Reproductive Behaviour and Habitat Use in the Blue-Eyed Black Lemur (*Eulemur flavifrons*, Gray, 1867) at the Sahamalaza-Iles Radama National Park, Madagascar

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Submitted in fulfilment of the academic requirements for the degree of

DOCTOR OF PHILOSOPHY

in the Discipline of Zoology

School of Biological and Conservation Sciences

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Pietermaritzburg

2009

ABSTRACT

The critically endangered blue-eyed black lemur (*Eulemur flavifrons*) is one the least-studied day active lemurs because of the recent rediscovery and limited distribution. This thesis examined the habitat use, reproductive parameters and the population viability of the blue-eyed black lemur population at Ankarafa Forest, Sahamalaza-Iles Radama National Park, Madagascar. The main aim was to gather fundamental information on the natural history of the blue-eyed black lemur and to propose conservation approaches for both the species and its habitat. Data were collected over 14 month-period between 2006 and 2008. Six groups of the blue-eyed black lemur were studied, four of which were collared and two uncollared.

Ankarafa Forest, the largest forest blocks of the Sahamalaza-Iles Radama National Park, is dominated mainly by *Mangifera indica*, *Garcinia pauciflora*, *Sorindeia madagascariensis, Grangeria porosa, Bambou* sp. and *Mascarenhasia arborescens* species. The forest is vulnerable to degradation by both anthropogenic activities and abiotic factors. The population density of the blue-eyed black lemur at Akarafa Forest was estimated to be 97.3 individuals km^{-2}, with group size ranging from 4 to 11 individuals. The home range use and day path length of the blue-eyed black lemur varied seasonally. The lemur occupied a larger home range in the dry season than in the wet season. The age of first reproduction in the blue-eyed black lemurs is about 3 years. They bear offspring seasonally (late August-October), all adult females in groups bred and females produce singletons offspring. Females were dominant over males. The sex-ratio at birth was male-biased but not significantly different from 1:1. Females were the primary caretakers of infants but group members other than the mother also provided alloparental care. For the first 3 weeks of life, infants were carried constantly on their mothers' bellies. Infants developed independent locomotion and fed on solid food by 10 weeks. Increased probability of extinction, as shown by population viability models of the blue-eyed black lemur population, is affected by various of their reproductive parameters. However, these do not account for changes in their primary habitat forest. The latter is under increased human pressure and continues to decline in area. Education awareness and community involvement are required if the habitat and the blue-eyed black lemur are to survive.

Findings of this study serve not only important data to understand the life history of the blue-eyed black lemur but also suggest conservation approaches for both the species and its natural habitat.

PREFACE

The data described in this thesis were collected in the Sahamalaza-Iles Radama National Park, Madagascar August 2006 to March 2008. Experimental work was carried out while registered at the School of Biological and Conservation Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Judith C. Masters and Prof. Colleen T. Downs.

This thesis, submitted for the degree of Doctor of Philosophy in the Faculty of Science and Agriculture, University of KwaZulu-Natal, Pietermaritzburg, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

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Maria S.N. Volampeno

August 2009

I certify that the above statement is correct…

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DECLARATION 1 - PLAGIARISM

I, Maria S.M. Volampeno, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1

MNS Volampeno, JC Masters and CT Downs. Structure and composition of trees in Ankarafa forest, Sahamalaza-Iles Radama National Park Madagascar: implications for blue-eyed black lemurs

Author contributions:

MSNV conceived paper with JCM and CTD. MSNV collected and analysed data, and wrote the paper. CTD and JCM contributed valuable comments to the manuscript.

Publication 2

MSN Volampeno, JC Masters and CT Downs. A population estimate of blue-eyed black lemurs in Ankarafa Forest, Sahamalaza-Iles Radama National Park, Madagascar

Author contributions:

MSNV conceived paper with JCM and CTD. MSNV collected and analysed data, and wrote the paper. CTD and JCM contributed valuable comments to the manuscript.

Publication 3

MSN Volampeno, JC Masters and CT Downs. Home range size in the blue-eyed black lemur (*Eulemur flavifrons*): A comparison between dry and wet seasons

Author contributions:

MSNV conceived paper with JCM and CTD. MSNV collected and analysed data, and wrote paper. JCM and CTD contributed valuable comments to the manuscript.

Publication 4

MSN Volampeno, JC Masters and CT Downs. Life history traits, maternal behaviour and infant development of the blue-eyed black lemur (*Eulemur flavifrons*): Implications for its conservation

Author contributions:

MSNV conceived paper with JCM and CTD. MSNV collected and analysed data, and wrote paper. JCM and CTD contributed valuable comments to the manuscript.

Publication 5

MSN Volampeno, JC Masters, CT Downs and GH Randriatahina. A preliminary population viability analysis of the critically endangered blue-eyed black lemur (*Eulemur flavifrons*)

Author contributions:

MSNV conceived paper with JCM, CTD and GHR. MSNV collected and analysed data, and wrote paper. JCM, CTD and GHR contributed valuable comments to the manuscript.

Publication 6

MSN Volampeno and CT Downs. Involving local community: A model of blue-eyed black lemur (*Eulemur flavifrons*) conservation

MSNV conceived paper with CTD. MSNV collected and analysed data, and wrote paper with CTD. JCM and CTD contributed valuable comments to the manuscript.

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Maria S.N. Volampeno

August 2009

ACKNOWLEDGEMENTS

First of all, I thank **Lord God** who gave me health, strength and courage for the fulfillment of this thesis.

I express my profound gratitude to my supervisor Prof. Judith Masters and my co-supervisor Prof. Colleen Downs. Many thanks Judith and Colleen for your precious guidance, tireless instruction, invaluable assistance, kindness and generosity throughout this Ph.D. Many thanks to Colleen for providing me with a peaceful office throughout my writing-up stage in South Africa. Many thanks to Judith for giving me opportunities to attend several conferences, including the Prosimian Conference in South Africa.

It was Dr Steve Goodman who advised me to register at the University of KwaZulu-Natal and helped me to find my supervisor. Many thanks Steve for helping me to make the right choice.

I am thankful to Dr Helen Crowley for supporting and helping me to find research grants. She allowed me to use some field equipments from Wildlife Conservation Society Madagascar throughout my field work. Thank you very much Helen for your generosity.

I thank Dr Steve Goodman, Dr David Meyers and Dr Christoph Schwitzer for providing me constructive comments on the research proposal. I am grateful to Dr Jonah Ratsimbazafy for providing me advices and recommendation letters to my sponsors.

I am also grateful to Prof. Mike Perrin for providing me constructive comments early thesis contents and for supporting me to receive the Gay Langmuir Bursary. I would like to thank Dr Fabien Genin for helping me with methodology issues and useful suggestions and comments early in the thesis contents.

I thank to Tina Rakotosamimanana and Paul Gordijn for providing me study site maps and Geographical Information System analysis. I am thankful to Naly Ramasinoro for providing me advices before starting my field work.

I would like to thank Madagascar National Parks for giving me research permit to work at the Sahamalaza-Iles Radama National Park.

I am very grateful to Terry, Sue and Kate Mears who always welcomed me to their house, and for their kind hospitality and generosity during my stay in South Africa. (Kate, you were a sister for me!). I thank my landlord Angus and Jane

Flockhart for taking care and considering me as part of their families me during my stay in South Africa. I wish to thank Halima, Zama, Precious, John, Marnie, Akeem, Seth, Papi, Desale, Caroline, Sahara, Zoe, Kirsten, Joy, Ebrahim, Amy, Lorinda, Justin, Zivanai, Ashwell and Sandy for their friendship and assistance. My sincere thanks guys for keeping me happy and making me laugh during stressful moments in South Africa.

I also thank my best Malagasy friends Rita, Rindra and Mamisolo for their encouragement and support.

I cannot forget to thank my assistants Zafihita, Richard, Tombomisy, Yvess, Jose, Florent Adeline, Mareline who helped me for data collection and made the jungle life warm. I would also like to thank the villagers of Marovato village for helping us to extinguish the forest fire.

I owe special thanks to my husband Guy Randriatahina for always being there, unconditional love and unfailing support. He taught me to be courageous and strong in the field whatever happened including forest fire, cyclone and during my lonely stay in South Africa. And last but not least infinite thanks to my parents, sisters and brothers who always encouraged and prayed for me throughout my life. Sincere thanks for all my families who forgave me for missing important family events and for sharing only little time for their care.

To Association Européenne pour l'Etude et la Conservation des Lémuriens (AEECL) ; Conservation International (CI) especially Dr Russell Mittermeier; Third World Organization for Women in Sciences (TWOWS) for providing me financial support, without their help this thesis would not have been possible.

To Idea Wild, Wildlife Conservation Society Madagascar and School of Biological and Conservation Sciences, University of KwaZulu-Natal South Africa for providing me with research equipment during field work. I am also most grateful to the secretarial staff of the School of Biological and Conservation Sciences, University of KwaZulu-Natal, Pietermaritzburg campus Jane Flockhart and Tanya Karalic, and the Head of School Prof Kevin Kirkman for all their support and assistance

Table of Contents

Chapter 1
Introduction

The blue-eyed black lemur (*Eulemur flavifrons*), which is the subject of this dissertation is one of the least-studied day active lemurs. This research focused one gathering data on the natural history of the blue-eyed black lemur.

Madagascar as a "hotspot country "

The majority of plant and animal species found in Madagascar are endemic because Madagascar separated from the African continent some 166 millions years ago (de Wit 2003). Madagascar is considered one of the world's biodiversity hotspots ranking among the top 5-6 megadiversity countries in the world (Mittermeier *et al*. 2006). Biodiversity hotspots refer to areas that have exceptional species richness and many endemic species (Myers *et al*. 2000). This island is also among the top 12 priority countries for biodiversity conservation (Myers 1988) and the second highest on the world list of primate species diversity (Mittermeier *et al*. 2006).

For its size (587.000 km²), Madagascar possesses a high diversity of both plants and animals. About 15.000 species of plants exist in Madagascar, 83% of which are endemic (Goodman & Benstead 2005). The 112 species of palm that exist in Madagascar represent a quarter of the whole world's species (Rubel *et al.* 2003). Fifty one per cent of birds (Hawkins & Goodman 2003), 92% of reptiles (Raxworthy 2003), 99% of amphibians (Glaw & Vences 2003) and 100% of lemurs are endemic (Mittermeier *et al.* 2006).

Despite the high level of endemism among plant and animal species, the island is facing a major biodiversity threat from development. In particular, the forest is threatened by deforestation for slash and burn agriculture and logging (Ganzhorn *et al.* 1996-7). Du Puy and Moat reported in 2003 that primary forest occupied only 18% of the surface area of the island. It is estimated that 80% of the original forest cover of Madagascar has already been converted for agriculture, fuel-wood and extraction of precious woods (Mittermeier *et al*. 2006) and the area burned annually varies between 0.5% and 5% of the island (Kull 2003).

In view of the high level of biodiversity and the serious threat to these habitats, the past president of Madagascar, Marc Ravalomanana announced during the fifth

World Park Congress in Durban, South Africa in 2003 his plan to triple the protected areas network over the succeeding next five years, from 1.7 million hectares to 6 million hectares (Mittermeier *et al.* 2006). This tremendous declaration encouraged and increased the Malagasy people's awareness to contribute to biodiversity conservation efforts. The Ministry of Environment, Water and Forest and Tourism together with the National Association for the Management of Protected Areas (ANGAP now known as Madagascar National Parks (MNP)) and conservation Non-Governmental Organizations worked hard to define new protected areas in order to achieve the challenge made by the president. For example in 2005, 919.254ha and in 2006, 1080.314ha were declared as new protected areas in Madagascar. Implementation of new future protected areas is on going (www.smbmada.net).

Lemurs

Lemurs are strepsirhine primates confined to Madagascar and nearby Islands while the other strepsirhines (galagos and lorises) occur in Africa and Asia (Stevens & Heesy 2006). There are 15 genera and 99 species and subspecies of lemurs, which are divided into five families: Lemuridae including only diurnal and cathemeral species Indriidae containing two diurnal and one nocturnal species, and Cheirogaleidae, Daubentoniidae and Lepilemuridae comprising only nocturnal species (Mittermeier *et al.* 2008). All except two lemur species occur only in Madagascar. The two exceptions (*Eulemur mongoz* and *E. fulvus*) are found on the Comoros islands but were almost certainly introduced several hundred years ago from Madagascar (Mittermeier *et al*. 2006). In body size, lemurs range from 30g, the pygmy mouse lemur (*Microcebus berthae*) up to 6 to 9.5kg, the indri (*Indri indri*) (Mittermeier *et al*. 2006) although at least two families of giant lemurs went extinct within the last several hundred years (Godfrey & Junger 2002).

There are three main vegetation types where lemurs are found in Madagascar: the tropical humid eastern rain forest, the western dry deciduous forest and the subarid spiny forest in the south and southwest (Ganzhorn *et al*. 1996/1997; Vences *et al*. 2009). It has been reported that some lemur species are important for forest tree species seed dispersal including *Eulemur fulvus, E. rubriventer*, *E. macaco*, *Varecia variegata, Cheirogalus medius, Microcebus* spp. and *Propithecus verreauxi* (Dew 1991; Ganzhorn & Kappeler 1996; Ralisoamalala 1996; Scharfe & Schlund 1996; Birkinshaw & Colquhoun 1998; Birkinshaw 1999). Seed dispersal plays an important role in forest regeneration (Medjibe & Hall 2002; Wehncke *et al*. 2003; White *et al*. 2004).

Since the arrival of humans 1500 to 2000 years ago in Madagascar, many animals have become extinct or threatened, whilst forests and other habitats have been degraded by human impacts (Green & Sussman 1990). A typical example of this is the extinction of the giant lemurs. Eight genera of lemurs have gone extinct during the past 1000 years (Cowlishaw & Dunbar 2000). The largest subfossil lemur was *Archaeoindris* (Godfrey *et al*. 1997) weighing more than an adult gorilla at about 200 kg (Cowlishaw & Dunbar 2000). The major threats to lemurs' survival are habitat destruction due to slash and burn agriculture and erosion after deforestation, timber production, charcoal production and hunting (Ganzhorn *et al*. 1996/1997; Mittermeier *et al*. 2006).

Family Lemuridae

Five genera exist within the Lemuridae: *Lemur*, *Eulemur, Varecia*, *Hapalemur* and *Prolemur (*Mittermeier *et al*. 2006). All of these genera are diurnal and living in groups. Locomotion is quadrupedal along branches with vertical clinging and leaping, practiced by bamboo lemurs. In all lemurids the hindlimbs are longer than forelimbs *(*Mittermeier *et al*. 2006). The diets of *Lemur, Eulemur* and *Varecia* consist mainly of fruits and leaves (Mittermeier *et al*. 2006) while *Hapalemur* and *Prolemur* feed primarily on bamboo (Mutschler & Tan 2003). *Varecia* is the largest lemurid species; an adult can weigh from 2.6 to 4.1 kg (Vasey 2003). *Eulemur* species are arboreal and vulnerable to predation by fossas (*Cryptoprocta ferox*) and diurnal raptor (Overdorff & Johnson 2003). Cathemeral activity is a characteristic of the genus *Eulemur* (Overdorff & Johnson 2003) and has been reported *Eulemur flavifrons* (Schwitzer *et al.* 2007), *E. fulvus* (Tattersall 1977; Meyers 1988), *E. rubriventer* (Overdorff 1988), *E. coronatus* (Wilson *et al*. 1989), *E. mongoz* (Curtis *et al.* 1999) and *E. macaco* (Andrews 1996; Colquhoun 1998).

Background information on *Eulemur macaco* and *E. flavifrons*

Eulemur macaco was the unique species of *Eulemur* to have a subspecies (*Eulemur m. macaco* and *E. m. flavifrons*) (Mittermeier *et al*. 2006). In consideration of genetic divergence and the distribution of these forms, recent studies considered them as separate species: *Eulemur macaco,* the black lemur and *E. flavifrons*, the blue-eyed black lemur or Sclater's lemur (Mittermeier *et al.* 2008). Sexual dichromatism is present in both species. These taxa differ in their coat, eye colour and habitat distribution. In black lemurs, males are brown-black while females are golden-brown. Both sexes have ear tufts and yellow-orange eyes. In contrast, blue-eyed black lemur males are completely black and females are reddish-orange. The blue-eyed black lemur does not have ear tufts and both sexes have blue-eyes (Figure 1.) (Porton & Wilson 1997). The behaviour, biology and ecology of the black lemur are well known (Bayart *et al.* 1993; Colquhoun 1993; Colquhoun 1997; Andrews & Birkinshaw 1998; Colquhoun 1998; Bayart & Simmen 2005; Simmen *et al.* 2007), but little behavioural and biological information exists for the blue-eyed black lemur. Both forms of *Eulemur macaco* species are forest dwellers living in mutli-male mutli-female groups, and they are primarily frugivores (Andrews & Birkinshaw 1998; Bayart & Simmen 2005; Randriatahina in prep.), exhibit cathemeral activity (Andrews & Birkinshaw 1998; Colquhoun 1998; Schwitzer *et al.* 2007) and breed seasonally from April to June (Colquhoun 1993; Bayart & Simmen 2005; Randriatahina in prep.).

The two species occur in the northwestern part of Madagascar (Figure 2). *Eulemur macaco* is present in three protected areas: the Nature Reserves of Lokobe and Tsaratanana and the Special Reserve of Manongarivo (Mittermeier *et al.* 2006) while *E. flavifrons* occurs only in one protected area: Sahamalaza-IlesRadama National Park. It has been reported that there is a hybrid population between black lemur and blue-eyed black lemurs locating in the north of the Andranomazala River in the Manongarivo Mountains and foothills of the southern Sambirano (Meyers *et al.* 1989; Rabarivola *et al.* 1991; Goodman & Schutz 2000). Schwitzer and Lork (2004) noted that the hybrids differ in coat colouration and ear tufts from the black lemurs and the blue-eyed black lemurs.

The blue-eyed black lemur (*Eulemur flavifrons*)

Nomenclature

Eulemur flavifrons belongs to the Order Primates, Suborder Strepsirrhini, Superfamily Lemuroidea and Family Lemuridae (Mittermeier *et al.* 2006) Koenders *et al.* (1985) reported that the karyotype of the blue-eyed black lemur is identical to that of the black lemur (2N = 44). Each sex of the blue-eyed black lemur was identified separately. Gray (1867) discovered the female, while Sclater discovered the male thirteen years later (Lernould 2002). Thus Gray firstly described the female blue-eyed black lemur as *Lemur flavifrons,* while later Sclater (1880) proposed another name *Lemur nigerrimus* for the males (Simons 1997). The resultant taxonomic confusion was clarified when a team composed of French and Malagasy biologists carried out two expeditions to the northwestern part of Madagascar in 1983 and 1984. During these trips they rediscovered a wild population of the blue-eyed black lemur. After genetic studies, it was verified that the two forms belong to the same species Gray had described as *E.flavifrons* (Koenders *et al*. 1985). Before its rediscovery, the blue-eyed black lemur was considered a mythical animal because nobody knew exactly where this lemur occurred (Tattersall 1982).

Morphology

The blue-eyed black lemur is unique, being the only non-human primate with blue-eyes (Mittermeier *et al*. 2006). It is a medium-sized lemur and an adult has a body weight of 1.87 – 2.04 kg (Randriatahina in prep.). The head and body length is between 39- 45cm, and the tail length is between 51-65cm long (Mittermeier *et al*. 2006).

Social behaviour

The blue-eyed black lemur lives in groups of six to 10 individuals, usually with more males than females in a social group and adult females form the core of the groups (Randriatahina in prep). The species is arboreal and cathemeral. Like the other species of *Eulemur*, the blue-eyed black lemur breeds seasonally at the beginning of the dry season, between April and June. Gestation lasts 120 days or more, and females generally give birth to a single infant (Randriatahina in prep). Blue-eyed black lemur females carry their infants on their bellies (pers.obs.).

Habitat and diet

The blue-eyed black lemur is a forest dweller. It is lives in degraded secondary forest and dry forest, which is a transition zone between the Sambirano region in the north and the western dry deciduous forest region in the south (Mittermeier *et al*. 2006). It is mainly frugivorous (Randriatahina, in prep). They use their hands to pick fruit or leaves and when they eat relatively large fruit, they often hold it with the hands while eating (pers. obs.).

Geographical distribution

The distribution of the blue-eyed black lemur is very restricted. It occurs only in the northwestern forests of Madagascar, limited by the Andranomalaza River from the north and the Sandrakota River from the east (Meyers *et al*. 1989). The major part of the range occurs on the Sahamalaza-Iles Radama (Mittermeier *et al*. 2006, Figure 3).

Threats and conservation status

Like most lemurs, the blue-eyed black lemur is primarily threatened by habitat destruction due to slash and burn agriculture and uncontrolled fire (Mittermeier *et al*. 2006, pers obs.). This reduces the extent of available habitat and leads to forest fragmentation which in turn results in a reduction of lemur population sizes (www.iucnredlist.org). From 1996, *E. flavifrons* has been classified as a critically endangered species (Appendix 1 of CITES, www.iucnredlist.org). The blue-eyed black lemur can be bred successfully in captivity and currently around 80 blue-eyed black lemurs live in captivity in 22 different institutions. Two of these institutions are located in its country of origin, Madagascar: the Tsimbazaza Botanical and Zoological Park, Antananarivo and the Ivoloina Zoological Park, Toamasina. Outside of Madagascar, blue-eyed black lemurs are maintained in captivity in Europe and in the United States. Duke Primate Centre in the United States hosts the largest number of captive blue-eyed black lemurs with 16 individuals (Porton 2008).

