Chapter 4.7
Ecology and Conservation of Bats in the Southern Anosy Region

Richard K. B. Jenkins[1,2], Amyot F. Kofoky[1], Jon M. Russ[2], Daudet Andriafidison[1, 3], Björn M. Siemers[4], Félicien Randrianadrianina[1,4], Tsibara Mbohoahy[5] Volana N. Rahaingondrahety[6] and Paul A. Racey[2]

Abstract

Trapping programs to compile species lists, studies on diet and seed dispersal, acoustic sampling of microchiropterans, and conservation assessments of fruit bat roosts have been undertaken in the Tolagnaro region. A maximum of 11 microchiropteran and three megachiropteran species have been documented. Only single roosts of the fruit bats *Eidolon dupreanum* and *Rousettus madagascariensis* have been identified, but 11 *Pteropus rufus* roosts are known, though not all are occupied simultaneously. In a *P. rufus* roost survey in December 2005, population abundance ranged from 40 to 1,000 bats per roost, with the largest colonies reported from sites protected by local communities as sacred forests. Fruit bats play an important role as seed dispersers and pollinating agents in the fragmented forests of the Anosy Region, and conservation plans are needed to safeguard them and the ecosystem services they provide. Microchiropteran surveys were undertaken in three littoral forests, Petriky, Sainte Luce, and Mandena. Bat activity and taxon richness were highest in the latter site, probably because of its proximity to potential day roosts in nearby rocky outcrops, and suitable foraging areas in the open trails of the Mandena forest. The two microchiropteran species, *Myzopoda aurita* and *Hipposideros commersoni*, that were only recorded in Sainte Luce, roost in vegetation and are therefore independent of rocky features. Acoustic sampling recorded unusual echolocation calls at Mandena and Sainte Luce characteristic of the Hipposideridae, which did not correspond to any known Malagasy hipposiderid. Further surveys in both forests and at potential roosts are therefore required to document the complete microchiropteran fauna of the region, and to determine conservation priorities.

Résumé

Écologie et conservation des chauves-souris dans la région sud de l'Anosy. Des programmes de capture pour dresser des listes d'espèces, des études sur le régime alimentaire et la dispersion de graines, des enregistrements acoustiques de microchiroptères et des évaluations relatives à la conservation des dortoirs de chauves-souris frugivores ont été menés dans la région de l'Anosy. Au total, 11 espèces de microchiroptères et trois espèces de mégachiroptères ont été documentées. Pour les chauves-souris frugivores, un seul dortoir a été identifié jusque là pour chacune des espèces *Eidolon dupreanum* et *Rousettus madagascariensis* mais 11 dortoirs sont connus pour abriter *Pteropus rufus* bien qu'ils ne soient pas tous occupés simultanément. Dans une étude portant sur l'inventaire de dortoirs de *P. rufus* en décembre 2005, l'abondance des populations variait de 40 à 1000 chauves-souris par dortoir, les plus grandes colonies étant rencontrées dans des sites protégés par les communautés locales qui respectaient des forêts sacrées. Les chauves-souris frugivores jouent un rôle important dans la dispersion

[1] Madagasikara Voakajy, BP 5181, Antananarivo 101, Madagascar. Email: ramanavy@wanadoo.mg

[2] School of Biological Sciences, University of Aberdeen, Aberdeen, AB24 2TZ, United Kingdom. Emails: r.jenkins@abdn.ac.uk, j.russ@abdn.ac.uk, p.racey@abdn.ac.uk

[3] Département de Biologie Animale, Faculté des Sciences, Université d'Antananarivo, BP 906, Antananarivo 101, Madagascar.

[4] Tierphysiologie/Animal Physiology, Zoologisches Institut, Universität Tübingen, Morgenstelle 28, 72076 Tübingen, Germany. Present address: Max-Planck Institut, 82319 Seewiesen. Email: siemers@orn.mpg.de

[5] Département des Sciences Biologiques, Faculté des Sciences, Université de Toliara, Toliara 601, Madagascar. Email: tmbohoahy@yahoo.fr

[6] Département des Eaux et Forêt, Ecole Supérieure des Sciences Agronomiques, BP 1250, Université d'Antananarivo. Antananarivo 101, Madagascar

des graines et en tant qu'agent de la pollinisation dans les forêts fragmentées de la région de l'Anosy et des projets de protection de la nature sont nécessaires pour sauvegarder les chauves-souris et les services qu'elles rendent à l'écosystème. Des inventaires de microchiroptères ont été réalisés dans trois forêts littorales, soit Petriky, Sainte Luce et Mandena. L'activité des chauves-souris et la richesse taxinomique étaient plus élevées dans le dernier site, probablement car il était plus proche de dortoirs diurnes potentiels dans les affleurements rocheux voisins et qu'il offrait des zones plus favorables à la recherche de nourriture grâce aux pistes ouvertes à l'intérieur de la forêt de Mandena. Les deux espèces de microchiroptères, *Myzopoda aurita* et *Hipposideros commersoni* qui n'ont été recensées qu'à Sainte Luce, établissement leur dortoir dans la végétation et ne sont donc pas liées aux formations rocheuses. Les enregistrements acoustiques ont montré des sons d'écholocations atypiques à Mandena et Sainte Luce, caractéristiques des Hipposideridae mais qui ne correspondent à aucun Hipposideridae connu de Madagascar. De plus amples études sont donc requises dans ces deux forêts et dans les zones de dortoirs potentiels pour documenter complètement la faune microchiroptère de la région et pour déterminer les priorités en matière de protection de la nature.

