Not rare, but threatened: the endemic Madagascar flying fox *Pteropus rufus* in a fragmented landscape

Richard K.B. Jenkins, Daudet Andriafidison, H. Julie Razafimanahaka, Andriamanana Rabearivelo, Noromampiandra Razafindrakoto, Zo Ratsimandresy, Rabe H. Andrianandrasana, Emilienne Razafimahatratra and Paul A. Racey

Abstract The endemic Madagascar flying fox *Pteropus rufus* is threatened by habitat loss at roost sites and hunting for bushmeat. There is no conservation plan for this species, even though it is categorized on the IUCN Red List as Vulnerable and plays an important role as a seed disperser. In the Mangoro valley of central eastern Madagascar we monitored roost occupancy and abundance of *P. rufus* on 15 occasions at six sites over a 12-month period and conducted a detailed assessment of eight roosts during July 2004. There was considerable monthly variation in bat abundance and only two sites contained bats during every visit. Three sites were occupied only between September and March and may act as maternity or nursery roosts. Evidence of hunting was found at three roosts, and fire and forest clearance are ubiquitous threats. Two roosts were in *Eucalyptus* plantations and six were in small (2.2 - 28.7 ha) isolated fragments of degraded, mid elevation dense humid forest. All roosts were outside protected areas but were within 20 km of relatively intact forest. Faecal analysis revealed a diet of native forest tree species, cultivated fruits and *Eucalyptus* flowers. *P. rufus* in the Mangoro valley, and elsewhere in Madagascar, appears to survive in human-impacted environments by the inclusion of exotic plants in its diet and the ability to move between roosts. We provide conservation recommendations for *P. rufus* at both local and national levels.

Keywords Diet, flying fox, fragmentation, hunting, plantations, *Pteropus rufus*, Madagascar.

Introduction

Whilst significant efforts have been made to conserve *Pteropus* species of the western Indian Ocean islands through population surveys (Reason & Trewhella, 1994; Entwistle & Corp, 1997b; Powell & Wehnelt, 2003), ecological research (Entwistle & Corp, 1997a; Granek, 2002) and environmental education initiatives (Trewhella *et al*., 2005), attention has only recently been drawn to the conservation of the endemic Madagascar flying fox *Pteropus rufus*, despite decades of research and conservation on endemic Malagasy mammals. There are estimated to be 300,000 *P. rufus* in Madagascar (MacKinnon *et al*., 2003), two orders of magnitude more than some other *Pteropus* species in the western Indian Ocean (Powell & Wehnelt, 2003). However, even though *P. rufus* is categorized as Vulnerable on the IUCN Red List (IUCN, 2006), the observation that it is locally common has led to complacency with respect to its conservation status.

P. rufus is threatened by disturbance to roosts sites from fire, logging and clearing forest for agriculture (CBSG, 2002; MacKinnon *et al*., 2003). The species also suffers from heavy and sustained hunting for bushmeat in some areas (MacKinnon *et al*., 2003). *P. rufus* is classed as game and can be legally hunted in Madagascar but the restrictions aimed at preventing overexploitation (permits, a defined hunting season) are difficult to enforce. Conservation of *P. rufus* therefore represents a challenge because the species is without a protected status and most of the roosts are outside protected areas. Investigations of the diet of *P. rufus* from south-eastern Madagascar have revealed the important role of these bats in ecosystem function (Bollen & Van Elsacker, 2002;

Richard K. B. Jenkins* (Corresponding author) and **Paul A. Racey** School of Biological Sciences, University of Aberdeen, Aberdeen, AB24 2TZ, UK. E-mail jenkins@wanadoo.mg

Daudet Andriafidison*, **Noromampiandra Razafindrakoto*** and **Emilienne Razafimahatratra** Département de Biologie Animale, Faculté des Sciences, Université d'Antananarivo, B.P. 906, Antananarivo (101), Madagascar.

Andriamanana Rabearivelo and **Zo Ratsimandresy** Arongampanihy, Culture, Communication et Environnement, Lot A 422, Moramanga 514, Madagascar.

Rabe H. Andrianandrasana* Département de Biologie Végétale, Faculté des Sciences, Université d'Antananarivo, B.P. 906, Antananarivo (101), Madagascar.

H. Julie Razafimanahaka* Département des Eaux et Forêt, Ecole Supérieure des Sciences Agronomiques, Université d'Antananarivo, B.P. 175, Antananarivo (101), Madagascar.

*Also at: Madagasikara Voakajy, B.P. 5181, Antananarivo (101), Madagascar.

Received 1 August 2005. Revision requested 14 December 2005. Accepted 25 April 2006.

Long, 2002; Raheriaisena, 2005), especially as seed dispersers (Bollen *et al.*, 2004) and pollinators. Through an ability to defaecate the seeds of many plant species over a wide area and to travel regularly across habitats that are avoided by other frugivores, *P. rufus* plays a significant role as a seed disperser in fragmented forest landscapes (Bollen & Van Elsacker, 2002; Bollen *et al.*, 2004). Local extinctions of *P. rufus* are therefore likely to be followed by decreased recruitment of seedlings necessary for forest regeneration.

