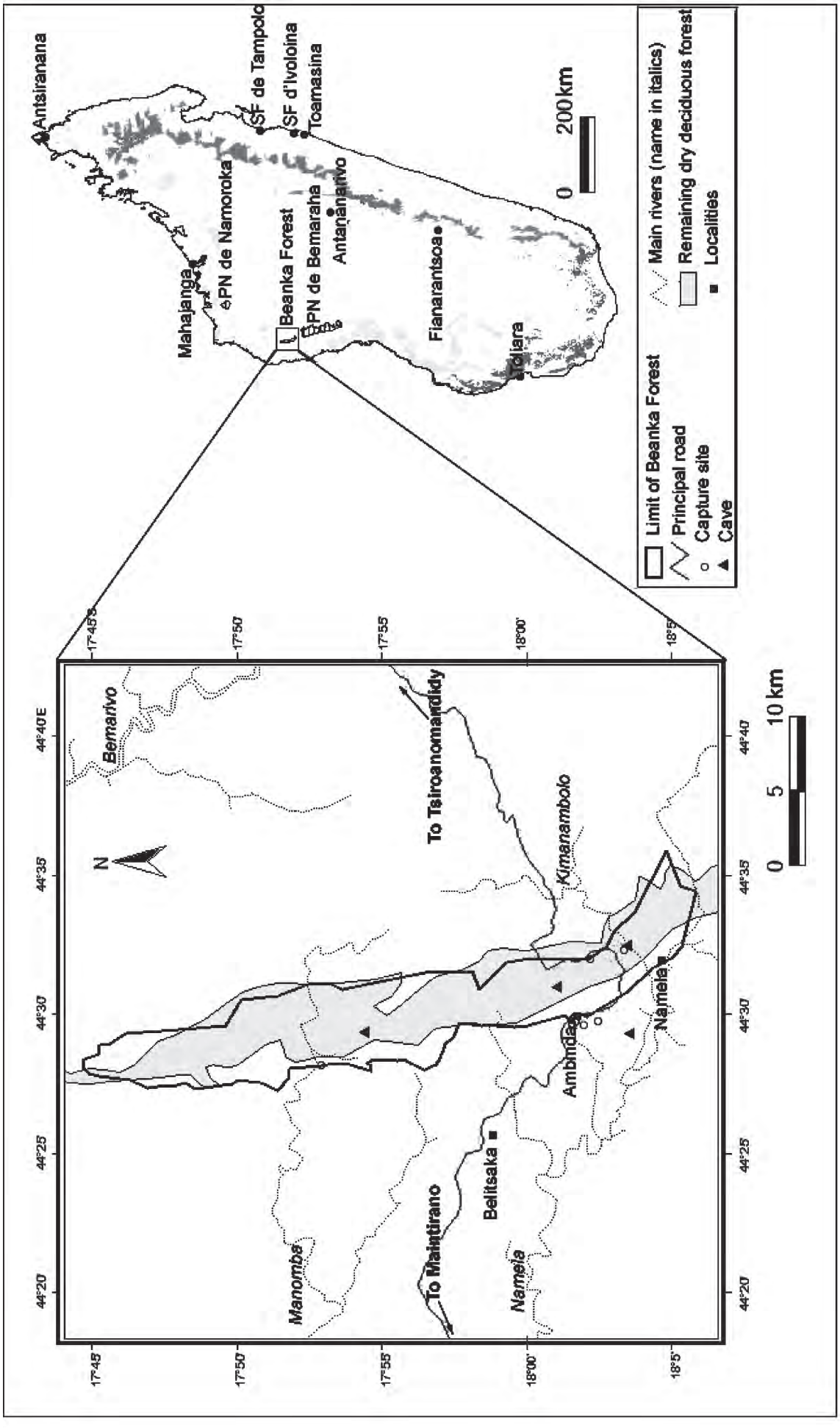

Figure 1. Map of the Beanka Forest and other localities mentioned in the text.