Introduction

The bats of Madagascar have only received the attention of biologists relatively recently. For several years, the most complete synthesis of Malagasy bats was a monograph by Peterson *et al.* (1995) based on earlier collections. Since the mid-1990's, a number of surveys have been undertaken within and outside Madagascar's protected areas, and the actual diversity of the island's chiropteran fauna is gradually being revealed (e.g., Goodman and Cardiff 2004, Goodman *et al.* 2005a, 2005b, 2006). In addition to bat species inventories, which complement the extensive database on Malagasy vertebrates, biologists have also started to record and document the echolocation calls of microchiropterans (Russ *et al.* 2003), as well as their diets (e.g., Razakarivony *et al.* 2005).

Surveys and research on bats in Madagascar have been conducted at scattered localities throughout the island. Microchiropterans in the east have occasionally been included in vertebrate surveys (e.g., Goodman 1999), while forests and caves in the west have been more extensively surveyed (e.g., Goodman *et al.* 2005a). Most echolocation recordings are of bats in the humid forests in the northeast and east (Russ *et al.* 2003), although acoustic methods were also used to assess habitat use in Parc National Tsingy de Bemaraha in the west (Kofoky *et al.* 2007). Fruit bat diet has been described at many locations, including the west near Mahajanga (Andriafidison 2004), the northeast on the Masoala Peninsula (Hutcheon 2003), and the southeast in the general vicinity of Tolagnaro (Bollen and van Elsacker 2002, Long 2002, Raheriaisena 2005). Therefore, the littoral forests near Tolagnaro are unique not only because the bat fauna has been surveyed as part of an effort to compile species lists for areas of conservation importance (Goodman 1999), but also because they have been the focus of detailed investigations into frugivory and seed dispersal (Bollen and van Elsacker 2002), as well as the use of acoustic sampling techniques to investigate habitat use and activity (Jenkins and Kofoky unpubl. data).

In this chapter, we aim to give a brief description of the bat species known in the littoral forests of Tolagnaro and the surrounding region. Further, we discuss important aspects of their ecology and conservation. We use existing literature and field surveys conducted by various combinations of the authors during November 2002, April 2003, February 2004, and May and December 2005.

Megachiroptera

Diversity and distribution

All three of Madagascar's endemic species of fruit bats are known near Tolagnaro. *Pteropus rufus* is one of the largest bat species in the world (MacKinnon *et al.* 2003), and although distributed widely in Madagascar, its conservation status is of growing concern in many areas because of disturbance to roost sites and hunting (CBSG 2002). *Pteropus rufus* has been collected from Tolagnaro (Peterson *et al.* 1995) and two other sites in the region (Goodman 1999). The holotype of the subspecies *P. r. princeps*, a form which is no longer accepted (Simmons 2005), was also collected near Tolagnaro. A number of colonies have also been located in the coastal zone of Tolagnaro (Fig. 1).

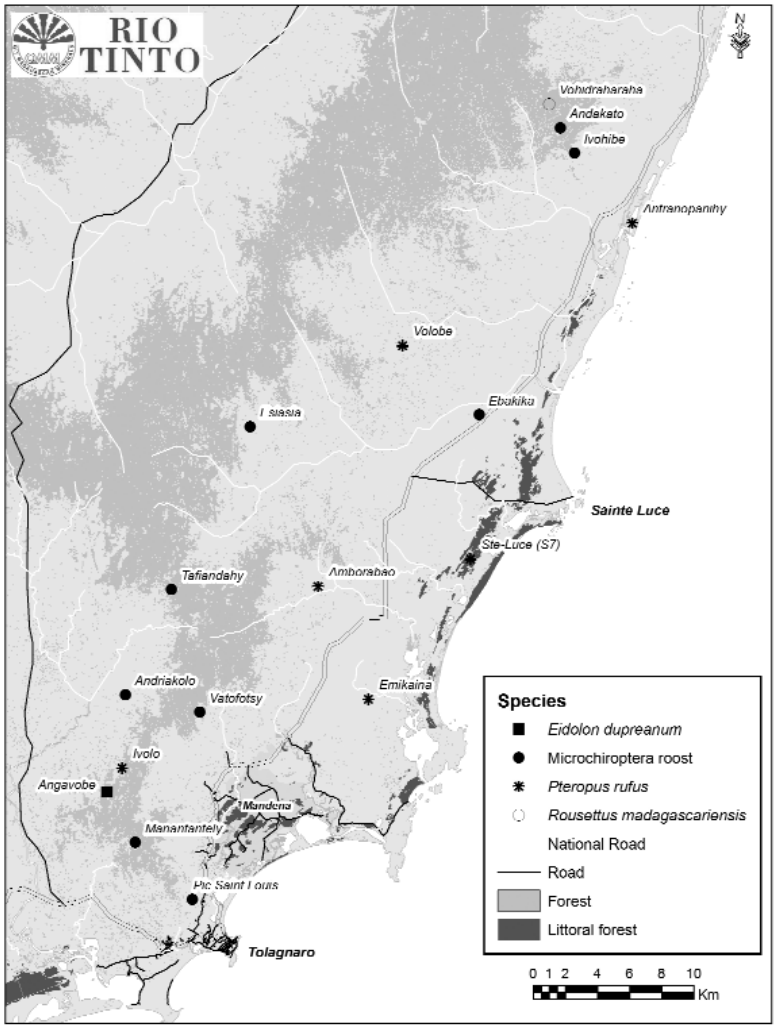

Figure 1. Map of the littoral forest zone of Tolagnaro showing roosts located and sites visited.