Previous studies on *Eulemur flavifrons* in the wild and in captivity

Geographic distribution

Initial studies focused on the description of this species' morphology and distribution (Koenders *et al*. 1985). Koenders and colleagues rediscovered the lemur in the forest of Befotaka (Figure 2). Later, Meyers *et al*. (1989) studied the distribution of the blue-eyed black lemur and revealed that a putative hybrid population between black lemurs and blue-eyed black lemurs occurs to the north of the Andranomalaza River in the foothills of the southern Sambirano (Figure 2). They proposed that the Andranomalaza River is the geographical barrier between these two closely related species (Figure 2). The hybrid population was found in the same habitat as the black lemur population. Surveys of blue-eyed black lemurs in the remaining forests of the Sahamalaza-Iles Radama carried out by Rakotondratsima (1999), and Volampeno (2003) showed that this lemur occurs in three different forest blocks: Anabohazo, Analavory and Ankarafa. Andrianjakarivelo (2004) inventoried the population of the blue-eyed black lemur outside the Sahamalaza-Iles Radama.

The genetic variability of subpopulations of the blue-eyed black lemurs from inside and outside the Sahamalaza-IlesRadama was investigated using RAPD markers by Fausser *et al*. (2000). No significant difference in genetic variability between subpopulations inside and outside the Peninsula was found. Fausser *et al*. (2000) suggested that the Sahamalaza-Iles Radama was the only site, which could provide an appropriate long-term habitat for the blue-eyed black lemur.

Natural history

The blue-eyed black lemur was reported to be cathemeral, with peaks of activity at dawn and dusk (Schwitzer *et al*. 2007). The amount of nocturnal activity increased with the percentage of lunar illumination (Schwitzer *et al*. (2007).

Social behaviour

A long-term study (Randriatahina in prep.) of its social organization revealed that the blue-eyed black lemur lives in multi-male and multi-female groups, with the mean group size ranging from 7.5- 8.75 individuals The adult sex ratio is male-biased and if the number of adult females in a group exceeds two, then one female leaves the group. Adult males disperse during the mating season when agonistic aggression encounters increase between males.

In captive studies female blue-eyed black lemurs were dominant over males in all groups. Adult female blue-eyed black lemurs used aggressive dominance behaviours such as chase, cuff and bite in all interactions. Older females were dominant over younger females and young males received less aggression from the females than older males (Digby & Kahlenberg 2002; Digby & Stevens 2007).

Reproduction

Reproduction in the blue-eyed black lemur has only been studied in captivity. The first captive breeding of blue-eyed black lemurs started between 1984 and 1986. During this time wild-caught blue-eyed black lemurs were exported from the Ivoloina Zoological Park to both Mulhouse and Strasbourg (Lernoud 2002). De Michelis *et al*. (1999) studied the behavioural development of three infant red-bellied lemurs and one blue-eyed black lemur in captivity for the first 12 weeks. The infant started visual and olfactory exploration at 4 weeks of age.

Historical background of the study site

Since 1988, the Sahamalaza-Iles Radama has been the focus of scientific and conservation interest by l'Association Européenne pour l'Etude et la Conservation des Lémuriens (AEECL), a consortium of European zoos for lemur research and conservation due to the presence of the blue-eyed black lemur in this region. Furthermore, the blue-eyed black lemur has been selected as the flagship species for all conservation efforts in the region (www.aeecl.org).

AEECL, together with its partners the Wildlife Conservation Society (WCS) and the national association for the management of protected areas (ANGAP now MNP) has been working on the establishment of a national protected area on the Sahamalaza-Iles Radama (Rumpler *et al*. 1996; Lernould 2002; Schwitzer & Kaumanns 2005). Since 1995, AEECL supported species inventories in Sahamalaza in order to evaluate the biodiversity richness of the region (Lernould 2002) including reptiles and amphibians (Raselimanana 1996), mammals and lemurs (Rakotondravony 1996; Rakotondratsima 1999), birds (Ravokatra 1996) and plants (Ralimanana & Ranaivojaona 1999). The coastal marine area also has a very rich ecosystem and UNESCO declared Sahamalaza-Iles Radama as a Marine Biosphere Reserve in 2001 (WCS/DEC 2002). The Sahamalaza-Iles Radama was inaugurated officially as a National Park in July 2007.

Geographical location

The Sahamalaza-Iles Radama National Park (SIRNP) is located in northwestern Madagascar in the province of Mahajanga (between 14° 04'and 14° 37' S lat and between 47° 52'and 48° 04' E long) with altitude varying from 0 to 355m (WCS/DEC 2002). The peninsula covers an area of approximately 26000ha (MNP pers. comm.), limited by the Sahamalaza Bay in the east, the Mozambique Channel in the west and the Loza River in the south (Figure 3).

The forest of SIRNP is fragmented, comprising blocks of forest such as Anabohazo, Analavory and Ankarafa Forests. These forest blocks are composed of smaller fragments either isolated or connected to each other by corridors. Anabohazo Forest is situated on the northeastern side of the SNPS (14° 18' 55''S 47° 54' 92''E) and 170m above sea level (Vences *et al.* 2005). Due to uncontrolled man-made fire in 2004, the forest of Analavory was burned entirely (pers.obs.).

My study was carried out in Ankarafa Forest (14° 22' 64.2''S, 47° 45' 31.5''E) on the western side of the SIRNP. Ankarafa Forest can be reached by a 2h boat trip from Analalava to the small village of Marovato followed by a hike of about 2h (6km) from Marovato. In 2004, AEECL have established a research station at Ankarafa Forest, which is still in use.

Climate

The Sahamalaza-Iles Radama is characterized by a subhumid climate with two distinct seasons: a hot and rainy season (December-April) and a dry season (May-November) (WCS/DEC 2002). Daily temperatures (minimum, maximum and mean) were recorded from thermometers placed in a shady location in camp for a 34-month period from May 2005 to February 2008. The highest temperatures were recorded during the wet season in December for both 2006 and 2007 while the lowest temperatures occurred in the dry season in July for both 2006 and 2007 (Figure 4). The mean monthly maximum temperature ranged from about 28.5°C in July to 39.14°C in February and the mean monthly minimum from 13.24°C in October to 21.81°C in January (Figure 5). Rainfall data were not collected due to the absence of a rain gauge. According to records from the nearest town of Analalava collected over 34 years, the mean annual rainfall for the area was 1824mm and the index of predictability of monthly rainfall was 0.438 (Dewar & Richard 2007).

The northwest monsoon wind blows obliquely onto the west coast, including the Sahamalaza-Iles Radama. This wind brings rain to the northwest coast of Madagascar during summer. Heavy rains took place at the beginning of January until the middle of March in both 2007 and 2008 (pers.obs.). The southeast trade wind blows throughout the year, and is very strong on the west coast from May to October.

Geology

The western part of the Sahamalaza-Iles Radama is composed of Albian continental sandstones with Hauterivian clays and schist in the east (Besairie 1973). The clays and schist support a rich in vegetation.

Floral and faunal richness

The vegetation of the SIRNP comprises degraded semi-deciduous forest and subhumid forest. Two hundred plants species comprising 68 families including 56 dicotyledons, 10 monocotyledons and two brackens have been recorded in the area (Ralimanana & Ranaivojaona 1999). Dominant plant families are Anacardiaceae; Apocynaceae; Ebenaceae; Euphorbiaceae; Fabaceae; Flacourtiaceae and Sapindaceae.

The Sahamalaza sportive lemur (*Lepilemur sahamalazensis*), a nocturnal lemur was recently described as a distinct species endemic to the peninsula (Andriaholinirina *et al*. 2006). This species is classified as one of the top 25 most endangered primates in the world by the IUCN/SSC Primate Specialist Group (www.conservation.org). Lemur surveys conducted by Rakotondravony and Andrimanandratra (1996) reported that *Phaner furcifer*, *Mirza coquerili*, *Cheirogaleus medius* and *Microcebus murinus* occur in the region.

At least 20 species of reptiles and three species of amphibians are found in the area (Raselimanana 1996). Recently, a new species of arboreal microhylid frog (*Cophyla berara)* was discovered at Berara a site within the Anabohazo Forest, in the northeastern part of the SIRNP (Vences *et al.* 2005). Twenty-four species of birds have been recorded including the critically endangered fish eagle (*Haeliaeetus vociferoides*) (Ravokatra 1996). I observed the carnivore *Cryptoprocta ferox* both near the campsite and in the forest in 2007. The bush pig *Potamochoerus larvatus* was frequently encountered in the forest. More than 210 coral and invertebrate species as well as three species of marine turtles are found in the coastal waters of the peninsula (WCS/DEC 2002).

Specific aims of the study

The purposes of this study were: to examine the habitat use and reproductive parameters of the blue-eyed black lemur population and to assess its viability. The main reason for choosing *Eulemur flavifrons* as a study species is that it is one of the least-studied day-active lemurs and yet is classified as critically endangered. Because of its recent rediscovery little is known about its behaviour, ecology and biology. Assessing the survival prospects of the blue-eyed black lemurs is important for both taxon and habitat conservation.

To determine the home range used by the blue-eyed black lemur, I conducted the study over two successive dry and wet seasons. In primates, food distribution and abundance have been demonstrated to affect the home range size (Takasaki 1984; Rylands 1986; Kirkpatrick *et al.* 1998; Su *et al.* 1998). Generally, home range of frugivorous species is greater that of a folivorous species (Milton & May 1976; Clutton-Brock & Harvey 1977; Mace & Harvey 1983; Nunn & Barton 2000). Because fruit trees are widely distributed in time and space, animals sometimes have to travel far to search for fruits whereas leaves are more abundant and evenly distributed thus folivorous animals spend less time moving and travel shorter distance per day (Milton & May 1976; Clutton-Brock & Harvey 1977; Robbins & McNeilage 2003). I hypothesised that the home range sizes in the blue-eyed black lemur vary seasonally due to the effect of rainfall on fruit availability. Fruits will be less available during the dry season so the blue-eyed black lemur will range further to find them. I predicted that the blue-eyed black would occupy larger home ranges in the dry season. It has been reported that seasonal home ranges indicate that the animal is able to adapt to a changing environment (Nugent 1994).

To examine the reproductive parameters of the blue-eyed black lemur, the study was carried out over two successive birth seasons. Non-human primates have been reported to prolong their period of infant development and reach maturity later and have longer life-spans compared with other mammals (Harvey & Clutton-Brock 1985; Napier & Napier 1985; Austad & Fischer 1992; Janson & van Schaik 1993; Ross 1998; Kappeler *et al*. 2003). According to Harvey and Clutton-Brock (1985) primate life history parameters are highly correlated with body size. Small-bodied primates reproduce earlier and have a higher birth rate (Isbell *et al*. 2009). Our results were compared with life history data taken from the literature to investigate the prediction that life history parameters including first age of reproduction, gestation length, birth rate and lifespan correlate with body size.

Contents of the thesis

The thesis was prepared as a series of manuscripts for submission to international peer-reviewed journals that may be read independently of each other. Papers are presented in the format required for each journal. Overlap and repetition of some details in the introduction, methodology and reference sections between chapters were therefore unavoidable.

In Chapter 2, habitat characteristics and tree diversity at Ankarafa forest are described. In Chapter 3, population size and density for the blue-eyed black lemur in Ankarafa Forest was estimated and an extrapolation of the total number of surviving individuals making up the species today was made. In Chapter 4, home range of five groups in the dry and wet seasons over two years was investigated. In addition, daily path length in the dry and wet seasons was evaluated. In chapter 5, life history traits, maternal behaviour and infant development of blue-eyed black lemur are described for the first time in order to provide the baseline information necessary to assess the survival prospects of the species. Chapter 6 is a population viability analysis using the VORTEX computer software package. In Chapter 7, a community outreach programme is documented in which I have been involved to generate local population awareness of blue-eyed black lemur and the need to conserve them and their habitat. In Chapter 8, I summarize the most relevant findings of the thesis and provide recommendations for future research in the context of conservation and primate research.

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www.aeecl.org

www.iucnredlist.org

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Figure 1. An adult female (left) and adult male blue-eyed black lemur (right).

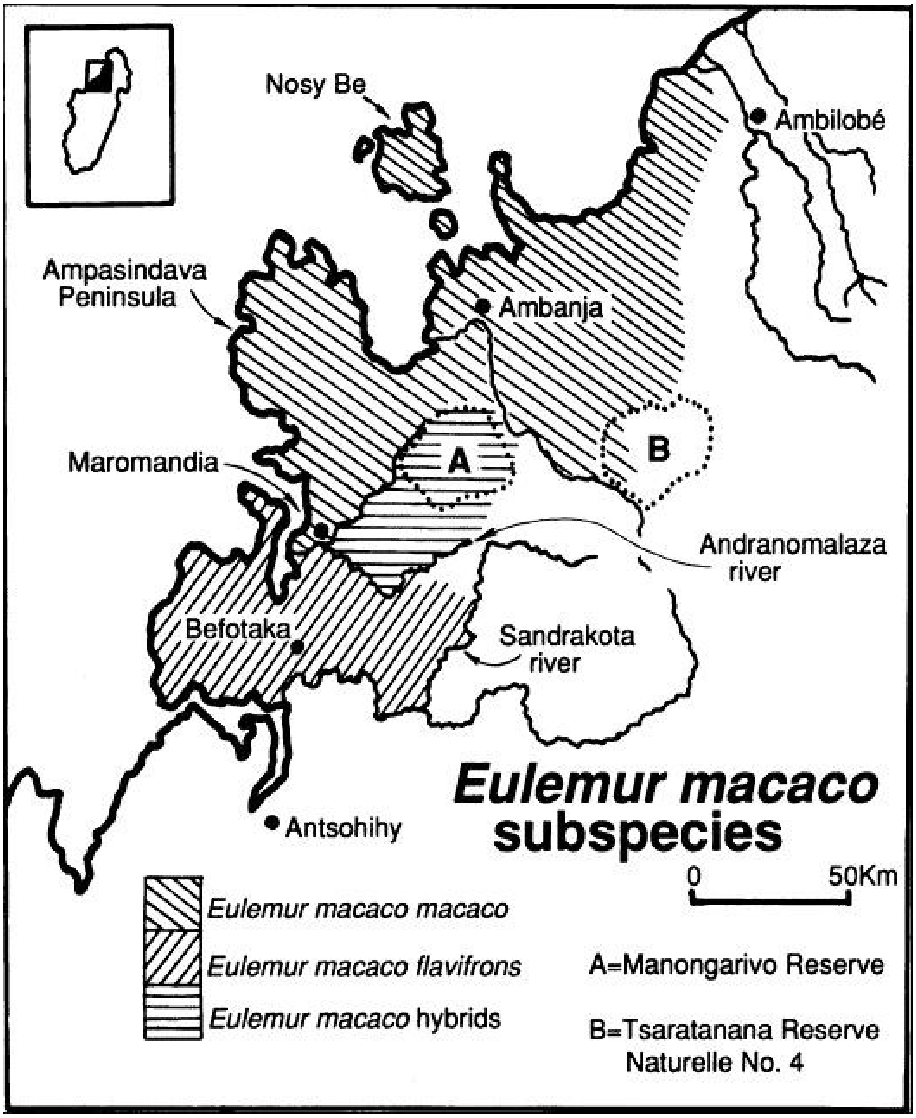

Figure 2. Distribution of *Eulemur macaco* subspecies. Map from: http://www.iucn.org**.**

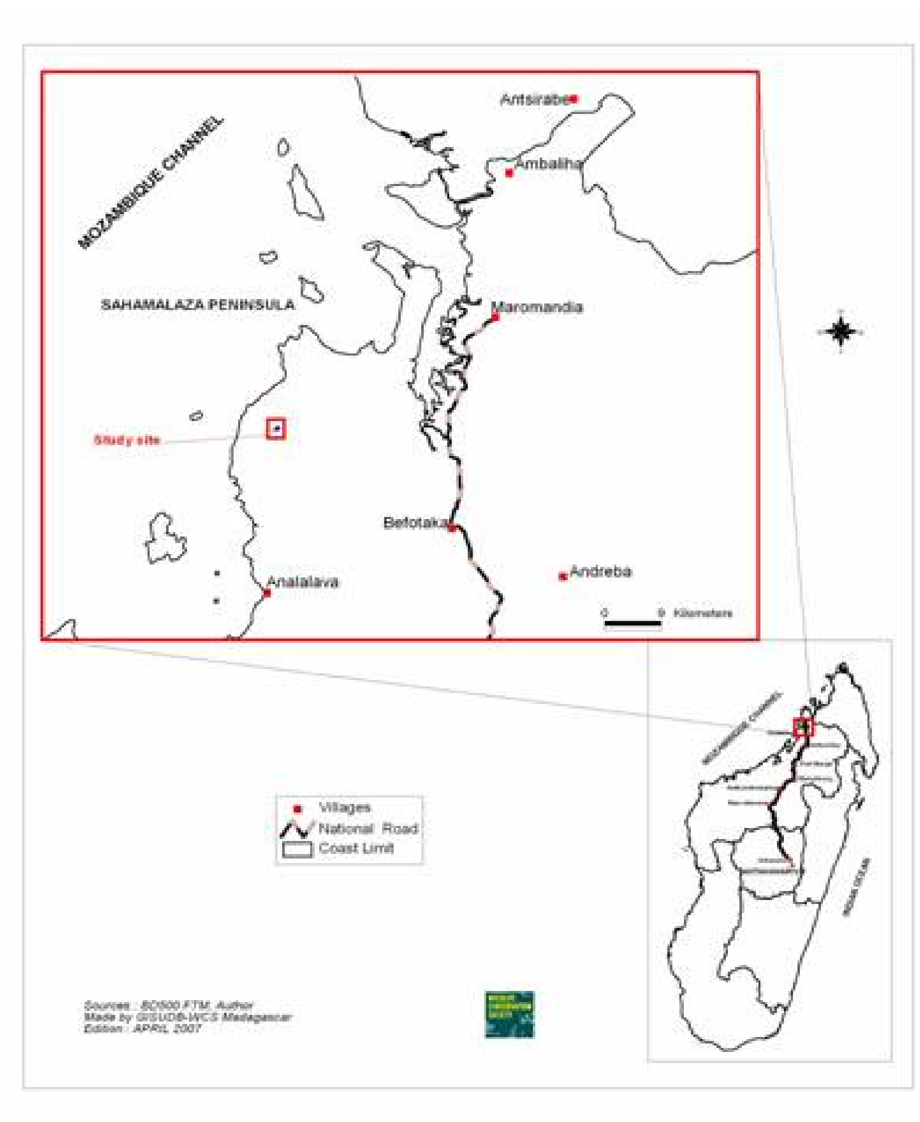

Figure 3. Location of the Sahamalaza-Iles Radama National Park, Madagascar.

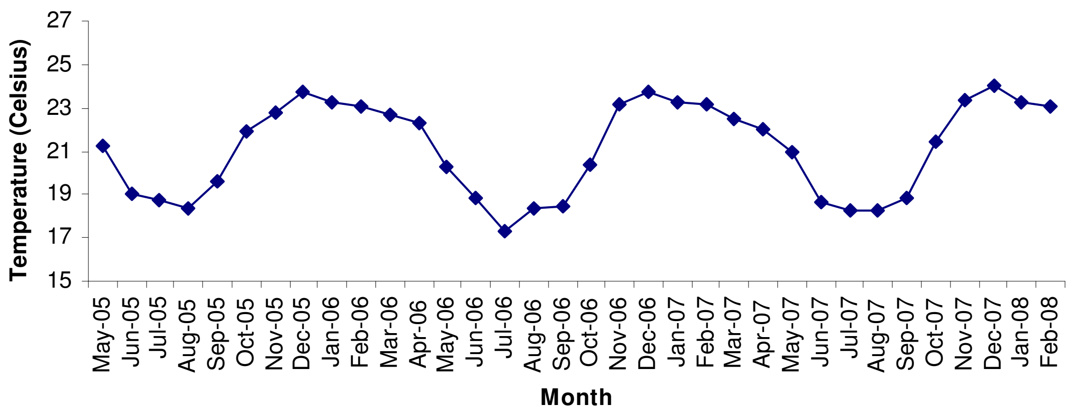

Figure 4. Monthly temperature at Ankarafa Forest between May 2005 - February 2008.

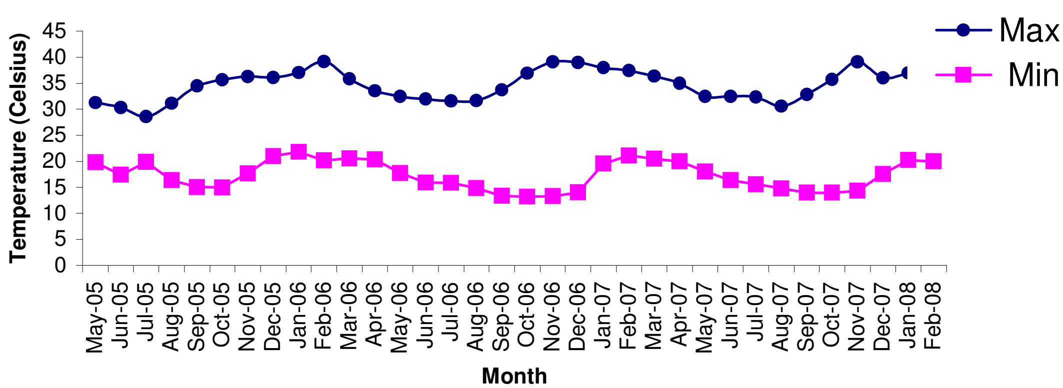

Figure 5: Monthly mean minimum and maximum temperature at Ankarafa Forest (May 2005-February 2008).

