7-027: DARWIN INITIATIVE FINAL REPORT

1. Basic Project Details

Project title:
The role of fruit bats in maintaining biodiversity in Madagascar

Contractor:
University of Aberdeen

Host country collaborating institute(s): University of Antananarivo, University of Tulear, ANGAP (the Malagasy National Parks authority), and the Ministry of Waters and Forests

Grant round: 5

Grant value: £98 396

2. Project Expenditure

Total grant expenditure:

Breakdown of expenditure (using expenditure categories in the original application form):

Expenditure details				
	Jan – March 1999	April 1999 – March 2000	April 2000 – Dec 2000	Total
Total	**31,227.00**	**39,541.09**	**27,627.91**	**98,396.00**

Explain any variation in expenditure +/- 10%:

3. Project Background/Rationale

Why was the project needed? Please explain the project development process:

- Mickleburgh, S., Hutson, S.M. & Racey, P.A. (1993). Old World Fruit Bats: an action plan for their conservation. 223 pp IUCN, Gland, revealed:
  - Fruit bats are more important than birds or primates in reseeding cleared forest in Africa
  - Many tropical forest trees have co-evolved with fruit bats and depend on them for pollination
  - Malagasy fruit bats have been neglected in research and conservation. All three species are endemic and there are no recent introductions. All are thought to be declining in numbers due to loss of habitat.
- Pilot studies by P.A. Racey and E. Long in Madagascar revealed that the diet of fruit bats included both endemic plants and introduced cultivars.

How was it related to conservation priorities in the host country?

Establishing the status of endemic species and the production of management plans for species groups is a priority of the Environmental Action Plan for Madagascar.

How was the project intended to assist the host country to meet its obligations under the Biodiversity Convention?

The project addresses Articles 6, 7, 8, 12 and 13 of the Biodiversity Convention.

Was there a clear 'end-user' for the project in the host country? Who?

There were several direct 'end-users', with whom we held formal Protocols of Collaboration:

The University of Antananarivo
The University of Tulear
The Ministry of Waters and Forests
ANGAP (the National Parks authority)

4. Project Objectives

What were the objectives of the project (as stated in the original application form)?

- To establish the role of the endemic fruit bat *Pteropus rufus* in pollination and seed dispersal of endemic Malagasy forest trees by studies of feeding ecology and foraging range.
- To initiate and drive by active participation a countrywide survey of the status of the three endemic Malagasy Megachiroptera, and to incorporate the results, together with the existing patchy and anecdotal information, into a national bat database.
- To encourage conservation of fruit bats through a programme of conservation education and encouragement of local ownership of roosts.

- To produce a National Action Plan for the conservation of Malagasy fruit bats.
- To produce Species Action Plans for Malagasy fruit bats.
- To train staff and students of the Universities of Antananarivo and Tulear, The National Botanical Garden and Zoological Park and the Libanona Ecology Centre in Fort Dauphin in the methods of field research, survey, database management and conservation through workshops and by direct personal involvement in order to build their capacity to continue the initiative after Darwin Funding has ceased.

Were the objectives of the project revised? No.
If so, how?

Have the objectives (or revised objectives) been achieved? Yes.
If so, how?

1. Studies of feeding ecology and foraging range

The studies listed below, some of which are still at the analysis stage, have so far generated a list of over 100 plant species which have been identified through their pollen or seeds as food species for Malagasy fruit bats. A plant thus identified is likely to be pollinated, or to have its seeds dispersed, by the fruit bats.
Feeding ecology studies were carried out not only on *Pteropus rufus*, but also on *Eidolon dupreanum* and, to a lesser extent, *Rousettus madagascariensis*.

a) *Pteropus rufus*
Five Malagasy students carried out their DEA (equivalent to Masters) projects, solely or partly on the feeding ecology of *Pteropus rufus*: Andriafidison Daudet, Andrianaivoarivelo Radosoa, Fidiarisoavoninarivo Salomon, Raheriarisena Martin and Razafindrakoto Noromampiandra. Emma Long's fieldwork for her PhD (based at the University of Aberdeen and funded by the Lubee Foundation) at Berenty Private Reserve on the Ecology of *Pteropus rufus* overlapped the Darwin project by five months and James MacKinnon and Clare Hawkins joined her in May 1999, to carry out a brief study of the foraging range of *Pteropus rufus* before she returned to Aberdeen.

b) *Eidolon dupreanum*
Four Malagasy students carried out their DEA projects, solely or partly, on the feeding ecology of *Eidolon dupreanum*: Andriafidison Daudet, Andrianaivoarivelo Radosoa, Nirina Clarice and Rakamiarison Stephania.

c) *Rousettus madagascariensis*
Two Malagasy students carried out their DEA proejcts partly on the feeding ecology of *Rousettus madagascariensis*: Andriafidison Daudet and Razafindrakoto Noromampiandra.

2. Countrywide bat status survey and compilation of national bat database

Ten different regions were surveyed for bat roosts and these included every major vegetation type in Madagascar. In total approximately half of the area in the country with suitable habitat was surveyed for roost sites. Population sizes at each roost were estimated. Two Malagasy students carried out their DEA projects on hunting levels of *Pteropus rufus* and *Eidolon dupreanum*: Ranivoarimanana Julie and Razakarivony Vola. These studies were important for our assessments of the conservation status of these species. The results of the survey have been entered into a national bat database which will be available for all interested parties. In particular, the database will contribute to a national species database, or 'Platforme d'Analyse', which is being managed in Madagascar for all conservation organisations and is currently being established and curated by the Wildlife Conservation Society.

3. Promotion of fruit bat conservation

a) Village visits

During all surveys, the pollination and seed dispersal role of fruit bats was discussed with villagers. Leaflets explaining this role were distributed, along with stickers in Malagasy with the message ‘Protect bats, protect forest’ and posters encouraging the preservation of fruit bats. In particular, such materials were presented to schools, local government offices (Communes/Mayors' offices), police stations and village meeting places.

b) Regional conservation office information and visits

Similar materials were sent to all ANGAP offices in protected areas, to all Ministry of Waters and Forests offices (responsible for biodiversity conservation outside protected areas) and the offices of environmental NGOs. Where possible, these materials were given by project staff in person, with a detailed explanation.

c) Radio interviews

Seventeen radio interviews were broadcast, communicating the role of fruit bats in pollinating and dispersing the seeds of forest plants. Four were conducted in French, but the majority were in Malagasy, depending on the requirements of the radio station. Thirty cassettes of a final interview were sent out to regional radio stations throughout the country. Although we cannot be sure how many of these were used, because they are so eager to have new material to broadcast, it is likely that most stations used the cassettes.

d) Television features

Two short features on the project appeared on national television. The first was to announce the start of the project, on the national news. The second was a 5 minute broadcast as part of the Environment Day celebrations in June 2000

e) Bat Protection Association

A group of villagers established a small organisation for the promotion of the preservation of their fruit bats. We visited them several times, gave seminars on bat biology, trained them in fruit bat surveys and helped them to initiate applications for funding to local conservation organisations and the US embassy

f) Research into pest status

In some cases, fruit bats are viewed as pests, particularly to mangoes and lychees. This perception impedes fruit bat conservation. We therefore set up studies to investigate their impact on fruit crops, through questionnaires and observation of fruiting trees.

g) Workshops

Two workshops were held, in Tulear and Antananarivo, to communicate the results of two years of research by the 14 project members. Approximately 230 people attended these workshops, including relevant senior staff from the Ministry of Waters and Forests, ANGAP (the protected areas management agency), l'Office National pour L'Environement (ONE) and conservation NGOs (including WWF, Wildlife Conservation Society, Conservation International, Durrell Wildlife Conservation Trust, the Peregrine Fund, Missouri Botanical Gardens).

h) Written articles

Seven newsletters were sent out to 83 individuals and offices, relating to approximately 50 environmental organisations and governmental bodies. These explained the importance of fruit bats and the aims and progress of our project. An eighth will be sent out at the time of the distribution of the National Action Plan. Articles about Malagasy bats were published in Vintsy, a nationally distributed environmental magazine produced by WWF, the Tribune national newspaper and La Plume, a specialist newspaper distributed to all teachers in the country. This last article included several lesson plans for teachers.

4. Production of a National Action Plan

A National Action Plan for the three Malagasy fruit bat species was drafted and presented at a workshop in the country's capital, Antananarivo. This consisted of the following chapters, based on our findings:

(i) Introduction
(ii) Biology of Malagasy fruit bats
(iii) The role of Malagasy fruit bats in pollination and seed dispersal
(iv) Fruit bats and the Malagasy economy
(v) The conservation status of Malagasy fruit bats
(vi) Conservation recommendations

At the workshop, representatives of ANGAP (the National Parks authority), the Ministry of Waters and Forests, the University of Antananarivo and the environmental NGOs listed in 3f above discussed the plan and in particular the conservation recommendations. Comments from the meeting are being incorporated into a final version of the plan, which will distributed later in 2001. English versions of Chapters (iii) and (v) are attached to this report.

5. Production of Species Action Plans

Species Action Plans were incorporated into the National Action Plan. The conservation status of each species was discussed in the light of the roost surveys and the hunting studies. Recommendations were then made for the conservation of each species.

6. Staff and student training

a) Darwin trainees

Twelve Malagasy biologists, listed below, have received a personal and comprehensive training in the methods of bat field research and surveys. They have had the opportunity to observe for themselves the conservation problems of the fruit bats of Madagascar. These students (plus some others who worked part time with the project) have formed the Malagasy Bat conservation Association, a non-profit association aimed at promoting bat conservation and research in Madagascar.

Eight zoology students from the University of Antananarivo were selected as Darwin trainees, and carried out the fieldwork for their DEA (Diplômes d'études approfondies)with the project. They also received supervision by project personnel during the analysis and thesis write-up. The project also funded each student to attend short computer courses. Two students have passed their DEAs (Raheriarisena Martin) with "Mention Bien" and Ranivoarimanana Julie, also with "Mention bien". The others are at various stages of writing up. All have completed their fieldwork and are therefore within the schedule specified in the original proposal

Two botany students from the University of Tulear (Fidiarisoavoninarivo Salomon and Nirina Clarice) were selected as Darwin trainees, and took their DEA projects through to completion under the supervision of Darwin fellows. Both passed their projects with "Mention Très Bien". Their theses accompany this report.

Ralisoamalala Rosette, a former DEA student from the University of Antananarivo, was employed as a research assistant on the project, and trained in bat survey techniques, education techniques and data entry. Once he had completed his DEA, Raheriarisena Martin was also taken on as a research assistant and similarly trained. Rakotondratsimba Gilbert, a postgraduate was also taken on and trained as a part-time research assistant.

b) Other

Many other staff and students also received some training in bat field techniques.

Two students, Razafimanantsoa Ndjella and Rakotovao Seta worked for the project as temporary field assistants for several weeks and two ornithologists, Enahalala and Ramiarison Robert worked with us for three weeks each helping with survey and radio-tracking studies.

ANGAP and Ministry of Eaux et Forêt's field staff were often involved in survey work carried out within their region. In all the regions we visited, these staff provided invaluable local knowledge and were often able to accompany our survey teams to the field.

Two supervisors of the zoology students from the University of Antananarivo (Dr. Rakotomalala Marlene and Mme. Raminosoa Noro) were brought by the project to visit their students in the field and learn the field techniques involved.

A DEA student studying microchiropterans (small bats), Kofoky Amyot Felix, assisted with the preparation of the Antananarivo workshops.

Guides were very often employed to take us to bat roosts and act as field assistants. Some of these worked for several days or weeks on the project, and became fully trained in field techniques. Those working in national parks were alerted to the tourism potential of their local roosts

We were invited by the Peace Corps to talk to their volunteers about the fruit bats of Madagascar. Volunteers subsequently located roosts for us and talked to their fellow villagers about the role of fruit bats.

If relevant, what objectives have not been achieved, or only partially achieved, and why?

Not applicable

5. Project Outputs

(see the attached list of project outputs which we would like you to use in compiling this section of the report).

What output targets, if any, were specified for the project? (Please refer to the project schedule agreed with the Department where relevant):

PROJECT OUTPUTS		
Date	**Output Ref. no.**	**Details**
Jan – March 1999	12A	Arrive early February. Fruit bat colony database to be initiated by March.
	16A/B	1 newsletter distributed in March to ministries and government departments, Universities and all conservation NGOs.
	19A	1 broadcast on Malagasy radio.
April 1999 – March 2000	2	6 trainees complete field studies by March 2000
	16A/B	4 newsletters distributed as before, in June, September, December and March.
	19A	2 broadcasts on Malagasy radio.
April - Dec 2000	14A	3 workshops held to disseminate the results to staff, trainees, government departments and NGOs in May, June & September.
	2	6 trainees complete field studies by December 2000.
	12A	Fruit bat colony database completed by October 2000.
	9	Draft National Action Plan produced for Malagasy Megachiroptera and individual plans for each of the three endemic fruit bat species, and handed to the relevant government departments in October 2000.
	11A	4 papers drafted for submission to research journals by December 2000.
	16A/B	3 newsletters distributed as before, in June, September and December.
	19A	2 broadcasts on Malagasy radio.

Have these been achieved? Yes, some changes have been made to deadlines and in most cases the quantities of the outputs have been increased.

If relevant, what outputs were not achieved, or only partially achieved, and why?

- 16A/B: Newsletters. Production was not always on the months originally scheduled, due to fieldwork constraints.
- 14A: Workshops were held at the end of the project. We chose to hold two workshops at the universities which had been involved with the project. In the end there was no logical reason to have three and the budget was insufficient.

Were any additional outputs achieved?

Yes:

4C/D 23 post-graduate students trained:(a) 11 Malagasy post-graduate students at the University of Antananarivo attended a short lecture course on mammalian behaviour and ecology given by Clare Hawkins as part of their DEA Animal Biology class; (b) 12 Malagasy post-graduate students at the University of Tulear attended a week-long, full-time population dynamics course given by James MacKinnon as part of their DEA Environment and Biodiversity class.

7 1 training materials produced for use by the host country: (1) A two-page lesson plan was accepted for publication in 'La Plume', the national newspaper distributed to all primary school teachers in the country.

8 158 person weeks of UK staff spent on project work in Madagascar

12A 1 computer-based database (on location and size of roosts of each species of fruit bat) established and handed over to host country.

13A 2 plant species reference collections have been established, and have been or will soon be handed over to the host country: (1) A collection of plant samples from Malagasy dry deciduous forest (to the University of Tulear). Once all DEA students have finished, the following specimens will be handed to the botany department at the University of Antananarivo: seeds and pollen from the Highlands of Madagascar; seeds and pollen from the rainforest of the National Park of Ranomafana; seeds and pollen from the rainforest of the National Park of Masoala; seeds and pollen from the western dry deciduous forests.

14C Two conferences/seminars/workshops: (1) Presented a poster of project work for the exhibition celebrating the 40th anniversary of the Faculty of Science of the University of Antananarivo. (2) Ran a stand at an environmental fair at the national zoo, as part of the celebrations for World Environment Day. Our stand was the most visited out of approximately 20.

14D Two conferences outside Madagascar already attended: (1) 30th North American bat research symposium, Miami, Florida October 2000, where an overview of the project was presented; (2) British Ecological Society winter meeting January 2001, where a poster was displayed on the feeding ecology studies of three Malagasy students. Results will also be presented at the 12th International Bat Research Conference, Kuala Lumpur, in August 2001, in three podium presentations.

15A Two articles: (1) A full-page article was published in the weekend edition of the Tribune, one of Madagascar's national newpapers; (2) A full-page article in the national children's conservation magazine, Vintsy.

15C 1 national press release in UK: *The Times Higher,* March 12 1999.

15D 2 local press releases in UK: *The Press & Journal,* December 28 1998
The Press & Journal, February 17 1999

18A Two national TV features.

19A Four national radio interviews/features broadcast in Madagascar

19C Thirteen local radio interviews/features broadcast in Madagascar. A further 30 cassettes of an interview were sent to other local radio stations. (The original outputs specified only five broadcasts).

20 & 21 We signed a Memorandum of Understanding with WWF Madagascar, making them an official partner of the University of Aberdeen. They have agreed to take over maintenance of the project vehicle and the computer, which will be available for use by students in their 'Ecological Training Programme', and will also be made available for any future University of Aberdeen projects on bats in Madagascar. In return WWF will encourage Darwin trainees to continue work on fruit bats in their 'Ecological Training Programme', as part of the legacy of the present Darwin project.