Rousettus madagascariensis is a relatively small fruit bat widely distributed across Madagascar (MacKinnon *et al.* 2003). Although reported in a range of habitat types including areas that have relatively little remaining forest cover (Goodman *et al.* 2005a), the location of only a few roost sites are known to biologists (MacKinnon *et al.* 2003). Goodman (1999) reported trapping 30 animals in a single night near litchi (*Litchi chinensis*) trees at the base of Pic Saint Louis near Tolagnaro. *Rousettus madagascariensis* has also been found in Nahampoana, Petriky, and Mandena forests (Goodman 1999; Table 1), and Peterson *et al.* (1995) collected some individuals at a site 30 km NE of the town. Only one roost site of *R. madagascariensis* is known near the littoral forests (Fig. 1).

There are few records of *Eidolon dupreanum* around Tolagnaro (Peterson *et al.* 1995). Rakotonirainy (2001) observed this species feeding on fruiting *Ficus* trees in Mandena and Sainte Luce, but this is the only record of which we are aware for this species in the regional littoral forests. A single roost of *E. dupreanum* is known in the area (Fig. 1), although it is likely that other roosts exist, undiscovered.

Table 1. Results from mist netting in three littoral forests near Tolagnaro in 2004 and 2005. Nets of varying lengths were used and were place at ground level across trails, rivers and in open ground, both inside intact forest and in agricultural areas.

Species	Site			
	Sainte Luce		Mandena	
	February 2004 (576 nmh)	May 2005 (1,062 nmh)	February 2004 (256 nmh)	May 2005 (324 nmh)
Rousettus madagascariensis	0	0	6	1
Hipposideros commersoni	0	7	0	0
Myotis goudoti	0	1	1	0
Scotophilus robustus	0	0	1	0
Myzopoda aurita	1	1	0	0
Mormopterus jugularis	0	0	1	0
Tadarida fulminans	1	0	0	0

nmh = (total number of meters of nets) x (total trapping hours)

Ecology

Pteropus rufus roosts in trees and is usually associated with forest fragments or linear patches of vegetation alongside water. *Rousettus madagascariensis* is a cave-dwelling bat, and its distribution is presumably limited by available roost sites (MacKinnon *et al.* 2003). *Eidolon dupreanum* usually roosts in rock fissures or large caves, but can occasionally be found in large trees. It is widely distributed across Madagascar and is one of the few native mammals that persist in the pseudo-steppe of the Central Highlands.

Frugivorous bats play an important role in the dispersal of plants (Cox *et al.* 1991, Mickleburgh *et al.* 1992, Shilton *et al.* 1999, Hodgkinson *et al.* 2003), and many tree species have evolved fruit and seed characteristics to attract fruit-eating vertebrates (Van der Pijl 1982). In Madagascar, lemurs are widely cited as the principal frugivores (Birkinshaw 2001) and seed dispersers in forests (Dew and Wright 1998, Bollen *et al.* 2004), and are vital to the process of regeneration (Ganzhorn *et al.* 1999). However, there is also growing evidence of the importance of Malagasy fruit bats in seed dispersal and pollination (Baum 1995, Bollen and van Elsacker 2002, Long 2002, Andriafidison *et al.* 2006). Given that Madagascar has a species-poor frugivore community, the megachiropterans are an important group of seed dispersers, especially in fragmented forest formations.

Bollen and van Elsacker (2002) found, based on scat analyses, the fruit of at least 40 endemic plant species in the diet of *P. rufus* at Sainte Luce over a 13-month period. The most important food plants included *Ficus guatteriifolia* (Moraceae), *Syzigium* sp. (Myrtaceae), *Terminalia fatrea* (Combretaceae), and *Uapaca thouarsii* and *U. littoralis* (Euphorbiaceae). The contribution of *P. rufus* to the ecological function of the forests was probably underestimated during this study because pollen grains found in the feces were not identified, and because large seeds, which are carried in the jaws, are not recovered in the feces of flying foxes. Germination tests on seeds that passed through the gut of *P. rufus* were inconclusive (Bollen and van Elsacker 2002). However, other studies have suggested that passage through the digestive tract of *P. rufus* has a positive effect on germination (Andriafidison 2004).