Chapter 2

Structure and composition of trees in Ankarafa forest, Sahamalaza-Iles Radama National Park Madagascar: implications for blue-eyed black lemurs[1]

Abstract

Composition, structure and distribution of trees in Ankarafa forest in the Sahamalaza-Iles Radama, the most recent area inaugurated officially as a National Park in Madagascar were evaluated to determine their influence on the spatial and temporal ecology of the blue-eyed black lemur (*Eulemur flavifrons*). Plots of 20 x 20 m were placed within the forest core (n = 15) and on the forest edges (n = 15). A total of 848 trees belonging to 42 species, 39 genera and 28 families were recorded. Ankarafa forest is dominated mainly by *Mangifera indica*, *Garcinia pauciflora*, *Sorindeia madagascariensis, Grangeria porosa, Bambou* sp. and *Mascarenhasia arborescens.* Canopy height was lower than most tropical forests but similar to other Malagasy forests with average tree height of 10 ± 3.6 m and mean diameter at breast height of 13.8 ± 11.7 cm. Height and diameter of trees differed significantly between the edge and core of the forest. Along the forest edge, many trees were burnt by uncontrolled fire. Trees felled by cyclones were recorded both on the edge and in the core of the forest. Although relatively high in tree species diversity, Ankarafa forest needs to be protected if it is to continue to support fauna, particularly those with restricted distribution such as the blue-eyed black lemurs. In particular, the impact of human activities needs to be restricted to prevent further forest degradation and fragmentation.

Keywords: Ankarafa forest, core, edge, fire, Sahamalaza-Iles Radama National Park, Madagascar

[1] Revised for the *South African Journal of Botany*: Maria S. N. Volampeno, Judith C. Masters and Colleen T. Downs, Structure and composition of trees in Ankarafa forest, Sahamalaza –Iles Radama National Park Madagascar: implications for blue-eyed black lemurs

1. Introduction

The forests of Madagascar represent one of the world's most exceptional concentrations of plant diversity and endemism (Barthlott et al., 1996). Vegetation types of the island continent vary widely: the east has rainforest; the west has dry, deciduous forest and the south is characterised by dry, spiny forest (Du Puy and Moat, 1998). Madagascar's plants represent 3.2 % of the world's plant species (Dumetz, 1999; Myers et al., 2000). More than 80% of the vascular plants in Madagascar are endemic (Robinson, 2004). Despite the high level of plant endemism, Malagasy vegetation is highly threatened by forest overexploitation, logging, and by slash and burn agricultural practices (Ganzhorn et al., 2001).

Since the arrival of humans approximately 2000 years ago, the dry deciduous forest of western Madagascar has become highly fragmented (Smith, 1997). Primary forest cover in the western dry forests declined from 12.5% in 1950 to 2.8% in 1990 (Smith et al., 1997). Decline of the dry forest is due to clearing for agriculture, timber harvest and charcoal production (Sussman and Rakotozafy, 1994; Sussman et al., 2003) which are common as the west has a short growing season and poor soils (Sorg et al., 2003). The west and southern dry forests have lower species richness compared with the eastern rainforests, but contain important fauna and flora including the baobab tree (*Andansonia* spp.), of which six species are endemic to Madagascar (Razanameharizaka et al., 2006). The dry forest of the semi-arid south and southwest contain an estimated 48% of endemic genera and 95% of the endemic plants species (Koechlin, 1972; Rabesandratana, 1984). Dry forests remnants in Madagascar are reported to be not only biologically rich and important but also listed among the ecosystems of highest conservation priority (Laurance and Bierregaard, 1997; Ganzhorn et al., 1997).

Forest fragmentation reduces the forest area, increases the number of forest patches, decreases the forest patch size and increases the patch isolation (Fahrig, 2003), has an effect on ecosystem services (Bodin et al., 2006), and affects seed dispersal of trees (Cramer et al., 2007). It has been demonstrated that forest fragmentation affects the diversity and abundance of plants and animals (Tabazanez and Viana, 2000; Ganzhorn et al., 2003; Benitez-Malvido et al., 2003; Cushman, 2006; Barlow et al., 2006). In tropical rainforests, fragmentation has been reported the main cause of reduction in biological diversity (Laurence et al., 1997). Because of forest fragmentation, forest edges increase whereas forest cores become smaller

(Laurance et al., 2000; Wei and Hoganson, 2007). Forest cores are areas which are free of edge effects (Zipper, 1993; Baskent and Jordan, 1995). It has been reported that plant diversity and characteristics differ between the forest core and the forest edge (Honnay et al., 2002), and the degree of degradation is severe at the forest edge (Laurance et al., 2000; D'Angelo et al., 2004; Nacimento and Laurance, 2004). Long-term studies have demonstrated that the mortality of large trees is higher near forest edges (Laurance et al., 2000; Nascimento and Laurance, 2004). In addition, the lifespan of large trees at the forest edge may be a third of the lifespan of those located over 300m into the forest (Laurance et al., 2000).

Ankarafa forest is situated within the Sahamalaza-Iles Radama National Park (SIRNP), Madagascar, and is the main habitat of the critically endangered blue-eyed black lemur (*Eulemur flavifrons*) (Mittermeier et al., 2006). The SIRNP is located in north-western Madagascar and comprises dry, deciduous forest. The first census of the vegetation of the Sahamalaza Peninsula, conducted at three forest sites including Ankarafa forest, revealed at least 200 plant species; 42% of which are endemic to Madagascar (Ralimanana and Ranaivojaona, 1999).

For an understanding of the spatial and temporal dynamics that affect the ecology of the blue-eyed black lemur, a description of the tree diversity, distribution and structure in this poorly known forest type in Madagascar was needed. Consequently the aims of this study were to assess the plant diversity, particularly tree species, and investigate the distribution and structure of tree species in Ankarafa forest. In addition, we compared trees occurring in the forest core with those growing at the edges to determine if these were different and possibly affect spatial distribution and movement patterns of these lemurs. Furthermore, we assessed the seasonal availability of fruits in the study site for these frugivores, as well as determined evidence of human disturbance.

2. Materials and methods

2.1. Study area

The largest forest block of the SIRNP is fragmented, and includes Ankarafa forest. The study was carried out in Ankarafa forest (14° 22' 64.2''S, 47° 45' 31.5''E; 0-355m asl) in the western part of the SIRNP (Fig. 1) which is 234.23ha in area and is characterised by deciduous/evergreen species. The area is characterised by a sub-humid climate with two distinct seasons: a hot rainy season (December-April) and a dry season (May-November) (WCS/DEC, 2002). According to records taken at the nearest town Analalava, the mean annual rainfall for the area is 1824 mm (Dewar and Richard, 2007). SIRNP is both protected and managed, and timber and wildlife harvesting is not permitted.

2.2. Vegetation sampling

Data were collected in September 2008. We used the quadrat method to assess the forest species diversity and characteristics (Sorrells and Glenn, 1991). Plots measuring 20 x 20m were established in Ankarafa forest, with 15 near the forest edge and 15 within the forest core. Edge plots were 10m within the forest while core plots were >30m from the forest edge. Plots were spaced approximately 100 m apart and covered a total area of approximately 1.2 ha for the cumulative 30 plots. Within these plots, the species identities of all trees with a diameter at breast height (dbh) >5 cm were recorded, and their heights estimated by eye. To minimise observer-linked variation in height estimates, these were performed by the same observer in all the plots. Furthermore, any evidence of human disturbance, such as tree felling or poachers' traps, was recorded. Geographical coordinates of each plot were recorded using a Global Positioning System (GPS) (e-Trex, Garmin Inc., USA) so that plots may be reassessed in future studies. Trees were identified to species (where possible). For each sample plot we briefly described type of terrain (e.g. flat or slope) and estimated slope.

Madagascar's forest vegetation consists mainly of trees. We assessed the degree of stratification of trees with a dbh $\geq$ 5 cm by assigning them to three categories identified by Mueller-Dombois and Ellenberg (1974): tree/canopy layer: plants taller than 5 m; shrub layer: plants with a height between 1 and 5 m and herb layer: plants with a height between 50 - 100cm.

Fruiting tree species were identified, and grouped into four categories on the basis of phenological data previously collected (Randriatahina unpubl. data), as follows: beginning of dry season (April and May); middle of dry season (June to August); end of dry season (September and November) and wet season (December to March).

2.3. Data analyses

The following parameters were evaluated after Kershaw (1973), Venter (1976) and Mueller-Dombois and Ellenberg (1974): relative density (RD): number of individuals of one tree species as a percentage of the total number of individuals of all species; relative frequency (RF): number of plots containing a given tree species as a percentage of total number of plots in which all tree species were sampled; relative dominance (RDo): total basal area of one species as a percentage of the total basal area for all species; and importance value (IV) as the sum of RD + RF + RDo.

Simpson's index was used to calculate the species diversity between forest edges and forest cores (Ludwig and Reynolds, 1988):

$$\lambda = \sum \frac{ni(ni-1)}{N(N-1)}$$

where *ni* = number of individuals of each species; N = total number of individuals of all species for forest core or forest edge.

Chi-square tests were used to compare parameters between core and edge of the forest including species diversity of fallen trees. We used the Mann-Whitney test to evaluate whether relative density and relative frequency of tree species differed between forest egdes and core areas. All data were expressed as mean ± SD.

3. Results

3.1. Vegetation structure and diversity

Within the 30 plots sampled, 848 living trees belonging to 42 species, 39 genera and 28 families were recorded. The vegetation of Ankarafa Forest was dominated mainly by *Mangifera indica, Garcinia pauciflora, Sorindeia madagascariensis, Grangeria porosa, Bambou* sp. and *Mascarenhasia arborescens* (Table 1). The most frequent species were *M. indica, G. porosa, G. pauciflora, M. arborescens, S. madagascariensis, Homallium axillare* and *Macarisia lanciata* (Table 1). The families with high importance values (IV) were Anacardiaceae (84.5%); Clusiaceae (23.9%); Burseraceae (20.6%) and Fabaceae (17.3%, Table 1). Overall, tree height ranged from 2.5 - 25m (10.5 ± 3.1 m). The dbh of trees (> 5 cm) varied between 5.1 to 109.3 cm (mean: 13.8 ± 11.7 cm). Most (92%) plant species belonged to the tree/canopy layer with only 8% in the shrub layer.

On the forest edge 368 trees were recorded in the 15 plots. Average number of trees per plot was 24.5 ± 16.6 (range 4-53 trees). Tallest tree species were *M. lauciolata* (20 m) and *G. porosa* (19 m) on the forest edges. Within the forest cores 480 trees were recorded. Numbers of tree species per plot varied between 10 and 60, and the mean per plot was 32 ± 16.6. *Canarium madagascariensis* (25 m) and *M. indica* (20 m) were the tallest tree species within the forest core. Mango (*M. indica*) was ranked the most common species in both forest edges and forest cores (Table 2). The forest core had trees larger in height (11.1 ± 3.7 m) and diameter (14.4 ± 13.7 cm) compared with the forest edges (height: 9.6 ± 3.2 m; diameter: 13.06 ± 9.92cm). Height (χ^2 = 52.43, df = 4, P < 0.05, Fig. 2) as well as the diameter (χ^2 = 33.25, df = 4, p < 0.05, Fig. 3) of tree species between the forest edges and cores differed significantly. There was no significant difference between forest core and edges for relative density of tree species (Mann-Whitney test U = 42, p > 0.05) as well as the relative frequency (Mann-Whitney test U = 42, p > 0.05) and relative dominance (RDo) (Mann-Whitney Test, U = 42, p > 0.05). Species diversity on the forest edges (λ = 0.067) was not significantly different to the forest cores (λ = 0.121), (χ^2 = 0157, df = 1, p > 0.05). The heterogeneity of the forest core was evident from the size class distribution of trees (Figs 2 and 3).

The forest was generally flat with 16 of the 30 (54%) quadrats sampled on flat terrain while 14 were on slopes (46%). In the forest core slope ranged from 3 to 75% while on the forest edge slope varied between 5 to 45%.

Of the 42 species recorded in the 30 quadrats and used for the phenological analysis, 33 (78%) produced fruits. Only 3% of these fruited all year around; 11% at the beginning of dry season; 23% in the middle of dry season; 28% at the end of dry season and 35% in the wet season (Table 3). Food availability in terms of fruit is similar throughout on a spatial scale, but differs in availiability on a temporal scale.

3.2. Forest disturbance

Relatively few trails used by humans or zebu cattle were present in both the forest edges and core. Only three clearings from human exploitation (former slash and burn agricultural fields) were found. In September 2007 we discovered an area of approximately ½ ha in the forest core containing felled trees that would be burned to make way for a rice paddy field. We also found a felled rosewood tree (*Dalbergia* sp.), which had been cut into a beam within the forest (Fig. 4).

In total, 747 trees were recorded that had died naturally or as a result of fire. Seventy-four percent of these trees were on the forest edge while 26% were found within the forest core. Two cyclones occurred during the study period, and the numbers of trees felled as a result of these events were similar between the edge (n= 50) and core of the forest (n= 55) ($\chi^2 = 0.23$, df. = 1, $P > 0.05$

During our study in 2006, a fire spread from a nearby grassland to Ankarafa forest. The fire coincided with a strong trade wind which aided its development and spread. Sections of the forest were destroyed, and many plants on the forest edge and in a part of the forest core were burned. This fire was apparently started by humans, but spread to the forest accidentally.

4. Discussion

Ankarafa forest trees within the forest core had a greater mean height and diameter than those at the forest edges. These tree heights are typical of Malagasy forests that generally exhibit relatively low canopy heights compared with other tropical forests (D'Amico & Gautier, 1999; Dumetz, 1999; Rakotomalaza & Messmer, 1999; de Gouvenain & Silander, 2003; Grubb, 2003). These heights are similar to those tropical forests that have frequent disturbance such as cyclones (de Gouvenain & Silander, 2003). Madagascar is subject to cyclones annually and probably for a very long-time (Jury, 2003). In 2006 a strong cyclone damaged the western part of Madagascar, including the Sahamalaza Peninsula where many trees were damaged by strong winds (pers. obs.). Tropical storm regimes with frequent cyclones are known to affect the forest canopy height (de Gouvenain & Silander, 2003) and damage trees (Curran et al., 2008). In addition, the low stature of the forests and paucity of large girth trees in Malagasy lowland forests is possibly a consequence of the relatively old and nutrient-poor soils (Grubb, 2003).

The tree composition of Ankarafa forest was relatively high but similar to other lowland tropical rainforests (LaFrankie et al. 2006). Malagasy forests are characterised by their high species richness and high endemicity in the lowland rainforests relative to other tropical rainforests, especially the closely related African ones (Grubb, 2003).

Generally, species diversity in Ankarafa forest was similar between forest edges and the core suggesting even distribution of tree species. This suggests that the entire forest is suitable habitat for the endemic mammalian frugivorous species found there. Food availability in terms of fruit is similar throughout on a spatial scale, however differs on temporal scale. Previous studies have indicated that the forest edges were primarily responsible for forest heterogeneity (Lyon and Jensen, 1980; Alverson et al., 1988; Decalesta, 1997), whereas in our study, the core areas are equally or even more heterogeneous when trees >5cm dbh were considered.

Forest edges differed to the forest core in Ankarafa forest in terms of number of dead trees. Generally abiotic conditions (e.g. exposure to sunlight, wind speed, temperature and humidity fluctuations) on forest edges are different from those in forest cores (Saunders et al., 1991; Matlack, 1993; Murcia, 1995), and these conditions affect vegetation composition and structure (Malcolm, 1994; Kapos et al., 1997). Because of this dissimilarity, mortality of large trees may be higher at the edges (Laurance et al., 2000). In addition, trees at the edges are more susceptible to fire (Cochrane and Laurance, 2002), uprooting or breakage because the wind turbulence (Dewalle, 1983; de Gouvenain & Silander, 2003; D'Angelo et al., 2004). In our study it was evident that forest edges were affected by abiotic as well as human factors.

Of all major lowland tropical forest habitats, tropical dry forest is the most threatened because of its susceptibility to fire and ease of farming (Janzen, 1988). Despite the fact that the Sahamalaza Peninsula is a protected area, human impacts such as tree felling and forest clearance for slash and burn agriculture are still present. However, human exploitation has decreased since the establishment of the research site in Ankarafa in 2004. Before this many lemur traps and felled trees were found (Randriatahina pers comm.). The western part of Madagascar is characterised by a long, dry season (Scholz and Kappeler, 2004). Consequently, rainfall is insufficient to support agriculture in this region (Villagers pers. comm), and fewer local people practice slash and burn methods to grow rice, the Malagasy staple food. However, in the Sahamalaza Peninsula most of the households have free-ranging cattle (MSNV pers. obs.). The local population burns grass on the forest edges and in grassland areas to allow the growth of young grasses for their livestock pastures (pers. obs.). This occurs particularly toward the end of the dry season (September-October) just before the first rains. This practice results in regular uncontrolled fires on the peninsula. Fire from the grasslands spreads through the forest edge and into the forest core if it is not extinguished (pers. obs.). In Madagascar most fires occurring in the western region are caused by humans (Urs, 1999).

Thus, Ankarafa forest is an area that is vulnerable to degradation by both anthropogenic and abiotic factors, which act synergistically to drive forest fragmentation and loss. During the period of this study, we witnessed significant impacts on the forest structure, which underlines the crucial importance of protection for the area and its wildlife.

4. Conclusion

This study showed high diversity of trees in Ankarafa Forest. Most trees bore fruits, and fruit availability occurred mainly in wet season. Forest edges did not differ significantly from the core areas in terms of tree species diversity. Although the Sahamalaza-Iles Radama National Park is a protected area, human impacts still have a negative effect on forest structure (e.g. the presence felled trees and clearings). As anthropogenic disturbance impacts threaten the forest it is need of greater protection. In particular, firebreaks surrounding the forest borders are recommended to avoid fires spreading into the forest.

Acknowledgements

This research was supported by grants to MSNV from Conservation International (CI), Association Européene pour l 'Etude et la Conservation des Lemuriens (AEECL) and the Third World Organization for Women in Sciences (TWOWS). The research of JCM is supported by the National Research Foundation. We thank the School of Biological and Conservation Sciences, University of KwaZulu-Natal, IdeaWild and Wildlife Conservation Society Madagascar Program. We also thank ANGAP for giving us permission to conduct our research in Sahamalaza-Iles Radama National Park. We are grateful to Guy Randriatahina for his advice and assistance in the field, and for sharing his phenological data. Special thanks are due to Zivanai Tsvuura for sharing his botanical expertise, and to our local assistants Tombomisy, Zafihita, Yvess, Florent, Adeline and Marlyne.

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Figure legends

Figure 1: Location of the Sahamalaza-Iles Radama National Park, Madagascar.

Figure 2: Comparison of forest tree height on the edges and cores of Ankarafa Forest, Sahamalaza Peninsula National Park, Madagascar.

Figure 3: Comparison of forest tree diameters on the edges and cores of Ankarafa Forest, Sahamalaza Peninsula National Park, Madagascar.

Figure 4: A felled rosewood tree found in Ankarafa Forest showing impact of human exploitation.

Table 1: Phytosociological parameters of all tree species recorded in Ankarafa forest, Sahamalaza-Iles Radama National Park, Madagascar.

Family	Species	n	D (stems.ha^{-1})	BA (m^2.ha^{-1}).	IV
Anacardiaceae	*Mangifera indica*	188	156.67	0.02916	98.25
Clusiaceae	*Garcinia pauciflora*	97	80.83	0.01079	72.45
Chrysobalanaceae	*Grangeria porosa*	57	47.5	0.01066	67.73
Apocynaceae	*Mascarenhasia arborescens*	48	40	0.00669	52.84
Anacardiaceae	*Sorindeia madagascariensis*	68	56.67	0.00873	52.16
Erythroxylaceae	*Erythroxylum platycladum*	31	25.83	0.02069	43.24
Poaceae	*Bambou sp*	49	40.83	0.00248	42.55
Fabaceae	*Albizia sp*	11	9.17	0.02794	40.77
Ebenaceae	*Diospyros sp*	13	10.83	0.19455	39.79
Fabaceae	*Hymenaea verrucsa*	41	34.17	0.00580	37.53
Tiliaceae	*Grewia sp*	14	11.67	0.01393	36.30
Euphorbiaceae	*Antidesma petiolare*	3	2.5	0.00608	34.25
Menispermaceae	*Burasaia madagascariensis*	6	5	0.01491	32.11
Clusiaceae	*Harongana madagascariensis*	13	10.83	0.00406	31.91
Olaceae	*Olax sp*	3	2.5	0.01251	31.53
Burseraceae	*Canarium madagascariensis*	12	10	0.01727	26.25
Euphorbiaceae	*Bridelia pervilleana*	11	9.17	0.01911	26.08
Arecaceae	*Dypsis lutescens*	8	6.67	0.03934	24.42
Moraceae	*Treculia perrieri*	16	13.33	0.00906	22.74
Fabaceae	*Milletia aurea*	6	5	0.00431	21.94
Euphorbiaceae	*Petalodiscus platyrachis*	16	13.33	0.00588	21.04
Sapindanceae	*Macphersonia gracilis*	9	7.5	0.17209	19.70
Anacardiaceae	*Poupartia silvatica*	1	0.83	0.02711	18.83
Ochnaceae	*Campylospermum anceps*	9	7.5	0.01373	18.79
Rhamnaceae	*Zizyphus jujuba*	1	0.83	0.04242	18.51
Fabaceae	*Dalbergia sp*	7	5.83	0.14515	17.15
Rhizophoraceae	*Macarisia lanciolata*	24	20	0.02092	16.13
Combretaceae	*Terminalia perrieri*	10	8.33	0.01137	14.98
Loganiaceae	*Strychnos madagascariensis*	7	5.83	0.00384	14.39
Asteraceae	*Brachylaena perrieri*	5	4.17	0.00982	14.23
Rubiaceae	*Garderus runterbergiana*	6	5	0.00412	11.45
Flacoutiaceae	*Homalium axillare*	28	23.33	0.02071	8.85
Moraceae	*Bosqueia sp*	11	9.17	0.00515	8.22
Moraceae	*Ficus tiliaefolia*	2	1.67	0.01050	8.12
Fabaceae	*Albizia gummifera*	1	0.83	0.12728	8.10
Clusiaceae	*Mammea punctata*	2	1.67	0.03573	6.82
Clusiaceae	*Mammea vatoensis*	1	0.83	0.03262	6.52
Saliaceae	*Scolopia madagascariensis*	1	0.83	0.00334	4.35
Asteraceae	*Brachylaena ramiflora*	1	0.83	0.00639	4.28
Rubiaceae	*Canthium sp*	6	5	0.00716	4.12
Ptaeroxylaceae	*Cedrelopsis grevei*	3	2.5	0.00716	4.12
Aphloiaceae	*Alphoia theiformis*	2	1.67	0.00244	3.79

n= number of stem for each species; D= mean tree density for each species; BA= mean basal area per species; IV = importance value

Table 2: The 10 most common tree species at the edges and in the core of Ankarafa forest.