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Similarity analysis

In order to examine differences in bat species richness and community composition between several well-inventoried sites, the Jaccard Index was employed. These data were then entered into a cluster analysis using a SYSTAT Program (complete Linkage, Euclidian distance). The Jaccard Index is based on the following formula:

$$I = C/N_1 + N_2 - C$$

where N_1: species richness in site 1; N_2: species richness in site 1; and C: number of species common to both sites.

Sites other than the Beanka Forest used in this analysis include the Namoroka National Park and Bemaraha National Park, both large limestone massifs (Goodman *et al*., 2005a, 2005b, 2007, 2009a, 2009b; Kofoky *et al*., 2006), as well as the eastern lowland sites of the Ivoloina and Tampolo Forestry Stations, to the north of Toamasina (Ifticene *et al.,* 2005; Ramasindrazana, 2009; Figure 1). Bat specimens from all of these sites have been the subject of taxonomic studies and the species limits of most taxa are well defined.

Results

Twelve species of bat belonging to six families were documented in the Beanka Forest and surrounding areas (Table 1), which include two species of Pteropodidae (*Pteropus rufus* and *Rousettus madagascariensis*); three species of Hipposideridae (*Hipposideros commersoni*, *Triaenops menamena*, and *T. furculus*); one species of Emballonuridae (*Emballonura tiavato*); three species of Miniopteridae (*Miniopterus aelleni*, *M. gleni*, and *M. griveaudi*); one species of Vespertilionidae (*Myotis goudoti*); and two species of Molossidae (*Mops leucostigma* and *Chaerephon leucogaster*). The molossids were found only occupying local buildings. The external measurements of captured animals are presented in Table 2.

The five sites included in the similarity analysis hold approximately half of the total number of bat species known from the island. Species diversity per site ranged from six to 18 (Table 3). Eastern sites (Ivoloina and Tampolo Forestry Stations) have lower species richness than the western sites (Beanka Forest and National Parks of Bemaraha and Namoroka). Bemaraha and Namoroka have the highest similarity coefficients (I = 0.737). Additionally, the Jaccard Index shows close faunal affinities between the Beanka Forest and Namoroka (I = 0.687) and between the Beanka Forest and Bemaraha (I = 0.667) (Table 4), and these three sites hold 11 species in common (Table 3). Species such as *Hipposideros commersoni* and *Mops leucostigma* were recorded in both eastern and western sites, whereas some other species, *Myzopoda aurita* and *Chaerephon atsinanana*, were only found in the eastern part of Madagascar.

Table 1. Bat diversity of the Beanka Forest and surrounding areas based on the habitat of inventoried sites. + = presence of a given species, * = observed but not captured. Other habitats include gallery forest, open water in marshes, agricultural zones, open areas near banana trees, and across streams.

Species	Building	Cave	Other habitats
Pteropodidae			
Pteropus rufus			*
Rousettus madagascariensis			+
Hipposideridae			
Triaenops furculus			+
Triaenops menamena		+	+
Hipposideros commersoni		+	
Emballonuridae			
Emballonura tiavato		+	
Vespertilionidae			
Myotis goudoti		+	+
Miniopteridae			
Miniopterus aelleni		+	+
Miniopterus griveaudi		+	+
Miniopterus gleni		+	+
Molossidae			
Chaerephon leucogaster	+[1]		
Mops leucostigma	+[1]		
Total number of species	2	7	8

[1] Captured while exiting a day roost site within a building in the village of Belitsaka.

Discussion

Numerous bat inventories have been conducted in Madagascar in a range of different habitats, as well as across the island's altitudinal and bioclimatic clines. Data from these surveys provide important information on local bat species diversity, distribution, and biogeographic patterns. However, to date, some important localities with potentially rich bat faunas such as the Beanka Forest have not been inventoried.

Faunistics

Our rapid surveys of the Beanka Forest region found 12 bat species (Table 1), an important level of species

Table 2. External measurements of bats captured in Beanka Forest. For species represented by at least three individuals, measurements are presented as mean ± SD (minimum – maximum, number of specimens). For sexually dimorphic species, the sexes are separated. Information is also included on the percentage of pregnant females.