We surveyed roosts at mid elevation sites in eastern Madagascar where *P. rufus* is threatened by human activities and where conservation research has been requested by local land managers. Our objectives were to (1) identify the most important *P. rufus* roosts, (2) determine monthly variation in abundance and occupancy of roosts, (3) investigate factors influencing roost selection, (4) make a preliminary assessment of *P. rufus* diet in eastern Madagascar, and (5) suggest conservation measures for *P. rufus*.

Study area

The work was conducted in the Alaotra-Mangoro region, Province of Toamasina, eastern Madagascar, in the Mangoro River valley (Fig. 1). The landscape consists mainly of pine tree plantations, savannah grasslands and rice fields with a few *Eucalyptus* plantations and fragments of mid elevation dense, humid forest.

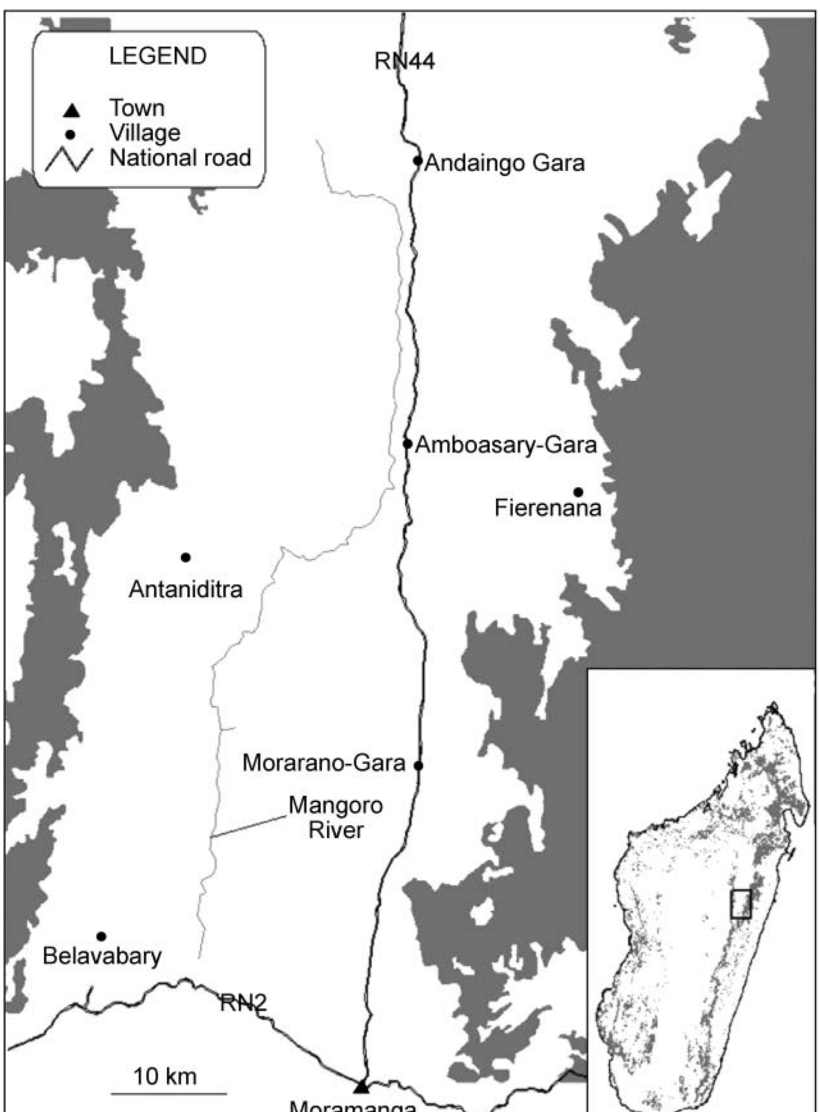

Fig. 1 Location of the Mangoro valley and two corridors (north-south) of intact, mid elevation humid forest (shaded): Manjakadriana – Anjozorobe to the west and Parc National de Zahamena – Parc National de Mantadia to the east. Inset shows location of main map in Madagascar.

Methods

Fifteen visits were made by survey teams between August 2003 and August 2004 to count *P. rufus* at seven roosts in fragments of humid forest. These roost sites were selected based on local knowledge of bat presence and the proximity to the villages of our volunteers. Roosts were visited in Ambohimanatrika, Vahamainty (Commune Rural (CR) Amboasary), Analabe (CR Morarano), Amparihimarotanana, Andriambondro and Ambakoana (CR Antaniditra). The monitoring team consisted of 14 local villagers who belong to a grassroots non-governmental conservation organization Arongampanihy, Culture, Communication et Environnement (ACCE). Training in techniques to count roosting bats was provided by biologists from Madagasikara Voakajy. Teams of two or three people with binoculars (8 * 40 and 10 * 40) visited each roost in the early morning and counted roosting bats. Morning visits were favoured over evenings because local volunteers were reluctant to return home, after the counts, in darkness. Observers first searched the forest fragment to identify the area used by bats. Then, standing on adjacent hillsides, sections of the forest were scanned slowly and bats counted before moving to a new vantage point to continue the survey. Counts were made of groups of bats and the observer called out a running tally to an assistant. All monthly counts were usually made within a 3-day period.