20 Donated approximately £1250 worth of camping/field equipment, books and slide projector to the University of Antananarivo.

If output targets were not specified, please state the outputs achieved by the project. As far as possible, we would like you to work through the list of outputs attached to this paper and to report on those which are relevant to your project.

Not applicable.

Project Operation/Management

Research projects - please provide a <u>full</u> account of the scientific work undertaken, outlining the methodology adopted, the staff employed and the research findings. The extend to which research findings have been subject to peer review should be addressed.

A full account of the scientific work is provided in two draft papers attached as appendices.

Training projects - please provide a full account of the training provided. This should cover the content of the training, arrangements for selecting trainees, accreditation, etc.

1. Content of the training

DEA students:

- All students were required to write a project proposal which was used as the basis for training in experimental design.
- Each student was accompanied for at least the first 3 weeks of their fieldwork, and no less than 50% of their entire field work, in order to train them in appropriate field techniques and to ensure that their proposed project was viable. All students were taught roost survey techniques and faecal and plant collection techniques. Five of the students were shown how to capture, handle and measure bats during their projects.
- Once fieldwork was completed, each student attended a basic computer course, funded by the project. Students then came regularly to the project office to use the project computer and for one-on-one discussion of the analysis of their data.
- Drafts of completed theses were corrected by at least one of the project personnel.

Post-graduate research assistants:

- All assistants were trained in techniques for roost surveys and faecal and plant collection. Two were also trained in data entry and villager education, and one was furthermore trained in gathering questionnaire information.

2. Arrangements for selecting trainees

DEA students were identified by post-graduate coordinators at the University of Antananarivo and Tulear, and then interviewed by Darwin fellow James MacKinnon. A weakness of our commitment to take 12 trainees over the two year period, was the lack of sufficient high quality students and therefore we were obliged to take anybody who applied.

The two additional Darwin trainees were identified through recommendation and subsequent interview.

3. Accreditation

Project proposals were developed between the students and James MacKinnon, and then approved by their university supervisors. Ten of the trainees were enrolled on DEA programmes (8 at the University of Antananarivo and 2 at the University of Tulear), which are roughly equivalent to UK taught masters courses. Hence the quality of research projects was directly assessed by both project and University staff. At the end of the student's research they have to present a thesis and have a public oral examination. To date, 4 have completed this exam.

Did any issues or difficulties arise in running and managing this project?

- We already had a formal Protocol of Collaboration with the University of Antananarivo before the start of the project. During the project, we set up further Protocols of Collaboration with the University of Tulear, the Ministry of Waters and Forests and with ANGAP. These collaborations were the key to overcoming the bureaucracy that can otherwise stall projects, and they have enabled us to work more closely with the agencies involved in conservation work.
- It became clear that the Francophone teachers' packs and video presentations that we initially planned for distribution in rural areas were inappropriate as few people in these regions speak French. After discussions with other agencies involved in education work we decided to explain environmental issues by direct discussion with villagers, using simple materials such as models of animals and plants as well as posters and information leaflets in Malagasy.
- It was essential to work closely with Malagasy students and assistants during our survey work to gain the trust of villagers, who are usually afraid of foreigners. Explaining exactly what we were doing, and why, was very important, especially during night work.
- The production of newsletters every 3 months was too frequent for a project of this type as the research work was repetitive and did not therefore make for interesting news. Newsletters twice a year would have been more informative and probably better received.
- We are concerned that some of the trainees may find it difficult to finish writing up their projects without the support of the Darwin fellows in Madagascar. Malagasy university supervisors are notoriously slow in commenting on work submitted by students (several of the students had to wait more than 6 months for such comments). We encouraged those at the start of their analysis to complete much of their analyses in time for the workshops at the end of the project, and Darwin fellows will remain in contact with them by electronic mail.
- Darwin fellows resident in Madagascar expended a lot of time attempting to lever additional funding for this project which was initially cut back from the submitted budget by approximately £19,000 . Fortunately 6 out of the 15 grant proposals written by Darwin fellows and the project leader to make up this deficit were successful and we were able to do the planned work. However, the project would have been much more efficient if the full amount requested initially had been granted. The issue of having to secure additional funding while the project was underway is not only that it reduced the amount of research, conservation and educational work that we were able to do, but it seriously reduced our ability to plan work and in retrospect we should perhaps have reduced the number of trainees. We were rarely able to plan fieldwork in a satisfactory way, and planned work was frequently delayed while we waited for the results of grant applications. In addition the quality of student training could have been better if we had the funds available for them to attend computer and language classes – most students need both French and English lessons to make effective use of available literature. Most of the fieldwork and computer training that was done was only possible because project staff contributed money from their own pockets, the majority of which was finally recouped through the sale of a vehicle used for two previous University of Aberdeen

projects (not the Darwin vehicle!). Similarly it would have been impossible to do this project if the Darwin fellows had not provided their personal equipment- notably two laptop computers, binoculars, cameras, camping equipment and books, and had allowed the use of their house as an office and a library.

- The project took on too many trainees for such a short period. Particularly in the second year, this meant that the trainee students had too little supervision in the field as the Darwin fellows had to divide their time between all the students at the fieldwork stage, the write-up stage, the two trainees working on the national survey, writing grant proposals and report writing. Such a workload is not realistic in a third world country when the project has no administrative or logistical support. Few academics working at a British University would take responsibility for the research projects of 5 Masters students a year for two consecutive years!

7. Project impact

To what extent has the project assisted the host country to meet its obligations under the Biodiversity Convention, or to what extent is it likely to do so in the future? Please take account of the following in preparing this section of the report:

> **The way in which research findings have been <u>used</u> to address biodiversity objectives. what actions have been taken, or are expected to be taken, as a result of the project? How will these contribute towards the conservation of biodiversity in the host country concerned?**

<u>Article 6, General Measures for Conservation and Sustainable Use</u>

Each Contracting Party shall, in accordance with its particular conditions and capabilites:

(a) Develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes which shall reflect, inter alia, the measures set out in this Convention relevant to the Contracting Party concerned; and

(b) Integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies.

(a) We have drafted a National Action Plan for the Malagasy government. This presents the project's findings, including a list of plants for which fruit bats may be seed dispersers and pollinators, and an assessment of the conservation status of each bat species in light of their population sizes and current hunting levels. It further presents a series of recommendations for the conservation of fruit bats. We have discussed this Plan with a wide range of individuals involved in biodiversity conservation and sustainable resource use, in order to ensure that its content and recommendations are as informative, useful and realistic as possible. The information in the plan and its recommendations were presented at two workshops in Madagascar in November and December 2000.

The completed National Action Plan will be presented to all relevant government bodies and all other interested organisations involved in biodiversity conservation and sustainable use. These organisations have been identified through their responses to our newsletters and workshops. We anticipate the production of at least 50 copies in French

(b) Representatives from the Ministry of Waters and Forests have agreed, using our findings, to apply to the IUCN for changed protected status of *Pteropus* and *Eidolon*, and subsequently to apply for a change in the status of *Rousettus* and *Eidolon* in Malagasy law, from 'Game' species to 'Protected' species. At the time of preparing this report, the possibility of a new category under Malagasy law – that of managed species is under active consideration for *Pteropus*, as a result of our work and discussions between James MacKinnon and the Ministry of Water and Forests, ANGAP and the National Office for the Environment. This would allow local communities to take responsibility for the management of a roost, and to set a hunting quota in collaboration with the relevant authority (the Ministry of Water and Forests). It would then be up to local communities to decide whether to use it for themselves, or sell the rights to the quota to visiting hunters. Hunting within roosts would remain illegal. This new category was attractive because it could be applied to other species.

<u>Article 7. Identification and Monitoring</u>

Each Contracting Party shall, as far as possible and as appropriate, in particular for the purposes of Articles 8 to 10:

(a) Identify components of biological diversity important for its conservation and sustainable use having regard to the indicative list of categories set down in Annex 1;

We identified two of the three fruit bat species as species which are threatened (one of the indicative categories set down in Annex 1). This conclusion was based on analysis of the criteria of threatened species as defined by IUCN (1998).

(b) Monitor, through sampling and other techniques, the components of biological diversity identified pursuant to subparagraph (a) above, paying particular attention to those requiring urgent conservation measures and those which offer the greatest potential for sustainable use;

We gathered baseline data on roost sizes throughout Madagascar. In the recommendations set out in our National Action Plan, we identified specific roosts which could easily be monitored regularly by organisations with projects in the areas where these roosts were located. We further recommended that a larger selection of the sites for which we have already collected data should be visited in several years time to measure rates of roost desertion and changes in roost size. Monitoring will be particularly important in assessing the effects of any changes in the law regarding hunting.

(c) Identify processes and categories of activities which have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity, and monitor their effects through sampling and other techniques; and

Two Darwin trainees carried out studies on hunting of *Pteropus rufus* and *Eidolon dupreanum* respectively, and used population viability analyses to predict the effects of measured hunting levels.

(d) Maintain and organize, by any mechanism data, derived from identification and monitoring activities pursuant to subparagraphs (a), (b) and (c) above.

For each fruit bat species, we have recorded locations and population sizes of roosts in a database which is being given to the Malagasy government. The databases will be incorporated into a 'Platform of Analysis' of such information for all Malagasy species for which there is appropriate data. This Platform of Analysis is currently managed by the Wildlife Conservation Society until such time as a Malagasy institution is ready to take responsibility for it. The aim of the database is to repatriate existing biodiversity data and make it accessible for use by Malagasy researchers, NGOs and institutions.

Article 8. In-situ Conservation

Each Contracting Party shall, as far as possible and as appropriate:

(a) Establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity;

(b) Develop, where necessary, guidelines for the selection, establishment and management of protected areas or areas where special measures need to be taken to conserve biological diversity;

The inclusion of our data into the existing database will help develop this tool for identifying new areas appropriate for protection of biodiversity.

(d) Promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings;

(f) Rehabilitate and restore degraded ecosystems and promote the recovery of threatened species, inter alia, through the development and implementation of plans or other management strategies;

Assisting with the fulfilment of both 8d and 8f, we developed a National Action Plan, as described for Article 6a. The Plan made recommendations for the preservation of fruit bats. During our work, we carried out a wide-ranging education programme on the value of protecting fruit bats, described in our account of the fulfilment of our Objective 3.

(j) Subject to its national legislation, respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity and promote their wider application with the approval and involvement of the holders of such knowledge, innovations and practices and encourage the equitable sharing of the benefits arising from the utilization of such knowledge, innovations and practices.

(k) Develop or maintain necessary legislation and/or other regulatory provisions for the protection of threatened species and populations.

Representatives from the Ministry of Waters and Forests have agreed, using our findings, to apply for a change in the status of all three fruit bat species in the Malagasy law, from 'Game' species to 'Protected' or ‘Managed’ species. (as stated in Article 6b). We will continue to collaborate with them in order to achieve this.

Article 12. Research and Training

The Contracting Parties, taking into account the special needs of developing countries, shall:

(a) Establish and maintain programmes for scientific and technical education and training in measures for the identification, conservation and sustainable use of biological diversity and its components and provide support for such education and training for the specific needs of developing countries;

(b) Promote and encourage research which contributes to the conservation and sustainable use of biological diversity, particularly in developing countries, inter alia, in accordance with decisions of the Conference of the Parties taken in consequence of recommendations of the Subsidiary Body on Scientific, Technical and Technological Advice; and

(c) In keeping with the provisions of Articles 16, 18 and 20, promote and cooperate in the use of scientific advances in biological diversity research in developing methods for conservation and sustainable use of biological resources

Twelve Darwin trainees received a thorough training in research into fruit bat biology and conservation, and into the role of fruit bats in promoting forest biodiversity. Ten of these trainees have obtained, or expect to obtain, their DEA (equivalent to UK taught Masters) qualifications from the work they carried out during the project. Much of their research has already been incorporated in a National Action Plan. We also plan to publish trainees' research in peer-reviewed journals. Further details of the training are given in the section on 'Project Operation/ Management'.

Article 13. Public Education and Awareness

The Contracting Parties shall:
(a) Promote and encourage understanding of the importance of, and the measures required for, the conservation of biological diversity, as well as its propagation through media, and the inclusion of these topics in educational programmes.

The dissemination of information on the role of fruit bats in maintaining forest biodiversity was a very important feature of our project, and we realised it in a number of ways. These are listed and explained in the section 'Project Objectives': 3. Promotion of Fruit Bat Conservation.

The extent to which training provision has improved the capacity of the host country to conserve biodiversity in the future, and the extent to which the training has addressed real skill needs. Information should be provided on what each student/trainee is now doing (or what they expect

to be doing in the longer term), and the extent to which their skills are being used in a positive way to promote biodiversity conservation in the host country.

- There were no Malagasy experts on fruit bats before this project began.
- The availability of two UK post-docs as Darwin fellows meant that the Darwin trainees were taught, one-to-one, the full gamut of skills required to produce a piece of research. These included project planning and design, proposal writing, field methods, computer skills, data and statistical analysis, report and thesis writing.
- Current activities of each trainee:

Andriafidison Daudet has completed the fieldwork for his DEA project, has finished the analysis and produced a first draft of his thesis.

Andrianaivoarivelo Radosoa has completed the fieldwork for his DEA project, , has finished the analysis and produced a first draft of his thesis.

Fidiarisoavoninarivo Salomon has completed his DEA project, which was awarded a 'Mention Très Bien'. He is currently applying for jobs in bat research and been involved in some short-term ecological consultancies. His DEA is in botany and we anticipate that his combination of skills in both plant and animal research render him highly employable. His DEA study is being incorporated into a paper to be submitted for publication.

Nirina Clarice has completed his DEA project, which was awarded a 'Mention Très Bien'. He is currently applying for ecological research possibilities. His DEA is in botany and we anticipate that his combination of skills in both plant and animal research render him highly employable. His DEA study is being incorporated into a paper to be submitted for publication.

Raheriarisena Martin has completed his DEA with ‘mention bien’ and is currently working with Professor Rakotondravony Daniel of the University of Antananarivo, as a consultant specialising in small mammal and bat surveys.

Rakamiarison Stephania has completed the fieldwork, analysis and first draft of his thesis for his DEA project.

Ralisoamalala Rosette is currently searching for a new post. With her skills in bat research field techniques, which build on her skills with other taxa, together with her experience in education, questionnaire surveys and data entry, we are confident that she will swiftly find further employment.

Ranivoarimanana Julie passed her DEA with a ‘mention bien’. After trying, and failing, to find funds to do a PhD on the effects of insectivorous bats as pest control agents, she started a PhD on bilharzia in southern Madagascar. Data from her study on fruit bats are being incorporated into a paper for publication.

Ratrimomanarivo Fanja has submitted her DEA thesis and is waiting for the exam. Her study is being incorporated into a paper to be submitted for publication.

Razafindrakoto Noromampiandra has completed the fieldwork for her DEA project, and is approximately half way through her analysis

Razakarivony Vola has completed the fieldwork, analysis and first draft of her DEA thesis.

Rakotondratsimba Gilbert worked with MICET (Malagasy Institute of Conservation and Tropical Ecology) when not working with us. He continues in this post, as the only employee with expertise in fruit bat research. MICET primarily works in the Ranomafana National Park, where Rakamiarison Stephania carried out his fieldwork. We anticipate that Gilbert's presence will ensure that MICET gives appropriate attention to the preservation of Ranomafana's fruit bats, along with a general recognition of their importance to the maintenance of biodiversity.

- All students will be encouraged to publish their work, reprints of which will be delivered to the relevant decision-making bodies.

The wider impacts of the project in terms of the level of collaboration achieved between UK and host country institutions, and the prospects for greater joint working/information exchange in the future. To what extent has good collaboration been achieved?

The University of Aberdeen was already collaborating with the University of Antananarivo before the start of this project. This collaboration has been strengthened during this project which has led to the establishment of a number of new and highly fruitful links between the two countries.