Rank	Forest edge	Number of trees	Forest core	Number of trees
1	*Mangifera indica*	59	*Mangifera indica*	129
2	*Garcinia pauciflora*	36	*Sorindeia madagascariensis*	61
3	*Grangeria porosa*	34	*Garcinia pauciflora*	61
4	*Erythroxylum platycladum*	31	*Bambou sp*	43
5	*Homalium axillare*	24	*Mascarenhasia arborescens*	30
6	*Hymenaea verrucsa*	25	*Grangeria porosa*	23
7	*Macarisia lanciolata*	21	*Hymenaea verrucsa*	17
8	*Mascarenhasia arborescens*	17	*Treculia perrieri*	15
9	*Petalodiscus platyrachis*	16	*Canarium madagascariensis*	12
10	*Grewia sp*	11	*Diospyros sp*	9

Table 3: Fruiting periods of tree species in Ankarafa forest, Sahamalaza-Iles Radama National Park, Madagascar.

Family	Species	BD	MD	ED	W
Anacardiaceae	*Mangifera indica*			X	X
Anacardiaceae	*Sorindeia madagascariensis*		X	X	X
Anacardiaceae	*Poupartia silvatica*			X	X
Aphloiaceae	*Alphoia theiformis*				X
Apocynaceae	*Mascarenhasia arborescens*				
Arecaceae	*Dypsis lutescens*				X
Asteraceae	*Brachylaena perrieri*				
Asteraceae	*Brachylaena ramiflora*				
Burseraceae	*Canarium madagascariensis*				X
Chrysobalanaceae	*Grangeria porosa*			X	X
Clusiaceae	*Garcinia pauciflora*	X	X	X	X
Clusiaceae	*Harongana madagascariensis*		X	X	
Clusiaceae	*Mammea vatoensis*		X	X	
Clusiaceae	*Mammea punctata*				
Combretaceae	*Terminalia perrieri*				
Ebenaceae	*Diospyros sp*				X
Erythroxylaceae	*Erythroxylum platycladum*				X
Euphorbiaceae	*Petalodiscus platyrachis*				X
Euphorbiaceae	*Bridelia pervilleana*	X	X		X
Euphorbiaceae	*Antidesma petiolare*				X
Fabaceae	*Hymenaea verrucsa*		X	X	X
Fabaceae	*Albizia gummifera*				
Fabaceae	*Milletia aurea*			X	
Fabaceae	*Dalbergia sp*		X	X	
Fabaceae	*Albizia sp*				
Flacoutiaceae	*Homalium axillare*				X
Loganiaceae	*Strychnos madagascariensis*			X	X
Menispermaceae	*Burasaia madagascariensis*		X	X	
Moraceae	*Treculia perrieri*		X	X	X
Moraceae	*Bosqueia sp*	X			X
Moraceae	*Ficus tiliaefolia*	X	X	X	
Ochnaceae	*Campylospermum anceps*			X	X
Olaceae	*Olax sp*				X
Poaceae	*Bambou sp*				
Ptaeroxylaceae	*Cedrelopsis grevei*		X	X	
Rhamnaceae	*Zizyphus jujuba*		X		
Rhizophoraceae	*Macarisia lanciolata*		X	X	
Rubiaceae	*Garderus runterbergiana*	X	X		
Rubiaceae	*Canthium sp*				X
Saliaceae	*Scolopia madagascariensis*				
Sapindanceae	*Macphersonia gracilis*	X			X
Tiliaceae	*Grewia sp*	X	X	X	X

BD: beginning of dry season (April-May); MD: middle of dry season (June-Aug); ED: end of dry season (Sept-Nov); W: wet season (Dec-March).

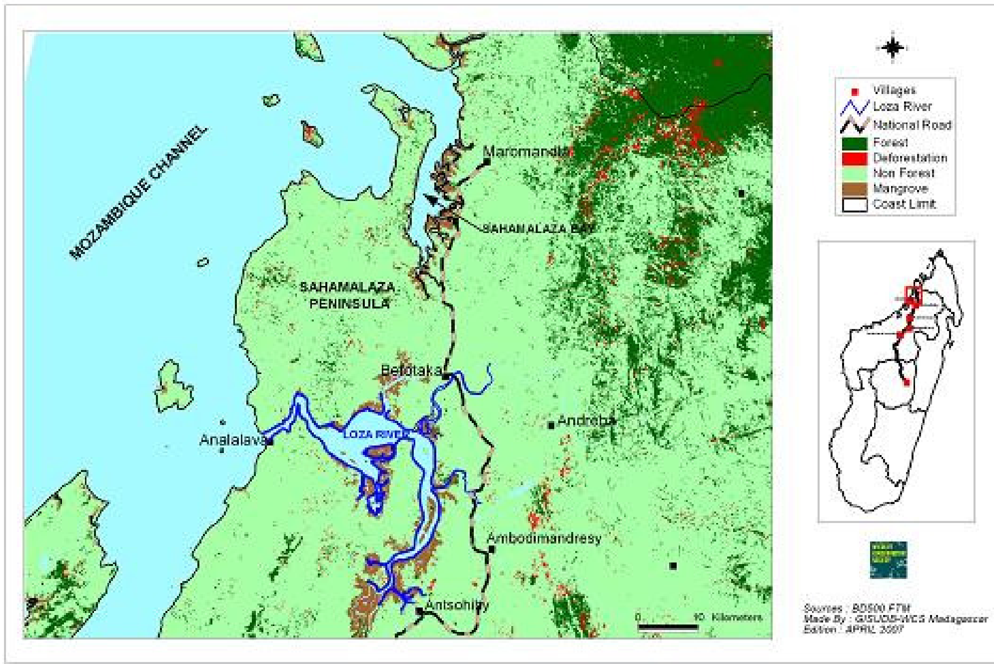

Figure 1: Location of the Sahamalaza-Iles Radama National Park, Madagascar.

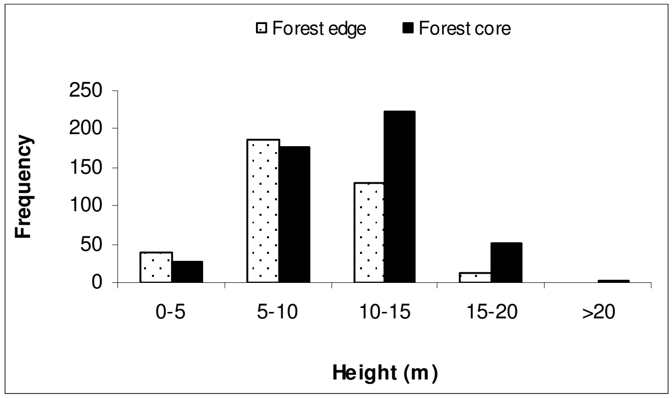

Figure 2: Comparison of forest tree height on the edges and core of Ankarafa Forest, Sahamalaza-Iles Radama National Park, Madagascar

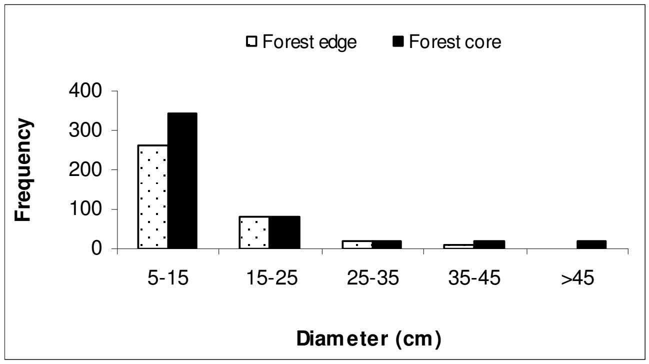

Figure 3: Comparison of forest tree diameter on the edges and core of Ankarafa Forest, Sahamalaza-Iles Radama National Park, Madagascar.

Figure 4: A felled rosewood tree found in Ankarafa Forest showing the impact of human exploitation

Chapter 3

A population estimate of blue-eyed black lemurs in Ankarafa Forest, Sahamalaza-Iles Radama National Park, Madagascar[2]

Abstract

The critically endangered blue-eyed black lemur (*Eulemur flavifrons*) has one of the smallest distributions among day active lemurs, occurring only in the north-western forests of Madagascar. We report the results of a population estimate of this taxon in the Sahamalaza-Iles Radama National Park, a dry deciduous forest. We collected data between September 2007 and February 2008 using a modified direct total count with marked individuals. In all, 228 individuals comprising 29 groups were counted. Group sizes ranged from 4 to 11 individuals with a mean of 8 ± 1.8. We estimated population density to be 97.3 individuals km^{-2}, which is higher than previous estimates reported for Ankarafa and other sites within the Sahamalaza Peninsula. However, our mean group size was similar to those determined in previous studies. Both group size and density were higher within the National Park than in previous studies outside the Park.

Keywords: blue-eyed black lemur, direct count, *Eulemur flavifrons*, Madagascar, density, Sahamalaza-Iles Radama

Introduction

Estimating animal densities and distributions are essential procedures for wildlife conservation and habitat management (Thomas, 1991; Hoare 2000). Direct animal counts provide baseline densities against which future surveys can be measured (Plumptre and Cox, 2006), and allow assessment of the conservation status of species (Rylands et al., 1997; Cowlishaw and Dunbar, 2000). Density and distribution data also facilitate estimates of the importance of different habitats for conservation, and are crucial for the development and monitoring of management strategies.

Most primate species, because of their reliance on forests, are particularly vulnerable to ongoing habitat disturbance (Fashing, 2002), and many species show

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[2] Revised for *Mammalia* : Maria S. N. Volampeno, Judith C. Masters and Colleen T. Downs, A population estimate of blue-eyed black lemur in Ankarafa forest, Sahamalaza-Iles Radama National Park, Madagascar.

evidence of declining population densities (Cowlishaw and Dunbar, 2000). The lemuroid primates of Madagascar are some of the most threatened taxa, due chiefly to the loss of 80-90% of forest habitats on the island (Du Puy and Moat, 1998). Since the arrival of humans 1500 to 2000 years ago in Madagascar, at least 17 lemuroid species have become extinct (Godfrey and Jungers, 2003; Mittermeier et al., 2006). Lemur habitats are constantly being destroyed by slash and burn agriculture and erosion after deforestation, timber exploitation and charcoal production (Mittermeier et al., 2006). Some lemur species are hunted for food (Nicoll and Langrand, 1989; Mittermeier et al., 1992), although the impact of these practices on population viability is not known. For the majority of lemur species, accurate estimates are still unavailable (Mittermeier et al., 2006).

To our knowledge, only three surveys of blue-eyed black lemur (*Eulemur flavifrons*) populations have been conducted within the Sahamalaza Peninsula (Rakotondratsima, 1999; Volampeno, 2003; Randriatahina and Rabarivola, 2004). Previously *Eulemur macaco* had two subspecies *E. macaco macaco* and *E. macaco flavifrons* (Mittermeier et al., 2006) but recent studies consider them as separate species based on genetic divergence and distribution: *E. macaco*, the black lemur and *E. flavifrons,* the blue-eyed black lemur or Sclater's lemur (Mittermeier et al., 2008). The blue-eyed black lemur is the least-studied member of the genus *Eulemur*; it was rediscovered only recently (Koenders et al., 1985). It has one of the smallest geographic ranges (Mittermeier et al., 2006). Most of its range falls within the Sahamalaza-Iles Radama. *E. flavifrons* is classified as critically endangered (Appendix 1 of CITES, www.iucnredlist.org) due to habitat destruction and increasing forest fragmentation from forest exploitation, uncontrolled fire and slash and burn agriculture (Mittermeier et al., 2006). The urgent need to conserve this lemur necessitated the establishment of Sahamalaza-Iles Radama National Park (SIRNP) in 2007.

Our study aimed to determine the population size of the blue-eyed black lemur in Ankarafa Forest, Sahamalaza-Iles Radama and to contribute an update on the population's conservation status and to keep track of the population's prospects for survival. A direct total count method was used and this was reportedly a first for lemuroid primates.

Materials and Methods

Study site

The study was carried out in Ankarafa Forest (47° 45' E long, 14° 22' S lat; 0-355m above sea level), in the western part of the SIRNP which is 234.23ha in area (see Volampeno et al. in prep.). The SIRNP is located in north-western Madagascar in the province of Mahajanga. The vegetation is composed of degraded semi-deciduous forest. Volampeno et al. (in prep.) describes the vegetation structure of Ankarafa Forest in detail. The study site is characterized by a sub-humid climate with two distinct seasons: a hot and rainy season (December-April) and a dry season (May-November). Mean monthly temperature maxima ranged from about 28.5°C in July to 39°C in February and mean monthly minima from 13°C in October to 22°C in January. According to records taken at the nearest town, Analalava, the mean annual rainfall for the area is 1824mm (Dewar and Richard, 2007).

Data collection

Whereas previous surveys of lemur populations have used line transect techniques, we chose instead to employ a modified direct total count method with marked individuals to estimate the population size and density of blue-eyed black lemurs in Ankarafa Forest which was limited in size. Lemur groups were already habituated to the presence of researchers as research has been conducted in the area since 2004. Four of the groups were marked with collars of a group-specific colour (green, blue, pink and yellow) marked by a previous researcher (Randriatahina). In addition, each animal within a group had its own unique mark on its collar and a name for individual identification.

We conducted censuses between September 2007 and February 2008. A pair of observers walked the existing trails, which covered all appropriate forest types (Table 1). Trails had been prepared by local guides and ranged in length from 700 to 1300m were 683 ± 3.24m far apart, and covered 65% of the forest. The mean sighting distance was 4.5± 1.0m. Trails were used occasionally by local people. Each trail was walked once a week from 06h:00 to 10h:00, when blue-eyed black lemurs are most active (Schwitzer et al, 2007). During counting, observers walked slowly and silently. When a group of lemurs was sighted, observers remained with the group and followed until all individuals had been counted. Our method was based on repeated identification of social groups. We identified and differentiated the free-ranging groups because we noted the place that we found the group; group size and group composition and were confident that we were discriminating between unique groups. Each trail was walked twice over two consecutive weeks. To avoid double-counting the groups encountered along the same path, we considered only groups of maximum group size. During the observations we noted the time, location of the group, and number of individuals per group.

In addition, we determined the age-sex classes of each group encountered. Distinguishing between adults and juveniles was difficult because of similarities in body size. In addition, all but six of the groups counted were not habituated to the presence of humans. When we approached the groups more closely in order to determine individual ages, the animals fled. We therefore grouped together adult and juvenile males and non-lactating females with juvenile females. We categorized only lactating females as adult females. Our census coincided with the birth season, and identification of the sexes of many of the newborn infants was not possible. We therefore excluded infants of unknown sex from the sex-ratio calculation.

Blue-eyed black lemur densities were calculated by dividing the number of individuals recorded by the total area covered during the survey. A Global Positioning System (GPS) (E-Trex Garmin Inc.USA) was used to record the study site borders. For preparation of a detailed accurate map of the area all GPS locations were entered into Geographical Information System (GIS) ArcView 3.2 (Environment System Research Institute Inc., (ESRI), Redlands, California).

Results

Abundance and group size

Walking 10 trails, we recorded 228 individual blue-eyed black lemurs comprising 29 groups. Group sizes ranged from 4 to 11 individuals (Mean = 8, SD = 1.8) (Table 2). Five of the 29 groups encountered did not have infants. The population density of the blue-eyed black lemur in Ankarafa Forest was estimated to be 97.3 individuals km^{-2} with 12.4 groups km^{-2} (Table 3).

The forest of SIRNP is fragmented, comprising blocks of forest including Ankarafa, Anabohazo, Analavory and Ambohitra. These blocks are far apart and not connected to each other by corridors. In addition, the blue-eyed black lemurs might be completely missing from Analavory Forest because of an uncontrolled man-made fire that burnt the entire forest. Therefore, we can only reliably predict the population size of the blue-eyed black lemurs in the Ankarafa forest and not the entire SIRNP. So if the total area of SIRNP or its forest fragments is used to extrapolate the population size, this resulted in a highly erroneous estimate of abundance of 25308 individuals in the total forest area.

Age-sex classes and sex ratios

Differentiation of the blue-eyed black lemur in Ankarafa Forest according to age and sex was as follows: 18% infants, 18% adult lactating females, 16% non-lactating and juvenile females, and 48% adult and juvenile males. We found a male-biased adult/juvenile sex ratio (1.42), which deviated significantly from the expected ratio of 1:1 (χ^2=5.19, $P<0.05$). The infant sex ratio did not deviate significantly from 1:1 (χ^2=0.042, $P>0.05$). Including all animals of known sex, the sex ratio was male-biased (1.43) and deviated significantly from 1:1 (χ^2=4.3, $P<0.05$).

Discussion

Social group size and sex-ratio

Our results of numbers of blue-eyed black lemur in social groups in Ankarafa Forest were consistent with previous studies with group size ranging from 4 to 11 individuals (mean ± SD, 8 ± 1.8. individuals). Randriatahina and Rabarivola (2004) reported that the group size ranged from 7 to 11 individuals (mean ± SD, 7.8 ± 1.9 individuals). In a long-term study of the blue-eyed black lemur in Ankarafa Forest from 2004 to 2007 (Randriatahina in prep.) found group size ranged from 6 to 11 individuals (mean ± SD 8.6 ± 1.1 individuals). Rakotondratsima (1999) found group size ranged from 5.2 ± 4.5 to 6 ± 3.7 (mean ± SD) individuals at three other sites (Anabohazo, Analavory and Ambohitra) which were lower than Ankarafa Forest. This may be a consequence of several factors including forest habitat size and quality as well as degree of illegal hunting. Rakotondratsima (1999) reported a high incidence of lemur traps in the forests he surveyed and observing villagers returning with hunted blue-eyed black lemurs from the forest. Outside the Sahamalaza-Iles Radama, Andriajankarivelo (2004) estimated 112 individuals in 17 groups distributed in 10 sites with a mean group size of 4.7 (± 2.9) individuals which was lower than our study.

Regarding the other closely taxa *E. macaco*, the black lemur, investigators have reported that the groups range in size from 4 to 14 individuals (Colquhoun, 1993; Bayart and Simmen, 2005) showing that group size is similar between this species and the blue-eyed black lemur. The geographic range of the former is broader than that of the latter.

We had difficulties in distinguishing the age classes of each sex so we grouped adults and juveniles together. We found a male-biased sex ratio for the adult/juvenile groups. Our results support those found by Randriatahina (in prep.) and Rakotondratsima (1999). According to Randriatahina (in prep.), males usually outnumber females in social groups, and the number of adult females do not exceed three per group. Similarly a male-biased sex ratio has also been observed in *E. macaco* (Bayart and Simmen, 2005).

Numbers of blue-eyed black lemurs

Our estimate of numbers of blue-eyed black lemurs in Ankarafa Forest was higher (228 individuals) than previous studies. Rakotondratsima (1999) conducted a brief survey of blue-eyed black lemurs on the Sahamalaza-Iles Radama (three sites other than Ankarafa Forest) and found 77 individuals. Randriatahina and Rabarivola (2004) carried out a population estimate in Ankarafa Forest and found 39 individuals, while Volampeno (2004) estimated 145 individuals in Ankarafa Forest. Several factors may have resulted in our increased estimate of numbers of blue-eyed black lemurs in Ankarafa Forest, including the method used, the survey period and duration, and the habitat conditions. Previous population surveys were conducted using the line transect method, while we used direct counts. Our survey was conducted over a period of six months, while previous surveys were of much shorter duration. Finally, our survey concided with the birth season and did not include the individual migration period, while previous studies were carried out before the birth season. According to Randriatahina (in prep.) female migration takes place before the birth season while male migration coincides with mating period (March-April). We suggest that migration might have affected the previous surveys results as all of the survey coincided with both female and male migration.

The population density of blue-eyed black lemurs in Ankarafa Forest was higher than outside the Sahamalaza-Iles Radama where the estimated population density was 24 individuals km^{-2} (Andriajakarivelo, 2004). Again this may be a consequence of several factors including forest habitat size and quality, as well as degree of illegal hunting. For instance, Andrianjakarivelo (2004) reported relatively high levels of illegal hunting with 88 lemur traps counted in the 10 sites he visited. This suggests that hunting represents a major threat to the blue-eyed black lemur, and may be a signigicant factor affecting numbers. In addition, forests outside the SIRNP are not yet protected, and human pressures continue to be a problem. Consequently habitat quality differs between the non- and protected areas which may further affect numbers of blue-eyed black lemur present.

Since the establishment of the research camp in the Ankarafa Forest in 2004, we have not found any lemur traps in this forest. Further, establishment of the SIRNP in 2007 has led to a decline in human impacts on the environment, like slash and burn agriculture, the establishment of fields inside the forest, and forest exploitation (Volampeno et al., in prep.). Nevertheless, villagers still practice some logging inside the forest. During our surveys, we found a rosewood tree (*Dalbergia* sp.) that had been cut down and had already been transformed into a beam (Volampeno et al., in prep.).