While its ability to disperse seeds and pollen between fragments makes *P. rufus* a key species in the area, there are limits to its capacity as a seed disperser. An important factor is the dimension of the alimentary canal, since this imposes a restriction on the size of the seeds that can be ingested (Tedman and Hall 1985). Lemurs and possibly bush pigs (*Potamochoerus* sp.) are the only forest animals capable of ingesting large seeds. For example, the regionally endemic lemur *Eulemur collaris* is the only local frugivore capable of ingesting large seeds, and five tree species in the littoral forest near Tolagnaro probably depend on this lemur for their survival (Bollen *et al.* 2004,

see Bollen Chapter 3.4). Nevertheless, as a locally abundant species capable of transferring seeds and pollen over large distances and between isolated fragments, *P. rufus* plays an important role in the maintenance of the littoral forests.

An assessment of the ecological role of *E. dupreanum* and *R. madagascariensis* in the littoral forests of the Tolagnaro region is not possible because of the lack of information on their respective diets. Rakotonirainy (2001) observed both fruit bat species visiting fruiting trees of *Ficus soroceoides*, *F. pyrifolia*, and *F. guatteriifolia*. *Eidolon dupreanum* has a remarkably varied diet elsewhere in Madagascar (e.g., Ratrimomanarivo 2003, Picot 2005), and introduced plants are an important food resource in the Central Highlands, where there is little natural forest cover remaining (Ratrimomanarivo 2003). *Rousettus madagascariensis* has been reported feeding extensively on the fruits of banana (*Musa* sp., Musaceae) and litchi near Tolagnaro (Goodman 1999).

The conservation of fruit bats

Six extant *Pteropus rufus* roosts were located during our survey in 2005, and the colony size ranged from 40 to over 1,000 individuals (Table 2, Fig. 1). Three of the roost sites benefited from the protections of local taboos and ancestral traditions. In two cases, protection of these sacred forests allowed fruit bats to roost within 300 m of a village. Sites without traditional protection, such as those of Sainte Luce (S7) and Antranopanihy, appear to be regularly visited by sport and bushmeat hunters.

The S6 fragment at Sainte Luce, which supported a colony of *P. rufus* until recently (Bollen and van Elsaker 2002), contained no bats during our visits, and local people reported that the bats had abandoned the site. Enato Ananadrano, another site used by roosting *P. rufus* (Bollen and van Elsaker 2002), also appears to have been deserted. This site is also a sacred forest and the reason for the desertion is unclear. Further evidence of movement between roosts comes from the large roost at Ivolo. Local people reported that historically there was no *Pteropus* at the site, but a colony took up residence in 1999. It appeared to be increasing in size and recently divided into two sub-colonies, occupying areas of natural forest and *Eucalyptus* plantations in close proximity. The roosts at Ivolo and Amborabao contained over 1,600 *P. rufus* during our survey, making them of major, regional conservation importance.

The Sainte Luce roost in S7 contained low numbers of *P. rufus* (47-104 bats) during two visits in 2005. The site, however, may have an important role if all the roosts act as a single network, or 'meta-roost,' with bats moving regularly between the different sites in response to reproductive activity, natal dispersal, human disturbance, or food availability, as may be the case elsewhere in Madagascar (Jenkins *et al.* 2007). Roost switching could occur on a regular basis with some animals moving between sites throughout the year. Another possibility is that the bats move less frequently, but *en masse* when switching occurs. Two roosts, including one of over 1,000 bats, were found using *Eucalyptus* plantations. Although there are few records of *P. rufus* roosting in *Eucalyptus* trees (MacKinnon *et al.* 2003), the nectar of this tree is an important food source during certain seasons (Razafindrakoto 2006).

There have been a number of conservation projects conducted on *Pteropus* bats elsewhere in the western Indian Ocean (Bowen-Jones and Entwistle 2002, Trewhella *et al.* 2005), and these should be used as a basis to initiate conservation programs at threatened roost sites in Madagascar. Given the pending environmental change and increase in human population in Tolagnaro associated with the ilmenite mine, *P. rufus* roosts are likely to face growing threats. Fruit bats are already frequently eaten in the region, and visitors are less likely to respect the traditional laws that govern forest use. Because of the temporal variation in occupancy and abundance of *P. rufus* roosts, monitoring programs should assess the roost sites frequently. Through engaging the local communities, who already inadvertently preserve *P. rufus* roosts in sacred forests, in a participatory monitoring program, the roosts will receive a higher profile in the region and important data on bat abundance and roost occupancy could be collected.

The *Eidolon dupreanum* roost at Angavobe is located high in a rock face and no threats were identified during a visit in 2005. *Rousettus madagascariensis* is particularly vulnerable to hunters because it roosts in caves. Using a trap made from local materials and thorns, a local farmer reported

Table 2. Bat roosts a) in caves and b) in trees, in the littoral and lowland forests near Tolagnaro.