- The University of Aberdeen now has links with the Ministry of Eaux et Forêts, which are formalised by a 'Protocol de Collaboration'. Members of staff from Eaux et Forêts attended our workshops and participated actively in the discussion of the legal conservation status of fruit bats and of action plan recommendations. They have agreed to apply for a change in Malagasy law for all three fruit bat species to be removed from the list of 'Game' species (on which there is a hunting season) and place in the list of 'Protected' species. A new category of 'Managed' species is being considered for *Pteropus*.
- The University of Aberdeen had a 'Protocol de recherche' with ANGAP, the protected areas management agency, which they are keen to renew for future projects. They were also active participants during fieldwork in protected areas and for the workshops and action plan discussions.
- The University of Tulear is keen to continue future collaborations with the University of Aberdeen
- An MOU was signed with WWF, which will lead to future encouragement of bat researchers through their ecological training program and will open up possibilities for future collaboration.
- The lessons learned from this project and the collaborations we have established will be especially useful to ensure the success of the forthcoming project on microchiropteran bats which is also funded by the Darwin Initiative.

8. Sustainability

Did the host country institute(s) contribute resources to this project (these may have been provided in-kind, for example staff, materials etc.)?

The Universities of Antananarivo and Tulear provided students to work with the project. Staff from the two universities also contributed their time to co-supervise the students.

The support of the University of Antananarivo was particularly important for the acquisition of research permits and visas for the British staff.

If so, what is the monetary value of the resources committed to the project by the host country institute(s)?

Impossible to evaluate – but not a lot, since Malagasy University staff are so underpaid that many have to seek additional income.

To what extent was Darwin funding a catalyst for attracting resources (including in-kind contributions) from other resources? Please provide details on the other sources from which resources were secured for this project.

See below

What is the monetary value of resources generated for the project from other sources (please provide an estimate for each funding source).

The Darwin funding provided for the major costs of the project in terms of salaries and capital items of equipment. We were therefore able to apply for other funds mainly for the costs of fieldwork. This task was divided between the project leader and the Darwin fellows and trainees to reflect the granting policy of the donors. However the fact that we had Darwin funding was also considered negatively by some funding bodies, as they did not want to be a minor contributor to a much larger project.

Source	Details of source	Monetary value of resource given
<u>Grants</u>		
Lubee foundation	The Lubee foundation, a foundation specialising in fruit bat conservation (Racey)	£48K overlapped present project by 5 months
National Geographic	National Geographic research grant (Racey)	£11,071
BCI	Bat Conservation International, an American organisation dedicated to bat conservation which supports students. (Razafindrakoto assisted by MacKinnon)	~£900
FFI	Flora and Fauna International, a UK-based conservation organisation with charitable status. (Hawkins)	£2,289
BES	The British Ecological Society, learned society of British ecologists, with charitable status. (MacKinnon in 1998)	£1,555
PTES	The People's Trust for Endangered Species, a UK-based trust for wildlife conservation. (MacKinnon)	£750
Tany Meva	A Malagasy organisation established for distributing small environmental grants, to date it has been funded by USAID. (MacKinnon)	~£1,700
<u>In-kind contributions:</u>		
WCS	Wildlife Conservation Society, a New-York based conservation NGO. (MacKinnon)	£250
Idea Wild	Idea Wild, an American based NGO, donated a laptop computer as a gift for the DEA class at the University of Tulear, with whom we worked. (MacKinnon)	£2,000

Applications to the Office National de l'Environnement (in Madagascar), the British Ecological Society Workshop grant, the British Ecological Society Small Grants Fund (in 2000) , Bat Conservation International's grassroots fund, the US Embassy (Madagascar), the UK Embassy (Madagascar), the University of Aberdeen's Principal's fund, the Lubee Foundation (in 2000) were unsuccessful.

To what extent is work begun by the project likely to be continued in the future (if this is relevant - some projects may come to a natural end at completion)? This is more likely to be relevant for research-based projects.

Research

Various organisations and individuals have expressed interest in continuing work on bat biology in Madagascar. The Missouri Botanical Gardens want to encourage more studies on plant-bat interactions. WWF has signed an MOU with the University of Aberdeen stating that they will encourage bat-related research in their training programmes. Several professors in the animal biology and botany departments of the University of Antananarivo have expressed interest in continuing research on bat-plant interactions. There are now 12 ex-Darwin trainees, most of whom would like to do PhDs on bat research, but who so far do not yet have funding. The establishment of a Malagasy Bat Conservation Association by the Darwin trainees will also help to ensure that some of this research is continued.

Conservation

The production of an action plan in collaboration with the Ministry of Eaux et Forêts, the involvement of the Darwin trainees and former Darwin fellows in the CAMP workshop in Madagascar in May 2001, and the continuing involvement of all the Darwin fellows and project leaders in Malagasy conservation will help to ensure that some aspects of the work we have started will continue.

Has the project acted as a catalyst for other projects/initiatives in the host country? Is it likely to do so in the future?

The project lead to the establishment of the Malagasy Bat Conservation Association, which aims to further the conservation of bats by encouraging research and education.

9. Outcomes in the Absence of Darwin Funding

Had Darwin funding been unavailable for the project, what would have been the most likely outcome:

> **The project would have proceeded with other funding? From whom?**
> **The project would have proceeded at a reduced scale? Please explain.**
> **The project would have been delayed? Please explain.**
> **The project would not have proceeded?**

The project would not have proceeded in its present form. We know of no other source of funding that enables this combination of research, conservation and education. Our interest in fruit bats could conceivably have continued in the form of three year PhD research projects, based in UK Universities, which would be limited by time and resources to only a certain type of research, with little opportunity for conservation and education work. However, the only source of such funding is the 2-year Leverhulme Trust Study Abroad Scholarships.

Had this project not been undertaken, how would the users/beneficiaries of the project have met their requirements? Would other organisations/initiatives have been able to meet their needs (at least to some extent)?

All foreign researchers are obliged to take on Malagasy students when carrying out research in Madagascar. However, there are more students than foreign researchers, and many students qualified to carry out a DEA are unable to do so. Thus, due to the project, 10 students were trained who would not otherwise have been trained.

Madagascar is host to many environmental organisations which are assisting them with their obligations to the Biodiversity Convention. However, this country has very few resources of its own and despite such aid, progress in biodiversity conservation is slow. Furthermore, apart from a PhD study by a University of Aberdeen student, which overlapped the Darwin project by 5 months, very little research has been carried out on fruit bats, which were listed by Malagasy law as 'Game' species. In fact *Pteropus rufus* was thought by all regional Ministry of Waters and Forests staff to be listed as 'Vermin' species, since these staff had not been informed of a change in the law in the mid 80s. Thus the Malagasy government is working on its obligations to the Biodiversity Convention, but without the project it would have been very unlikely to have incorporated fruit bats into these activities. It would have been unaware that this was appropriate, and it would not have had the information to do so. For example: (1) Action Plans would not have been prepared for these species; (2) distributions of the three fruit bat species would not have been incorporated into the government's database on the distributions of Madagascar's wildlife; (3) no one would have investigated the sustainability of current levels of hunting of fruit bats; (4) there would be no public awareness of the value of fruit bats to biodiversity.

10. Key Points

What would you identify as the key success factors of this project?

- Good links with several Malagasy institutions were already in place years before the start of the project, most notably the formal Protocol of Collaboration with the University of Antananarivo.
- The further collaborations set up early on in the project with key players led to their cooperation and useful advice.
- There are numerous other environmental organisations in Madagascar who gave us advice.

- We had two excellent assistants working with us (Ralisoamalala Rosette and Raheriarisena Martin) who not only helped with all fieldwork, but were particularly valuable for communication purposes and furthermore were able to take over part of the field supervision of students. This meant that the UK staff had more time to assist students who had already completed their field work with data analysis and thesis-writing, to co-ordinate the research, to deal with administrative matters and to raise additional funds.
- The grant allowed for a Darwin fellow (Dr. James MacKinnon) to be present full-time in Madagascar over the project lifespan. This ensured that activities were continued over the full two year period. The project also benefited enormously from the previous experience of research in Madagascar by Dr. Clare Hawkins, who was crucial to establishing the project during the first 6 months. Her contribution was also vital in the last 6 months which was an extremely busy period for the project as we tried to finish all the research projects, the national surveys, prepare the draft action plan and publications and organise workshops.
- The fluency of the Darwin fellows in French was also a major factor in the success of this project.

What were the main problems/difficulties encountered by the project?

- The reduced grant that we received from DETR meant that a lot of time had to be spent trying to raise further funds as opposed to carrying out activities.
- We took on too many students considering the budget available. We could have given better training with relatively small increases in funding per student (see section on Projection Operation/management).
- We were delayed by the schedules of other organisations, most notably the University of Antananarivo. The identification of students and the scheduling of lecture courses were often delayed. In particular, University staff were extremely slow to correct students' thesis drafts, which meant that progress towards completion of the students' degrees was severely delayed. Lecture courses and examinations were also often moved, at the last minute, to a time when we had been hoping to carry out fieldwork with the students.
- We had originally hoped to train 12 students but the Universities were only able to obtain a total of 10 for us. However, taking on two more experienced graduates as research assistants being trained in bat research turned out to be a success factor for the project (see above).
- Further delays were incurred due to the bureaucracy. For example, for each field trip, the following were needed: research permits; park entry permits; permits for students to leave the university; a mission statement to accompany the vehicle. Some permits can take several weeks to prepare. Communication in general, and education and questionnaire work in particular, was hindered by the fact that Madagascar is not an anglophone country, and the majority of people also speak little French. This problem was largely overcome through our working very closely with educated Malagasy who could speak French with us, and our hiring translators for essential documents. There were, however, further difficulties even for our Malagasy staff who often were of different tribes from those of the people with whom

we wished to converse. Their cultural and linguistic differences caused further problems in communication.

- Aside from the grant, the field staff felt a lack of support from the Darwin Initiative. Even a simple request for a computer image of the Darwin logo was repeatedly ignored throughout the project and hence we were unable to use the logo on any of the materials produced. There was no feedback on reports (until the last few months of the project where we were simply asked to produce more information during an extremely busy period of the project).

What are the key lessons to be drawn from the experience of this project? Please try to provide as much information on this point as you can so that others can learn from the experiences of your project.

- The formal Protocols of Collaboration that we set up with the Universities of Antananarivo and Tulear, the Ministry of Waters and Forests and ANGAP (the national agency for the management of protected areas) were the key to overcoming the bureaucracy that could otherwise stall projects. They also enabled us to work more closely with the agencies involved in conservation work. We also liaised closely with other NGOs, through newsletters and other regular communication. We received much valuable advice from these organisations. All these close links ensured the attention of key decision-makers at our workshops.
- The employment of local assistants/counterparts who could take over supervisory roles and who had enough experience to make decisions relating to the research when in the field was a very cost-effective measure for making this project a success.
- It was essential to be in close communication with villagers and authorities in study areas, even for surveys involving passing visits. Foreigners (including anyone from outside the region) were usually regarded with fear and suspicion. This required us always to work with Malagasy students and assistants, and preferably with Malagasy who could speak the local dialect.

Does the experience of this project imply a need to review arrangements for developing and managing projects funded as part of this Initiative?

Yes. The emphasis on using Darwin funding as a lever for other funding meant that a lot of time was lost trying to raise those other funds; time that would have been better spent by highly qualified, experienced and motivated Darwin fellows concentrating on the work of the project.

11. Project contacts

To assist future evaluation work, please provide contact details (name, current address, tel/fax number, e-mail address) for the following:

UK project leader (and other key UK staff involved in the project)

Professor Paul Racey
Regius Professor of Natural History
Department of Zoology
University of Aberdeen
Tillydrone Avenue
Aberdeen AB24 2TZ

Dr James MacKinnon
Technical adviser, Masoala National Park
Wildlife Conservation Society
BP 8500
Antananarivo 101
Madagascar

Dr Clare Hawkins
Department of Zoology
University of Aberdeen
Tillydrone Avenue
Aberdeen AB24 2TZ

Host country project leader/coordinator (and other key people involved in the project at the host country collaborating institute)

Dr Rakotondravony Daniel
Département de Biologie Animale
Faculté des Sciences
Université d'Antananarivo
BP906
Antananarivo 101
Madagascar

Dr. REJO-FIENENA Felicité
Departement de Biologie Vegetale
Université de Tulear
Tulear
Madagascar

'End users' for the output produced by the project in the host country (ie government departments, agencies, universities, local communities etc)

Mme. Andriantsilavo Fleurette
Directeur General
Direction des Eaux et Forêts
B.P. 243
Antananarivo 101
Madagascar

Mme. Harisoa Faramalala
Head of Research
ANGAP
B.P. 1424
Antananarivo 101
Madagascar

Project Trainees

Andriafidison Daudet
Andrianaivoarivelo Radosoa
Fidiarisoavoninarivo Salomon
Nirina Clarice
Raheriarisena Martin
Rakamiarison Stephania
Ralisoamalala Rosette
Ranivoarimanana Julie
Ratrimomanarivo Fanja
Razafindrakoto Noromampiandra

Razakarivony Vola
Rakotondratsimba Gilbert

Other project beneficiaries

Jean Paul Paddack
Head of Programme
WWF Madagascar
B.P. 738
Antananarivo 101

Other key players involved in the funding/operation/utilisation of the project

Mr. Matthew Hatchwell
Director
WCS Madagascar Programme
B.P. 8500
Antananarivo 101
Madagascar

Dr. Joanna Durbin
Director
Durrell Wildlife Conservation Trust
B.P. 8511
Antananarivo 101

M. Rasolofonirina Laurent
Directeur
Fondation Tany Meva
B.P. 4300
Antananarivo 101

People's Trust for Endangered Species, British Ecological Society,
Fauna and Flora International, Bat Conservation International, National Geographic

The rôle of Malagasy fruit bats in seed dispersal and pollination

James L. MACKINNON, ANDRIAFIDISON Daudet, ANDRIANAIVOARIVELO Radosoa, FIDIARISOAVONINARIVO Salomon, Emma LONG, NIRINA Clarice, RAHERIARISENA Martin, RAKAMIARISON Stephania, RATRIMOMANARIVO Fanja, RAZAFINDRAKOTO Noromampiandra and Clare E. HAWKINS.

Summary
Fruit bats in many parts of the world pollinate, and disperse the seeds of, many tropical forest plants. A group of studies was established in Madagascar, to ascertain if the island's three endemic fruit bat species have a similar rôle. The ongoing analysis has already identified pollen or fruit remains from 118 plant species of 70 genera from the faeces and ejecta of Malagasy fruit bats. For 80% of 20 species so far tested, seeds recovered from bat faeces were more likely to germinate within 4-6 weeks than those of the same species taken from intact fruit. The largest bat species, *Pteropus rufus*, has been observed to travel nightly distances of up to 30 km between feeding site and roost; thus this species may bring about genetic exchange between distant, isolated patches of forest. A substantial proportion of Madagascar's forest plants may thus be heavily dependent on fruit bats for pollination and seed dispersal.

Introduction

If a species goes extinct, we not only mourn its loss, we also fear the effect of its loss on other species that formerly interacted with it. How many further losses will this extinction lead to? Species vary in the strength and numbers of their interactions with other species, and such an effect would be particularly marked if fruit bats were lost. So numerous and strong are their connections with other species, that fruit bats have been proposed as 'keystone species' (Cox *et al.*, 1991, 1992). The position of fruit bats in an ecosystem is thus equated with that of a keystone in an archway: it is considered that the removal of the bats could bring about the collapse of the ecosystem.

Bats pollinate and disperse elsewhere in the world - the evidence
The 'keystone' role of fruit bats cannot realistically be demonstrated, at least not as part of a controlled experiment. Theoretically, it could be done by removing fruit bats from their ecosystem (ideally, several similar ecosystems) and recording the ecosystem's subsequent collapse. Such an experiment is clearly unacceptable. Nonetheless, studies of the interactions between fruit bats and other species can serve as a measure of the importance of fruit bats in maintaining ecosystems and promoting biodiversity.

Fruit bats are viewed to be so important to biodiversity because they pollinate and disperse the seeds of many plant species. A global review by Marshall (1985) already listed 145 plant genera of fruit from 30 families that are bat-dispersed. He also listed 31 genera from 14 families as likely to be bat-pollinated, many exclusively so.