As mentioned we could only reliably predict the population size of blue-eyed black lemurs in the Ankarafa Forest and not the entire SIRNP as the distribution of the species is fragmented and the blocks of forests are far apart. So if the total area of SIRNP or its forest fragments is used to extrapolate the population size, this resulted in a highly erroneous estimate of abundance within the SIRNP. The SIRNP represents the main part of the blue-eyed black lemur distribution but this lemur also inhabits areas outside the Peninsula. Therefore further studies are required to determine a total population estimate of the blue-eyed black lemur.

Method used

There are various methods to count animals for estimating population size (Buckland et al., 2005). The body size, activity patterns, habitat, visibility, abundance, time and budget constraints are important in determining which census method to use for a particular mammal species (Krebs, 2006). A direct count which attempts to count all the individuals in the population can be successful, particularly for small populations where individual recognition is possible (Greenwood and Robinson, 2006). The total count method is one such technique which observes a population of animals over time until no new individuals are seen, however this method can be time-consuming and there is the possibility that some animals are never observed (Greenwood and Robinson, 2006).

Another method, the mark-recapture method, is also suitable for small populations (less than a hundred) of small mammals that can be marked and identified individually (Borchers et al., 2002; Greenwood and Robinson, 2006) and the ratio of marked to unmarked individuals is applied to estimate the total population size. The assumptions of this method are that marks are not lost and that the capture and marking procedures do not affect the behaviour of the animals (Borchers et al., 2002; Greenwood and Robinson, 2006). Biases can occur if individuals are misidentified, either mistaking a marked individual for a new individual or vice versa (Borchers et al., 2002; Greenwood and Robinson, 2006). A further assumption of this method is that all individuals are equally trappable or detectable, otherwise the population size will tend to be underestimated (Borchers et al., 2002, Pollock et al., 2004; Greenwood and Robinson, 2006). However, Borchers et al. (2002) say the effects of heterogeneity are small if 80-90% of the population are identifiable. Open population mark-recapture methods require that the population be sampled at least three times (Southwood & Henderson, 2000).

The modified total count method with marked individuals was used to estimate the blue-eyed black lemurs in Ankarafa Forest in this study. According to our knowledge, this is the first published account estimating lemur population densities using this modified direct total count method. Direct total counts are only feasible in restricted areas like Ankarafa Forest. Compared with the line transect technique and as some individuals were marked, our method enabled us to record precise details of group size and composition, yielding more reliable estimates of population density. This method could give overestimates of population density if individuals or groups are counted more than once. To counter this, we performed repeated observations and had groups that had been marked. Repetition of observation is useful for the estimation of primate population because it provides an improved estimate. The direct total count has been used successfully for other primate species such as the gorilla (*Gorilla beringei*) in the Virunga Volcanoes and Bwindi Impenetrable National Park (Harcourt and Fossey, 1981, Harcourt et al., 1983, Mcneilage et al., 1998). This appears to be a reliable estimator particularly when groups are known.

Conclusions

Our study shows the value of using the modified direct total count method with marked or known individuals to estimate the size and density of primate populations living in restricted areas, particular when the species are diurnal or cathemeral with peaks of activity in the morning as is characteristic of the genus *Eulemur* (Overdorff & Jonhson, 2003) and has been reported *E. flavifrons* (Schwitzer et al., 2007). Our results provide the most recent update on the size of the blue-eyed black lemur population in Ankarafa Forest. However, the population should be monitored on a regular basis in order track of the population's prospects for survival. Assessing the population status of such critically endangered species is crucial for park managers and decision makers to construct successful conservation plans. No population survey has yet been conducted across the entire forest area of the Sahamalaza-Iles Radama. We believe this is an essential exercise if we are to gain insight into the survival prospects of the entire blue-eyed black lemur population.

Acknowledgments

We thank the ANGAP for giving us permission to conduct our research in Sahamalaza National Park. Our research was funded by Association Européenne pour l'Etude et la Conservation des Lémuriens (AEECL), Conservation International (CI), and the Third World Organization for Women in Sciences (TWOWS). We acknowledge the School of Biological and Conservation Sciences, University of KwaZulu-Natal, South Africa, IdeaWild and Wildlife Conservation Society Madagascar Program for equipment support. Special thanks are due to Guy

Randriatahina, Tiana Rakotosaminanana our local assistants Tombomisy, Zafihita, Yvess, Florent, Adeline and Marline.

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Table 1. Description of each census trail in this study.

Trail	Description
1	About 80% burned due to man-made uncontrolled fire Many died tree cutting down including bamboo trees Tall trees still alive including mango trees and *Canarium madagascariensis*
2	Near a paddy field and a former hamlet
3	Near a halmet, close to clearings for a slash and burn agriculture
4	Presence of a stream and of bamboo trees Lemurs were seen sometimes drink water from the stream
5	Presence of a stream, Raffia plantation Clearing for a former paddy field and former hamlet Many mangos trees, few cashew nut trees, coconut trees and lemon trees
6	Dominated by *Soreindeia madagascariensis* tree Presence of tree cutting down by the cyclone
7	Dense vegetation with tall trees,
8	Presence of bamboos trees and mangos trees
9	A part of this area was burned in October 2006 Few died trees cutting down Dominated by mango trees
10	Presence of mango trees, cashew nut trees, bamboo trees Many young trees.

Table 2. Number of blue-eyed black lemur recorded in each trail in Ankarafa Forest, Sahamalaza-Iles Radama National Park using the direct count method.

Trail	1	2	3	4	5	6	7	8	9	10	Total
No. of individuals	30	25	23	9	28	36	34	7	15	21	228
No. of groups	4	3	3	1	3	5	4	1	2	3	29
Range in size	4 to 9	6 to 11	7 to 9	9	8 to 10	5 to 9	6 to 11	7	7 to 8	4 to 11	
Mean ± SE group size	7 ± 2.4	8 ± 2.5	8 ± 1.2	9	9 ± 1.2	7 ± 1.5	9 ± 2.1	7	8 ± 0.7	7 ± 3	

Table 3. Summary of the abundance estimates of blue-eyed black lemur

Site	Sex Ratio	Density (ind/km²)	Total. Individuals	Total numbers of groups	Mean group size (± SE or SD)	Method	Sources
Ankarafa (Sahamalaza)	1.42	97	228	29	8 ± 1.8	Direct count	This study
Ankarafa (Sahamalaza)	1.43	Not determined.	39	5	7.8 ± 1.9	Survey	Randriatahina and Rabarivola 2004
Other site (Sahamalaza)	0.71	129.76	77	13	5.2 ± 4.5	Survey	Rakotondratsima 1999
10 sites out of Sahamalaza	1.03	24	112	17	6.0 ± 3.7	Survey	Andrianjakarivelo 2004

Chapter 4

Home range size in the blue-eyed black lemur (*Eulemur flavifrons*): A comparison between dry and wet seasons[3]

Abstract

Western Madagascar is subjected to a long, dry winter season which coincides with food scarcity. We investigated the effect of this seasonal variation in food availability on the home ranges of blue-eyed black lemurs (*Eulemur flavifrons*) in the Sahamalaza – Iles Radama National Park, north-western Madagascar. It was expected that home range would increase and overlap more in dry season. The study was conducted in an area of dry rainforest from September 2006 to March 2008 with five lemur groups. Animals were located by direct observation and geographical locations recorded to determine the daily path length and the home range sizes of the study groups in the respective seasons. Daily path length and home range size varied significantly between seasons. Daily path length was significantly greater in the dry season (673.4 ± 539.2 m) than in the wet season (423.6 ± 183.2 m). Home ranges overlapped between groups in both seasons, but were significantly larger during the dry season (MCP: 7.5 ± 6.6 ha, 95% Kernel: 8.5 ± 6.6 ha) than in the wet season (MCP: 3.0 ± 1.6 ha, 95% Kernel: 4.1 ± 1.6 ha). There was no clear relationship between home range size and group size in either the dry or the wet season. Seasonal changes in home range area are likely to be a consequence of reduced food availability in the dry season. Compared to other primates, including some lemur species, the home range size of the blue-eyed black lemur is relatively small.

Key words. lemur · home range · seasonal variation ·food scarcity · group size

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[3] Revised for *Mammalian Biology* : Maria S. N. Volampeno, Judith C. Masters and Colleen T. Downs, Home Range size in the blue-eyed black lemur (*Eulemur flavifrons*): A comparison between dry and wet seasons

Introduction

The home range of an animal is traditionally defined as the area that the animal traverses "in its normal activities of food gathering, mating and caring for young "(Burt, 1943). A home range can be measured on an annual or longer, seasonal or daily time scale (Jewel, 1966; Warren and Crompton 1997). As the home range size is related to the availability of environmental resources, various factors including season, habitat quality, weather, age-sex class, distribution of mating partners, and activity pattern affect home range size. A home range may therefore be used as a rough indicator of the animal's resource requirements (Perry and Garland, 2002). Seasonal changes in home ranges indicate that the animal is able to adapt to a changing environment (Nugent, 1994). Home range studies are important because they provide important information for habitat evaluation and conservation planning (Li et al., 2000).

Primate home range sizes have been shown to be influenced by many factors such as distribution and availability of food resources, diet, group size, specific dietary requirements, presence and density of neighbor groups (Isbell, 1983; Rigamonti, 1993; Watts, 1998; Tan, 1999; Scholz and Kappeler, 2004). According to Milton and May (1976) and Lehman et al. (2007) home range size is correlated with body size in primates species. Because of increased energetic requirements, large animals occupy large home range areas with high productivity to meet their metabolic demands (Swihart et al., 1988; Fernandez and Vrba 2005). For similar reasons, group size has been documented as affecting home range size in primate species (Davidge, 1978; Suzuki, 1979; Takasaki, 1981). Large groups occupy larger home ranges than small groups in many, but not all, primate populations (Takasaki, 1984; Isbell et al., 1998; Watts, 1998). Large groups also travel longer distances depending on the size, density and distribution of preferred food patches (Chapman et al., 1995).

The present study investigated the seasonal home range size variation in the blue-eyed black lemur (*Eulemur flavifrons*). Previously it was considered a subspecies but recent studies consider it as separate species based on genetic divergence and distribution (Mittermeier et al., 2008). This lemur is a unique non-human primate as it has blue eyes (Mittermeier et al., 2006). It is a medium-sized (1.87 to 2.04kg) (Randriatahina in prep.), cathemeral member of the family Lemuridae (Mittemeier et al., 2006; Schwitzer et al., 2007a). The species is arboreal, frugivorous, and lives in social groups where the sex ratio is male biased (Randriatahina in prep; Volampeno, 2009). The distribution of the blue-eyed black lemur is restricted to a small area of forest in north-western Madagascar, and the Sahamalaza-Iles Radama National Park (SIRNP) is situated in the heart of the subspecies' range (Mittermeier et al., 2006). The forests of the Sahamalaza-Iles Radama are transitional sub-humid forest, with plants from both the Sambirano region in the north and the western dry deciduous forest region in the south (Schwitzer et al., 2007b). They also affected by timber exploitation, forest fires, and the practice of slash and burn agriculture (Mittermeier et al., 2006). Due to habitat destruction and increasing forest fragmentation, the blue-eyed black lemur is classified as a critically endangered subspecies (Mittermeier et al., 2006). The taxon was described by Gray in 1867 but no detailed research was done until its "rediscovery" in 1985 (Koenders et al., 1985*)*. Little is known about its behaviour, ecology and biology (Mittermeier et al., 2006; Schwitzer et al., 2007b). They breed seasonally, with births occurring at the end of the dry season and infants are weaned by week 25 (Volampeno, 2009).

The climate of Madagascar may be divided into two separate seasons: the wet season in summer (December-March), during which monsoon winds bring storms, and the dry season in winter (May-September), when the trade-wind blows (Jury 2003). The climate of the island is characterized by extremely unpredictable rainfall (Dewar and Richard 2007). The western and southern regions of the island are characterized by several months without precipitation (Richard et al., 2002), and the winter dry season may extend for eight months (Sorg and Rohner, 1996). The period of abundant fruiting trees is typically during the wet season, so that the dry season coincides with food shortage (Wright, 2006).

Consequently, this study mapped the daily and seasonal home ranges of blue-eyed black lemur groups. We hypothesised that the home range sizes vary seasonally as consequence of the effect of rainfall on fruit availability, and predicted that home ranges would be greater and overlap in the dry season. Understanding the ranging patterns of blue-eyed black lemurs is important for quantifying their spatial and ecological needs, which in turn are crucial for conservation and management of small populations that inhabit fragmented forests.

Materials and methods

Study site

We carried out the study in Ankarafa Forest (14° 22' 64.2''S lat and 47° 45' 31.5''E long), in the western part of the SIRNP. The vegetation of the SIRNP comprises a mixture of degraded semi-deciduous forest and subhumid forest (WCS/DEC 2002). The area is characterized by a subhumid climate with two distinct seasons: a hot and rainy season (December-April) and a dry season (May-November). Monthly mean maximum temperature ranged from 28.5 ± 3.6ºC in July to 39.1 ± 2.1ºC in February and monthly mean minimum temperature ranged from 13.2 ± 0.8ºC in October to 21.8 ± 0.8ºC in January. According to records taken at the nearest town Analalava, the mean annual rainfall for the area is 1824 mm (Dewar and Richard 2007) with most of the rain in December-April.

Study period and study groups

We conducted the study from September 2006 to March 2008. This period included the end of two dry seasons (September to November, 2006 and 2007), and two wet seasons (January to March, 2007 and 2008). Five focal groups of blue-eyed black lemur were chosen, four of which were marked by a previous researcher (Randriatahina) who fitted them with collars of a group-specific colour (green, blue, pink and yellow). In addition, each animal within a group had its own unique mark on its collar and a name for individual identification. The collar was made of nylon and approximately 10 cm in circumference, depending on the neck size of the individual. The fifth group was uncollared, but easily recognized by the group size and daily movements in the forest. This group fed on mango trees (*Mangifera indica*) close to the research camp each day.

Data collection

Individuals could readily be located in the study area, which was of limited size, so that radio-telemetry was not necessary. Furthermore, the lemur groups were already habituated to the presence of researchers, as research has been conducted in the area since 2004. One group was followed per day on a rotational schedule. Each group was followed for an uninterrupted period from 07:00 until 17:30. Overall, 10 days were dedicated to following each group within each three month period, making a total of 40 days' all-day follows per group. Geographic coordinates of the focal groups' locations were recorded every 30 min using a Global Positioning System (GPS) (e-Trex, Garmin Inc., USA). Trees used by the group were individually tagged using a coded fluorescent flag. If the group returned to a place where they had been seen previously, the same waypoints were not re-recorded, while the code of the flag on the tree was. We followed zebu and human trails while searching for the animals. Trails had been prepared by the local guides and ranged in length from 700 to 1300m, were 683 ± 3.24m far apart, and covered 65% of the forest. We recorded the time when we entered the forest and the time when we found the groups, to evaluate the time spent searching for a particular group on any given day.

Data analyses

All GPS waypoints were converted into decimal degrees and entered into Geographical Information Systems Arcview 3.2 and ArcGIS 9.3 software (Environmental Systems Research Institute Inc., Redlands, California) with the Home Range Extension (HRE; Rodgers and Carr 1998) to calculate the home range size. Two methods were used to determine the home range size: the Minimum Convex Polygon (MCP) method (Hayne, 1949) to calculate maximum home range size and the Fixed Kernel method (Worton, 1989) to determine 95% of home range. The MCP method has been widely used and allowed comparison for our data with previous studies. It has been demonstrated for home range estimates that, when the time interval between locations is short, location data are autocorrelated (Swihart and Slade 1985; 1997), yielding underestimates of home range size (Mares et al., 1980; Swihart and Slade 1985). Independent observations contain more spatial information than autocorrelated observations (Swihart and Slade 1985). Therefore, for unbiased estimates, location data should be collected at longer sampling intervals and the number of observations should be maximized (De Solla et al., 1999). The Fixed Kernel method was chosen because it has been shown to be less sensitive to autocorrelation biases (Swihart and Slade 1997). It was reported the best method for home range estimate (Worton, 1989; Seaman et al., 1996; Kemohan et al., 2001). For the daily path length calculation, we summed the distance between consecutive GPS locations over a day. We considered only complete follow days (≥ 7 hours) to calculate the daily path length for each group during the dry and rainy seasons. As this is a cathemeral species this only gives an estimate of path length during the day.

Statistical analyses were performed using Statistica (6.0, Tulsa, USA) and non-parametric tests were used as the data were not normally distributed. We used the Wilcoxon test to evaluate whether home range sizes differed between wet and dry seasons, and conducted a Spearman rank correlation test to examine whether group size correlated with home range size. A Chi-square test was used to compare total home range sizes among the five groups studied. All data were expressed as means ± SD.

Results

Group search duration

Because the five lemur groups were not radio-collared, the time spent searching for each varied between groups and seasons (Table 1). Mean time spent searching for the five groups followed was 15 ± 17 min (range 0 - 70 min) during the dry season and 20 ± 23 min (range 0 - 90 min) in the wet season. However, the duration of search time during the two seasons did not differ significantly (Wilcoxon test, $Z = -1.71$, $P = 0.08$).

Location records and group size

In total, 552 locations were recorded for the five lemur groups over 200 days in 2006-2008, with 376 locations during the dry season and 176 locations during the wet season. An average of 110 ± 28.4 locations was recorded per group. Over the study period mean group size was 7.8 ± 1.1 individuals. During the dry season group size ranged from 6 to 10 individuals (8.1 ± 1) while from 6 and 9 individuals (7.6 ± 1) in the wet season (Table 2). Group size did not differ significantly between seasons (Wilcoxon test, $Z = -1.15$, $P = 0.24$).

Daily path length (dpl)

Overall, mean dpl of blue-eyed black lemur groups were 645.2 ± 517 m (range 48.1 - 2707.6 m). Green group had the longest dpl (2707.5 m) during the dry season while blue group had the longest dpl (696.4 m) during the rainy season. Mean dpl during the dry season was 673.4 ± 539.2 m (minimum = 48.1 m, maximum = 2707.6m) while in the wet season it was 423.6 ± 183.2 m (minimum = 258 m, maximum = 696.4 m). Dpl differed significantly between dry and wet seasons (Wilcoxon test, Z = -1.96, P = 0.04).

Home range size

Using the MCP Method, the average total home range size of the blue-eyed black lemur groups over the study period was estimated to be 5.3 ± 5.2 ha. Using the Fixed Kernel method, 95% of home range size was estimated to be 6.3 ± 5.7 ha.

Seasonal home range size

The MCP data were combined for the dry seasons of 2006 and 2007 and for the wet seasons of 2007 and 2008. Home range sizes of blue-eyed black lemur groups determined using MCP method differed significantly between the dry and wet seasons (Wilcoxon test, Z = - 2.80, P = 0.005, Fig. 1). They occupied larger home ranges during the dry season (7.5 ± 6.6 ha) than in the wet season (3.0 ± 1.6 ha). Dry season home range sizes ranged from 2.7 ha to 25.2 ha, while the wet season home range sizes varied between 0.8 ha to 5.5 ha. Of the five groups followed, pink group occupied the largest home range in both the dry and wet seasons while green group had the smallest range during both the dry and wet seasons (Table 2). Using the Fixed Kernel method to determine 95% of home range size, there was also a significant difference between seasons (Wilcoxon test, Z= - 2.70, P=0.007, Fig. 2) with more extensive size in the dry season (8.48 ± 6.57 ha) than in the wet season (4.12 ± 1.65 ha).

Overlap between groups

Home range overlap between groups of blue-eyed black lemurs using the MCP method varied (Table 3). During the second dry season (2007) the overlap between the pink and yellow groups represented 100% of the yellow group's range. Similarly the overlap between pink and blue groups also represented 100% of the blue group home range.

Relationship between home range size and group size

Generally the home range size of the blue-eyed black lemur was relatively small and not related to group size (Table 2). There was no correlation between home range size and group size in both seasons (dry season MCP method, Spearman rank correlation, r

= -0.04, P>0.05; n = 10) and wet season MCP method, Spearman rank correlation, r = - 0.27, P> 0.05; n = 10).

Discussion

It has been demonstrated in some primate species that daily path length varies seasonally due to food resource availability and diet (e.g. Norscia et al., 2006; Stevenson, 2006; Zhou et al., 2007; Irwin, 2008). There was seasonal variation in daily path length of the blue-eyed black lemurs: during the dry season, they travelled further per day than in the wet season. We suggest this seasonal difference in distance covered is dependent on food resource availability. The diet of this lemur consists mainly of fruits but it also eats leaves, buds and insects, and sometimes fungi on the ground (pers. obs.). During observations, we twice saw *E. flavifrons* travelling to water sources to drink water. During the dry season most water sources dry up, and only during the wet season do streams inside in the forest have water except places where there are raffia palms *Raphia* sp., which have water permanently. During the dry season fruits were not as abundant (Volampeno et al. in prep.), so the lemurs travelled further to find preferred foods. A similar result has been reported for other primates (Dunbar, 1988).

Our study on the blue-eyed black lemur was conducted in the wet season and at the end of the dry season. In another study of the same lemur groups, during the middle of the dry season (May until July) the groups travelled less (Schwitzer et al., 2007b; Randriatahina in prep.) which was contrary to our results. We suggest that the southeast trade winds, which blow very strongly during the middle of the dry season, may have influenced this observation. Lemurs do not travel far in high winds (pers. obs.). In addition, mating and gestation coincide with the middle of the dry season, which may restrict the groups' movements and foraging forays. The birth season coincides with the end of the dry season, when it is expected that the animals will travel further to obtain sufficient food for suckling and infant care (Volampeno, 2009). Seasonal variation of daily path length has also been observed in folivorous lemurs including *Propithecus verreauxi* and *P. diadema* (Norscia et al. 2006; Irwin 2008).