Species	Sex	Total length	Tail length	Hind foot length	Ear length	Tragus length	Forearm length	Weight	Percentage of ♀♀ pregnant
Rousettus madagascariensis	♂♂	129.3 ± 0.58	14.3 ± 0.58	15.0 ± 0.0	17.3 ± 0.58		73.0 ± 2.00	60.7 ± 2.57	
		129 - 130	14 - 15	15 - 15	17 - 18		71 - 75	58.5 - 63.5	
		n = 3	n = 3	n = 3	n = 3		n = 3	n = 3	
	♀♀	120.7 ± 5.02	13.7 ± 3.55	15.3 ± 1.60	17.6 ± 0.79		69.0 ± 3.05	45.9 ± 6.20	57%
		113 - 128	11 - 21	14 - 18	17 - 19		65 - 73	36.5 - 53.5	
		n = 7	n = 7	n = 7	n = 7		n = 7	n = 7	
Triaenops furculus	♂	70	22	6	19		44.5	6.2	
		n = 1	n = 1	n = 1	n = 1		n = 1	n = 1	
Triaenops menamena	♂♂	91, 94	33, 35	6, 7	14, 15		51, 55	7.3, 9.1	
		n = 2	n = 2	n = 2	n = 2		n = 2	n = 2	
Hipposideros commersoni	♂♂	138, 141	31, 33	14, 18	30, 31		89, 96	49.5, 61.4	
		n = 2	n = 2	n = 2	n = 2		n = 2	n = 2	
	♀	125	28	18	30		85	33	
		n = 1	n = 1	n = 1	n = 1		n = 1	n = 1	
Emballonura tiavato	♂	58	12	5	18	5	39	3.4	
		n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	
Myotis goudoti	♂	87	40	6	15	8	37	4.6	
		n=1	n=1	n=1	n=1	n=1	n=1	n=1	
	♀♀	92.2 ± 2.06	44.7 ± 2.36	6.5 ± 1.00	15.0 ± 0.0	8.0 ± 0.82	39.5 ± 1.29	6.2 ± 0.52	100%
		90 - 95	43 - 48	6 - 8	15 - 15	7 - 9	38 - 41	5.8 - 6.9	
		n = 4	n = 4	n = 4	n = 4	n = 4	n = 4	n = 4	
Miniopterus aelleni	♂♂, ♀♀	89.0 ± 1.87	42.4 ± 2.51	5.2 ± 0.45	10.8 ± 0.45	5.6 ± 0.55	37.1 ± 1.14	4.2 ± 0.80	75%
		87 - 91	39 - 46	5 - 6	10 - 11	5 - 6	36 - 38.5	3.5 - 5.4	
		n = 5	n = 5	n = 5	n = 5	n = 5	n = 5	n = 5	
Miniopterus griveaudi	♂♂, ♀♀	86.2 ± 1.61	41.8 ± 2.83	5.1 ± 0.35	10.4 ± 0.68	5.6 ± 0.48	36.3 ± 0.82	4.4 ± 0.90	67%
		83 - 89	36 - 48	5 - 6	9 - 11.5	5 - 6	35 - 37.5	3.3 - 6.3	
		n = 15	n = 15	n = 15	n = 15	n = 15	n = 15	n = 15	
Miniopterus gleni	♂♂, ♀♀	120.0 ± 3.03	56.5 ± 1.87	7.3 ± 0.82	12.8 ± 0.75	7.5 ± 0.55	48.7 ± 0.82	13.0 ± 1.32	75%
		115 - 123	55 - 60	6 - 8	12 - 14	7 - 8	48 - 50	11.0 - 14.5	
		n = 6	n = 6	n = 6	n = 6	n = 6	n = 6	n = 5	
Chaerephon leucogaster	♂	87	34	5	17		36	8.5	
		n = 1	n = 1	n = 1	n = 1		n = 1	n = 1	
Mops leucostigma	♀♀	110.7 ± 1.60	38.6 ± 2.22	8.4 ± 0.53	17.1 ± 0.69		43.7 ± 0.95	16.6 ± 1.99	86%
		108 - 113	35 - 42	8 - 9	16 - 18		43 - 45	13 - 18	
		n = 7	n = 7	n = 7	n = 7		n = 7	n = 7	