To complement the monthly counts we visited six of the seven roost sites in July 2004 to conduct a more detailed assessment of their conservation status and to count bats during the evening dispersal and morning return. During this period we were unable to visit Ambohimanatrika but we made visits to two additional roost sites reported from *Eucalyptus* plantations, at Marovitsika (CR Belavabary) and Mahatsinjo (CR Andaingo). We were unable to count the roosts simultaneously because of logistical constraints. At each site we counted bats dispersing to their foraging site. Teams were installed 30 minutes before dark (*c*. 18.00) and bats were counted as they left the roost until 20.00 hours or until no further bats were observed leaving the roost for a 30 minute period. Morning counts were as described above.

We walked around the circumference of each forest fragment and logged our position with global positioning systems approximately every 100 m. These points were later used to calculate the surface area of each fragment in the geographical information system *ArcView v. 2.3* (ESRI, Redlands, USA). We also added the major habitat types from digitized maps (Foiben-Taosarintanin'I Madagasikara BD500) to illustrate the proximity of the roosts to cultivated land and relatively intact humid forest.

Within each forest fragment we categorized areas *a priori* as either a permanent roost (bats are always present although in variable numbers) or a temporary roost (sites that are used only occasionally) or a non-roost (no records of use by roosting *P. rufus*) based on discussions with local people. During a vegetation survey along transects (50 m) in each forest (R.H. Andrianandrasana, unpubl. data), we measured the diameter at breast height (DBH) of each canopy-forming tree within 1 m of the tape measure used to delineate transects, and the slope and aspect of the site.

We collected faecal pellets from six roosts (four in humid forest and two in *Eucalyptus* plantations) by placing plastic tarpaulins under the *P. rufus* colony for 4-7 days or by collecting fresh faeces from leaves underneath the roosting bats. Faeces were stored in paper envelopes in the field and were later identified by comparing seeds, fruit and leaves collected during the study with those housed at Parc Botanique et Zoologique de Tsimbazaza and Programme GEREM-Fianarantsoa, IRD/CNRE. Previous work on *P. rufus* in south-eastern Madagascar has shown that pollen and nectar are an important food source (Long, 2002) and we therefore sampled *c*. 5% of each faecal pellet for pollen grains under a microscope.

Results

All of the eight roosts were situated within 20 km of either the corridors of dense humid forests at Manjakadriana - Anjozorobe to the west or the Parc National de Zahamena – Parc National de Mantadia to the east (Fig. 2). The roosts were located in a mosaic of anthropogenic landscape that consisted predominantly of savannah grasslands, pine tree plantations and rice fields. Six roosts were in degraded dense humid forest fragments and two in *Eucalyptus* plantations. The fragments that contained *P. rufus* were small (2.4 - 28.7 ha) and all roosts were within 10 km of a village (mean distance = 4.2 km; Table 1). The combined area of the fragments used by *P. rufus* totaled 130 ha. The total area within all roosts, calculated from the area inside a polygon linking the outermost sites, was 83,800 ha.

Combining monthly counts across all sites over a 13-month period gave a mean monthly population estimate of 3,873 $\pm$ SD 4,483 (range 1,871–6,163). The most important roosts in terms of mean and maximum counts were Ambakoana, Fanafana and Amparihimarotanana, and Andriambondro. Fanafana and Amparihimarotanana were the only roost sites that contained *P. rufus* during each of the 15 monthly counts (i.e. 100% occupancy; Table 2). There was considerable monthly variation at the other sites. For example, Ambakoana