Over the 14-month study period, the mean total home range size was estimated as 5.28 ha. The most closely related taxon, *E. macaco*, has a home range size of 5.5 ha in forest (Colquhoun, 1993), while in cultivated areas the home range was estimated as 18.2 ha (Bayart and Simmen 2005). The black lemur has a large and varied distribution, including primary and secondary forest, mangroves, forest-agricultural mosaics and timber plantations (Mittermeier et al., 2006) while the blue-eyed black lemur inhabits primary forest (Schwitzer et al., 2007b) and disturbed secondary forest (presence of clearings, felled trees, former slash and burn agriculture), which is limited in distribution (Mittermeier et al., 2006). Consequently, habitat differences might explain differences in home range size between blue-eyed black lemurs and black lemurs. Our results are consistent with those reported by Overdorff and Johnson (2003) that for most *Eulemur* species (with the exception of *E. fulvus rufus*), home ranges are relatively small (about 10 ha). Previous home range studies on various Lemuridae species demonstrated that home range sizes of species from western Madagascar are smaller than those of species from eastern and southern Madagascar (Table 4). It has been suggested that fruit abundance in the eastern rain forest is more seasonally variable than in the western dry forest (Curtis and Zaramody 1998) and this affects home range size.

Seasonal home range variation in the blue-eyed black lemur can most likely be explained by seasonal variation in food availability resulting from annual rainfall patterns (Volampeno et al. in prep.; Volampeno, 2009) with an increase in the dry season. Scarcity of food during the dry season caused these lemurs to travel further in search of food. During the dry season we observed that the normally frugivorous lemurs consumed food items that did not generally form part of the diet, such as cicadas (pers. obs.). During the wet season, rainfall contributes to increased fruit availability (Wright, 2006). Therefore, in the wet season the lemurs find sufficient food with shorter forays through the forest, resulting in a decreased home range size. Seasonal home range variation can therefore most likely be explained by seasonal variation in food availability resulting from annual rainfall patterns (Takasaki, 1984; Rylands, 1986; Kirkpatrick et al., 1998). In particular, increase in home range size during the dry season and decrease in the wet season was also observed in some species such as chacma baboons (*Papio ursinus*) (Gwenzi et al., 2007) and François' langur (*Trachypithecus francoisi*) (Zhou et al., 2007).

In primates, diet is generally a major influence on the home range size (Milton & May 1976). In forests, leaves are more abundant and uniformly distributed, so folivorous animals travel shorter distances and cover smaller areas (Milton and May, 1976; Clutton-Brock and Harvey, 1977; Mace and Harvey, 1983; Nunn and Barton, 2000; Robbins and McNeilage, 2003). Frugivorous species tend to use larger home ranges than folivorous (Clutton-Brock and Harvey, 1977; Mace and Harvey, 1983; Nunn and Barton, 2000). Home ranges of frugivorous lemurs are generally larger (e.g. *E. f. rufus*: 45 ha, Erhart and Overdorff 2008; *Varecia variegata*: 197 ha, White 1991) than those of folivorous lemur species (e.g. *Indri indri:* 18 ha, Glessner and Britt 2005; *Propithecus diadema*: 21.2 ha, Irwin, 2008). This implies that *E. flavifrons* is not strictly frugivorous and as we observed switches diet opportunistically supporting why their home ranges are smaller than would be expected if they were only frugivorous.

Home ranges of blue-eyed black lemur groups overlapped both in the dry and wet seasons. Because of food scarcity during the dry season, groups sometimes met coincidentally in the same place while searching for food (pers.obs.). During the wet season, when fruits were abundant, different groups fed in the same tree or in the vicinity of each other. In addition, the study area was relatively small so groups sometimes travelled, searched for food and rested in the same areas. This may explain why home ranges overlap between groups. Overlapping home ranges have also been observed in *E. macaco* (Bayart and Simmen 2005). It has been documented that home ranges of *Eulemur* species and some nocturnal lemurs (e.g. *Cheirogaleus medius* and *C. major*) show high degrees of overlap between groups (Vasey, 2000; Lahann, 2008). Some *Eulemur* groups enlarge home ranges to ensure access to water sources resulting in overlap (Scholz and Kappeler 2004). Home range overlap occurs in other forest primates species including *Pongo pygmaeus*, *Gorilla b. beringei*, *Gorilla g. gorilla, Pan troglodytes*, and *Colobus guereza* (Singleton and van Schaik, 2001; Robbins and McNeilage, 2003; Bemerjo, 2004; Basabose, 2005; Harris and Chapman, 2007).

Despite the fact that, for most primates, group size influences home range size (Davidge, 1978; Ikeda, 1982; Suzuki, 1979; Takasaki, 1981), and large groups generally occupy larger home ranges than small groups (Schoener, 1971; Takasaki, 1984; Isbell et al., 1998; Watts, 1998), home range size did not correlate with the group size in blue-eyed black lemurs. During the course of our study, the five groups remained relatively unchanged in numbers of individuals.

Compared to the other social species of primates, average total home range of the blue-eyed black lemur is relatively small. Our study conforms with previous analyses (Milton and May, 1976; Lehmann et al., 2007) that home range size generally correlates with body size in primates, however the smaller than expected home range for these sized lemurs appears to be a consequence of several factors including diet switching and habitat quality.

Fragmentation has affected most of the natural forests of Madagascar (Green and Sussman, 1990; Nelson and Horning, 1993; Smith, 1997). It is a major threat to the island's biodiversity because the remaining forest patches are sometimes too small to maintain viable populations, and this leads to the loss of animal communities (Ganzhorn et al., 2000; Ramananjatovo, 2000). Because of the degradation of the western dry forest and eastern littoral forest, it has been predicted that the remaining fragments will be unable to maintain viable populations by 2040 if the present rate of habitat loss is not halted (Ganzhorn et al., 2001). The impacts of forest degradation os seasonal variations in home range size of the blue-eyed black lemur are unknown.

In conclusion our study demonstrated that home range use in the blue-eyed black lemur varies seasonally. During the dry season daily path length was longer than in the wet season. The lemurs occupied larger home ranges during the dry season compared with the wet season. Food resource availability is the most likely factor influencing variations in home range size but requires further study. Home range estimates are crucial information for conservation planning and habitat management. Further studies of home range use over entire dry and wet seasons are needed in order to gain a more comprehensive understanding of ranging patterns of blue-eyed black lemurs and to evaluate their spatial requirements.

Acknowledgments

This research was supported by grants from Association Européene pour l 'Etude et la Conservation des Lemuriens (AEECL), Conservation International (CI), and the Third World Organization for Women in Sciences (TWOWS). We wish to thank the School of Biological and Conservation Sciences, University of KwaZulu-Natal, South Africa, IdeaWild and Wildlife Conservation Society. We would also thank the Madagascar National Parks for giving us permission to conduct our research in Sahamalaza-Iles Radama National Park. Special thanks are due to Guy Randriatahina, Tiana Rakotosamimanana, Paul Gordijn and the local assistants.

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Figure legends

Fig.1: Home range of the five study groups (MCP method) in the Sahamalaza - Iles Radama National Park: (a) 1st study period and (b) 2nd study period.

Fig 2: Home range of the five study groups (95% Kernel method) in the Sahamalaza - Iles Radama National Park: (a) 1st study period and (b) 2nd study period.

Table 1. Duration of search time for the blue-eyed black lemur groups in dry (2006-2007) and wet (2007-2008) seasons at the Sahamalaza-Iles Radama National Park.

Group	Season	Mean ± SD (min)	Min	Max
Blue	Dry	14.63 ± 9.76	2	25
	Rainy	16.67 ± 7.52	10	30
Green	Dry	9 ± 7.19	0	20
	Rainy	16.83 ± 14.5	6	40
Pink	Dry	27.86 ± 23.2	10	70
	Rainy	29.17 ± 30.4	10	90
Yellow	Dry	6 ± 7.57	0	20
	Rainy	12.5 ± 13.4	0	40
Uncollared	Dry	38.33 ± 30.1	10	70
	Rainy	47.5 ± 60.1	5	90

Table 2. Group size, home range estimate (MCP) and 95% use estimate (Fixed Kernel method) sizes of blue-eyed black lemur groups in the Sahamalaza-Iles Radama National Park.

	Group size				MCP (ha)				95% use Kernel method (ha)			
Group	D 2006	W 2007	D 2007	W 2008	D 2006	W 2007	D 2007	W 2008	D 2006	W 2007	D 2007	W 2008
Blue	10	8	8	6	8.78	5.47	5.53	2.6	9.77	6.8	7.01	3.98
Green	8	9	9	8	5.12	0.85	3.28	1.8	6.43	1.36	4.3	2.95
Pink	9	7	7	7	9.89	2.69	25.21	4.75	10.89	4.67	25.87	6
Yellow	8	6	6	8	5.99	2.43	6.02	5.33	6.38	2.93	6.91	5.32
Uncollared	8	8	9	8	2.86	2.49	2.68	1.97	3.59	4.25	3.62	2.89
Mean	8.6	7.6	7.8	7.4	6.53	2.79	8.54	3.29	7.41	4	9.54	4.23
SD	0.9	1.1	1.3	0.9	2.83	1.67	9.42	1.64	2.93	2.03	9.25	1.4

D: dry, W: wet

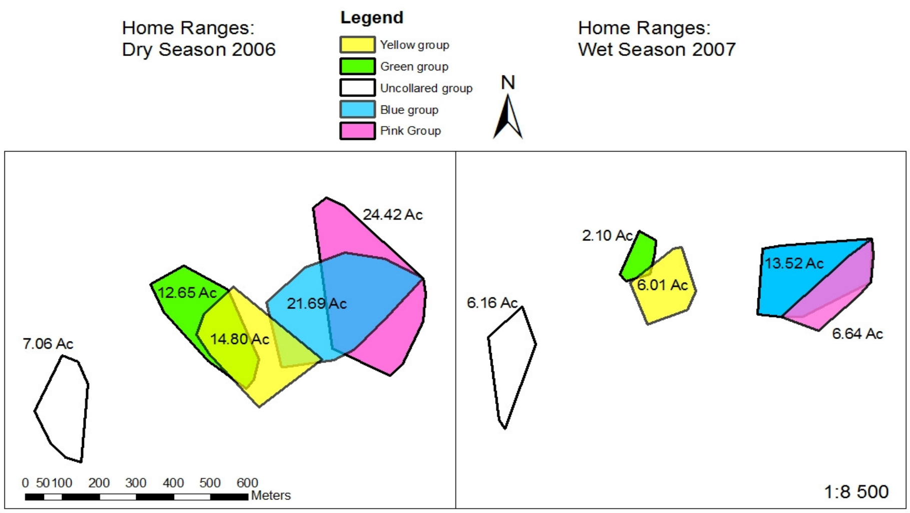
Table 3. Matrix of percentage of home range overlaps among groups of blue-eyed black lemurs over the study period in Sahamalaza-Iles Radama National Park.

	Yellow	**Pink**	**Blue**	**Green**
1. Percentage overlap in the dry season 2006				
Yellow			15.19	42.9
Pink			49.44	
Blue	10.36	55.69		
Green	50.19			
2. Percentage overlap in the dry season 2007				
Yellow		100		
Pink	21.93		20.87	7.57
Blue		100		
Green		58.23		
3. Percentage overlap in the wet season 2007				
Yellow				4.7
Pink			34.91	
Blue		71		
Green	1.64			
4. Percentage overlap in the wet season 2008				
Yellow				13.5
Pink			13.05	
Blue		23.84		
Green	40			

Table 4. Comparison of home range sizes in lemur species from western and eastern forest regions in Madagascar.

Species	**Habitat**	**Home range (ha)**	**Reference**
Eulemur flavifrons	Western forest	5.28	This study
Eulemur macaco	Western forest	5.5 ; 18.2	Colquhoun (1993); Bayart and Simmen (2005)
Eulemur mongoz	Western forest	2.8	Curtis and Zaramody (1998)
Eulemur coronatus	Western forest	6.4/8.4	Mittermeier et al. (2006)
Eulemur rubriventer	Eastern forest	15	Mittermeier et al. (2006)
Eulemur fulvus rufus	Eastern forest	95-100	Overdorff (1993); Overdorff et al. (1999)
Varecia rubra	Eastern forest	57.7	Vasey (2006)
Varecia variegata	Eastern forest	100-150; 197	White (1991); Balko (1998)

a)



b)

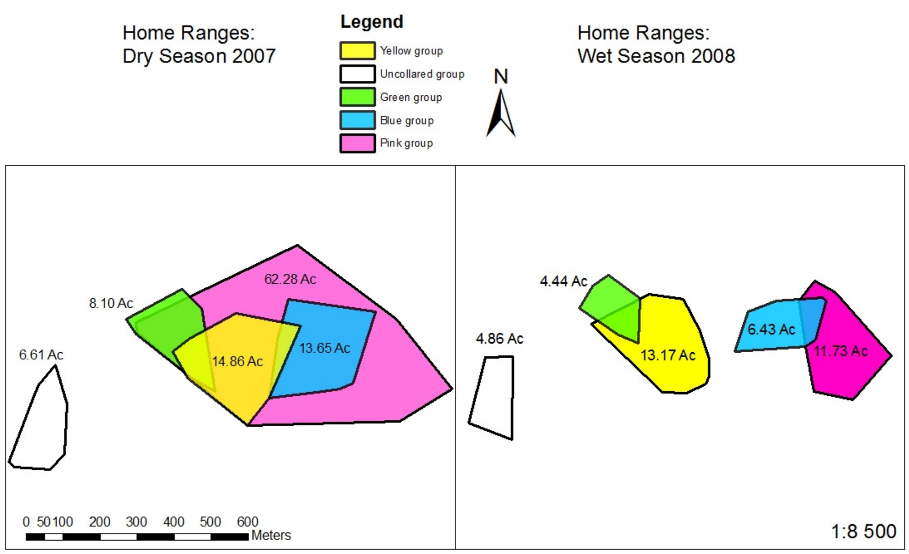
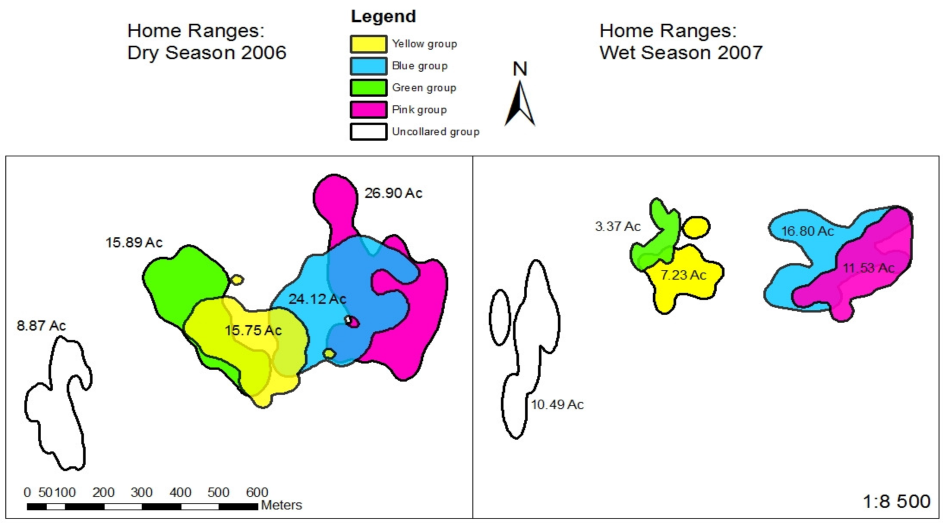


Fig. 1. Home ranges of the five study groups (MCP method): (a) 1st study period and (b) 2nd study period (Ac = Acre but in text are expressed in ha).

a)



b)

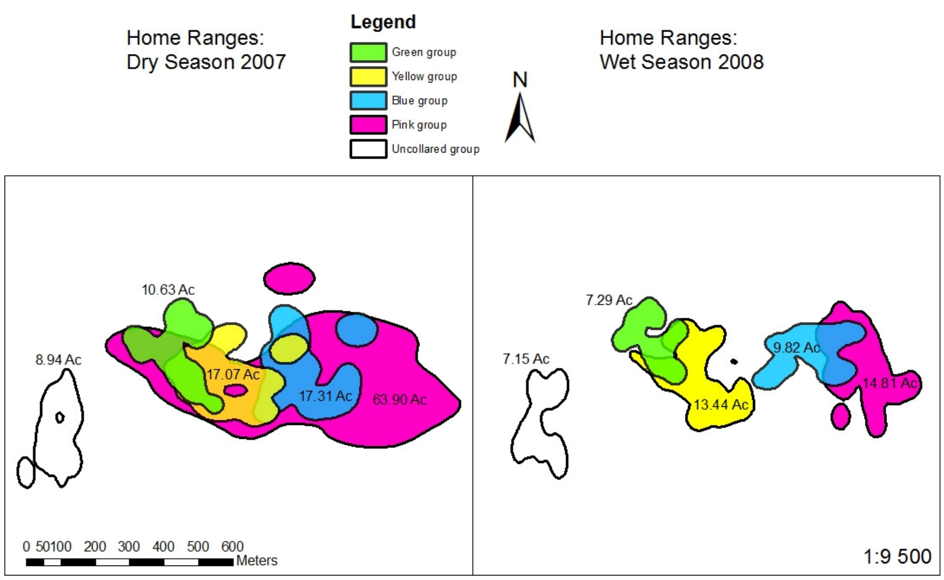


Fig. 2. Home ranges of the five study groups (Kernel method): (a) 1st study period and (b) 2nd study period (Ac = Acre but in text are expressed in ha).

Chapter 5

Life history traits, maternal behaviour and infant development of the blue-eyed black lemur (*Eulemur flavifrons*): Implications for its conservation[4]

Abstract

An understanding of population recruitment is important for developing population viability models and determining conservation implications and strategies. We present the first results regarding the life history, maternal behaviour and infant development of the critically endangered blue-eyed black lemur (*Eulemur flavifrons*) in the north-western forest of Madagascar. We found that they breed seasonally, with births occurring at the end of the dry season, between late August and October. During two successive birth seasons in 2006 and 2007 we observed a total of 13 lactating females and 22 infants from six groups. We found their age of first reproduction is 3 years and we calculated birth rate at 1.0 infant per female per year with a mean inter-birth interval of 358 ± 24.81 days (319 - 410 days). We found that infants spent the first 3 weeks of life constantly with their mothers, their ingestion of solid food and locomotory independence began at week 10 and they were weaned by week 25. We found that by the end of 28th week infants spent less than 20% of their time in contact with their mothers. We observed group members other than the mother provided alloparental care to infants, including carrying, grooming and playing. Over the study period we found that infant mortality was 22.7% with predation and sickness observed as causes. Our results suggest that population recruitment is slow and this has implications for the conservation of the taxon particularly in their restricted habitat range that is currently facing several threats.

Key words *Eulemur flavifrons*, life history, maternal behaviour, infant development, recruitment

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[4] Revised for *International Journal of Primatology*: Maria SN Volampeno, Judith C. Masters and Colleen T. Downs, Life history traits; maternal behaviour and infant development

Introduction

The life history patterns of mammals fall along a "fast-slow" continuum ranging from r-selected to K-selected species (Pianka 1970; Promislow and Harvey 1990). And these patterns are unchanged when body size effects are removed (Stearns 1983; Harvey and Nee 1991). Generally K-selected organisms occur in stable environments, whereas r-selected taxa are associated with unpredictable environments (Pianka 1970). Several mammals studies, including non-human primates, have supported r- and K-selection theory (e.g. Bronson 1979; Chism *et al.* 1984; Zammuto and Miller 1985; Cords and Rowell 1987; Ross 1991; Kraus *et al.* 2005), but others have shown it to be insufficient in explaining all life history parameters, and demonstrated the influence of other ecological factors in shaping life histories (Stearns 1992; Oli 2004). Compared with other mammals of similar body mass, non-human primates prolong their period of infant development and reach maturity later (Harvey and Clutton-Brock 1985; Napier and Napier 1985; Janson and van Schaik 1993; Ross 1998; Kappeler *et al.* 2003), and have longer lifespans (Austad and Fischer 1992). However, within the primates, life history parameters are highly correlated with body size with smaller bodied primates reproducing relatively earlier and having relatlively higher birth rates (Harvey and Clutton-Brock 1985; Isbell *et al.* 2009). Currently these parameters are important in terms of conservation of the world's primate fauna that is worldwide under threat and has 48% listed as threatened (IUCN 2008), and the conservation of biodiversity significant areas, such as Madagascar. Here the biodiversity is under threat, particularly that of the forest habitats and the primates species that are restricted to these (Mittermeier *et al*. 2006).

An understanding of population recruitment is important for developing population viability models and determining conservation implications and strategies. Among the ten extant species in the genus *Eulemur*, the blue-eyed black lemur (*Eulemur flavifrons*) is one of the least-studied and is described as critically endangered (Mittermeier *et al.* 2006). It is a medium-sized diurnal member of the family Lemuridea (Mittermeier *et al.* 2006). The taxon was described in 1867 but no study was undertaken prior to its rediscovery in 1985 (Koenders *et al.* 1985). Little is therefore known about its behaviour, ecology and biology (Mittermeier *et al.* 2006). The distribution of this lemur is very restricted, occurring only in a small area of north-western Madagascar, with the Sahamalaza-Iles Radama National Park (SIRNP) constituting a major part of its distribution range (Mittermeier *et al.* 2006). Its' habitat is facing degradation due various factors including wood exploitation, uncontrolled fire and slash and burn agriculture (Mittermeier *et al.* 2006; pers obs.) which reduce the size of available and suitable habitat and lead to forest fragmentation. The blue-eyed black lemur is arboreal, frugivorous and lives in social groups (Randriatahina in prep.). Sexual dichromatism is marked, with males being completely black and females, reddish-orange. The blue-eyed black lemur is a cathemeral animal (Schwitzer *et al.* 2007), like its close relative the black lemur *E. macaco* (Colquhoun 1993; Andrews and Birkinshaw 1998).