Table 3. Comparison of bat diversity from western and eastern Malagasy sites, including the Namoroka National Park and Bemaraha National Park (based on Goodman *et al.,* 2005a, 2005b, 2007, 2009a, 2009b; Ramasindrazana, unpublished data), the Ivoloina Forestry Station (Ramasindrazana, 2009), and the Tampolo Forestry Station (Ifticene *et al*., 2005) (Figure 1). +/- = presence/absence of a given species, * = seen but not captured.

Sites	**Beanka**	**Namoroka**	**Bemaraha**	**Ivoloina**	**Tampolo**
Elevational range	135 – 305 m	71- 227 m	150 - 750 m	15 m	5 - 10 m
Natural habitat	Dry deciduous forest	Dry deciduous forest	Dry deciduous forest	Eastern lowland humid forest	Eastern littoral forest
Species					
Pteropus rufus	+*	+*	+*	+*	-
Eidolon dupreanum	-	+	+	-	-
Rousettus madagascariensis	+	+	+	-	+
Hipposideros commersoni	+	+	+	+	+
Triaenops furculus	+	+	+	-	-
Triaenops menamena	+	+	+	-	-
Myotis goudoti	+	+	+	+	-
Miniopterus gleni	+	+	+	-	-
Miniopterus aelleni	+	+	+	-	-
Miniopterus brachytragos	-	+	+	-	-
Miniopterus griveaudi	+	+	+	-	-
Pipistrellus raceyi	-	-	-	+	+
Scotophilus robustus	-	-	+	-	-
Scotophilus tandrefana	-	-	+	-	-
Myzopoda aurita	-	-	-	+	+
Myzopoda schliemanni	-	+	-	-	-
Emballonura tiavato	+	-	+	-	-
Taphozous mauritianus	-	-	+	-	+
Chaerephon atsinanana	-	-	-	+	-
Chaerephon leucogaster	+	+	+	-	-
Mops leucostigma	+	+	+	+	+
Otomops madagascariensis	-	+	+	-	-
Total	**12**	**15**	**18**	**7**	**6**

richness and paralleling patterns at other limestone sites in western Madagascar (Goodman *et al.,* 2005a). In the Beanka Forest, two similar-sized species of *Miniopterus* (*M. griveaudi* and *M. aelleni*) were found living in sympatry. Another important record is the local presence of *Emballonura tiavato* that helps to fill in a gap in this species' known distribution. Further, we found in a synanthropic setting two species of Molossidae, *Mops leucostigma* and *Chaerephon leucogaster,* which are broadly distributed in western Madagascar.

Table 4. Degree of similarity of bat faunas based on Jaccard Index of five sites surveyed for bats. Nam = Namoroka, Bea = Beanka, Bem = Bemaraha, Ivo = Ivoloina, and Tam = Tampolo.

Site	**Nam**	**Bem**	**Bea**	**Ivo**	**Tam**
Nam	1				
Bem	0.737	1			
Bea	0.687	0.667	1		
Ivo	0.222	0.190	0.267	1	
Tam	0.167	0.200	0.200	0.444	1

Biogeography

A comparison of the sites included in the biogeographic analysis, all at lower elevations, comprising the western sites of Beanka, Bemaraha, and Namoroka resting on limestone, and the eastern sites of Ivoloina and Tampolo on alluvial soils, clearly shows a considerable separation of the bat faunas of these two portions of the island. In general, the species composition of the three limestone sites is notably similar with 11 taxa shared in common (Tables 3 and 4, Figure 2). This is almost certainly associated with the ecological parallels of these three sites, particularly the presence of caves and different types of crevices in the limestone and a variety of different habitats for day roost sites. The absence of *Miniopterus brachytragos* in the Beanka region is notable, as this species is widely distributed in limestone areas of the west, including Namoroka and Bemaraha (Goodman *et al.,* 2009b).