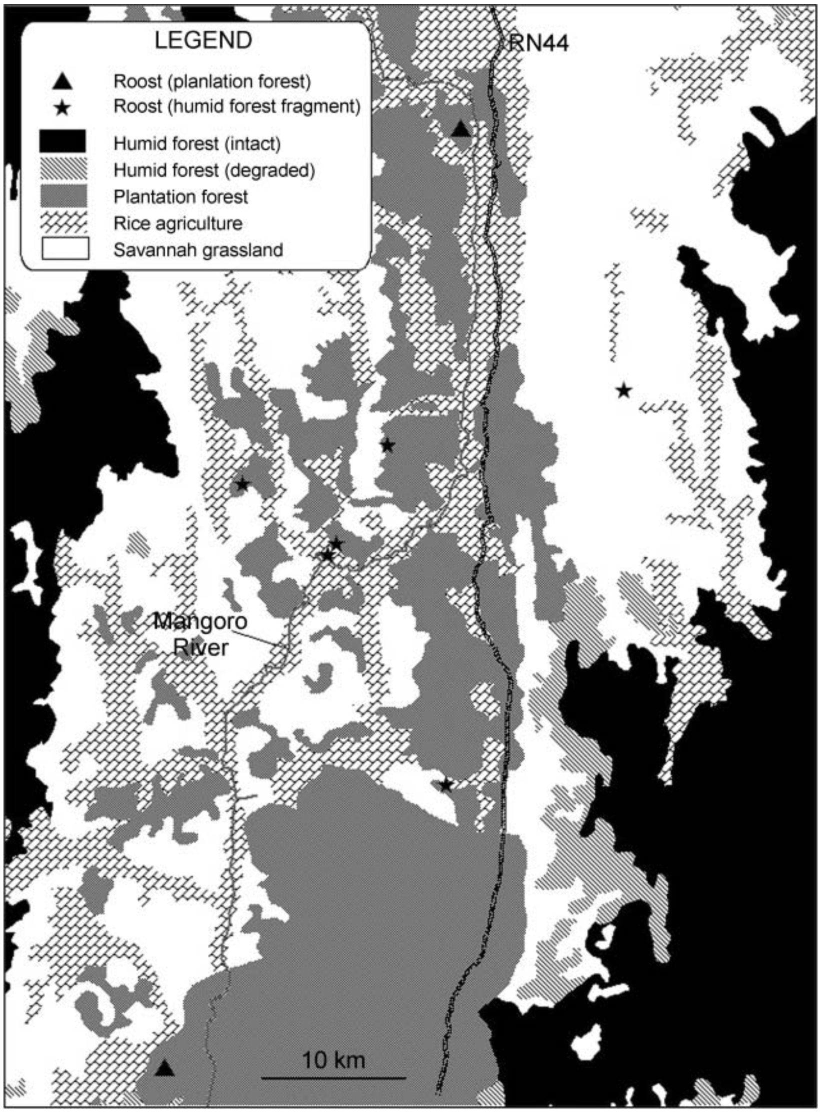

Fig. 2 Distribution of *P. rufus* roosts in fragments of degraded humid forest and *Eucalyptus* plantations in the Mangoro valley (see Fig. 1 for location in Madagascar).

contained >1,200 *P. rufus* in March 2004 but no bats during the ensuing 5 months. With each roost recording its monthly maxima during a different month it appears that the population of *P. rufus* in the valley frequently moves between these seven, and possibly other, roosts.

There was evidence of human disturbance at all six of the roosts in forest fragments (Table 1). At two, signs of hunting included short throwing sticks that are used to knock roosting bats out of trees, and discharged shotgun cartridges that had not yet rusted provided evidence of recent shooting. Indirect disturbance at the roosts was also noted, with bush fires and removal of large trees observed at three and six fragments, respectively. Hunters in the region have been reported to cut through trunks of roost trees at night and then return in the morning to fell trees with resting bats (A. Rabearivelo, pers. obs.). Sticks are then used to beat fallen bats or are thrown to knock down escaping bats. No evidence of any threat was found in the two *Eucalyptus* plantations during the survey, but a hunting net was located in the canopy of the Marovitsika roost during April 2005 (E. Razafimahatratra, pers. obs.). At the Mahatsinjo plantation the *Eucalyptus* trees will probably be harvested before 2010 and this site cannot be considered as a long-term option for roosting *P. rufus*.

Amparihimarotanana contained the largest colony of *P. rufus* in the humid forest fragments with a total of >2,000 bats counted on the morning of 13 July. Other roosts held 50–430 bats, depending on the method of assessment, date and location. The two roosts in

Table 1 Conservation assessment of eight *P. rufus* roosts (Fig. 2), with the fragment size and type of forest in which the roost is located, distance to intact humid forest and the nearest village, number of bats in each roost determined from morning counts (MRC) and evening dispersal counts (EDC) during July 2004, evidence of hunting at the roosts, and occurrence of threats to the roosts.

		Forest type		Distance to (km)		Abundance estimate		Evidence of hunting			Threats	
Roost	Fragment size (ha)	Humid forest	Eucalyptus plantation	Nearest intact humid forest	Nearest village	MRC	EDC	Shotgun cartridges	Net	Discarded hunting sticks	Felled trees	Fire
Ambakoana	28.7	+		12.0	2.4	0	0				+	+
Amparihimarotanana	6.5	+		7.9	7.0	1,033	2,188				+	
Analabe	3.4	+		13.0	5.1	541	230	+		+	+	+
Andriambondro	2.2	+		12.0	1.6	0	0				+	+
Fanafana	2.4	+		8.6	9.0	57	421				+	
Mahatsinjo	n/a		+	19.0	1.1	388	1,222					
Marovitsika	n/a		+	12.7	1.1	1,887	1,775		+			
Vahamainty	4.1	+		18.1	6.6	91	430	+		+	+	

Eucalyptus plantations contained >1,000 bats each and, based on the maximum counts for each roost, held 55% of all *P. rufus* counted during the survey. There were considerable differences between abundance estimates made during the evening and the morning with the former method usually producing higher counts (Table 2). These differences can be attributed to a variety of factors including the behaviour of the bats, viewing conditions and foliage cover, and they illustrate the importance of using both methods.