In addition to life history parameters, infant development, maternal behaviour, and alloparental care affect population recruitment. Three general stages in developmental process of infant primates are described (Poirier 1972; Fragaszy and Mitchell 1974). The mother-infant bond is formed in stage one, with the beginning of the infant's cognitive and locomotor development. In stage two, the infant begins to explore the environment beyond its mother. The infant starts to recognise conspecifics and interact with other individuals. Stage three is marked by the weaning process and a decrease in infantile behaviour patterns.

In non-human primates alloparental plays a number or roles. It has an important role in the socialization, and developmental processes of infants (Suomi 1982; Pereira and Leigh 2003) and infants, mothers and non-maternal group members gain advantages from this care. Infants are provided with protection from predators if their mothers are absent (Whitehead 1996), mothers can forage, feed and rest efficiently when their infants engage in social interaction with other group members (Gould 1992; Stanford 1992), and by interacting with infants group members learn and enhance their parental skills (Riedman 1982).

We determined the life history parameters and maternal behaviour of blue-eyed black lemurs in conservation context. We predict that their life history parameters, including first age of reproduction, gestation length, birth rate and lifespan, and correlate with those of relatively small sized primates. In addition, our study was the first on their social development in the wild and we examined the development of infants from birth until approximately 28 weeks of life, and assessed the degree of alloparental care. Although the social development of infant behaviour in wild anthropoid species is well studied compared with strepsirhine species (Gould 1990), the details of infant social development in wild, diurnal lemur populations is poorly known. Some studies of ring-tailed lemur *Lemur catta* (Gould 1990); black-and-white ruffed lemur *Varecia variegata* (Morland 1990); Milne-edwards'sifaka *Propithecus edwardsi* (Grieser 1992) and red ruffed lemur *Varecia rubra* (Vasey 2007) have been conducted. We expected blue-eyed black lemurs to have slower physical development than the less arboreal L. catta which have been reported to display rapid physical development compared with most anthropoid and some strepsirhine species (Gould 1990).

Materials and methods

We carried out the study in Ankarafa Forest (14° 22' 64.2''S lat and 47° 45' 31.5''E long), in the western part of the SIRNP. The vegetation of the SIRNP comprises a mixture of degraded semi-deciduous forest and subhumid forest (WCS/DEC 2002). The area is characterized by a subhumid climate with two distinct seasons: a hot and rainy season (December-April) and a dry season (May-November). The monthly mean maximum temperature ranged from 28.5 ± 3.6ºC in July to 39.1 ± 2.1ºC in February and monthly mean minimum temperature ranged from 13.2 ± 0.8ºC in October to 21.8 ± 0.8ºC in January. According to records taken at the nearest town, Analalava, the mean annual rainfall for the area is 1824 mm (Dewar and Richard 2007).

We chose six focal groups, four of which were identified by coloured collars and two of which were uncollared. Group composition in terms of age and sex class is shown in Table 1. Two uncollared groups were easily recognized by the group size, the colour of the lactating females and their daily movements in the forest. The collars had a group-specific colour (green, blue, pink and yellow respectively) and had been fitted by a previous researcher (Randriatahina) (Volampeno 2009). Moreover, each animal within a group had its own unique mark on its collar and a name. The collar was made of nylon with a size of about 10 cm long.

We collected data over two successive birth seasons: from September 2006 to March 2007 and from September 2007 to March 2008. Each study period included the infant births to the end of the 28th week of the age. We measured the stages of infant development in weeks. Exact birth dates of each focal infant were known. Each group was followed on a rotational schedule and each focal animal was recognized by its own mark on its collar. We collected behavioural data on lactating females and infants from 07:00 to 12:00 and 14:00 to 17:30 in notebooks using abbreviated codes.

Between observations sessions, an observer remained with the group in order not to lose sight of the animal. Data were collected using continuous-time focal sampling (Altmann 1974). Data were collected using continuous-time focal sampling (Altmann 1974). Binoculars were used to assist with observations when necessary. An ethogram was established before collecting the behavioural data (Table 2). During data collection, the following parameters were noted: date and hour of the observation, age and sex class of the nearest neighbour of the focal animal, distance between the focal animal and the nearest neighbor, height (estimated by eye) and vernacular name of trees where the individuals were found, substrate used (tree, ground), food item consumed, distance between infants and mothers and position of infants when in direct contact with their mothers (on nipple, ventral or dorsal position).

Although the blue-eyed black lemur is a cathemeral animal, active during both day and night (Schwitzer *et al.* 2007) we were unable to collect data during the night because the groups fled when illuminated. Nevertheless, they have peaks of activity (Schwitzer *et al.* 2007) that coincided with our observation times.

Inter-birth intervals were calculated using survival analysis where the infant survived until the next birth season or died before the reproduction of a new offspring. We excluded data when focal subjects were out of sight from dataset. We used Statistica (version 6.0, Tulsa, USA). We excluded data when focal subjects were out of sight. We used non-parametric tests to analyze both lactating females' activity budgets and infants' behavioural development data over the study period. We used the Mann-Whitney test for unmatched pairs to determine whether the activity budgets of the lactating females and infants differed across the two successive birth seasons. We used Spearman's correlation test was used to examine if there was a relationship between the infant's age and the time spent with the mother, between infant's age and maternal grooming and between infant's age and mother as nearest neighbour. We used the age of infant from birth (0 week) until 28 weeks of life for analysis. All data were expressed as means ± SD.

Results

Our study confirmed that the age of producing first offspring in the blue-eyed black lemur females was 3 years old. We found that they breed seasonally with births at the end of the dry season between August and October and peaked in September (Fig.1).

Of the 22 births during the study period, 20 cases were singletons (90%), and one was a twin birth (10%). The latter, which occurred in 2007, was the first twin birth recorded since observations began in 2004. We did not witness any parturition directly during data collection. However, in the first birth season we noticed that, during a morning rest period, one of the lactating females from pink group "Nora", was sitting alone in a tree when she moved away from the group and disappeared. In the late afternoon, she returned to the group and was seen with a newborn infant. It was thus clear that birth took place during the day.

We found that all blue-eyed black lemur females bred in groups and each group contained two lactating females. We recorded 22 births from 13 females over the study period. The mean annual birth rate was 1.04 births. The mean inter-birth interval was 359 ± 32.7 days (n= 5) if an infant survived until the mother reproduced again. If the infant died, the mean inter-birth interval was 358 ± 1.7 days (n = 3). During the first birth season 8 out of 10 (80%) infants born (excluding the individual of unknown sex) were males, while during the second birth season 7 of 11 (64%) infants were females. Thus, we found a strong male-biased birth sex-ratio in the first season and a female-biased sex/ratio in the second. However, combination of the two birth seasons showed a male-biased (1.62) but did not deviate significantly from 1:1 ($\chi^2 = 0.76$, d.f = 1, $p > 0.05$). Six of the 13 focal lactating females during the first birth season alternated the sex of their offspring from one birth season to the next.

Maternal behaviour

We collected data on the activities of 13 lactating females were collected for 12 weeks following the birth of their infants, to yield a total of 608 observation hours over the two successive birth seasons. Identities of lactating females are shown in Table 3. We divided activity budgets into six categories: feeding; travelling; resting; social interaction (e.g. playing or grooming another individual); infant care (e.g. grooming or nursing the infant); and other (e.g. self-grooming, defecation, and vocalization). Overall, we found that lactating females spent most of their time resting with their infants (66%), 19% of their time in feeding, 12% in travelling, 1.5% in social interaction, and 1.5% in other behaviour. Lactating females groomed or nursed their infants only 1% of their time. We found no significant difference in the activity budgets of lactating females over the two successive birth seasons (Mann-Whitney U test, $U = 18$, $p > 0.05$, Fig. 2).

We found that lactating blue-eyed black lemur females in two of the groups (blue and yellow) had priority of food access over the males in their groups. Males (especially adults) waited until the lactating females left the fruit trees before they started feeding. We found that in all the groups studied, lactating females always led the groups during travelling. Defence of fruiting trees was perfomed by the lactating against intruding groups.

We found that the diets of the lactating blue-eyed black lemur females comprised mainly fruits (73% of total feeding records), leaves (17.1%), flowers and buds (3.7%), while the remaining 6.3% was made up of diverse, opportunistically acquired components (e.g. water, soil, insects, cicadas and chameleons). Lactating females fed on 37 plant species belonging to 23 families (Table 4).

In terms of habitat use, we observed that lactating blue-eyed black lemur females spent most of their time 5-10 m above the ground (63.2% of observation time), 22.2% of their time in the highest forest stratum (>15 m), 11 % at 0-5 m and only 0.6% of their time on the ground. The average height at which they were found was 8.6 ± 2.8 m in the first birth season, and 9.2 ± 3.5 m during the second year. We found no significant difference in vertical use between the two successive birth seasons (Mann-Whitney U test, $U = 10$, $p > 0.05$).

Over the study period, we observed that the preferred nearest neighbours of lactating females were adult males (37%), their own infants from previous birth seasons (34%), adult females (19%) and infants of other lactating females (10%). We found these proportions did not differ significantly between the 2006 and 2007 birth seasons (Mann-Whitney U test $U = 8$, $p > 0.05$).

Observations of blue-eyed black lemur infants

During the first birth season (2006) we observed that two infants died and another disappeared at the age of 27 weeks. The first infant of unknown sex died after an attack by a fossa (*Cryptoprocta ferox*) in its second week of life (Fig. 3a). In the 28th week of life, a few days before the end of the study period, we found the second infant, an infant male "Pat" dead in the forest and reason for death unknown although we saw that he was weak a few days before his death (Fig. 3b). The infant was unable to jump between trees, and walked on the ground when he moved from tree to tree.

From about 18 weeks of life, this infant was seen travelling and feeding quite far from the group, sometimes out of sight. Poor maternal care (or early weaning) may have caused the weakness and death of this infant, or it may have been suffering from disease. During the second birth season (2007) we found that two infants disappeared at the age of 13 and 14 weeks for unknown reasons. The infants who disappeared were all apparently healthy when last seen. They did not emigrate to neighbouring study groups and so were presumed dead. The infant mortality rate for the study period was 22. 7%.

We found that blue-eyed black lemur infants followed the three stages of infant development (Poirier 1972; Fragaszy and Mitchell 1974). During the first three weeks we observed that infants spent all their time on the ventral surface of their mothers hidden from view. Around week three, we saw that infants began to leave their mothers' bellies regularly and climb on their backs. At birth the pelage colour of all infants was light black. At the end of week three the tail started to change colour, growing lighter, although the sex of infants was still unknown.

By the fourth week, we were able to identify the infants' sex based on colour. At the beginning of week four, we observed that during the mother's resting time, infants moved around their mothers' bodies and tried to touch and lick objects such as branches, leaves and fruits. At the end of the sixth week, we saw that infants began to leave their mothers and walked quadrupedally on branches. These excursions were very short, a few centimetres from their mothers. By the end of the sixth week we observed that infants spent 90% of their time with their mothers.

We observed social as well as independent play activities in infant blue-eyed black lemurs at the beginning of the seventh week. We saw that infants started to travel more than one metre from their mothers during the ninth week, but were still in contact with their mothers 84% of the time by the end of this period.

By the beginning of weeks 10, we observed that blue-eyed black lemur infants moved independently and started to ingest solid foods. From weeks 12-15 there was a change in the amount of time infants spend with their mothers as they became independent (Fig. 4). We saw infants suckling up until week 24 during the first, and week 25 during the second birth season. By the age of 28 weeks, we saw the infants appeared to be weaned. At the end of this period we observed that they began to display adult behaviours patterns including feeding, travelling, social behaviour (e.g.

social play; allogrooming) and aggressive behaviour such as fighting. After 28 weeks, we saw that infants were in contact with their mothers less than 20% of the time.

Mother-infant relationships

We found a strong negative correlation between blue-eyed black lemur infant age and time spent on the mother, including ventroventral carrying, sitting, suckling and grooming (Spearman rank correlation, $r = -0.97$, $n = 28$) (Fig. 4). We found there was a weak correlation between the amount of maternal grooming and the age of infants (Spearman rank correlation, $r = 0.40$, $n = 28$). We observed that rejection of the infant from the mother's nipple commenced around the eleventh week and peaked at 25 weeks of infant age, when infants were weaned. We found a strong negative correlation was found between an infant's age and its mother as nearest neighbour (Spearman correlation $r = -0.94$, $n = 28$).

Alloparental care

Over the two birth seasons we recorded three types of alloparental care: carrying, grooming and playing. Playing was the most frequent form (94% of observation time), followed by grooming and carrying. We found that no infant was carried by non-mothers during the first birth season. However, in the second season, adult males were the most frequent non-mothers seen carrying infants (67%), followed by juvenile males and siblings. In the second season, the earliest infant age at which an older sister was seen carrying an infant was five weeks, while the earliest age for infant carrying by adult males was six weeks. Irrespective of season we found that all non-mother age and sex classes groomed infants with following amount of grooming by caretaker: sibling 37.9%, adult male 31.6%, juvenile male 14.7%, adult female 9.5%, juvenile female 6.3%. Among the other group members, siblings groomed the infants more often than any other individuals. An adult male was seen grooming the infant for the first time in the third week, while this occurred in week four for a sibling. We found no significant difference in the total amount of grooming performed by group members other than mothers between the two birth seasons (Mann-Whitney U test, $U = 18.5$, $p > 0.05$), although neither adult nor juvenile females groomed infants in the 2007 birth season.

We found that social play includes jumping on another individual, chase-biting one another and/or riding on another individual. We observed infants engaged in social play with all non-mother age/sex classes. Over the two birth seasons, infants engaged in social play with one another more than with any other group member, especially the infant females. We found the amount of social play caretaker as follows: infant female 35%, infant male 19%, juvenile male 15%, sibling 15%, juvenile female 15%, adult male 6% and adult female 3%. We first observed social play in infants in week seven. We found no significant difference in the amount of social play between birth seasons (Mann-Whitney test $U = 23$, $N = 7$, $p > 0.05$).

Activity budgets of infants

We examined activity budgets of blue-eyed black lemur infants excluding time spent on the mother (e.g.: suckling, being carried on mother's belly, riding mother's back). We recorded five activity categories: resting, feeding on solid foods, travelling for environmental exploration, playing (including lone and social play) and other (e.g. grooming including self and allogrooming, vocalizations and fighting). We combined data over the two birth seasons and found that infants spent about 42% of their time resting, 25% travelling, 19% feeding, 12% playing and only 2% in other activities. Regarding play behaviour, we recorded that infants spent 46% of the observation time in lone play and 54% of their time in social play between weeks 0 and 28. We found that activity budgets of infants did not differ significantly between the 2006 and 2007 study periods (Mann Whitney test $U = 11$, $p > 0.0.5$, Fig. 5).

Solid food of infants we observed consisted of fruit, leaves, flowers, buds and other solids such as mushrooms, soil and insects. We observed that 94% of the solid food consumed consisted of fruit, 4% leaves, 1% flowers and buds and 1% other solids. Plant species most consumed by the infants included *Mangifera indica, Erythroxylum platycladum, Sorindeia madagascariensis, Macphersonia gracilis, Grewia* sp., *Bosqueia* sp., *Alphoia theiformis*, *Diospyro*s sp. and one unidentified plant.

In terms of habitat use, we categorized five levels of height use by infant blue-eyed black lemurs. Over the two birth seasons, the preferred level was 5-10 m (72.9% of observation time). Infants were seen on the ground only 1.1% of the time. We found height use did not differ significantly between the 2006 and 2007 birth seasons (Mann Whitney test $U = 10$, $p > 0.0.5$).

Over the two successive birth seasons, we recorded that infants were seen alone 38% of the time. They preferred mothers as nearest neighbours (31% of the observation time) compared with male (18%) and female (13%) non-mothers. We found that time spent in close proximity to other individuals did not differ significantly between the two birth seasons (Mann Whitney test $U = 6$, $p > 0.56$).

Discussion

Our study, together with data on lactating females collected from the same groups of blue-eyed black lemurs since 2004 (Randriatahina, pers.comm.), confirmed that females give birth for the first time at the age of 3 years. We were unable to determine the gestation length of blue-eyed black lemur because we did not collect data during the mating season. Randriatahina (pers. comm.) estimates gestation time as about 120 days. This is similar to gestation times reported by Lindenfors (2002) and Bayart and Simmen (2005) for *Eulemur macaco*. Overdorff and Johnson (2003) reported a gestation length of about 120 days for *Eulemur* species in general. We also found that the blue-eyed black lemur breeds seasonally with births at the end of the dry season between August and October with a peak in September. The estimate lifespan of the blue-eyed black lemur is unknown but we assume it is similar to the longevity estimate of its closest relative *Eulemur macaco* which is about 27 years old (Lindenfors 2002). In captivity the oldest blue-eyed black lemur is 21 years old (Digby pers. comm.). However, it is not know for how long females can breed. We found that blue-eyed black lemur as like other small-bodied primates reproduce relatively earlier, have relatively high birth rates and probably have a shorter longevity. However, our results suggest that population recruitment is slow and this has implications for the conservation of the taxon.

Over the two births seasons, we did not witness any parturition in blue-eyed black lemurs. Parturition is rarely observed in wild primates, and has been suggested that birth in diurnal non-human primates generally takes place at night time (Jolly 1972). Daytime birth has been witnessed in some free ranging primate species, including ring-tailed lemurs (*Lemur catta*) (Takahata *et al.* 2001), capped langurs (*Trachypithecus pileatus*) (Kumar *et al.* 2005), red-handed howlers (*Alouatta belzebul*) (Camargo and Ferrari 2007) and black and gold howlers (*Alouatta carya*) (Peker *et al.* 2009). Nocturnal births may be advantageous with avoidance of excessive attention from other group members towards the newborn, and protection from predators during or just after parturition (Bowden *et al.* 1967; Jolly 1972; Nowell *et al.* 1978; Honnebier and Nathanielsz 1994).

We found a strong male-biased birth sex ratio in the blue-eyed black lemur when the two birth seasons were combined but this was not significant. Interestingly several of the focal lactating females alternated the sex of their offspring from one birth season tp the next. Explanations of sex-ratio bias in non-human primate species are still ambiguous and remain problematic. In many primates, female philopatry, which leads to female offspring remaining in their natal range, is expected to generate a male bias among the offspring to limit local resource competition (Clark 1978). Alternatively, if high ranking females pass their ranks on to their daughters and not to their sons, they should produce more females (Altmann, 1980; Silk 1983). On the other hand an ecological model suggests that, when food availability is high, females should produce more female offspring, while they should produce more males when the resource availability is low, to avoid feeding competition and harassment from dominant females (Trivers and Willard 1973; van Schaik and Hrdy 1991). Our data, collected over only two seasons, suggest nothing more than stochastic effects. Long term data may change this view.

We found that infant blue-eyed black lemur mortality was 22% as a result of predation, suspected sickness and disappearance of apparently healthy infants. Similarly infant mortality in non-human primates has been attributed to predation, disease, accidental falls and infanticide with mortality rates of wild non-human primate infants higher than those in captivity (McFarland 1988; Morland 1990). In the wild, *V. variegate* have an infant mortality rate of 64% in the first 3 months of life (Morland 1990), while captive ruffed lemurs have a 21% mortality rate (Brockman *et al.* 1987). Reports of annual infant mortality in the wild vary widely for primates from 20 to 60% (McFarland 1988), 43-55% (Richard 1985) to 84% and even 100% (Richard 1978) at different sites. Consequently our mortality for infant blue-eyed black lemur was relatively low in comparison. However, this would still impact adversely on their population recruitment.

As in our study, fossa predation has been previously documented with them attacking adult, juvenile and infant lemurs (e.g. *Propithecus edwardsi*, Wright *et al*. 1997; *V. variegata*, Britt *et al.* 1999; Dollar *et al.* 2007) both day and night (Wright

1998). We observed an infant die at 28 weeks of age for unknown reasons although it had appeared weak a few days before its death. . In the study of Bayart and Simmen (2005), an infant black lemur died at the age of four weeks for unknown reasons. Disappeance of infants has been observed in other non-human primates (Cheney *et al.* 2004; Radhakrishna and Singh 2004) including *E. macaco* (Bayart and Simmen 2005). Accidental falls are a major cause of infant deaths in arboreal non-human primates including *V. variegata* (Morland 1990). Infanticide has been demonstrated as a cause of infant deaths in several species including *E. macaco* (Andrews 1998) with it suggested that infanticide might depend on the mode of maternal care, and mothers who carry their offspring may have a higher risk of infanticide than those do not (e.g. park or nest) van Schaik and Kappeler (1997).

We found that the behavioural development stages of infant blue-eyed black lemurs followed the three general stages (Poirier 1972; Fragaszy and Mitchell 1974). Infants were totally dependent on their mothers for the first three weeks of life. By week four, the infants started to manipulate objects and performed short movements as is characteristic of the first stage of mother-infant bonding and the beginning of locomotor skill development. The second stage was characterized by environmental exploration. By week seven infants were exploring their environment regularly. The third stage corresponded to the weaning process and a decrease of infantile behaviour patterns. We observed infants beginning to eat solids from week 10. By the end of the study period (about seven months), we found infants had been weaned, and began to display adult behaviours, including foraging and agonistic behaviour.