Location	Roost	Habitat	Longitude	Latitude
Ampalafa	Cave	Agriculture (banana/manioc)	46°58'05.9"E	24°57'32.5"S
André zanaky (Enato)	Cave	Agriculture (rice)	46°59'26.9"E	24°54'16.7"S
Agare (Enato)	Cave	Agriculture (banana/manioc)	46°59'10.9"E	24°53'23.4"S
Lakandava	Cave	Rain forest	46°57'54.3"E	24°57'07.7"S
Vatofotsy	Cave	Rain forest	46°58'40.0"E	24°54'08.3"S
Pic St Louis	Cave	Rain forest	46°58'30.1"E	25°00'25.1"S
Manantantely	Cave	Rain forest	46°55'52.2"E	24°58'21.5"S
Tafiandahy	Cave	Agriculture (banana/manioc)	46°56'35.5"E	24°49'47.0"S
Andriakolo	Cave	Agriculture (banana/manioc)	46°54'55.9"E	24°51'42.2"S
Antranokananavy	Cave	Agriculture (rice)	47°11'10.1"E	24°35'50.2"S
Andakato	Cave	Agriculture (banana/manioc)	47°12'30.2"E	24°33'28.7"S
Vohidraharaha	Cave	Agriculture (rice)	47°12'12.5"E	24°32'52.7"S
	Cave	Rain forest	47°12'47.9"E	24°33'54.1"S
Esiasia	Cave	Agriculture (banana/manioc)	47°00'24.0"E	24°44'35.1"S
Angavobe	Cliff	Agriculture (abandoned)	46°54'18.8"E	24°56'10.8"S
Marovony	Trees	Rain forest	47°20"E	24°05"S
Sainte Luce (S7)	Trees	Littoral forest	47°8'9.2"E	24°48'3.1"S
Sainte Luce (S6)	Trees	Littoral forest		
Ivolo (two roosts)	Trees Trees	Rain forest *Eucalyptus*	46°54'57.5"E	24°55'37.7"S
Antranopanihy (Analalava)	Trees	Littoral forest	47°13'58.5"E	24°37'08.9"S
Volobe	Trees	In a village	47°05'44.5"E	24°41'10.4"S
Emikaina Mahialambo	Trees	*Eucalyptus*	47°04'23.7"E	24°53'23.4"S
Enato Ananadrano	Trees	Rain forest	46°59.494"E	24°54.279"S
Amborabao	Trees	In a village	47°2'37.3"E	24°49'8.6"S

Alt.	Date	Species	Abundance	Observations
162 m	05.05.05	*Emballonura atrata*	10-15	Recent evidence of fire at cave entrance
20 m	06.05.05	*E. atrata*	10-15	Recent evidence of fire at cave entrance
30 m	06.05.05	*E. atrata* *Miniopterus manavi* *M. majori* *M. gleni*	80-120	Recent evidence of fire at cave entrance
21 m	07.05.05	*E. atrata*	15-20	
48 m	08.05.05	*E. atrata*	10-15	
85 m	10.05.05	*E. atrata*	10-15	
373 m	11.05.05	*E. atrata*	10-15	
220 m	02.12.05	*E. atrata*	10-15	Evidence of recent use by roosting fruit bats
87 m	03.12.05	*E. atrata*	10-15	Recent evidence of fire at cave entrance
48 m	13.12.05	no captures	0	
266 m	14.12.05	*E. atrata*	15-Oct	Recent evidence of fire at cave entrance
143 m	14.12.05	*Rousettus madagascariensis* *Triaenops rufus*	400-500 < 10	Hunted at the cave entrance with traditional trap
227 m	12.12.05	*E. atrata*	10-20	
139 m	18.12.05	*Miniopterus* sp.	< 10	Recent evidence of fire at cave entrance
343 m	06.12.05	*Eidolon dupreanum*	10-15	
?	n/a	*Pteropus rufus*	n/a	Reported to contain ca. 50 *P. rufus* in 2000 (Bollen and van Elsacker 2002)
20 m	10.05.05 3.12.05	*P. rufus*	104 47	Evening dispersal count Evening dispersal count
20 m	4.12.05	*P. rufus*	0	Reported to contain 300-350 *P. rufus* in 2000 (Bollen and van Elsacker 2002)
73 m	5.12.05	*P. rufus* *P. rufus*	180-220 ca. 1000	A roost site protected by local taboos. Used since 1999 by bats and only occasionally hunted. Two roosts sites < 800 m apart
12 m	13.12.05	*P. rufus*	100-150	Hunted with guns for sport/food by people from Tolagnaro
27 m	16.12.05	*P. rufus*	50-60	A roost site protected by local taboos
3 m	9.05.05 12.12.05	*P. rufus*	50-60 ca. 100	Hunting with guns.
?	10.05.05	*P. rufus*	0	A roost site protected by local taboos and reported to contain bats in previous years (Bollen and van Elsacker 2002)
?	11.12.05	*P. rufus*	412	A roost site protected by local taboos. Less than 0.5 km from nearest village

catching 170 *R. madagascariensis* from the Vohidraharaha Cave on a single night. It is clear that once people have located the roost caves of *R. madagascariensis*, the bats are highly vulnerable and severe reductions in their abundance and even extirpation are possible.

Microchiroptera

Eger and Mitchell (2003) reported 27 species of microchiropterans, all of which were insectivorous bats, on Madagascar, although subsequent survey work associated with taxonomic revisions has resulted in several species new to science and endemic to the island (e.g., Goodman and Cardiff 2004, Goodman *et al.* 2005b, 2006). We surveyed the microchiropterans of the littoral forests using both acoustic techniques and mist nets. The results, supplemented with information from the literature, were used to summarize the bat fauna of the littoral forests and surrounding area.