The DBH of canopy-forming trees differed significantly between areas used by *P. rufus* (ANOVA $F_{2,\ 294} = 6.73$, $P = 0.001$) and increased from the smallest trees in temporary roosts (mean 10.7 ± SD 4.89 cm), to permanent roosts (mean 12.7 ± SD 9.01 cm) and was highest in areas unused by bats (mean 14.2 ± SD 8.42 cm). Slope was not significantly different between areas used by bats (ANOVA $F_{2,14} = 0.24$) and was 2–32°. Most of the areas used by *P. rufus* were forested slopes and each faced a particular direction; forest areas used by *P. rufus* were between NNE and NW, and areas never used by *P. rufus* generally faced a northerly direction.

Faeces collected under *P. rufus* roosts in humid forest fragments contained seven plant species, whereas those roosting in plantations contained only two (Table 3). Pollen from *Dombeya* sp. (Malvaceae) was found in 3% of faeces from the humid forest fragments but was absent in the samples from the plantation roosts. *Eucalyptus robusta* (Myrtaceae) pollen was found in 54% of the faeces from the plantations and 45% of the faeces from humid forest fragments. Three ejecta pellets were collected from Amparihimarotanana and all contained remains of *Dracaena reflexa* (Convallariaceae) that was identified from partly-chewed leaves. Introduced plants (e.g. *Psidium guajava* and *Solanum mauritianum*) and species often associated with intact forest (e.g. *Ficus* spp. and *Polyscias ornifolia*) were both also found in the diet.

Table 2 Monthly counts to estimate the population size of *P. rufus* in seven fragments of degraded dense humid forest in the Mangoro region.

	2003							2004							
Site	Aug.		Sep.	Oct.		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
Ambakoana	1,629	1,937	0	1,322	1,178	2,880	2,660	2,947	370	1,254	0	0	0	0	0
Ambohimanatrika	0	0	350	0	0	80	163	266	209	186	0	0	0	0	0
Amparihimarotanana	979	515	938	926	625	135	204	443	457	489	574	605	922	1,061	1,410
Analabe	832	890	630	606	501	512	435	447	291	237	252	260	661	280	0
Andriambondro	0	0	1,243	1,180	1,350	0	1,261	97	668	746	0	0	0	0	0
Fanafana	1,756	1,019	820	805	460	1,756	1,355	1,271	1,670	1,583	765	855	820	421	600
Vahamainty	0	0	3	55	138	60	85	30	90	297	280	275	428	110	0

Table 3 Fruit diet of *P. rufus* in the Alaotra-Mangoro region, eastern Madagascar, calculated from faeces collected under roosts in degraded humid forest fragments and *Eucalyptus* plantations, expressed as a frequency of occurrence.

		Vegetation type	
Family	Species	Humid forest (60 faeces)	Plantation (28 faeces)
Myrtaceae	*Psidium guajava**	3	0
Moraceae	*Ficus brachyclada*	8	0
	Ficus pyrifolia	5	0
Araliaceae	*Polyscias ornifolia*	10	0
Aquifoliaceae	*Ilex mitis*	5	0
Solanaceae	*Solanum mauritianum**	2	0
Rubiaceae	*Psychotria* sp.	2	5
	Pauridiantha paucinervis	0	2

*Introduced taxa (Schatz, 2001)

Discussion

P. rufus in the Mangoro valley survives in a fragmented landscape that is without formal protection. Our study highlights the importance of small (<5 ha) forest fragments to *P. rufus* and demonstrates high variation in roost occupancy. Despite considerable pressure in this area from habitat degradation and hunting, our estimates of abundance indicate that the population is of considerable importance in that it represents *c*. 1.3% of the estimated national population (MacKinnon *et al*., 2003), and is particularly large for a non-coastal site. *P. rufus* used both native forest trees and introduced/cultivated plants for food and roosting and their continued presence in the valley indicates they can survive in human-modified landscapes if suitable roost sites and conditions are available.

All *P. rufus* roosts were located outside the relatively intact blocks of dense humid forest on the flanks of the Mangoro valley. Of the six roosts located in humid forest all were in small fragments surrounded by pine tree plantations, grasslands and rice fields. Although all the roosts were located outside protected areas, they were within 20 km of large expanses of dense humid forest, a distance well within the nightly foraging range of *Pteropus* spp. (Bannack & Grant, 2002; Long, 2002). Wells *et al*. (1995) searched for *P. rufus* in Parc National de Zahamena in eastern Madagascar, *c*. 100 km north of our study area, but found roosts only in degraded forest fragments outside the reserve. Other *P. rufus* roost sites in Madagascar are associated with small patches of natural forest (Bollen & Van Elsacker, 2002; Long, 2002). In many cases the roosts are found near ecotones (e.g. land-water, forest-grassland) and these may be important navigational aids for flying bats. The use of small, degraded forest fragments by roosting *P. rufus* may explain their rarity within protected areas because terrestrial reserves in Madagascar usually consist of large blocks of relatively intact forest (ANGAP, 2003).