Bats tend to be superior seed dispersers to other frugivores, since they rarely damage the seeds and they travel substantial distances. Small seeds are swallowed and voided far from the source. A single *Corollia perspicillata* (a phyllostomid bat from Costa Rica) can disperse 350-2500 seeds per night for plants like *Ficus ovota* or *Muntingia calabura* (Heithaus & Fleming 1978). Large fruits may be carried away in the bat's mouth, so that it may chew the pulp in the absence of interference by other bats. Even large seeds may be dropped some distance from the tree. *Pteropus vampyrus* (at 800 g, similar in size to Madagascar's 500-750 g *Pteropus rufus*) can carry fruits weighing more than 200 g. *Pteropus vampyrus* travels up to 50 km nightly (Lim, 1966), and *Pteropus mariannus* is thought to travel similar distances (Wiles *et al.*, 1989). A detailed study of the movements of *Pteropus poliocephalus*, in Australia, found these bats regularly visiting a feeding area located between 22 and 29.5 km from their roost, and travelling up to 8.3 km between successive feeding trees (McWilliam, 1985). In another study of the same species reliant on different food sources, commuting distances were up to 50 km and distances between feeding trees were up to 20 km (Eby, 1991). Thus the genus *Pteropus*, in particular, has the potential for very long distance dispersal. Fruit bats have fast digestion times, but these do not appear to be fast enough to reduce such long distance dispersal. In a study of the digestion time of *Pteropus vampyrus*, Richardson *et al.* (1987) found defaecation of marker pellets in bananas started 30 minutes after ingestion, but they were only completely eliminated after 5.5 hours. Shilton *et al.* (1999) consider that captive *Cynopterus* retained *Ficus* seeds in its digestive tract overnight.

Many bat-pollinated plants are specifically adapted to bats, exhibiting a suite of characteristics which could be expected to attract bats and maximise pollination by them (Heithaus, 1982). For example baobab (*Adansonia*) flowers have flowers at the ends of branches, with easy access to sturdy twigs for the bats to cling to; the flowers are large and robust enough to survive rough treatment from a large bat; the flowers open at night, when they supply maximum nectar at night and their light colour and strong perfume make them particularly noticeable to a bat. The stamens are presented in the form of a large brush, so that the muzzle is likely to be covered with pollen as the bat reaches for the flower's nectar. Other plants, such as the banana (*Musa*) have tube-shaped corollas which direct the bat's muzzle closer to the flower's reproductive parts.

It seemed likely that Madagascar's three species of fruit bats would have a similar rôle to bats elsewhere in maintaining and promoting the biodiversity of the island's forests. Fruit from species of the Palmae and the Anacardiaceae families are especially commonly visited by fruit bats elsewhere in the world, as are flowers from members of the Bignoniaceae and Bombaceae families. All four of these families are well represented in Madagascar. The baobab *Adansonia digitata* is pollinated by *Eidolon helvum* and *Rousettus aegyptiacus* (Baum, 1995); Madagascar has six endemic baobab species.

Representatives of the three fruit bat genera found in Madagascar (*Pteropus, Eidolon* and *Rousettus*) interact with large numbers of plant species elsewhere in the world. *Eidolon helvum*, an African fruit bat very similar to Madagascar's *Eidolon dupreanum*, feeds on the flowers of 10 genera and the fruit of 34 genera. Marshall (1983) recorded the genus *Pteropus* feeding on flowers of 26 genera and the fruit of 62. *Rousettus aegyptiacus* was found by Korine *et al.* (2000) to feed on the fruit of 8 genera.

Bats can improve the germination of plants elsewhere in the world
In the Philippines, Utzurrum & Heideman (1991) found an increased germination rate for fig seeds from bat faeces, relative to that from intact fruit. There is thus the possibility that bats are even more effective seed dispersers than previously thought. They suggested that bats prefer fruit containing viable seeds. Elsewhere, it has been suggested that the digestion process in some way prepares the seed for germination (Fleming & Heithaus, 1981).

Bats promote natural regeneration
The long distances covered nightly by fruit bats allow them to assist with genetic exchange of plants, in the movement of seeds from one area of forest to another. Since bats travel such large distances and do not need to fly through forest, they may link otherwise isolated parcels of forest, a feature of special importance in Madagascar where forests are often highly fragmented.

Charles-Dominique(1986) observed in French Guiana that birds commonly defecate seeds from branches at the edges of forest gaps, while fruit bats often defecate seeds while flying over gaps. Thus fruit bats, in addition to their rôle in the genetic exchange of plants, may also have an important rôle in the successional dynamics of forest gaps and deforested areas.

The consequence of losing fruit bats on forest composition
Many plants are exclusively bat-pollinated, and their future is thus dependent on that of the bats. *Oroxylum* flowers (Bignoniaceae) is morphologically adapted for pollination by the Malaysian fruit bat *Eonycteris spelaea* (Gould, 1978). Thus in this case the continued existence of an entire genus may largely depend on a single species of bat.

We accordingly set up a series of studies around Madagascar to identify the plants with which the Malagasy fruit bats interact.

Methods

1. Faecal analysis
Between 1997 and 2000, faeces ('splats') were collected from roosts around Madagascar: the Hauts Plateaux (RF) , the southern dry deciduous forests of the Mahafaly region (NC, FS) and of Berenty (EL, RM), the mid-altitude humid forest of Ranomafana National Park (RS) and the low-altitude humid forest of Masoala National Park (RN) and the western dry deciduous forests of Ankarana Special Reserve and of the Mahajanga region (AD). In Berenty, faeces were also collected under trees visited regularly by *Pteropus*. Various storage methods were used, but the most successful was to wrap each splat in a piece of paper and store a group of these in an envelope, to allow drying. During the same month as each collection, samples of fruit and flowers

were collected from the area surrounding the roost to assist with identification of seeds and pollen in the faeces. Pollen and seed reference collections at the University of Antananarivo and at the Tsimbazaza Zoological and Botanical Park were also consulted where necessary.

2. Observation
In the Menabe region of Morondava, 9 flowering *Adansonia grandidieri* individuals were observed for a minimum of 24 hours of darkness (such that each hour of the day, 1500-1600, 1600-1700..... 0200-300.... etc. was represented). In Antsirananana, 5 flowering *A. suarezensis* individuals were similarly observed. All animals observed visiting the flowers were recorded, along with the type of contact they made with the flowers: whether they touched the reproductive parts, and whether they caused damage likely to affect the reproductive potential of the flower. Similar observations were made at flowering kapok (*Ceiba pentandra*) trees.

3. Germination rate measurements
For plant species where sufficient numbers of seeds were extracted from bat faeces, germination rates were compared between seeds from bat faeces and seeds from intact fruit. Prior to planting, the seeds were dried in the sun over several days, washed in tapwater and then fungicide (10% Macozeb, ACM, Antananarivo), and then washed once more in water. Plastic 1.5 litre bottles were washed in fungicide, and then along the length of each, ten seeds of any one species and origin were placed in a row on damp filter paper. For seeds of each combination of species and origin, ten such bottles were thus set up and subsequently sealed.

4. Seed viability
For each plant species, seeds were cut open longitudinally. A few drops of 1% tetrazolium red were placed on the cut surface, and left for two hours. A red embryo after this period indicated that the seed had been viable prior to being cut. Twenty -five seeds from each source (faeces and intact fruit) for each species, where there were sufficient seeds available, were thus tested.

5. Radiotracking
Six *Pteropus rufus* were fitted with radiotransmitters (Holohill Systems Ltd., Ontario) in Berenty Private Reserve, Fort Dauphin, in May 1999. Their nightly movements were recorded in detail over a 2 week period, with the aid of two radioreceivers, a GPS and a vehicle.

Results

Plant species in the diet of Malagasy fruit bats
1. *Faecal analysis* So far, analysis has been completed on faeces from 11 *Eidolon* and *Pteropus* roosts from the Mahafaly dry forests, the Highlands and the Berenty gallery forest. Identification of seeds has been completed from a further collection of faeces from three *Eidolon* roosts from the humid forest of Ranomafana National Park. Analysis of pollen found in this collection continues, along with the analysis of seeds

and pollen from faeces collected from three *Pteropus* roosts from the humid forest of the Masoala National Park. Analysed faeces contained pollen, seeds, fruit pulp, occasional leaves, and very occasional flower parts. All seeds found in the faeces were intact.

2. *Observations* Fruit bats visited all three plant species observed (*Adansonia suarezensis, A. grandidieri* and *Ceiba pentandra*), touching the reproductive parts of the flower without damaging them. These observations were taken as strong evidence that fruit bat pollinate these plant species.

From faecal analysis, our observations and two findings prior to our work (Baum, 1995; J. Hutcheon, unpublished report), we already have evidence for interactions between Malagasy fruit bats and 118 species of plants, (at least 30 of which are endemic), in 70 genera, and 46 families (Table 1). The pollen from 22 species, and the remains of fruit from 44 species, have been found in *Pteropus* faeces and ejecta. The pollen from 40 species, and the remains of fruit from 41 species, have been found in *Eidolon* faeces and ejecta. Faeces from other parts of the island are still being analysed, including those of *Rousettus*. In summary, at the time of writing, we have identified in the faeces of the Malagasy fruit bats the pollen of a total of 52 species and the remains of fruit of 68 species.

This apparent broad diet is not simply due to the wide range of habitats in which we have visited roosts. From 150 faeces collected from just one *Eidolon* roost, at Lac Tritriva, near Antsirabe evidence of 22 species (from 21 genera) of plant were found (by RF). The faeces were collected over an 8 month period, so the total number of species visited throughout the year may be substantially higher. The roost is based in the Haut Plateaux, far from zones considered rich in biodiversity, surrounded primarily by savanna and *Eucalyptus* plantations.

Table 1: List of plant species found in Malagasy fruit bat faeces: P: *Pteropus rufus*, E: *Eidolon dupreanum*; R: *Rousettus madagascariensis*. Analysis of faeces from other regions of the island, and from *Rousettus*, is ongoing. Pollen: * Probable role of pollinator confirmed through observation. Fruit: +/- indicates a significant positive/negative effect on the germination rate of seeds from bat faeces, relative to that of seeds from intact fruit. References: 1: NC; 2: FS; 3: AD; 4: RF; 5: EL; 6: RM; 7: RS; 8: RALISOAMALALA Rosette (pers. comm.); 9: CEH (pers. obs.); 10: JLM (pers. obs.); 11: Hutcheon, unpublished report; 12: Long, 1995; 13: NC (pers. obs.), 14: Baum, 1995; 15: Birkinshaw & Colquhorn, 1998.

Plant family	Plant species (*=endemic to Madagascar)	Vernacular name	pollen:			fruit:			References
			P	*E*	*R*	*P*	*E*	*R*	
ABIATACEAE	*Pinus* sp.			y					4
AGAVACEAE	*Agava sisalana*	Laloasy, taretra	y	y					1,2, 5, 6
ANACARDIACEAE	*Mangifera indica*	Manga				y	y	y	1,2,5, 6, 8
ANACARDIACEAE	*Poupartia caffra*	Sakoambanditsy		y					1, 5, 6
ANACARDIACEAE	*Poupartia minor* *	Sakoa	y	y					1,2
ANACARDIACEAE	*Protochus grandidieri*	Sohihy	y						
ANACARDIACEAE	*Rhus perrieri* *	Tsilaitse					y		1
ANACARDIACEAE	sp. 1			y					4
APOCYNACEAE	*Pachypodium geayi**	Vontaka		y					1
ARALIACEAE	*Cussonia bojeri*						y		4
AVICENNIACEAE	*Avicennia marina*	Afiafy	y						2
BOMBACACEAE	*Adansonia grandidieri* *	Renala	y	y*					3
BOMBACACEAE	*Adansonia suarezensis**			y*					3, 14
BOMBACACEAE	*Adansonia za* *	Za	y						1
BOMBACACEAE	*Bombax* sp.			y					4
BOMBACACEAE	*Ceiba pentandra*	Kapoaky	y	y*	y				1,2, 6, 9
BURCENACEAE	*Commiphora* sp.	Daro				y			2
CACTACEAE	*Cerus* sp.	Raketam-bazaha				y			6
CACTACEAE	*Opuntia monocantha*	Raketa		y					1
CACTACEAE	*Opuntia vulgaris*	Raketa		y					1
CAPPARIDACEAE	*Crateva excelsa*					y			6
CAPPARIDACEAE	*Maerua filiformis*	Somangy				y	y+		1
CARICACEAE	*Carica papaya*	Papaier, papay				y	y		2, 7
CELASTRACEAE	*Gymnosporia polyacantha**	Tsingilofilo,filofilo				y	y+		1,2
CESALPINIACEAE	*Bauhinia hildebrandtii* *		y	y					1,2
CESALPINIACEAE	*Cassia siamea*		y						6
CESALPINIACEAE	*Colvillea racemosa*	Sarongaza	y	y					1,2
CESALPINIACEAE	*Delonix adansonoides* *	Malamasafoy	y	y					1,2
CESALPINIACEAE	*Tamarindus indica*	Kily				y	y		1,2, 5, 6
COMBRETACEAE	*Terminalia catappa*	Atafa, Badamier	y*						11
COMBRETACEAE	*Terminalia kobay*	Kobay					y		1
COMPOSITACEAE	*Helychrisum* sp.			y					4
COMPOSITACEAE	*Vernonia* sp.			y					4
CUNONIACEAE	*Cordia philippiensis*	Varo				y	y		1,2
CUNONIACEAE	*Cordia varo*	Varo				y	y		1,2,5, 6
CUPRESSACEAE	*Cupressus* sp.			y					4
CYPERACEAE	*Cyperus* sp.			y					4

Plant family	Plant species (*=endemic to Madagascar)	Vernacular name	pollen:			fruit:			Refer-ences
			P	*E*	*R*	*P*	*E*	*R*	
ERICACEAE	*Philippia* sp.			y					4
EUPHORBIACEAE	sp. 1			y					4
FLACOURTIACEAE	*Aphloia theaformis*	Voafotsy, thé malgache		y			y		4
FLACOURTIACEAE	*Flacourtia indica*	Lamoty				y	y		1,2
FLACOURTIACEAE	*Flacourtia* sp.	Lamoty				y			6
GENTIANACEAE	sp. 1					y			12
LILIACEAE	*Lilium sp.*			y					4
LILIACEAE	*Dianella usifolia*						y		7
MELIACEAE	*Azadirachta indica*	Nimo				y			1, 6, 13
MELIACEAE	*Melia azedarach*	Voandelaka		y		y	y		2,4, 6
MIMOSACEAE	*Acacia dealbata*	Dalbata, mimoza		y					4
MIMOSACEAE	*Acacia* sp.			y					4
MIMOSACEAE	*Albizzia lebbeck*	Bonara, bois noir	y	y					1,2
MIMOSACEAE	*Albizzia tuleariensis**	Maindoravy	y	y					1,2
MIMOSACEAE	*Parkia madagascariensis**		y*						15
MORACEAE	*Ficus antandroinarum**	Nahodahy				y			2
MORACEAE	*Ficus baroni**	Aviavy, aviavindrano				y	y+		12, 4
MORACEAE	*Ficus botroyides**	Lazo					y		2
MORACEAE	*Ficus brachyclada*	Fonofonjanahary				y			2
MORACEAE	*Ficus cocculifolia sakalavarum**	Adabo					y		1
MORACEAE	*Ficus grevei**	Amota, fihamy-be					y		1, 5, 6
MORACEAE	*Ficus humberti*	Maharesy				y			2
MORACEAE	*Ficus madagascariensis**	Aviavy				y			2
MORACEAE	*Ficus megapoda**	Fihamy					y		1, 5, 6
MORACEAE	*Ficus menabeiensis**	Fihamy				y			2
MORACEAE	*Ficus pachyclada*					y			5, 6
MORACEAE	*Ficus pyrifolia**	Nonoke				y	y+		1, 2, 4
MORACEAE	*Ficus sorocoides*						y		4
MORACEAE	*Ficus sp.*					y			5
MORACEAE	*Ficus sp.*					y			12
MORACEAE	*Ficus sp.*						y		7
MORACEAE	*Ficus sp.*						y		4
MORACEAE	*Ficus trichopoda **	Aviavy					y		1
MORACEAE	*Morus alba*						y		4
MORACEAE	sp. 1			y					4
MUSACEAE	*Musa musa*	Ankondro, bananier			y				10
MYRTACEAE	*Eucalyptus camaldulensis*		y						6
MYRTACEAE	*Eucalyptus citroidea*	Kininim-boasary	y						6
MYRTACEAE	*Eucalyptus* sp.		y						5
MYRTACEAE	*Eucalyptus* sp.		y						6
MYRTACEAE	*Eucalyptus* sp.			y					4
MYRTACEAE	*Eucalyptus* sp.	Kinina	y	y					1,2
MYRTACEAE	*Eucalyptus* sp.					y			12
MYRTACEAE	*Eugenia jambos*	Jambarao, rotra		y					4