Note on taxonomy

Miniopterus majori, a Malagasy endemic, and *M. fraterculus*, an African species, occur sympatrically in Madagascar. Based on current information, these species can only be distinguished by dental characteristics (S. M. Goodman, pers. comm.), and we were unable to definitively assign the recorded echolocations to members of this genus. We therefore refer to *M. majori/fraterculus* or *M. fraterculus* for the cases where voucher specimens are available.

Diversity and distribution

Hipposideridae

Hipposideros commersoni is a large insectivorous bat whose occurrence is widespread on Madagascar. It is known in parcel 1 of the Parc National d'Andohahela (Goodman 1999) and in Sainte Luce (Table 1). *Triaenops rufus* has been collected along the Itarana River (Goodman 1999) and near Tolagnaro (Peterson *et al*. 1995), and was found roosting in the Vohidraharaha Cave with *R. madagascariensis* (Table 2).

Emballonuridae

Emballonura atrata is reported in the literature to occur in the Marovony Forest and near Fanjahira on the western side of the Anosyenne Mountains (Peterson *et al*. 1995). An individual was captured at Mandena in April 2003, and our surveys located 11 small caves in the foothills of the Tsitongambarika Forest, which contained small colonies of *E. atrata* (Table 2).

Vespertilionidae

Myotis goudoti is a species of widespread occurrence in Madagascar that usually roosts in caves (Eger and Mitchell 2003). During an inventory of parcel 1 of the Parc National d'Andohahela, Goodman (1999) netted two individuals. Other regional records come from the littoral forests of Sainte Luce and Mandena (Table 1), and sites on lateritic soils in the Marovony, Manantantely, and Nahampoana forests.

Two individuals of *Miniopterus manavi*, a small species that roosts in caves, rocky overhangs, and tree cavities (Eger and Mitchell 2003) were found in the humid parcel of Parc National d'Andohahela, but there are no records of this taxon in the littoral forests (Goodman 1999). A slightly larger member of this genus has been collected from Manantantely and along the Itaranta River (Goodman 1999). The specific identities of these populations are currently under study (S. M. Goodman, pers. comm.). Few of the caves surveyed in 2005 contained roosting vespertilionids, although three species of the genus, *M. manavi*, *M. majori/fraterculus*, and *M. gleni*, were found in the Agare (Enato) cave.

The only other member of this family known to occur in the Tolagnaro region is *Scotophilus robustus*. A single individual was netted in semi-open farmland near Mandena (Table 1). Little is known about the habit of this species, but it has been captured in forested habitat (Goodman *et al*. 2005a) and roosts in synanthropic settings (Ratrimomanarivo and Goodman 2005).

Myzopodidae

The marshy grasslands and fragmented forests in the agricultural areas north of Tolagnaro are one of the few areas in Madagascar where the Old World,

Table 3. Results of an acoustic survey of three littoral forests (1) Petriky (25°03'42.8' S, 046°52'06.4"E, 06 -10 Feb. 2004), (2) Mandena (M1 & M11; 24°57'15.9"S, 046°59'19.5"E, 21 – 27 Feb. 2004), and (3) Sainte Luce (S9 & S17; 24°46'45.8"S, 047°10'16.6"E, 12 – 16 Feb. 2004; 24°48'15.9"S, 047°09'39.1"E, 17 – 20 Feb. 2004) using time-expanded recordings to identify free-flying bats. Values are the percentage frequency (e.g. number of point counts with sp. 1 in site 1 / total number of point counts in site 1 x 100).

	Site			Forest Habitat		
	Mandena (n = 84)	Sainte Luce (n = 94)	Petriky (n = 57)	Interior (n = 70)	Edge (n = 79)	Trail (n= 86)
Point counts with no recordings	48.8	73.4	80.7	77.1	69.6	54.7
Point counts with unidentified recordings	8.3	14.9	3.5	4.3	16.5	8.1
Point counts with identified recordings	42.9	11.7	15.8	18.6	13.9	37.2
Unidentified Hipposideridae (73.1 kHz)	0	0	1.8	1.4	0	0
Emballonura atrata (54.8 kHz)	2.4	0	0	0	0	2.3
Miniopterus majori/fraterculus (50-53 kHz)	26.2	3.2	0	2.9	6.3	20.1
Myotis goudoti (61 kHz)	33.3	2.1	1.8	11.4	10.1	17.4
Scotophilus robustus (35.5 kHz)	8.3	2.1	1.8	0	3.8	8.1
Unidentified Vespertilionidae (40-43 kHz)	1.2	1.1	0	0	0	2.3
Myzopoda aurita (42.3 kHz)	0	2.1	0	0	0	2.3
Molossid sp. 1 (15-19 kHz)	13.1	2.1	0	1.4	5.1	9.3
Molossid sp. 2 (20-30 kHz)	1.2	0	8.8	5.7	0	2.3
Molossid sp. 3 (> 30 kHz)	3.6	2.1	14	4.3	8.9	3.4