Granek (2002) found *P. livingstonii* roosting in forest on south-east facing slopes near to rivers and attributed this to the thermal characteristics of roost sites, and there is some evidence from our study that *P. rufus* avoids northerly facing forests. *Eucalyptus* has been planted extensively in Madagascar and helps to control erosion and provide fuelwood and charcoal. Although *Eucalyptus* pollen is frequently amongst the food types consumed by Malagasy fruit bats (Long, 2002; Ratrimomanarivo, 2003) there are few records of *P. rufus* roosting in plantations. The Marovitsika plantation has unusually large *Eucalyptus* trees, grown for telegraph poles. The extent to which *Eucalyptus* trees represent viable long-term roost sites of *P. rufus* requires further attention given the abundance of these trees in many parts of Madagascar.

Long (2002) reported that the maximum abundance of roosting *P. rufus* in a gallery forest in south-east Madagascar was during September–October. Other *Pteropus* species also exhibit seasonal changes in colony size and roost location (Mickleburgh *et al*., 1992; Bannack & Grant, 2002; Gumal, 2004). Increases in abundance that are not caused by local births are probably the result of movements between roosts. Although *P. rufus* has been the subject of two detailed research projects in south-eastern Madagascar at sites within 90 km of each other (Bollen & Van Elsacker, 2002; Long, 2002) there is no information on inter-roost movement. Our results indicate that Ambohimanatrika, Andriambondro and Ambakoana may act as maternity or nursery roosts because, although the bats were absent from these sites from April to August, large numbers were present from October onwards. *P. rufus* gives birth during October (MacKinnon *et al*., 2003) and females with young were observed during November in our study site (A. Rabearivelo, pers. obs.).

Our interpretation of the temporal variation in roost occupancy is that the fragments support a single breeding population that uses a number of different roost sites according to reproductive activity, disturbance events and perhaps food supply. In this sense, the fragments should be considered as a single conservation unit (or meta-roost) with equal importance given to permanently occupied roots and sites that are only used occasionally. This is consistent with the conclusions of a study on roosting dynamics of *P. tonganus* (Bannack & Grant, 2002). Observations by local people confirm that *P. rufus* leave favoured roosts and take up temporary residence in nearby fragments in response to disturbance in the form of fires, logging, hunting, stray cattle and farming activities adjacent to the roosts.

At a roost site within the same altitudinal range and habitat type as our study the diet of *P. rufus* consisted of 37% cultivated fruit, 24% *Ficus* spp., 25% leaf material, 7% pollen and 7% unknown (Wells *et al*., 1995). The results from our study also show that *P. rufus* feeds on introduced plants and confirms its dietary plasticity. In south-eastern Madagascar Long (2002) found *P. rufus* diet to consist of forest plants as well as cultivated and exotic fruits, and pollen and nectar of sisal *Agave sisalana*. Introduced and cultivated plants are also important dietary components for *Pteropus* species in the western Indian Ocean (Entwistle & Corp, 1997a; Trewhella *et al*., 2001; Nyhagen *et al*., 2005).

Entwistle & Corp (1997a) stressed the importance of assessing dietary differences between roost sites. Our investigation found lower dietary diversity in *Eucalyptus* plantations compared to forest fragments. The ability of *P. rufus* to feed on cultivated and introduced plants is advantageous in landscapes that are becoming increasingly fragmented and affected by people. Although *P. rufus* appears able to survive in a mosaic landscape through dietary plasticity and inter-roost movements, the degradation of forest roost sites, hunting and persecution continue to represent major threats.

Our results support previous assessments that highlight the importance of roost site conservation for *Pteropus* in the western Indian Ocean (CBSG, 2002; Granek, 2002; MacKinnon *et al*., 2003). As bats are legally hunted in Madagascar, conservationists face a difficult challenge. Without new conservation efforts to protect *P. rufus* roosts the important ecological services provided by these bats will be lost. In the Mangoro valley, where the drive to conserve *Pteropus* comes mainly from Malagasy organizations, we believe that there are six ways to safeguard this species: (1) Further develop the collaboration between pine forest managers and conservationists to include the maintenance and creation of fire breaks, better education, awareness, and monitoring of the frequency and location of fires, which threaten the commercial potential of the pine tree plantations as well as the integrity of the roosts; pine extraction is a potential threat to the bats, both directly (e.g. noise of chainsaws, disturbance) and indirectly (e.g. changing the thermal characteristic of the site), and should be undertaken in close consultation with conservationists to minimize negative impacts (e.g. by avoidance of the breeding season). (2) Improve the collaboration between government law enforcers and conservation groups to implement existing legislation more effectively (e.g. the hunting season and restrictions on hunting methods). (3) Create community contracts (*dinas*) to allow local conservation and management of forest products, and include a cessation of hunting *P. rufus* at threatened roosts. (4) Continue roost patrols by local people to monitor the abundance, occupancy and hunting events at the roosts. (5) Explore the ecotourism potential of *P. rufus*; the roosts are only a few hours drive from the Reserve Spéciale d'Analamazaotra, one of Madagascar's most popular nature reserves (Dolch, 2003). (6) Assess the faunal and floral biodiversity in forest fragments to determine the additional species that would benefit from conservation of flying fox roosts.