Plant family	Plant species (*=endemic to) Madagascar	Vernacular name	pollen:			fruit:			Refer-ences
			P	*E*	*R*	*P*	*E*	*R*	
MYRTACEAE	*Eugenia sakalavarum* *	Rotran'ala		y					1
MYRTACEAE	*Psidium cattlejanum*					y+	y		7
MYRTACEAE	*Psidium guajava*	Goavy, gavo					y		1,2,4-7
OLEACEAE	*Noronhia seyrigii*	Tsilatse				y			2
PALMACEAE	sp. 1			y					4
PASSIFLORACEAE	*Adenia olaboiensis**	Holaboay				y	y		1,2
PASSIFLORACEAE	*Adenia* sp.					y			2
PASSIFLORACEAE	*Passiflora caerulea*						y		4
PIPERACEAE	sp. 1					y			12
POACEAE	sp. 1			y					4
PORTUCALACEAE	*Talinella grevei* *	Dango				y+	y+		1
ROSACEAE	*Prunus* sp.						y		4
ROSACEAE	*Rubis mollicanus*	Framboisier de Java					y		4
ROSACEAE	sp. 1			y					4
RUBIACEAE	*Adina microcephala*	Soaravy		y					1
RUTACEAE	sp. 1			y					4
SALVADORACEAE	*Salvadora angustifolia**	Sasavy, tanisy					y		1
SAPINDACEAE	*Litchi chinensis*					y			8
SAPOTACEAE	sp. 1					y			12
SARCOLANACEAE	sp. 1					y			12
SMILACACEAE	*Smilax craussiana*						y		7
SOLANACEAE	cf. *erianthum?*					y			12
SOLANACEAE	*Solanum hippophaeoides**	Hazonosy				y	y		1,2
SOLANACEAE	*Solanum mauritianum*						y		4
STERCULIACEAE	*Dombeya* sp.					y			12
STERCULIACEAE	*Dombeya* sp. 1			y					4
STERCULIACEAE	*Dombeya* sp.2		y						5
TILIACEAE	*Grewia cyclea**	Selimpasy				y	y+		1,2
TILIACEAE	*Grewia grevei* *	Seliboka				y	y+		1,2
TILIACEAE	*Grewia salygna*						y		4
TILIACEAE	*Grewia* sp.					y			5, 6
TILIACEAE	*Grewia* sp. 3	Sely				y			2
TILIACEAE	*Grewia* sp. 5					y			2
TILIACEAE	*Grewia tuleariensis* *						y+		1
ULMACEAE	*Celtis bifida* *	Tsiambanilaza					y		1
ULMACEAE	*Celtis philippensis*		y			y			5, 6
ULMACEAE	*Trema orientalis?*	Andrarezo-rezina	y	y					1, 2

Other nectarivores observed

Other visitors to the observed *A. grandidieri* trees which regularly came into contact with the flowers' reproductive parts were: for two small species of lemur (*Phaner furcifer* and *Mirza coquereli*). No such visitors came to *A. suarezensis* or to *Ceiba* other than bats. Sunbirds (*Nectarinia* spp.) were very commonly observed but almost never touched the flowers' reproductive parts. Parrots (*Coracopsis* spp.) were observed to destroy baobab and kapok flowers.

Effect of frugivory on germination rates

For the majority of species tested, a positive effect on germination was found for seeds from bat faeces or ejecta (Table 2). For 16 out of 20 (80%) plant species, the proportion of seeds that germinated 4-6 weeks after planting was significantly higher in the case of seeds extracted from bat faeces than in those collected from ripe fruit. For all four plant species where seeds were also obtained from lemur species (*Lemur catta* and *Propithecus verreauxi*), a positive effect of frugivory was found in seeds from both lemur faeces and in those either from bat faeces or bat ejecta. For one of these four species (*Ficus antandroinarum*), the positive effect was significantly higher in the case of seeds from bat faeces than for seeds from any other source. For none other of the four species was the positive effect significantly higher for seeds of any one species.

Table 2. Differences in proportion of germinated seeds from different origins, 4-6 weeks after planting. '+' indicates that the proportion of seeds that had germinated after 4-6 weeks was significantly higher for those from the source in **bold** than that of seeds from ripe fruit, '-' indicates that a significantly lower proportion of the bold source had germinated, 'n.s'. indicates that there was no significant difference, and a blank cell indicates that no test was carried out. Where seeds of more than two sources were tested, '*' indicates that a significantly higher proportion of seeds from the first source stated in the column germinated, than that of those seeds from any other source tested. Bat faeces were collected from *Pteropus rufus* (P) and *Eidolon dupreanum* (E). Lemur faeces were from *Lemur catta* (Lc) and *Propithecus verreauxi* (Pv). Bird faeces were all from *Treron australis.* *n*=100 for all but *Ficus megapoda* where *n*=60.

Plant Species	seed origins			
	Bat faeces/ ripe fruit	**Bat ejecta**/ ripe fruit	**Lemur faece**s/ ripe fruit	**Bird faeces**/ ripe fruit
Ficus baroni	+E			
Ficus pyrifolia	+E			
Ficus grevei	+P	+P		
Ficus megapoda	+P	n.s.		
Ficus pyrifolia	+P*	+P		
Ficus menabeiensis	+P	+P	+Lc	-
Ficus madagascariensis	+P*	n.s.		
Ficus antandroinarum	+P*	n.s.	+Lc	
Ficus humberti	n.s.	n.s.		
Ficus sp. 1		+E	+Pv, +Lc	-
Psidium guajava	+P			
Maerua filiformis	+E			
Talinella grevei	+E, +P			
Grewia grevei	+E			
Grewia cyclea	+E			
Grewia salygna	n.s. (E)			
Grewia tulearienis	+E			
Gymnosporia polyacantha	+E		+Lc	
Aphloia theaformis	n.s. (E)			
Solanum mauritanium	n.s. (E)			

Radio-tracking

During the two week period of radio-tracking, 6 *Pteropus rufus* were observed to travel a typical distance from the roost per night of 12 km. The furthest a bat was ever recorded from the roost during this time was 15 km; in other words, this animal must have covered at least 30 km in a single night's round trip. At the beginning and end of the night, when bats were travelling between roost and food plant, bats were observed to travel up to 10 km in 40 minutes.

Discussion

The forests of Madagascar need fruit bats

Our findings suggest that fruit bats have an important rôle in the biology of 114 Malagasy plant species, 24 of which are endemic. The remains of fruit from at least 68 plant species have been found in Malagasy fruit bat faeces and must therefore inevitably be dispersed by bats. Similarly, the presence of the pollen of 52 species in bat faeces indicates that the pollen from these species may be transferred on the muzzle of a bat from one flower to another. The rarity of other flower parts in the faeces indicates that bats seldom damage flowers; this was confirmed for the species observed directly. Further work, particularly in eastern rainforests, may be expected to reveal that fruit bats interact with a much greater number of plant species, including a much higher level of endemic forest species.

Every reader of the Action Plan will be familiar with Madagascar's deforestation problems. The demonstration of the intimate links between fruit bats and so many of Madagascar's forest species provides good reason for those concerned with the protection of Malagasy forests to pay attention to these three mammal species. As shown by the continuing existence of the *Pteropus* roost at Berenty, Fort Dauphin, fruit bats can survive in a tiny patch of forest, if necessary relying primarily on domestic species such as sisal supported with occasional visits to various fig species. Our findings indicate that the forests of Madagascar may not be equally independent of fruit bats.

Rare plants need fruit bats

Baobabs in general appear to have very poor recruitment (eg Blaise Du Puy, pers. comm. and M.Sc. thesis). The low number of young trees observed remains unexplained, but its effects are clear. *Adansonia za* is already classified as Rare in the IUCN Red Data Book. These baobabs may be dependent on fruit bats for their continued existence. *Adansonia suarezensis* appears to be exclusively bat-pollinated. The same is true for isolated *Adansonia grandidieri* individuals, which cannot be reached by lemurs. More observation data is needed to ascertain whether *Adansonia za* and *Adansonia fony* , shown to be visited by bats through the faecal analysis, are also exclusively bat pollinated.

Differences in ecological role between fruit bats and other Malagasy frugivores

Pteropus rufus is confirmed to travel the substantial nightly distances seen in fruit bats elsewhere, and thus to have a vastly superior potential to disperse seeds and promote genetic exchange between forests to that of other Malagasy frugivores. Unlike birds, bats are not seed predators: all seeds found in Malagasy bat faeces were intact.

Further research

Results of diet studies of *Pteropus* and *Rousettus* in the region of Mahajanga and the Ranomafana and Masoala National Parks are currently being analysed, and this will add to the list of the plant species visited by Malagasy fruit bats. Such studies in each reserve would give managers important insights into the ecosystems under their care. For plant species of special interest, observations to confirm the pollinating ability of fruit bats should be carried out, along with, where possible, exclusion experiments to show whether or not pollination will occur if bats (as opposed to other frugivores) are prevented from visiting flowers.

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The Conservation Status of Malagasy Fruit Bats (Megachiroptera)

MacKinnon J.L., Hawkins C.E., Racey P.A., Ranivo, J. & Razakarivony, V.

Introduction

Many Megachiroptera species face threats from loss of habitat, hunting for food, disturbance or destruction of roost sites and hunting because they are considered pests of fruit crops (Mickleburgh *et al.* 1992; Eby 1995; Duncan *et al*. 1999). Three species of Megachiroptera occur on Madagascar and all are endemic (Peterson *et al*., 1995): *Pteropus rufus*, *Eidolon dupreanum* and *Rousettus madagascariensis*. Most Megachiroptera roost in large colonies, varying in size from tens to several thousand individuals. This concentration of animals in a single roost site makes them particularly sensitive to disturbances and in particular to hunting (Wiles *et al*., 1998). Megachiroptera are also long-lived animals with a low reproductive rate (Falanruw, 1988; Heideman, 1988 & Pierson & Rainey, 1992) and therefore populations do not recover quickly after declines (Mickleburgh *et al*., 1992). These aspects of the biology of fruit bats account for the high proportion that are classified as threatened species. The IUCN Conservation Action Plan for Megachiroptera (Mickleburgh *et al.* 1992) demonstrates that the conservation status of fruit bats is both poorly known and that a large proportion of species are threatened. For the 343 taxa (including some subspecies) listed in the document, 47% have insufficient data to make an assessment while of those with sufficient data, 37% qualify as threatened species. Since the action plan was published, the IUCN has revised the criteria for threatened species to make them more quantitative and objective (IUCN, 1994; IUCN, 2001). We present an assessment of the three Malagasy Megachiroptera using the new IUCN criteria and recently collected data from a national survey of bat roosts.

Detailed studies of the threatened species status of Megachiroptera have been conducted for only a few species. Entwistle & Corp (1997) estimated the minimum population of the endemic *Pteropus voeltzkowi* to be 4600-5500 on the island of Pemba, off Tanzania. Most (94%) of this small population appeared to be in just 10 roost sites and combined with its restricted range and continuing threats from hunting and deforestation was considered to warrant endangered status. Population estimates of *P. livingstonii,* an endemic species of the Comoros, suggest a minimum population of 410-460 individuals in the twelve known roosts and it is therefore considered a critically endangered species (Clark *et al*., 1997). It is relatively easy to classify species with small populations according to IUCN criteria, but determining whether large but declining populations qualify for threatened status can be difficult to assess. Bowen-Jones *et al.* (1997) made a cautious estimation, based on extrapolation, that the population of *P. rayneri grandis* on the Solomon Islands had declined from approximately 35,000 to 17,300 within the previous 10 years, therefore confirming its vulnerable status. The Action Plan for Australian Bats (Duncan *et al.*, 1999) carefully considered the IUCN categories of all Australian bat taxa through a series of workshops and invitations for comments from the 'bat community' over a 4-year period. Even so, the data required to make accurate assessments of IUCN categories was not available for all species and some required discussion. In particular, two widespread species, *Pteropus poliocephalus* and *Pteropus conspicillatus* required debate about projected declines, and in the case of *P. conspicillatus*, no consensus could be reached.

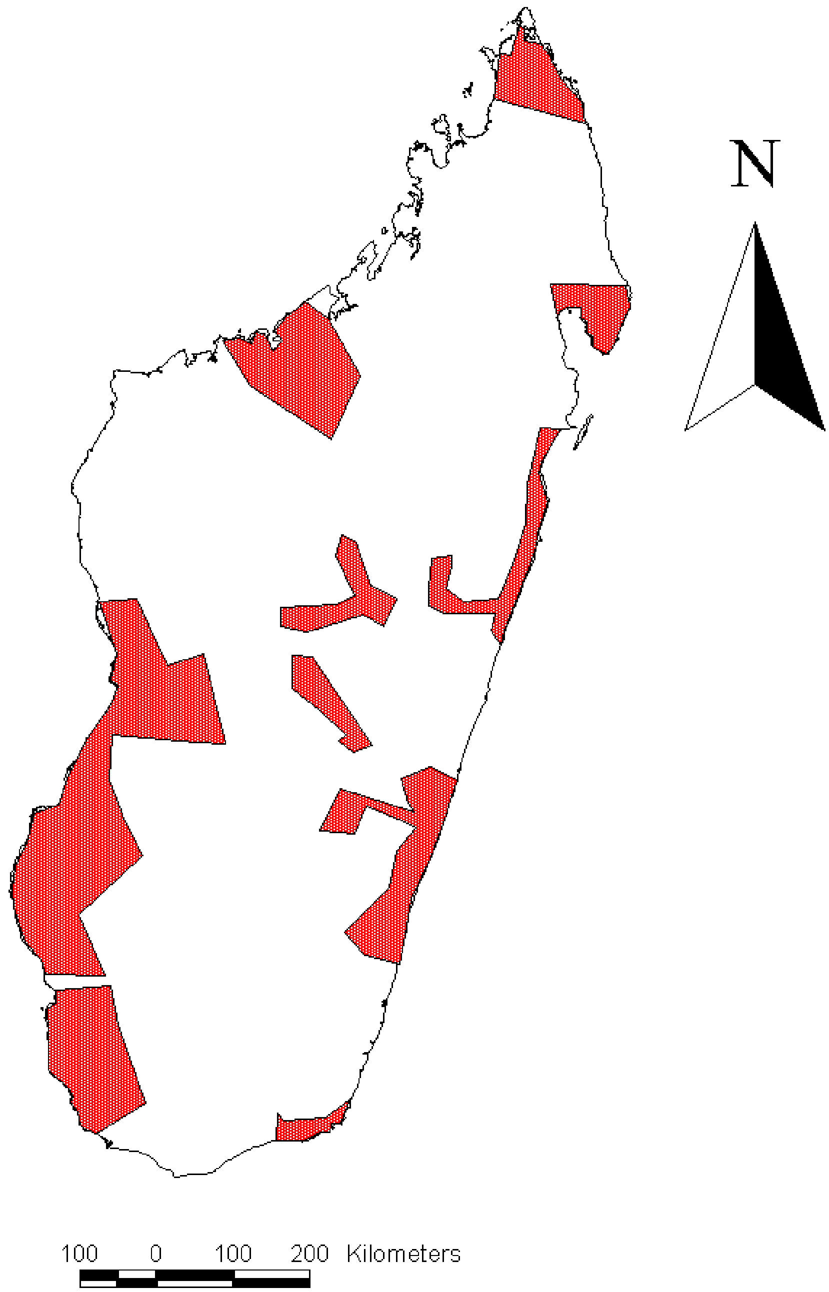
Pteropus rufus was listed as vermin under Malagasy law in 1961 (Decret No. 61-096). In 1987 the genus *Pteropus* was listed on CITES Appendix II and in 1988 Madagascar updated its classification of vermin species by removing all CITES listed species (Decret No. 88-243, 1981). Unfortunately, *Pteropus* is still widely assumed to be vermin and is therefore subject to hunting throughout the year with few restrictions. The superficial similarity of *Eidolon dupreanum* to *Pteropus* means that it is also hunted extensively. In Madagascar the hunting season extends from May to October each year and hunting is not permitted at night, but these laws are rarely adhered to, partly because of the assumption that the species is vermin *Rousettus madagascariensis* is also currently listed as a threatened species in the vulnerable category (IUCN, 2000). The aim of this paper is to review the status of the three Malagasy megachiroptera in light of the new information collected in recent years.