sucker-footed bat, *Myzopoda aurita,* can regularly be netted. Until recently, *M. aurita* was the only member of the endemic family Myzopodidae (Goodman *et al.* 2007). It is distinctive because of its long ears and adhesive discs (Schliemann and Maas 1978). In the eastern region, this species' range extends from the north to the south. Despite being recorded in a number of different sites in the east, there is very little information available on its ecology. Its distinctive echolocation calls were described by Göpfert and Wasserthal (1995) and by Russ *et al.* (2003). It is widely believed that *M. aurita* uses its discs to roost upright in the leaves of the Traveler's tree, *Ravenala madagascariensis* (Strelitziaceae). *Ravenala* is a plant associated with disturbed habitats, but is also found inside the forests. If this plant is indeed the preferred roost site of *M. aurita*, then it is likely that this bat species uses areas of degraded, as well as intact, forest vegetation. In Sainte Luce, we netted *M. aurita* on a trail inside relatively intact forest at the S9 fragment, and next to a river at least 1 km from the nearest intact forest (Table 1). This is consistent with the results of other workers who have reported *M. aurita* both inside and at the edge of relatively undisturbed forest (Goodman 1999), and in agricultural areas (Russ *et al*. 2003).

Molossidae

There are eight known species of molossids in Madagascar, and their day roost sites are often in buildings or caves (Goodman and Cardiff 2004). Probably reflecting the lack of trapping effort near human dwellings around Tolagnaro, only two molossid species have so far been recorded in the area. *Mormopterus jugularis* is a gregarious bat usually found roosting in buildings, although it does occupy caves. There are two records of this species from Parc National d'Andohahela (Goodman 1999), and we mist netted it in an agricultural setting near Mandena (Table 1). A single *Tadarida fulminans* was trapped near the Sainte Luce forest (Table 1), representing a considerable range extension for this species, since it was only previously known from Fianarantsoa and Parc National d'Isalo (Goodman and Cardiff 2004).

Roost Ecology

Very little information is available on the roosting ecology of Malagasy microchiropterans, even though the protection of cave roosts was highlighted as a priority for bat conservation in Madagascar (Goodman *et al.* 2005a). *Emballonura atrata* was common in the caves surveyed in 2005, but was never abundant at any site. Many of the caves were

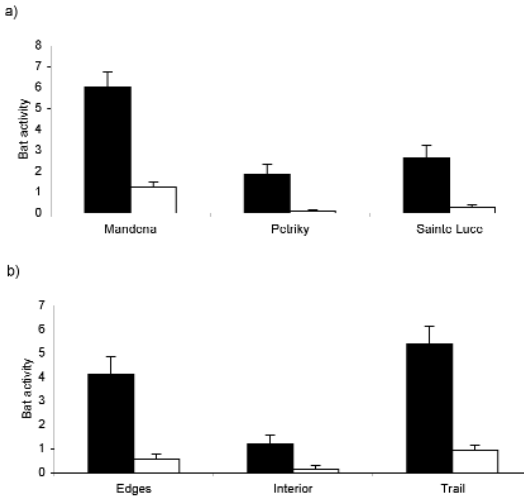

Figure 2. Mean ± SE bat passes (filled) and feeding buzz (open) per 5-minute point-count from three littoral forests along (A) and away (B) from trails.

in agricultural areas. It has a distinctive roosting posture in that it lifts itself off the substrate using its forelimbs, and can be identified without the use of special traps. It is, therefore, a suitable candidate for regular monitoring.

Acoustic survey of habitat use

Although mist nets are widely used to survey microchiropterans (e.g., Clarke and Downie 2001, Fenton *et al.* 2001, Bernard and Fenton 2002, Kofoky *et al.* 2007), biologists also use bat detectors to assess habitat use, activity, and species composition (e.g., Law and Chidel 2002, Russ and Montgomery 2002, Russo and Jones 2003). Although the echolocation of certain Malagasy bat species remain to be fully described, time-expanded, field recordings can be used to identify many bats in flight (Russ *et al.* 2003). This approach is commonly used in other countries, and requires the initial compilation of echolocation recordings from individuals of known identity (e.g., Russo and Jones 2002, Rydell *et al.* 2002). Echolocation identifications are made based on the shape, duration, and frequency of the calls.

We conducted acoustic surveys of Petriky, Mandena, and Sainte Luce to determine the species composition and patterns of habitat use of microchiropterans. A team of two people recorded the echolocation calls of flying bats from a series of 5-minute point-counts between 18h00 and 21h00. We surveyed 10-15 point-counts per night, approximately 200-250 m apart. The first person used a Pettersson bat detector (D240X or D980, Pettersson Electronik, Sweden), and all calls were recorded on mini-disks in the time-expansion (x 10) mode. Time-expanded recordings preserve the structure of original echolocation calls, and allow species to be identified with confidence (e.g., Rydell *et al.* 2002). The recordings were later analyzed using the software package BatSoundPro (v.3.31, Pettersson Electronik, Sweden), and measured parameters of echolocation calls were compared to those in the literature (Russ *et al.* 2003) and to our own reference recordings.

The second person used a 'Bat Box Duet' (Stag Electronics, U.K.) to record bat activity in frequency division and heterodyne. These methods permit bat activity to be assessed in two categories. 'Bat passes' are a measure of activity, and 'feeding buzzes' are an estimate of the foraging activity. Both are widely used as a means of determining the habitat use of bats (Vaughan *et al.* 1997).