The analysis shows a major split between the three western lowland limestone sites (Namoroka, Bemaraha, and Beanka) and the two eastern lowland sites (Ivoloina and Tampolo) (Figure 2). There are

several bat species not shared between these different portions of the island, which is related to the ecology of the different taxa, including aspects of day roost sites. Three bat species are shared between these two regions that are not obligatory rock crevice or cave roosting: a frugivorous taxon – *Pteropus rufus* and two insectivorous taxa – *Hipposideros commersoni* and *Myotis goudoti*. A non-vouchered *Miniopterus* species was recorded at the Ivoloina Forestry Station, which is not listed in Table 3; this taxon is probably referable to a recently described species, *M. egeri*, only known from the eastern lowlands (Goodman *et al*., 2011).

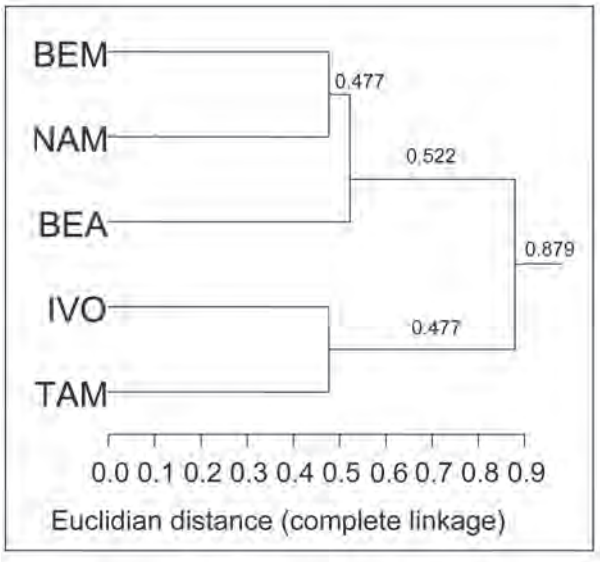

Figure 2. Dendrogram of the faunal affinities of bat species at five different sites on Madagascar. Nam = Namoroka, Bea = Beanka, Bem = Bemaraha, Ivo = Ivoloina, and Tam = Tampolo.

Aspects of natural history and seasonal reproduction

With the exception of animals captured within or close to cave entrances, most of the other sampled sites were within village settings or at the ecotone between *antsingy* forest and anthropogenic savannah habitat. Additionally, molossids were collected with a harp trap while exiting buildings in the nearby village of Belitsaka and no evidence of these taxa was found in any local cave. Hence, the presence of molossids in these anthropogenic settings, rather than natural forest, indicates an abundance of available prey surrounding these village settings. Kusch *et al*. (2004) presented a strong case for the ability of insectivorous bats to choose zones to inhabit, balancing aspects to minimize energy expenditure and maximizing prey capture.

Regarding the reproductive biology of bat species in the Beanka Forest, based on captured animals, a large proportion of the females were pregnant during the first survey (October – November) (Table 2). This period corresponds with the transition between the end of the cool/dry season and the start of the warm/wet season, with increasing temperatures and rainfall and greater abundance of fruits and insects. Hence, the season coincides with the greatest food availability, providing the means for females to increase their reproductive potential.

Conclusion

Herein we present data on the bat fauna of the Beanka Forest of central western Madagascar, occurring in a limestone karstic zone. While only a portion of this extensive massif has been surveyed for bats, it has a rich fauna, and shares close biogeographic affinities with the nearby limestone massifs of Namoroka and Bemaraha. Detailed research on bat ecology needs to be conducted in the Beanka Forest, including aspects as preferential habitats, diet, echolocation calls, and ecological niche partitioning. Such data will provide insight into the manner these animals live and further information for advancing local conservation programs.

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