Methods

Location of roost sites

Surveys to find roost sites were conducted in 10 different regions, representing all of the major habitat types defined by Du Puy & Moat (1996), Faramalala & Rajeriarison (1999) and DEF/IEFN (1997) (Fig. 1). These surveys provided data from the South, West, East and Central ecoregions as defined by ANGAP (2001). In each of these regions, roosts were located by interview with the local population, biologists, hunters, local authorities and conservation staff. Once the location of a site was determined it was visited by a survey team, and the species, numbers of individuals, habitat type and position (determined from GPS or from 1:500,000 maps) were recorded. Supplementary information about bats was collected by interview with locals from the settlements closest to the roost. We sought responses to questions relating to hunting of the bats, trends in the population and taboos relating to bats. Questions were posed during the course of conversations and questionnaires were completed later to avoid intimidating the interviewee. It was necessary to make a qualitative assessment of the information being provided and therefore only information provided by people who had some knowledge about bats was used. Information was taken only from people who met the following criteria: 1. They were able to give adequate descriptions of fruit bats, were aware they were different from microchiropterans and could describe aspects of their biology, 2. They had visited a roost site and 3. They had lived for more than 5 years in an area. Responses of interviewees who qualified for the first two criteria but not the third were used but information about long-term trends was ignored. Most information collected was from bat hunters, although in some cases it was clear that these hunters were not giving honest answers and so the information was ignored.

Figure 1. Map of Madagascar showing the ten regions (marked in red) where surveys for fruit bat roosts were conducted



Counting bats

There are no standard methods of counting bats that can be applied in all situations and for all species. The technique used depended on the species, their tolerance of disturbance and the environment concerned. In situations where it was possible to approach the roost, individuals were counted directly using binoculars or directly from beneath the roost tree (for *Pteropus*) in cases where the animals were not disturbed (Racey, 1979; Clark et al., 1997). At some extremely large roosts in caves, it was only possible to make a guess of the roost size. At some roosts, for example where *Eidolon dupreanum* roost in the fissures of cliff faces, animals were counted in the evening as they emerged (Wiles *et al*., 1988). Capture-mark-recapture techniques were used for two *Eidolon dupreanum* populations. At several large *Pteropus rufus* sites where it was not possible to view all the animals simultaneously, disturbance counts were used (Racey, 1979) in which some people entered the roost site and made a noise to disturb the bats. The observers counted from a distance or photographed the sky with a series of overlapping photos taken in quick succession and then counted the bats on the photos at a later date.

Studies of hunting pressure

The national survey provided information about the current state of bat populations throughout the country, but no quantitative data on projected changes. During the course of these surveys it became apparent that hunting at roosts was the single most threatening activity to the survival of bats in Madagascar. Two detailed studies were therefore conducted over smaller spatial scales to make predictions about the effect of hunting on the population dynamics of fruit bats. The first study concerned *Eidolon dupreanum* in the Central Highlands and the second focussed on *P. rufus* on the west coast. The aim of both studies was to collect quantitative information to predict the future survival probability of the species concerned by means of a Population Viability Analysis (PVA). A comparison of the levels of hunting that fruit bat populations could withstand, as predicted by the PVA, with the true levels of hunting that occur was used to help assess the conservation status of the bats according to the IUCN threatened species criteria (IUCN, 2001).

Initially, all roost sites within chosen study areas were located and counted using the variety of methods already described. This intensive survey was continued until all information relating to roost sites within the study boundaries had been checked. During these surveys, interviews were conducted with hunters to ascertain the different methods of hunting used, whether there was a hunting season, taboos relating to bats and the numbers of individuals taken. For the study of *Eidolon dupreanum*, a capture-mark-recapture study was conducted at Lac Tritriva (E46°55’ S19°56’) to establish the population size and collect demographic data such as sex ratios and reproductive rates. In the case of *P. rufus* the same information was collected by direct observations of animals in roost sites.

The VORTEX computer package was chosen to run the PVAs. The software is well suited to modelling the dynamics of species with low fecundity and long lifespans, such as mammals (Lacy *et al*., 1995). The user enters demographic information on the study species together with population specific data and estimates of variation of these variables and then the program runs multiple simulations to investigate population change over time. The user also determines the number of simulations to perform and the time period over which to run them. Mean population sizes and the probability of extinction can then be calculated at specified intervals. The user can therefore study the effects of various factors that may affect population survival by varying the initial parameters entered. In this study the main factors of interest were those that related to hunting, but initial population size, the effects of a catastrophe and the effect of dispersal between roosts were also considered.

Information collected from the field on mean population size, hunting, mortality rates of young and adults and mean litter size, was included in the PVA. Other information required by VORTEX was taken from the literature and the source of any information is noted in table 1. In many cases, species-specific data does not exist and in those instances information known for the genus or family was used instead. Various VORTEX simulations were conducted to explore the likely consequences of hunting on *E. dupreanum* and *P. rufus*. VORTEX allows for the inclusion of inbreeding depression in the population simulations but this aspect of the analyses was not the aim of this study and was therefore ignored. The carrying capacity of the population was set much higher than initial population size in all analyses to ensure that it had no effect on extinction probability. Density dependence in breeding rate was omitted from the model because any effects at high population sizes were not relevant to the study. It is unlikely that density-dependence is important for small population sizes as both the species considered in this study are colonial and therefore probably have no difficulty finding mates. In all analyses 500 iterations were used and the simulations extended to 100 years. A stable age distribution was assumed in all models. Two methods of modelling hunting were used: i. mortality rates were increased for the population and, ii. populations were harvested according to levels reported by the hunters. VORTEX parameters were set to report the population sizes and extinction probabilities at ten-year intervals. Environmental variability is modelled in VORTEX by asking for measures of variability (standard deviations) in the values of various parameters. Real data on environmental variability is rarely available for PVA analyses (Lacy *et al*., 1995) and the present study was no exception. Rather than ignore environmental variation, we set standard deviations to be 10% of the mean values. High levels of environmental variation lead to high extinction probabilities for small populations (Lacy *et al.* 1995). By keeping the environmental variation relatively low, our simulations are conservative with respect to predicting extinctions. In all analyses the environmental variation in reproductive rates and survival rates were set to be correlated.

Pteropus populations are severely effected by cyclones (Richards, 1990) and occasional disease epidemics (Flannery, 1989; Bowen-Jones *et al.*, 1997). The effects of such factors were modelled in VORTEX by allowing catastrophes to occur with a probability of 0.01 during a 100-year period. The effect of the catastrophe was to kill half the population and cut the reproductive rate for that year to one half of the usual rate. These figures are likely to be conservative estimates of the effects of cyclones on bat populations. In Madagascar, 362 cyclones occurred between 1920 and 1972

(Ganzhorn, 1995) and these are likely to have severe impacts on *Pteropus*. The *P. rufus* population in Berenty private reserve was apparently badly affected by storms at the end of November 1999 and the first cyclone of 2000. In 1997/1998 numbers of bats were estimated at 360 in Sept./Oct. 2000, as compared with approximately 1800 in the same period of 1997/1998 (Emma Long, pers. comm.). Local people in Choiseul (Solomon islands) reported that *P. rayneri grandis* populations had not yet fully recovered from a cyclone which occurred 23 years previously (Bowen-Jones *et al*., 1997).

Table 1. Information required for VORTEX simulations

Demographic variable	***Value used***	***Source of information***
No. populations modelled	Variable (1-3)	Exploration of the effect of dispersal
Inbreeding depression	Not included	Irrelevant to aims of the study
No. of catastrophes	Variable (0,1 and 5). Catastrophes were assumed to kill 50% of the population.	Exploration of the effect of cyclones and also disease epidemics.
Mating system	Polygynous	Puddicombe (1990) for *Pteropus* Mickleburgh et al. (1992)
Age of first breeding	Second year of life for both males and females	1.5-2 years old for various *Pteropus* spp. (Pierson & Rainey, 1992; Falanruw, 1988; Martine *et al*., 1987)
Maximum age	10	*Pteropus* achieved 31 years in captivity (Pierson & Rainey, 1992), *Pteropus alecto* averaged 7 years in wild (Vardon & Tidemann, 2000), 4-5 years known for small pteropodids: *Cynopterus brachyotis, Ptenochurus jagori* and *Haplonycteris fischeri* (Heideman & Heaney, 1989) and 5 years for *Eonycteris spelea* (Start, 1974)
Sex ratio at birth	1:1	Information from hunters; Personal observations; Generally 1:1 for *Pteropus* (Heideman & Heaney, 1989)
Proportion of adult females breeding	80%	66% pers. obs.; 83% for *Cynopterus horsfieldi* (Hodgkinson, 2001); 97% for *Pteropus mariannus yapensis* (Falanruw, 1988).
Frequency distribution of litter sizes	One young 99% twins 1%	Pers. Obs.; Emma Long pers. comm.; (usually 1 young per year according to Pierson & Rainey, 1992); rarely have twins (Peters *et al*., 1995)
Juvenile mortality	Variable	10-30% over first 2/3 of lactation period for a small pteropodid, *H. fischeri* (Heidmann, 1988); generally juvenile bats have higher mortality than adults (Tuttle & Stevenson, 1982)
Adult mortality	Variable	Subadult and adult mortality varied between 20-40% for 3 spp. of small pteropodids (Heideman & Heaney, 1989)
Carrying capacity	Much higher than initial population size (K=10,000)	Not of primary interest to the study.
Numbers harvested	Variable (0-100) for both males and females	Exploration of this parameter

Results

The Status of *Pteropus rufus*

Historically, museum specimens of *P. rufus* were collected from localities throughout the whole of Madagascar (Peterson *et al.,* 1995). Although many authors presume that the species is restricted to the lowlands, it is clear that *P. rufus* was formerly found throughout the central highlands as well as the coastal regions.

Ninety-eight occupied roost sites have been recorded in recent years. Bat roosts were located by project survey teams from April 1999-December 2000 (Fig. 2) and all analyses of population sizes and responses to questionnaires were analysed for those sites only to minimise observer and methodological biases. Other researchers have identified additional roost sites which are included in the maps of current distribution (the oldest record used in this analysis was from 1993).

Figure. 2. *Pteropus rufus* roost sites in Madagascar. The blue circles indicate currently occupied sites and red squares indicate roost sites reported to have been abandoned within the last ten years. Remaining original vegetation is indicated in green (rainforest), yellow (deciduous and thorn forest), brown (sclerophyllous forest)and pink (marshland)

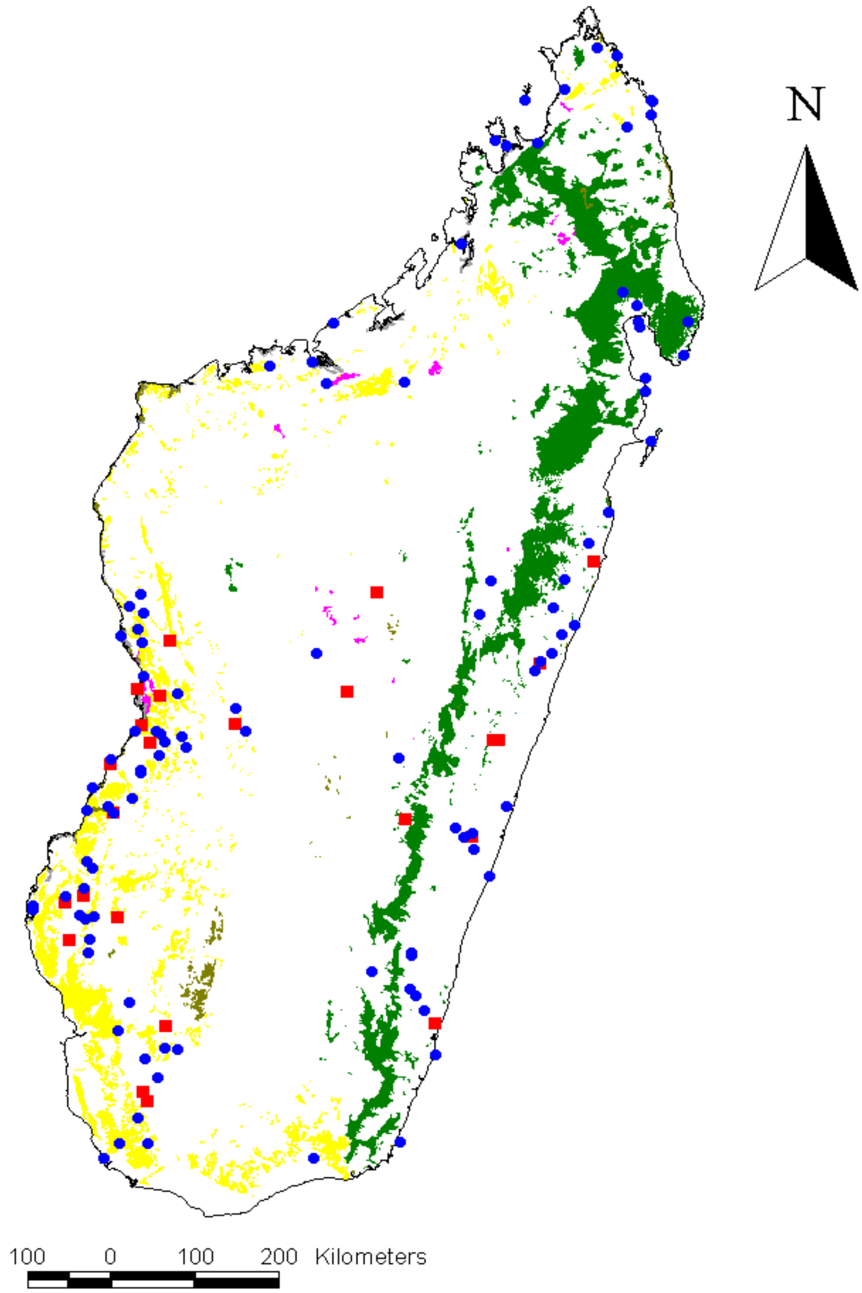
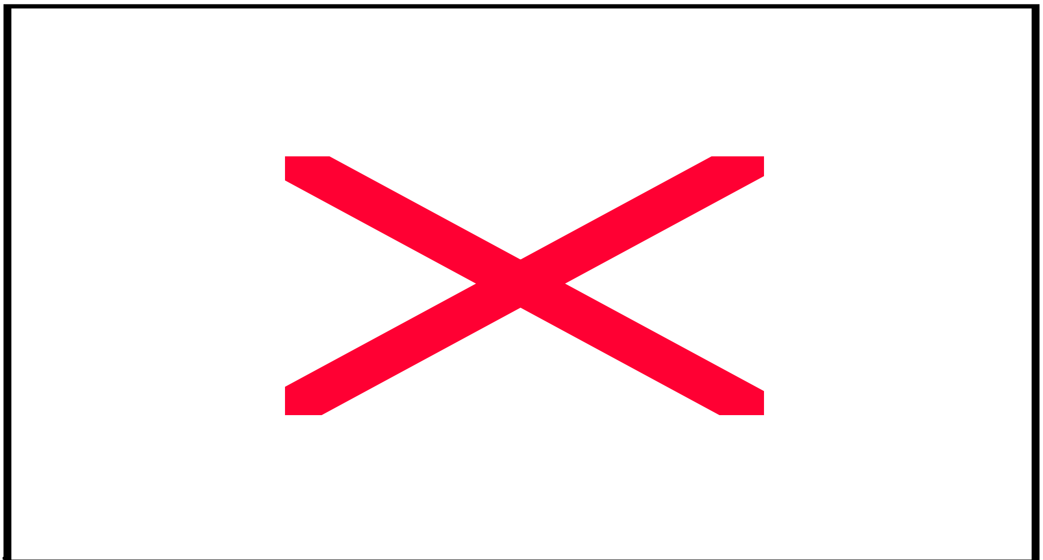