We detected 10 different microchiropteran "taxa" during the survey from the time-expanded echolocation recordings (Table 3). We were unable to identify the low-frequency recordings (< 35 kHz) at the species level, but we were able distinguish three different types of echolocation and tentatively assign them to three molossid taxa (Table 3).

Many areas were devoid of bat activity, and over 70% of point-counts at Sainte Luce and Petriky were without bats entirely (Table 3). Most echolocation recordings were made in Mandena, and we were able to determine the bat taxa in 42% of point-counts. At Sainte Luce and Petriky, few recordings were ascribed to one of the 10 taxa listed in Table 3. *Myotis goudoti* was detected at all three sites, but was most common in Mandena where it was recorded in a third of all point-counts (Table 3). *Miniopterus majori*/*fraterculus*, *Scotophilus robustus,* and *Emballonura atrata* were also most frequently recorded in Mandena. *Myzopoda aurita* was only detected in Sainte Luce. We recorded an echolocating bat in Petriky that was characteristic of the Hipposideridae, but with measured parameters outside that of any

known Malagasy species. This bat was also heard, but not recorded, in Sainte Luce.

Microchiropteran activity was significantly different between the three littoral forests with both bat passes (Kruskal-Wallis, $H = 39$, $p < 0.0001$) and bat feeding rate (Kruskal-Wallis, $H = 10$, $p < 0.002$) higher in Mandena than the other two sites (Fig. 2a). Acoustic surveys revealed higher taxon richness, higher activity, and a higher proportion of point-counts with bats at Mandena than Sainte Luce or Petriky.

We recorded bats more frequently on forest trails than either in the forest interior or at the edge (Table 3). Taxon richness was highest on forest trails, and *Miniopterus majori/fraterculus* in particular was most frequently recorded in this habitat. Two taxa, including *Myzopoda aurita*, were only recorded on forest trails. Bat activity, measured as 'bat passes' (Kruskal-Wallis, $H = 22$, $p < 0.001$) and 'feeding buzzes' (Kruskal-Wallis, $H = 11.6$, $p < 0.003$), was significantly different between forest habitats, was consistently lower in the forest interior than along the linear features, and was highest along forest trails (Fig. 2b).

The actual number of detections was much lower in the littoral forests than other sites on Madagascar. For example, bats were recorded on 76% of point-counts from Parc National Tsingy de Bemaraha in western Madagascar (A. Kofoky unpubl. data), while we detected bats in the littoral forest on 18 - 50% of the point-counts. This indicates that a low activity or abundance of microchiropterans may be characteristic of the littoral forest, and is probably related to the forests' lack of rock features (Goodman *et al.* 2005a).

Our acoustic survey indicates that the Mandena forest has the most diverse microchiropteran fauna. Bat activity was also highest at Mandena and along trails. Despite the proximity of Sainte Luce to Mandena, there are notable differences in the bat faunas of the two sites. The forest at Mandena is crossed with wide, straight trails, while at Sainte Luce there are only a few narrow paths inside the forest. It is widely known from studies elsewhere that linear features are important landscape elements for microchiropterans (Downs and Racey 2006), although the exact reason for this has yet to be identified (e.g., Verboom and Spoelstra 1999). Our data suggest that the trail system in Mandena is used by both feeding and non-feeding bats. Malagasy vespertilionids are unlikely to be able to fly and forage inside the dense forest vegetation of Mandena. Further, the wide trails at Mandena may serve, in a habitat sense, as forest edge.

Another possible explaination for the difference between Mandena and Sainte Luce is that the rocky outcrops at Nahampoana provide nearby day roosts for certain microchiropterans. There are no rocky outcrops near Sainte Luce and the forest itself is without caves or fissures. Indeed, the two microchiropterans found in Sainte Luce, but not in Mandena (*Myzopoda aurita* and *Hipposideros commersoni*) are both known to roost in vegetation.

Our acoustic survey of Petriky and Sainte Luce detected the presence of a hipposiderid species of which the vocalization was unknown. This bat was also detected at Mandena during an earlier acoustic survey in April 2003 when 12 recordings were obtained from a forest trail in a swampy area.

Conservation

Microchiropterans have received scant attention from conservation biologists in Madagascar. Recent advances in taxonomy should be followed-up by detailed ecological research into the reproduction, migration, roosting, foraging behavior, and diet of bats. With the exception of the study by Kofoky *et al*. (2007), there has been little effort to tease apart the roosting and foraging requirements of microchiropterans on the island.

Bats of the eastern rain forests are difficult to trap in large numbers and there are few data available on their ecology. Fire is a potential threat to *Emballonura atrata*, as many of the caves are situated in close proximity to agricultural land. Traces of fire were noted at the entrances of five caves in our survey. Data on monthly abundance and assessments of the foraging sites of these bats are needed for a better picture of their conservation status.

Although *Myzopoda aurita* is perceived to be a common species because of its wide distribution and association with *Ravenala* in degraded habitats, there are very few data available on its roost use or foraging habitats. Our acoustic survey and capture results from Sainte Luce suggest that the species is uncommon and difficult to detect or net, and that it uses both intact forest and open habitat.

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