In addition, we propose four recommendations for conservation of *P. rufus* roosts nationally: (1) Survey population size and conservation status of all *P. rufus* roosts occurring within Madagascar's existing protected area network. (2) Survey *P. rufus* roosts within 20 km of any proposed new protected area so that the sites receive either direct (included within new reserve boundaries) or indirect (e.g. occasional patrols by conservation agents and inclusion within environmental education initiatives) protection. (3) Reassess the status of the roosts that were visited during a national fruit bat survey in 2000 (MacKinnon *et al*., 2003). (4) Further develop community-based conservation projects to protect *P. rufus* in roosts that are unlikely to receive attention from international conservation organizations or major donors. This option could, where appropriate, assess the potential for sustainable exploitation through locally agreed harvests and use participatory monitoring techniques to assess flying fox abundance, hunting patterns and threats. Finally, it would be beneficial to raise the capacity of environmental professionals in Madagascar regarding their knowledge and understanding of bat conservation. This could be achieved through producing technical briefing documents and training sessions.

Since this research was carried out ACCE and Madagasikara Voakajy have continued to monitor the roosts. Fire remains a serious threat particularly as large areas of pine have recently been harvested and there is considerable build up of dead wood near the Ambakoana roost. The ongoing demand for new agricultural land also threatens the roosts as they are located in valleys that are suitable for growing rice. Damage to the forest occurred at the Ambakoana roost when a new rice field was created in 2005. A *dina* was signed in December 2005 in seven communes to work towards engaging villages in conserving the forest fragments, and surveys have begun to investigate the diversity of other small vertebrates in the fragments.

Acknowledgements

We would like to thank the following for financial support: Lubee Bat Conservancy (Publication No. 136), Bat Conservation International (Global Grassroots Fund), Fauna & Flora International (Flagship Species Fund), Cleveland Metroparks Zoo, the British Embassy, Antananarivo, and the Darwin Initiative (#162/10/024). We received excellent support from Professor Olga Ramilijaona at the University of Antananarivo and Hiarinirina Randrianizahana of the Direction Général des Eaux et Forets. Permission for this project was kindly granted by the Ministry of the Environment (#012/#171 MINENV.EF/SG/DGEF/DPB/SCBLF) and was conducted under a protocol of collaboration between ANGAP, the University of Aberdeen, and the Department of Animal Biology, University of Antananarivo. We thank Dr Stephanie Carrière, Monica Picot and Hanta Razafindraibe for access to plant reference collections. Fanja Ratrimomanarivo helped in the early part of the fieldwork. We are especially grateful to the members of ACCE, known as Ekipa Lubee, for their dedication to conserving the flying foxes of the region. Important support for the project was provided by the Chef de Region Alaotra-Mangoro (David Robinson Alexandre) and the former British Ambassador to Madagascar (Brian Donaldson).

References

ANGAP (Association Nationale pour la Gestion des Aires Protégées) (2003) *Madagascar Protected Area System Management Plan*. ANGAP, Ministry of the Environment, Water and Forests, Antananarivo, Madagascar.

Bannack, S.A. & Grant, G.S. (2002) Spatial and temporal movement patterns of the flying fox *Pteropus tonganus* in American Samoa. *Journal of Wildlife Management*, **66**, 1154–1163.

Bollen, A. & Van Elsacker, L. (2002) Feeding ecology of *Pteropus rufus* (Pteropodidae) in the littoral forest of Sainte Luce, SE Madagascar. *Acta Chiropterologica*, **4**, 33–47.

Bollen, A., van Elsacker, L. & Ganzhorn, J.U. (2004) Tree dispersal strategies in the littoral forests of Sainte Luce (SE Madagascar). *Oecologia*, **139**, 604–616.

CBSG (Conservation Breeding Specialist Group) (2002) *Evaluation et Plans de Gestion pour la Conservation (CAMP) de la Faune de Madagascar. Lémuriens, Autres Mammifères, Reptiles et Amphibiens, Poissons d'eau douce et Evaluation de la Viabilité des Populations et des Habitats de* Hypogeomys antimena *(Vositse)*. Species Survival Commission/IUCN, Apple Valley, USA.

Dolch, R. (2003) Andasibe (Perinét): are current efforts sufficient to protect Madagascar's biodiversity hot spot? In *The Natural History of Madagascar* (eds S.M. Goodman & J.P. Benstead), pp. 1480–1485. University of Chicago Press, Chicago, USA.

Entwistle, A.C. & Corp, N. (1997a) The diet of *Pteropus voeltzkowi*, an endangered bat from Pemba Island, Tanzania. *African Journal of Ecology*, **35**, 351–360.