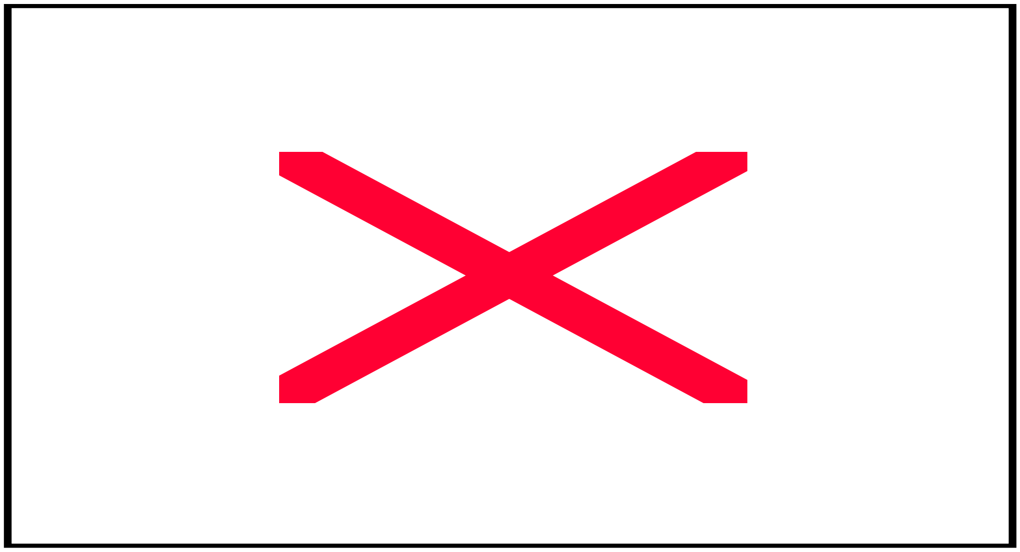
Fig 3. Population sizes at *Pteropus rufus* sites



A wide range of roost population sizes was found (Fig. 3). The median population size was 335. The species can, however, form much larger roosts, as indicated by the existence of several roosts of approximately 5000 individuals. *P. rufus* is commonest in the lowlands and relatively rare in the central Highlands. Twenty-four of the 122 sites (19.7%) visited during the course of the project were reported to have been abandoned within the previous ten years. These sites were found because we had been told of their existence, but on arrival at the site they had already been deserted. *Pteropus* species are well known to be habitual users of roosts for many years (e.g. Eby, 1995) and these desertions indicate that some roost sites must be subject to extensive disturbance. In the highlands the proportion of deserted sites is 70% (5/7), and this is due to extremely high pressure for wood on the remaining trees that can be used as roost sites. The two remaining roosts that were located are extremely small (approximately 50 and 250 animals respectively) and unlikely to survive for more than a few years. At all deserted sites the villagers were asked why the site went extinct. The cause of desertion was only recorded for those sites where there was a consensus of opinion about the cause of desertion. The most common cited cause of desertion was hunting using guns (33%). In general, this type of hunting is not done by local villagers needing food, but by more wealthy hunters from local towns shooting for sport. Other reasons given for site desertion were slash-and-burn (11%), cyclones (6%) and tree felling to catch bats (6%). The cause of roost desertion was unknown for 44% of cases.

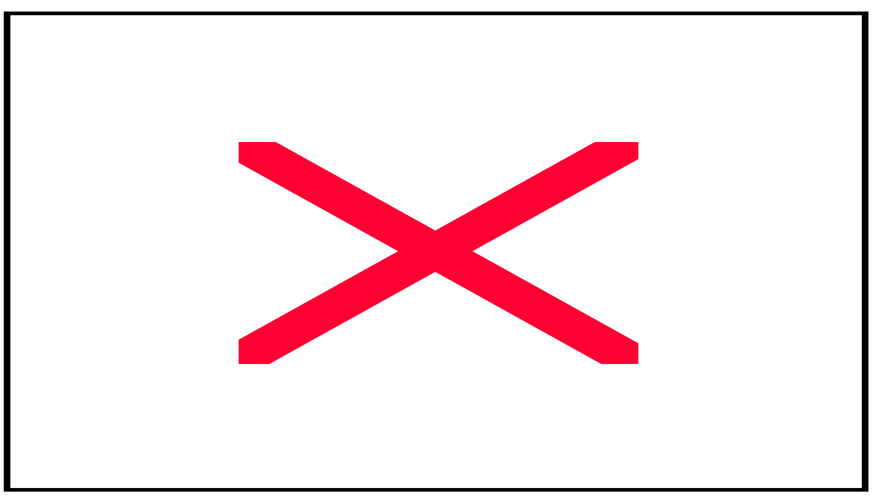
The eating of bats is taboo for the Mahafaly and the Antandroy and bat roosts are therefore relatively protected and appear to be stable in the areas where these tribes predominate. However, the large numbers of immigrants from other tribes results in at least some hunting of bats in almost all roost sites that were visited. It is also taboo for Moslems to eat bats and hence bat roosts in the north of Madagascar where Moslems predominate, tend to have less hunting than elsewhere. In many areas there are local taboos which restrict people from hunting in the roost site. Some roosts are found in taboo forests or sacred areas containing tombs, and acquire protection as a result. In addition to such sites that are protected by cultural taboos, some roosts are found in private or government managed protected areas.

Figure 4. Median population sizes at protected and unprotected sites. The error bars shown are quartiles.



Roosts sizes are smaller in unprotected sites than protected sites (medians of 250 and 650 respectively; Kruskall-Wallis test statistic = 7.22, d.f..=2, p<0.027). (Fig. 4) The analysis indicates that bat populations outside protected areas must be negatively affected by disturbance or hunting. We know only of four *P. rufus* roost sites within protected areas: Berenty private reserve, Nosy Atafana at the Mananara-Nord National Park, Zahamena Strict Nature Reserve, and Masoala National Park. Since many traditional taboos are being ignored and hunting now occurs in many traditionally sacred sites (pers. observations), the long-term protection of roosts outside official protected areas seems unlikely.

Figure 5. Population trends at *P. rufus* roosts

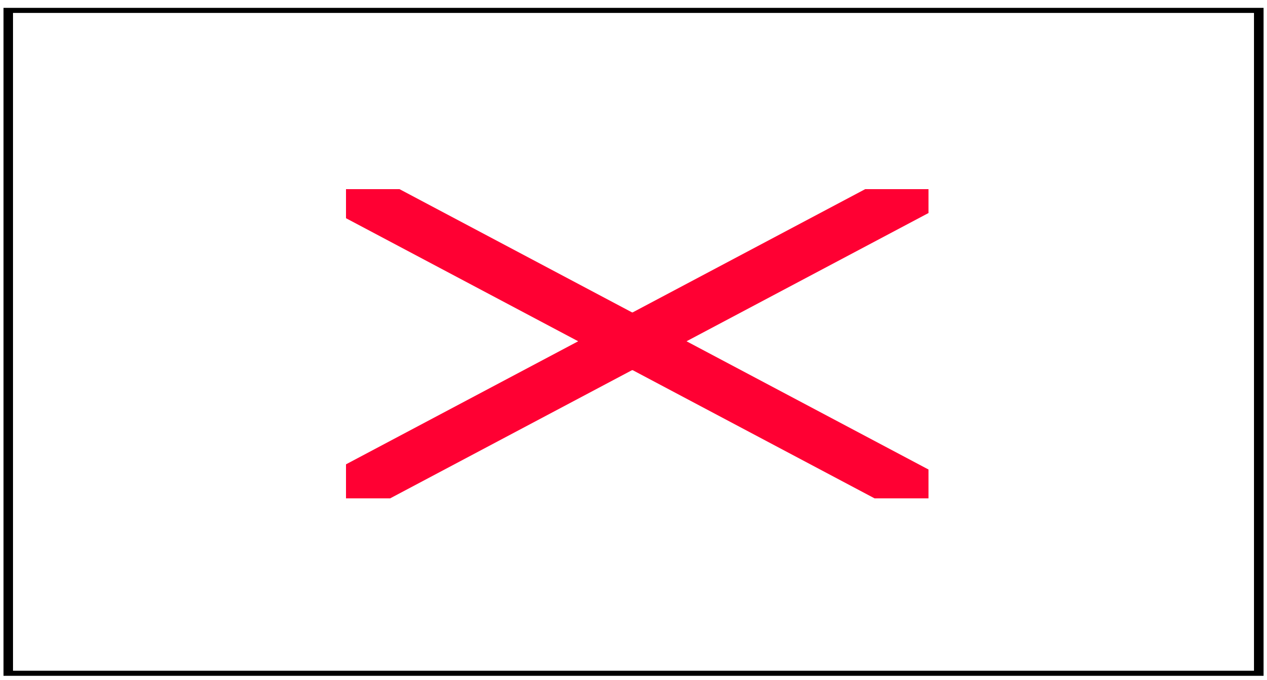


Villagers were also asked whether they thought the roost was increasing in size, stable or decreasing. For sites where an answer was given, most tended to be decreasing (Fig. 5). The causes of decrease were also enquired about and most declines at most roosts were attributed to the effects of hunting (65%). Other reasons cited for the declines were storms (5%), deforestation (3%), pest control (3%), disease (3%), fire (3%). The reason for declines at 18% of roosts was unknown.

Case Study of* Pteropus rufus *hunting in the region of Morondava

Seven *Pteropus rufus* roosts were found in the study region (Figure 6). The median roost size was 430 (range: 100-730). The total number of bats estimated in the study region was 2580. Five roost sites were also reported to have been deserted or become extinct within the last 10 years.

Figure 6. The study area between the Morondava and Tsiribihina rivers, indicating the positions of roost sites.



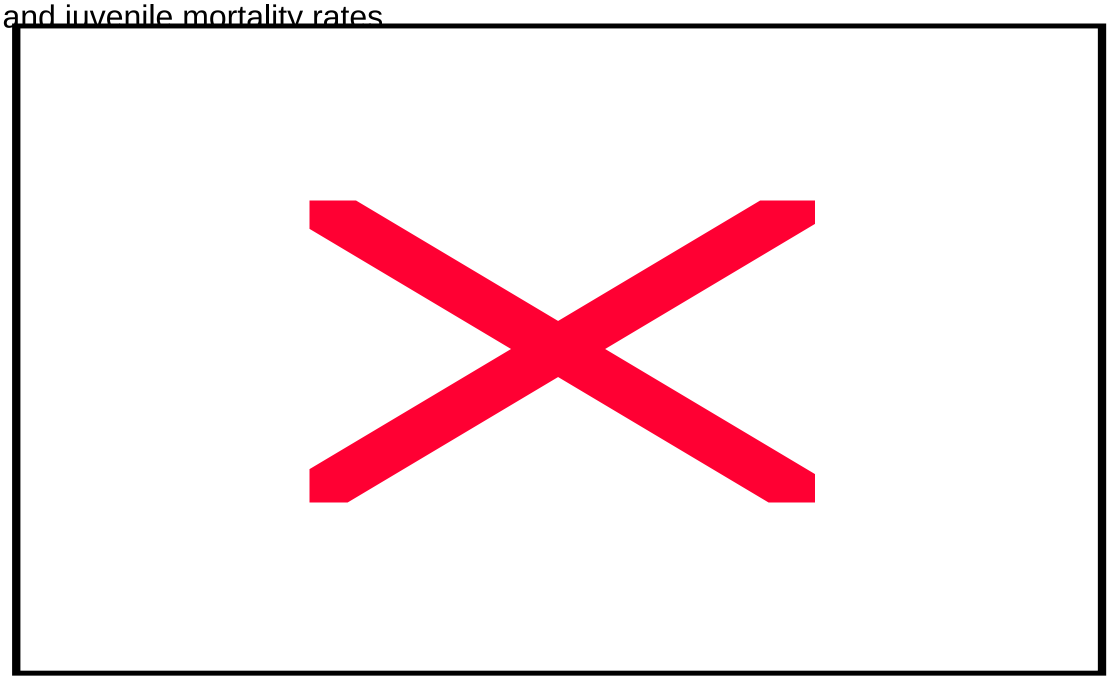
Interviews with groups of hunters were conducted in thirteen villages. Detailed information of hunting during the flowering season of kapok (July-September 2000) was collected from three of the ten villages where questionnaires had been left with hunting groups. A total of 15 groups of hunters provided data on the species and numbers of males and females that they captured. All hunting was conducted in trees around villages. Hunters used either nets or placed the barbed burrs of farehitra (*Uncarina grandidieri*) in kapok trees. As the bats climb through the tree, their fur or wings become attached to the burrs and they are stuck until the hunter kills them. At some roosts there were reports of hunting with guns by people from Morondava and other towns. Such hunting with guns appears relatively rare in this region except for a well-known roost at Ranomena on the Morondava river, where locals reported that hunters came approximately once a month from Morondava and would take away a sack of bats (approximately 30 animals) per hunt.

Average number of groups of hunters per village = 4.9 groups
Average number of animals taken per group, per night of hunting = 6.2 animals
Within 45 day kapok flowering period, average nights hunted = 17 nights
Therefore the number of animals taken per village per year = 516 animals

Therefore from the 13 interviewed villages - the main villages where hunting occurred - an estimated 6708 bats were taken per year. We take this figure as an estimate of the total number taken in the Morondava region. However, the 7 roosts identified in the region were estimated to hold only 2580 animals. There are three possible explanations for the disparity between these figures: 1. The number of bats taken in the region was overestimated, 2. The number in the region was undercounted or 3. The effective size of the study region was underestimated and we should have counted roost sites that were further away. In fact some roosts were reported at the periphery of the study area which were never located by the survey team. However the inevitable conclusion is that very high proportions of the existing bat population are being hunted in the region.

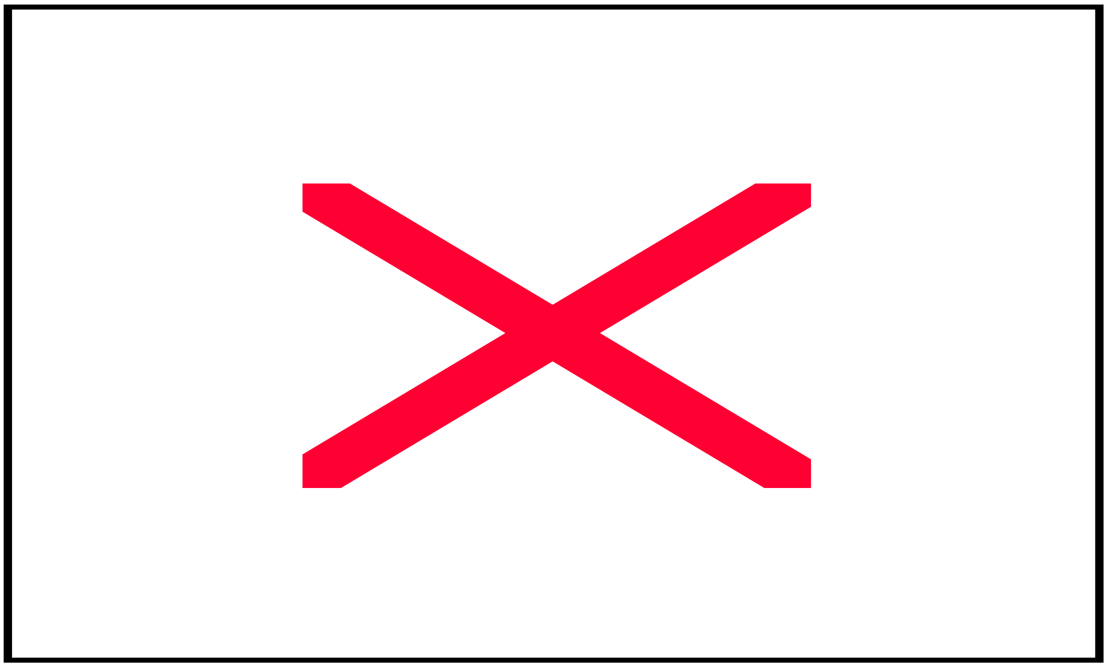
Investigation of the effects of mortality rate on survival probability
VORTEX simulations indicate that the probability of extinction of a theoretical bat population increased exponentially with increasing mortality rate (Fig. 7). although increases in adult mortality were the most important, differences in juvenile survival rate also made a substantial difference to the probability of a population surviving for 100 years.

Figure 7. The extinction probability of a population of 500 *P. rufus* under varying adult and juvenile mortality rates.



The probability of extinction within one hundred years under three different harvesting regimens is shown in Fig. 8. In all cases, the initial population was 500 individuals (i.e. slightly larger than the average population size in Madagascar) and natural mortality rates were estimated as 20% for juveniles and 20% for adults (low mortality rates according to existing literature). For all three regimens the probability of extinction of the population rises rapidly after a certain level of harvesting. For the most commonly practised hunting methods (equal numbers of males and females taken), populations become extinct when just less than 50 individuals are harvested. According to the model, higher harvests can be attained if hunters choose to take males rather than females. The most realistic simulation of the current hunting situation is the one including the effects of an occasional catastrophe (probability of occurring of 1% each year). Under these conditions, the populations start to become extinct for a harvest level of approximately 20 individuals per year, however the increase in extinction probability is slower and the catastrophe does not effect the harvest level at which there is a 50% or higher extinction probability.

Figure 8. The effect of different *P. rufus* hunting regimens on the probability of extinction within one hundred years. The solid line indicates a regimen where equal numbers of males and females are taken, the large dashed line represents a regimen in which two males are harvested for every female, and the fine dashed line is a regimen with equal numbers of each sex taken but the effects of an occasional natural catastrophe are added.

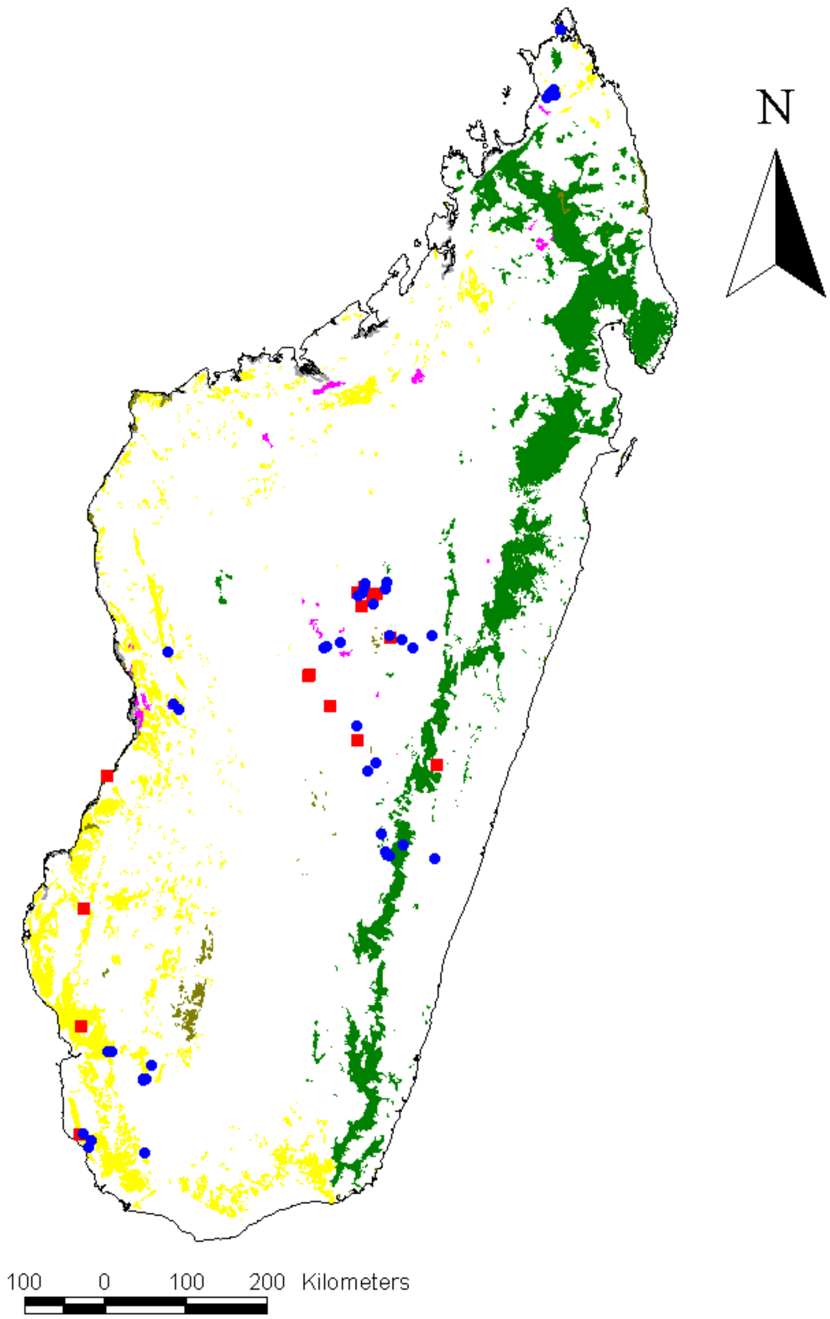


According to responses given during interviews and from questionnaires completed by hunters, the numbers of animals harvested per population by local hunters are much higher than the minimum levels which lead to population extinction in the VORTEX models.

The Status of *Eidolon dupreanum*

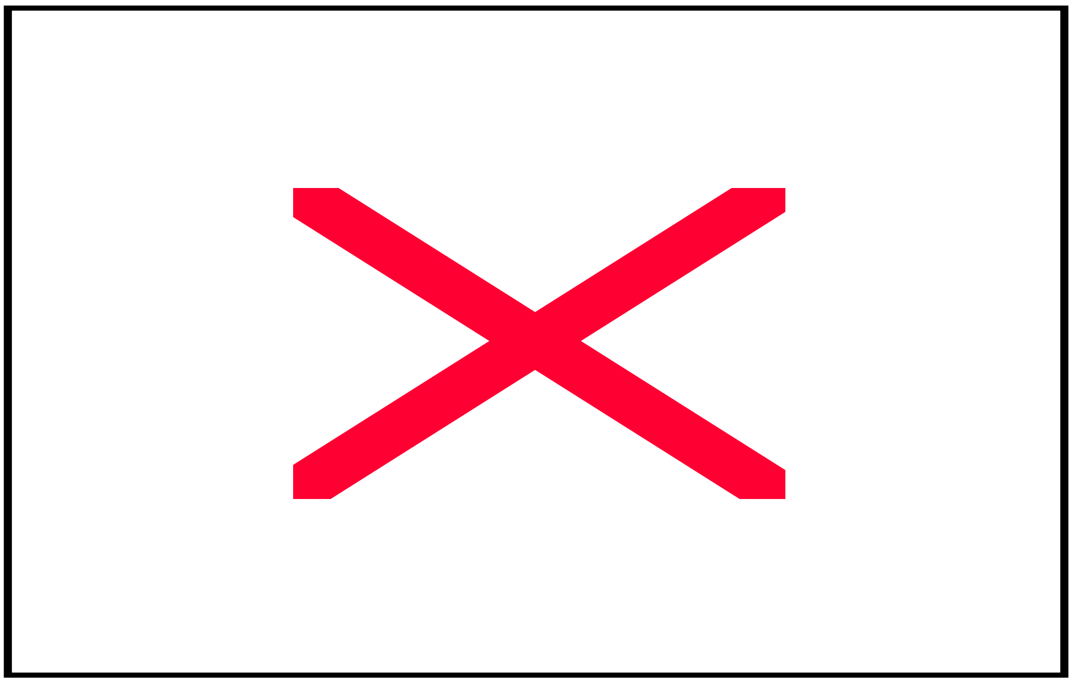
Historically, museum specimens of *E. dupreanum* were collected from localities throughout Madagascar (Peterson *et al*., 1995). The roost sites are usually in cliff faces, although *Eidolon* also roosts in palm trees and may therefore be more common in the western savannahs than indicated by the results of our surveys, which are shown in Figure 9.

Fig. 9. *Eidolon dupreanum* roosts located during April 1999-December 2000. Blue circles indicate existing roosts and red squares indicate roosts reported to have been deserted in the last ten years. Original vegetation is indicated in green (rainforest), yellow (deciduous and thorn forest), brown (sclerophyllous forest) and pink (marshland)



E. dupreanum tends to form small roosts by comparison to the other member of the genus, *E. helvum*, which is found in huge roosts of tens of thousands of individuals in Africa. The median roost size for *E. dupreanum* is 200. (Fig. 10) Three roosts of over over one thousand individuals were found, all of them in the Reserve Speciale d'Ankarana. Another difference with *E. helvum*, is that the roosts in Madagascar seem to be occupied throughout the year, whereas the African species is a seasonal migrator. Nevertheless, roosts in the forests of the south-west are smallest during the dry months when there are very few fruit to eat, which suggests some animals may migrate.

Figure 10. The number of *E. dupreanum* estimated at each roost site



The most common method of hunting *Eidolon* in cliff faces is to smoke them out of their roosts in the fissures of rocks. This method apparently often leads to desertion of the roost (hence the high incidence of deserted roosts - 18/60 or 30%). However, anecdotal evidence from hunters suggests that the roosts are reoccupied after a few years. During interviews with the local population, the most common reason cited for roost desertion was hunting using fire (60%), followed by bushfires (13%). At 27% of deserted roosts, no reason was known to explain why the animals had abandoned the site.

No statistical difference in roost sizes was found between roosts that were in protected and in unprotected areas (Mann-Whitney test, U = 96.5, d.d.l = 1, p = 0.12). The sample size used in this analysis was low (10 protected and 14 unprotected sites only), and further data might indicate a real difference between hunted and unhunted sites. However, *E. dupreanum* roosts are mostly in cliff faces which are inaccessible and therefore their roosting behaviour may give them a degree of natural protection.

Case Study of *Eidolon dupreanum* hunting in the Central Highlands
Information on hunting was collected from hunters at six roost sites in the Central highlands. Three methods of hunting *E. dupreanum* were used. The most complicated method involves a team of three to four men who light a fire under the roost site to smoke out the bats whilst one of them abseils down the cliff and hits the emerging bats with a large stick. The injured or stunned bats then fall to the ground where they are killed by the men waiting at the bottom. When the roosts are not high up a cliff this method can be used and the bats are hit with long sticks from the ground or catapults are used. The second method is to use large nets at the roost site to catch bats. This method is used by specialist bat hunters who will often camp at a site for up to a week before moving on to another site. Nets are also used near villages when there are trees in fruit. In contrast to the hunting of *P. rufus*, most hunting occurs at the roost site and is done by hunters who specialise in catching bats to supplement their incomes during the periods when there is less agricultural work. Many of these hunters respect the official hunting season and some of those who use nets to catch also claim to release females and young. It was impossible to obtain quantitative data on the number of animals captured per hunter, but all of them claimed to catch at least a hundred during the year.

The VORTEX simulations used for *Pteropus* are also adequate for *Eidolon* since as far as is known, there are few differences in the key demographic rates of these species. However, the average roost size was approximately 300 individuals and therefore the effects of harvesting were remodelled using the same parameters as for *P. rufus* but with a smaller initial population size of 300. The results showed that hunting of over 30 animals per year leads to extinction of the roost within 100 years. The average hunting levels reported for sites in the study region are higher than the sustainable levels predicted by VORTEX.

Status of *Rousettus madagascariensis*
The roost sites of *Rousettus madagascariensis* are difficult to find and few are known. The species seems to prefer large caves and their roosts are always beyond the twilight zone of the cave. Such roosts, consisting of several thousand individuals, were discovered during cave surveys in the karstic (“tsingy”) regions of Bemaraha and Ankarana national parks. However, *R. madagascariensis* is locally abundant and when present in an area they are easy to catch with mistnets. From these observations and published records it seems likely that they are associated with forest in addition to caves. The species has not been recorded from the spiny forests of the south-west and from the deforested Central Highlands. There is little threat to this species from hunting. However, its association with forests means that the continued deforestation of Madagascar poses a threat to its survival.

Discussion

Although a lack of historical data make it impossible to directly assess population changes, several different analyses and data sources consistently suggest that hunting of fruit bats poses a risk to their long-term survival in Madagascar. For *Pteropus rufus*, at least 20% of sites appear to have been abandoned within the last ten years and villagers report that 79% of sites have decreasing populations while only 13% are stable and 8% are thought to be increasing. Roost sizes are larger in protected areas, which also suggests that populations in unprotected areas are subject to human pressure which causes population decrease. Few roost sites are officially protected and in some of these the protection is ineffective. Hunting, particularly with guns, appears to be the biggest threat to *P. rufus* populations, but the case studies on hunting also indicates that the current extent of hunting with traditional methods is not sustainable.

The inaccessibility of *E. dupreanum* sites makes hunting these bats more difficult than for the tree-roosting *P. rufus*. Although there is a high rate of roost desertion, there may also be a high rate of colonisation of new sites after disturbance. *E. dupreanum* may be well adapted for migrations, like *E. helvum* in Africa, and indeed, some observations in the south-west suggest that *E. dupreanum* migrates naturally from areas where there are food shortages. Like the case studies on the hunting of *Pteropus*, harvesting at individual *Eidolon* sites is within the range likely to cause population extinctions. However, many *E. dupreanum* roosts are too difficult to hunt and therefore probably act as a source of animals for the sites that are hunted. There are even roost sites in the capital, Antananarivo, which suggests that *E. dupreanum* is able to survive high levels of exploitation.

The continued survival of *E. dupreanum* in the Central Highlands, even in urban areas and areas which have been completely deforested and where few other native vertebrates survive, suggests that this species will continue to persist even with continued hunting pressure. However, roost sizes in the Central Highlands are generally small (only two sites are known to have over 100 animals) and so the contribution of this species to the ecological processes of pollination and seed dispersal will be very limited due to the small numbers of bats.

IUCN threatened status

The total *P. rufus* population in Madagascar is still relatively large. Approximately 100,000 individuals were counted during surveys from April 1999-December 2000. The survey teams covered approximately one half of the area of Madagascar that has suitable habitat. Assuming that another 50% of the population was not counted due to undercounting in roost sites and there was incomplete coverage of the survey areas, the total population of *P. rufus* is estimated at approximately 300,000.

The available information can be used to assess the threatened status according to three of the IUCN criteria: A1,A2d and E (see IUCN 2001). The number of roost sites has declined by at least 20% during the last 10 years and although all these animals may not have died, most reports indicated that when roosts were abandoned they numbered less than 100 individuals. The data suggest that *P. rufus* is close to a 20% decline in 10 years, which would classify it as a vulnerable species (criteria A1). In addition to this, 79% of roosts are reported to have declining populations. The actual levels of exploitation of the species recorded in the region of Morondava are high enough to cause at least a 20% reduction in the population in that region within the next ten years (criteria A2d). Most bat hunting in this region occurs for just a few months during the year and hunting in the roost sites is uncommon. Elsewhere in Madagascar hunting does occur in roosts and therefore it can be assumed that the levels of hunting around Morondava are representative, if not lower than, the levels of hunting that occur elsewhere in the country.

Quantitative analysis using VORTEX shows that the levels of exploitation revealed by the present study are likely to cause the extinctions of populations of the average size of 500 animals within the next 100 years. The IUCN criteria consider species to be vulnerable if quantitative analysis shows that the probability of extinction in the wild is 10% within 100 years (criteria E).

Each of the three applications of the IUCN criteria indicate that even though the overall *P. rufus* population is still relatively large, the species is vulnerable because of rapid population decline. The main threat to the species is hunting and the use of shotguns in roost sites seems to be the main cause of roost extinction. The assumption that bats are classified as “pests” means that they are subject to unrestricted hunting throughout the year and at their roost sites. However, the predicted decline of *P. rufus*, its importance for the ecological processes of seed dispersal and pollination, and its vulnerable status justify the inclusion of this species on the Malagasy protected species list.

In the case of *E. dupreanum* there is insufficient data to document a real decline in the population. Although exploitation levels are relatively high, this species appears to have survived them for a long time and although most roosts in hunted areas are small, they still exist.

Very few *R. madagascariensis* roost sites are known, although the species appears to be locally common in some forested areas. It forms large colonies in caves which are themselves fragile habitats and thus individual bat roosts can easily be wiped out as they have been in many parts of the world (Vermeulen & Whitten, 1999). Its apparent association with forested areas means that its survival depends on the future of the forests. Currently there is very little information to assess the IUCN status of *R. madagascariensis* and we therefore suggest it should retain its current classification of vulnerable.

The information collected during the course of this study represents an initial assessment of the status of fruit bats in Madagascar. The continued decline of *P. rufus* threatens the existence of this species in the wild, even though the current population is relatively large. We recommend several measures to reduce the population decline. First, *P. rufus* should be considered for protected status under Malagasy law. Second, population monitoring should be started at several accessible sites where conservation projects already exist. The monitoring would provide information on population trends and would also indicate if measures taken against bat hunting were effective. Third, further research into the role of bats as pollinators and seed dispersers in Madagascar should be encouraged, particularly in sites within rainforests. Continued investment in research and education will help to ensure that bats remain on the conservation agenda in Madagascar.

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