Entwistle, A.C. & Corp, N. (1997b) The status and distribution of the Pemba flying fox *Pteropus voeltzkowi*. *Oryx*, **31**, 135–142.

Granek, E. (2002) Conservation of *Pteropus livingstonii* based on roost site habitat characteristics on Anjouan and Moheli, Comoros Islands. *Biological Conservation*, **108**, 93–100.

Gumal, M.T. (2004) Diurnal home range and roosting trees of a maternity colony of *Pteropus vampyrus natunae* (Chiroptera: Pteropodidae) in Sedilu, Sarawak. *Journal of Tropical Ecology*, **20**, 247–258.

IUCN (2006) *2006 IUCN Red List of Threatened Species*. IUCN, Gland, Switzerland [http://www.redlist.org, accessed 17 November 2006].

Long, E. (2002) *The feeding ecology of* Pteropus rufus *in a remnant gallery forest surrounded by sisal plantations in south-east Madagascar*. PhD thesis, University of Aberdeen, Aberdeen, UK.

MacKinnon, J.L., Hawkins, C.E. & Racey, P.A. (2003) Pteropodidae, fruit bats, *Fanihy, Angavo*. In *The Natural History of Madagascar* (eds S.M. Goodman & J.P. Benstead), pp. 1299–1302. University of Chicago Press, Chicago, USA.

Mickleburgh, S.P., Hutson, A.M. & Racey, P.A. (1992) *Old World Fruit Bats. An Action Plan for their Conservation*. Species Survival Commission/IUCN Chiroptera Specialist Group, Gland, Switzerland.

Nyhagen, D.F., Turnbull, S.D., Oleson, J.M. & Jones, C.G. (2005) An investigation into the role of the Mauritian flying fox *Pteropus niger*, in forest regeneration. *Biological Conservation*, **122**, 491–497.

Powell, V.J. & Wehnelt, S.C. (2003) A new estimate of the population size of the Critically Endangered Rodrigues fruit bat *Pteropus rodricensis*. *Oryx*, **37**, 353–357.

Raheriaisena, M. (2005) Regime alimentaire de *Pteropus rufus* (Chiroptera: Pteropodidae) dans le Region sub-aride du sud de Madagascar. *La Terre et la vie: Revue d'Ecologie*, **60**, 255–264.

Ratrimomanarivo, F.H. (2003) *Etude de régime alimentaire de* Eidolon dupreanum *dans les Hautes-terres centrales et son rôle dans la regeneration des plantes dans l'ecosysteme modifie par l'homme*. Mémoire D.E.A, Université d'Antananarivo, Antananarivo, Madagascar.

Reason, P.F. & Trewhella, W.J. (1994) The status of *Pteropus livingstonii* in the Comores. *Oryx*, **28**, 107–114.

Schatz, G.E. (2001) *Generic Tree Flora of Madagascar*. The Cromwell Press, Trowbridge, UK.

Trewhella, W.J., Rodriguez-Clark, K.M., Davies, J.G., Reason, P.F. & Wray, S. (2001) Sympatric fruit bat species (Chiroptera: Pteropodidae) in the Comoros Islands (Western Indian Ocean): diurnality, feeding interactions and their conservation implications. *Acta Chiropterologica*, **3**, 135–147.

Trewhella, W.J., Rodriguez-Clark, K.M., Corp, N., Entwistle, A., Garret, S.R.T., Granek, E., Lengel, K.L., Raboude, M.J., Reason, P.F. & Sewall, B.J. (2005) Environmental education as a component of multidisciplinary conservation programs: lessons from the conservation initiatives for critically endangered fruit bats in the Western Indian Ocean. *Conservation Biology*, **19**, 75–85.

Wells, W., Long, E., Palmer, G., Taylor, A., Tedd, J. & Grant, I. (1995) *University of Aberdeen Project Madagascar*. Unpublished Report, University of Aberdeen, Aberdeen, UK.

Biographical sketches

Richard K.B. Jenkins is the Director of Madagasikara Voakajy, a Malagasy conservation organization dedicated to conserving endemic vertebrates and their habitats.

Daudet Andriafidison has worked on Malagasy fruit bat conservation since 1999 and currently manages research, education and training projects.

H. Julie Razafimanahaka, a WWF Prince Bernhard Scholar, specializes in geographical information systems, environmental education and landscape ecology.

Andriamanana Rabearivelo is the president of the Malagasy NGO Arongampanihy, Culture, Communication et Environnement, and manages community conservation and education projects to protect flying foxes.

Rabe H. Andrianandrasana is a botanist, primarily interested in the pollination ecology of the endemic plants of Madagascar.

Noromampiandra Razafindrakoto has carried out investigations of the diet of fruit bats in eastern Madagascar.

Zo Ratsimandresy works for Arongampanihy, Culture, Communication et Environnement and coordinates the flying fox monitoring teams.

Emilienne Razafimahatratra is a specialist in tropical carnivore ecology.

Paul A. Racey has been involved in mammal research and conservation biology in Madagascar for over 20 years.