We found that wild blue-eyed black lemur infants were in contact with their mothers 100% of the time for the first three weeks of life and decreasing to 84% by week nine. Infants ingested solid food around week 10, coinciding with rejection from the nipple. Similarly *E. macaco* infants in captivity spend 100% of their time during the first four weeks with their mothers decreasing to 90% by week nine and fed on solid food around week six when rejection from nursing was seen (Harrington 1978). Consequently we found that infant development in these two subspecies was similar. The observed difference in the time of weaning may be due to the differences between wild and captive conditions.

Ring-tailed lemur (*L. catta*) infants have a rapid developmental trajectory with independent locomotion around sixth week (Gould 1990) while we found this occurs around week ten in blue-eyed black lemur infants. Ring-tailed lemur infants rejection from the nipple (around the eighth week) ingestion of solid foods (sixth week) and when they leave their mothers, are earlier than we found in blue-eyed black lemur infants. Possibly as *L.catta* are not completely arboreal, and spend 35% of their time on the ground (Jolly 1966) the risk of falling is likely to be lower for their infants and this may explain their relatively rapid physical development compared with most primate species (Gould 1990). By contrast, infant *V. rubra* and *V. variegata*, which are also arboreal, attained locomotor independence at the same age as we found in blue-eyed black lemurs (Morland 1990; Vasey 2007). Locomotor independence in such species should be delayed until their abilities are sufficiently advanced to avoid falling from the trees. Previous studies have suggested that an arboreal lifestyle slows infant development in non-human of primates because of the physical dangers from falls (Chalmers 1972, 1973; Sussman 1977; Johnson and Southwick 1987; Karssemeijer *et al.* 1990). As in other primates, we found that blue-eyed black lemur infants from birth were fed, groomed and cared for by their mothers who are a source of nutrition and security (Napier and Napier 1985). Development of locomotory independence and weaning age of small-bodied primates as in our study are relatively faster than those of large-bodied primates (Harvey and Clutton-Brock 1985). However, primate mothers respond in different ways to the needs and demands of their infants (Lee 1984) with females in a good physical condition with adequate nutrition invest relatively less in their offspring than those living under poor conditions with limited resources (Lee *et al.* 1991; Hrdy 1999). We also found that blue-eyed black lemur infats were similar to other primate infants that are generally dependent on the mother until they are physically and behaviourally mature enough to enable them to face the environment's demands (Nowell and Fletcher 2007). Furthermore, several authors have suggested that a prolonged period of infant development affects the behavioural and physiological development of the infants and their later reproductive success (Suomi 1979; Sapolsky 1994).

We found that lactating blue-eyed black lemur females spent most of their time resting (up to 66 %) and only 12% of their time travelling. The birth season coincided with the end of the dry season when food availability was still poor in terms of quality and quantity (Volampeno 2009). It has been documented that lactation is the most energetically expensive part of the reproduction cycle and imposes physiological stresses on the mother, (Portman 1970; Oftedal 1984; Lee 1996). We suggest that lactating females spent the majority of their time avoiding further high energy expenditure in order to conserve sufficient energy required for the infant care. Similarly, Erhart and Overdorff (2008) found E. fulvus rufus female behavioural responses to decreased fruit availability.

In general, non-human primate males are dominant over females (Smuts *et al.* 1987; Wright 1993; Strier 1996). On the contrary, adult females of most Malagasy lemur species are dominant over males (Richard 1987; White *et al.* 2007). We observed that blue-eyed black lemur females were dominant over males in terms of feeding priority, as shown for wild *E. macaco* (Colquhoun 1993) and and for captive blue-eyed black lemurs (Digby and Kahlenberg 2002).

We found in blue-eyed black lemurs that all individuals irrespective of age/sex class performed caretaking for the infants, including carrying, grooming and play. Even lactating females played with and groomed infants who were not their own offspring. As mentioned in non-human primates, alloparental care plays an important role in the socialization and developmental processes of infants (Suomi 1982; Pereira and Leigh 2003); protection of infants from predators (Whitehead 1996); freeing mothers to forage, feed and rest (Gould 1992; Stanford 1992), opportunity for group members learn and enhance their parental skills (Riedman 1982). Alloparental care, including play, carrying, grooming and nursing, has been demonstrated in several species of lemurs, both in the wild and in captivity (Table 5).

This study reports the first information on reproductive parameters and infant development in free-ranging blue-eyed black lemurs. This information is essential to the development of conservation strategies for this critically endangered lemur. Compared with larger species of primates, the blue-eyed black lemur reproduced relatively earlier and had a high birth rate. However, as mentioned population recruitment is slow and this has implications for conservation of the taxon. Further long-term studies of wild blue-eyed black lemurs are needed to understand the life history of these animals more completely and so contribute to the conservation and management of this species.

Acknowledgments

This research was supported by grants from Association Européene pour l 'Etude et la Conservation des Lemuriens (AEECL), Conservation International (CI), and the Third World Organization for Women in Sciences (TWOWS). We wish to thank the School of Biological and Conservation Sciences, University of KwaZulu-Natal, South Africa, IdeaWild and Wildlife Conservation Society. We would also thank the Madagascar National Parks for giving us permission to conduct our research in Sahamalaza-Iles Radama National Park. Special thanks are due to Guy Randriatahina, Tiana Rakotosamimanana and the local assistants.

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Table 1. Group size and composition of the study groups.

	Groups							
Age/sex class	Blue	Pink	Green	Yellow	Uncollared 1	Uncollared 2	Mean	SD
AM	3	2	2	2	2	3		
AF	2	2	2	2	2	2		
JM	2	1	3	1	1	1		
JF	1	2	0	1	1	0		
IM	2	1	1	2	2	2		
IF		1						
Total	10	9	8	8	8	8	8.5	0. 4

A= adult; M = male; F = female; J = juvenile; I = immature

Table 2. An ethogram showing activity descriptions for focal observations in blue-eyed black lemurs (modified from Patterson 2001).

Activity	Description
Resting	sitting or lying down, including sleeping and sunbathing, which is sitting or lying direct to the sun and ventral face to sunlight
Travelling	movement actions such as walking, jumping and running
Feeding	consuming any food or water, also foraging (searching for food by moving slowly and intentionally towards food and picking up objects to check food)
Vocalization	emitting a call, one long call or many shorts calls
Playing	social behaviour category exemplified by hanging in a substrate with head down, jumping around with another individual and chasing each other
Grooming	using the mouth and hands to pick through the fur; includes self-grooming (grooming own body) and allogrooming (one individual grooms another, which can be mutual)
Fighting	an aggressive behaviour between individuals such as biting and chasing another individual, usually accompanied by loud vocalizations

Table 3. Identities of lactating blue-eyed black lemur females over the two successive birth seasons.

Birth 2006				Birth 2007			
Group	Mother's name	Infant's name	Sex	Group	Mother's name	Infant's name	Sex
Green	Vola	Feno	M	Green	Vola	Rene	M
	Fideline	Koto	Unknown		Fideline	Zora	F
Blue	Nadia	Tom	M	Blue	Nathalie	Aicha	F
	Nathalie	Jerry	M		Anita	Yvess	M
Pink	Nora	Kiady	M	Pink	Nora	Marlene	F
	Fanja	Adeline	F				
Yellow	Nina	Pat	M	Yellow	Nina	Ravo&Tsiky	F
	France	Joe	M		France	Sarah	F
Uncollared 1	Marina	Moussa	M	Uncollared 1	Marina	Didier	M
	Rasoa	Molly	F		Rasoa	Camlle	M
				Uncollared 2	Soa	Adam	M
					Gila	Tony	M

Table 4. Plant species and items consumed by focal lactating blue-eyed black lemur females.

Family	Species	Vernacular name	Part (s) eaten
Anacardiaceae	*Mangifera indica*	Manga	unfr, rfr, lv
Anacardiaceae	*Sorindeia madagascariensis*	Sondririny	unfr, rfr
Anacardiaceae	*Anacardium occidantale*	Mahabibo	unfr, rfr
Annonaceae	*Xylopia sericolampra*	Amanin'ombilahy	rfr, lv
Annonaceae	*Monanthotaxis pilosa*	Fotsiavadika	rfr
Apocynaceae	*Landolphia tenius*	Vaheny	rfr, urfr, lv
Arecaceae	*Dypsis lutescens*	Kindro	rfr
Burseraceae	*Canarium madagascariensis*	Ramy	rfr. Lv
Chrysobalanaceae	*Grangeria porosa*	Morasiro	rfr, fl, bd
Clusiaceae	*Garcinia pauciflora*	Taranta	rfr. lv
Clusiaceae	*Psorospermum sp*	Harongana kely	rfr, lv, bd
Clusiaceae	*Harongana madagascariensis*	Harongambe	rfr, lv,bd
Combretaceae	*Terminalia perrieri*	Lonjo	rfr,lv
Ebenaceae	*Diospyros sp*	Hazo joby	rfr, bd
Erythroxylaceae	*Erythroxylum platycladum*	Tampika	lv
Euphorbiaceae	*Petalodiscus platyrachis*	Kiropoka	bd
Euphorbiaceae	*Croton mobilis*	Lazalaza	rfr
Fabaceae	*Hymenaea verrucsa*	Mandrirofo	rfr, fl, bd, lv
Fabaceae	*Albizia gummifera*	Sambalahy	rfr
Fabaceae	*Dalbergia sp*	Taitsindambo	lv
Lauraceae	*Cassytha filiformis*	Tsitafototra	rfr
Liliaceae	*Dracaena reflexa*	Hasina	rfr, bd
Loganiaceae	*Strychnos madagascariensis*	Vakakoana	rfr
Menispermaceae	*Burasaia madagascariensis*	Ambarasaha	rfr
Moraceae	*Streblus dimepate*	Tsitindry	rfr, lv
Moraceae	*Treculia perrieri*	Tsitindro	rfr, lv
Moraceae	*Bosqueia sp*	Tsimitombo	rfr, bd, lv
Moraceae	*Ficus tiliaefolia*	Adabo	rfr
Moraceae	*Ficus sp*	Harositra	rfr,lv
Olaceae	*Olax sp*	Amanin'omby	rfr,lv
Rhizophoraceae	*Macarisia lauciolata*	Korontsana	rfr
Rubiaceae	*Garderus runterbergiana*	Kimotimoty	rfr
Saliaceae	*Scolopia madagascariensis*	Hazomamy	rfr
Sapindanceae	*Macphersonia gracilis*	Maroampototra	bd
Tiliaceae	*Grewia boinensis*	Selivato	rfr
Tiliaceae	*Grewia amplifolia*	Sely kely	rfr
Tiliaceae	*Grewia sp*	Selibe	rfr

unfr: unripe fruit; rfr: ripe fruit; lv: leaves; bd: buds; fl: flower

Table 5. Alloparental care in lemur species.

Species	Type of allocare	Age/sex class	Location	Source
Eulemur flavifrons	carry, play, groom	AM, AF JM,JF,IM,IF,S	Wild	This study
Eulemur macaco	Play	S, F	Captivity	Harrington 1978
Eulemur mongoz	Carry	AM	Captivity	Wright 1990
Lemur catta	groom, nurse	AM,AF, JM,JF	Wild	Gould 1992
Propithecus candidus	carry, play, groom, nurse	AM,AF, J,M	Wild	Patel 2007
Propithecus verreauxi	Groom	AM,AF,JM,JF	Wild	Jolly 1966
Varecia variegata	groom, play	AM,AF	Wild	Morland 1990
Hapalemur griseus	Carry	AM, S	Wild	Wright 1990
Cheirogaleus medius	play, sleep	AM	Wild	Fietz and Dausmann 2003
Microcebus murinus	groom, nurse	AF	Wild	Eberle and Kappeler 2006

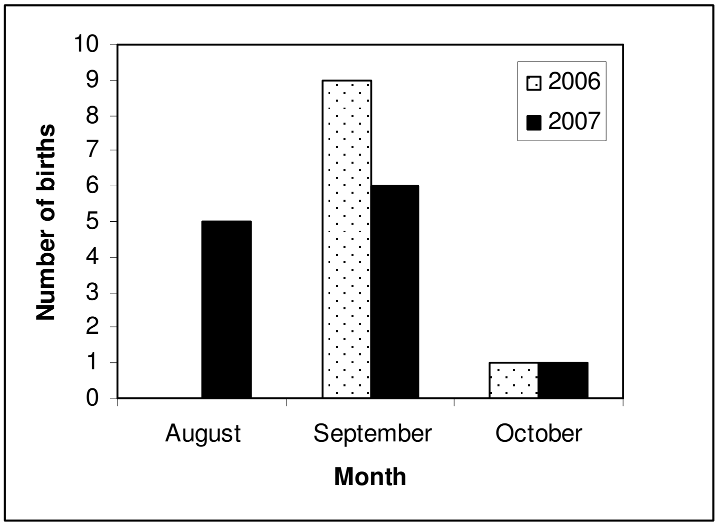

Figure 1. Distribution of births in the blue-eyed black lemur during two successive birth seasons.

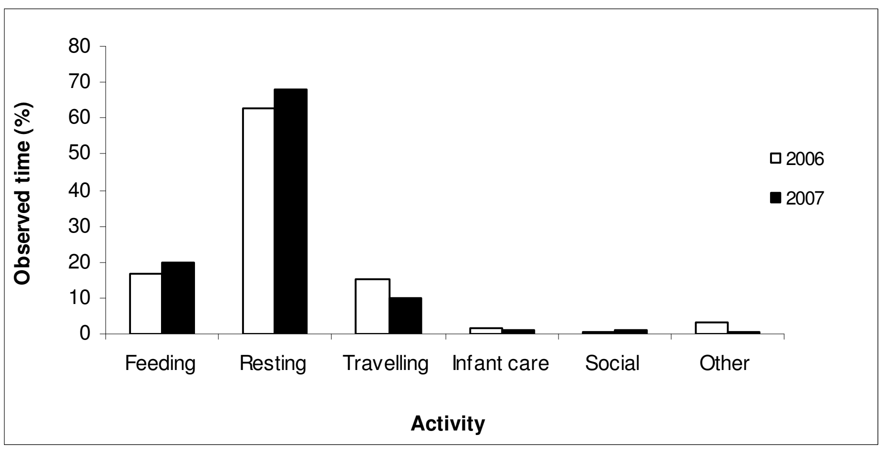

Figure 2. Comparison of activity budgets of the lactating females between 2006 and 2007 birth seasons.

a) b)

Figure 3. The dead infants located where a) shows wounds observed on the head of the infant after a fossa attack, and b) the infant "Pat" observed dead in the forest.

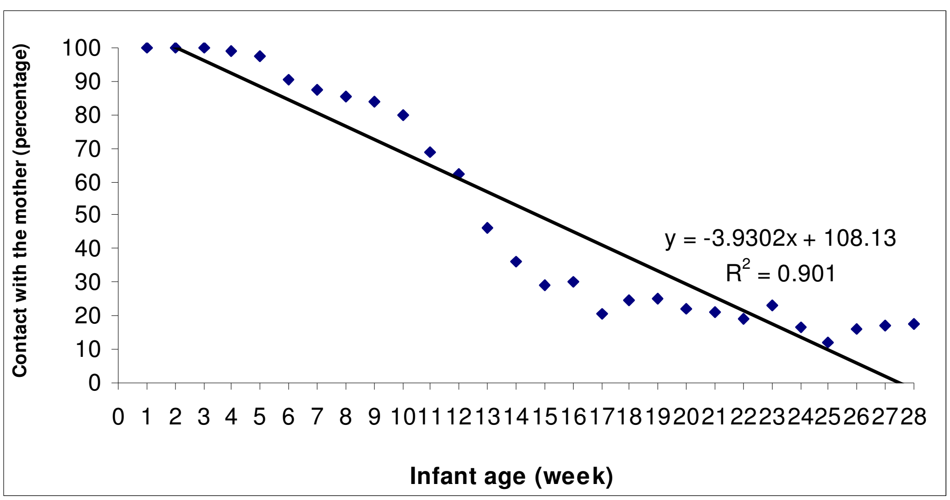

Figure 4. Percentage of *Eulemur flavifrons* infants 'observed time on mother.

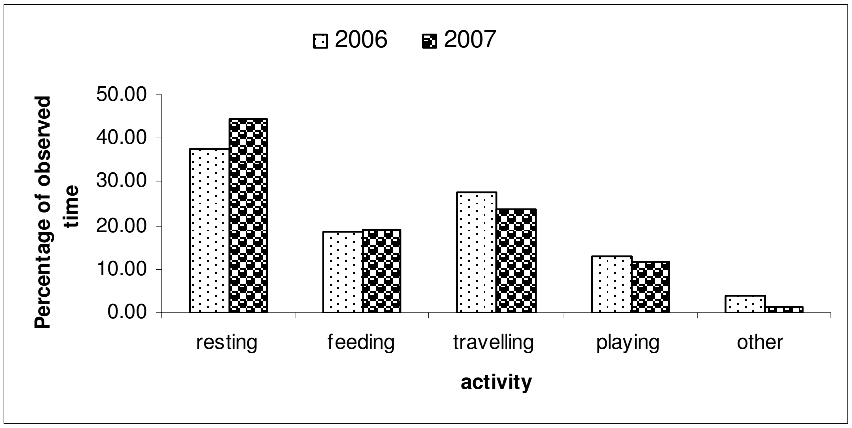

Figure 5. Comparison of activity budgets of the *Eulemur flavifrons* infants between 2006 and 2007 births.

Chapter 6

A preliminary population viability analysis of the critically endangered blue-eyed black lemur *(Eulemur flavifrons)* [5]

Abstract: We performed a population viability analysis (PVA) of the blue-eyed black lemur (*Eulemur flavifrons*) population located in Ankarafa Forest in the Sahamalaza-Iles Radama National Park, northwestern Madagascar, to assess the status of the population of this critically endangered lemur. The computer software package VORTEX was used under six scenarios with 100 iterations and simulated over 100 years. The population viability analysis showed that the population of the blue-eyed black lemur survived during the next 100 years. The baseline model determined that the blue-eyed black lemur did not go to extinct and the population would increase during the next 100 years. An estimation of 85% of extinction was predicted within 55 years when reproductive rate of adult females dropped to 50% and the maximum age of reproduction was 8 years. We assume that severe habitat destruction may affect the reproductive system of this lemur, increasing the risk of population extinction. This study was a preliminary analysis on population viability for the blue-eyed black lemur. Further data are needed for a complete analysis. Conservation strategies were proposed to both ensure the survival of this critically endangered lemur and to protect its habitat.

Key words: *Eulemur flavifrons;* population viability analysis, Ankarafa Forest, conservation strategy

Introduction

Half of all the plant and animal species known to exist have been found in tropical forests, which occupies less than 10% of the world's total land area (Park 1992; Mayaux *et al.* 2005). Ninety percent of nonhuman primates occur in the tropical forests (Whitmore and Sayer 1992). Because of the loss of the tropical forests primates species became vulnerable and population densities of many species had declined (Cowlishaw and Dunbar 2000; Fashing 2002; Chapman *et al.* 2007). The

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[5] Submittted to *Primate Conservation*: Maria S.N.VOLAMPENO, Judith C. Masters, Colleen T. Downs, Guy H. Randriatahina: A preliminary population viability analysis of the critically endangered blue-eyed black lemurs (*Eulemur flavifrons*)

major threats to non-human primates are habitat loss and fragmentation (Mittermeier and Konstant 2002).

Fragmentation leads to a reduction in original forest size and isolates remaining forest patches (Gascon *et al.* 2001; Laurance 2001; Fahrig 2003). Consequently animal populations become smaller in size and isolated; thus, they are more vulnerable and risk of becoming extinct (Gilpin and Soulé 1986; Hanski *et al.* 1996; Hedrick *et al.* 1996). Extinction risk of small populations is likely high than large population, thus population size estimate of organism is important for conservation biology (Pimm *et al*. 1988; Caughley and Gunn 1996).

Over the last decade, Population Viability Analysis (PVA) became one of the most powerful and widely used techniques in conservation biology to determine risk of extinction and decline of animal populations (Macc and Lande 1991; Boyce 1992; Coulson *et al*. 2001; Reed *et al.* 2002). PVA is a modelling tool which estimates extinction probabilities for a population of a threatened species over a given period of time (Boyce 1992; Lacy 1993; Brook *et al.* 1997; Brook *et al*. 2000). It is a useful technique to predict the future size of an animal population (Boyce 1992; Lacy 1993; Brook *et al* 2000). PVA also allows the determination of population declines under different scenarios subject to demographic, genetic and environmental stochasticities (Burgman *et al.* 1993; Brook *et al.* 1997). Previous studies reported that PVA should be used to assess threatened wildlife populations and to help their conservation and management (Brockelman 1993-4; Rylands 1993-4).

PVA has been used for several primate species, including: *Leontopithecus rosalia* spp. (Rylands 1993-4); *Brachyteles arachnoides* (Strier 1993-1994); *Cercocebus galeritus* (Kinnaird and O'Brien 1991); *Gorilla gorilla* (Harcourt 1995); *Brachyteles hypoxanthus* (Brito *et al*. 2008) and *Alouatta palliata mexicana* (Mandujano and Escobedo-Morales 2008).

Lemurs are threatened by habitat destruction due to slash and burn agriculture, timber exploitation and fragmentation (Mittermeier *et al.* 2006). Due to habitat loss eight genera of lemur have become extinct during the past 1000 years and more than half of the living species are classified endangered or vulnerable (Harcourt and Thornback 1990; Mittermeier *et al.* 1992; Cowlishaw and Dunbar 2000; Mittermeier *et al.* 2006).

The blue-eyed black lemur (*Eulemur flavifrons*) is one the least-studied day-active lemurs because it was rediscovered recently and has a restricted distribution in the northwestern forests of Madagascar (Koenders *et al.* 1985; Meyers *et al.* 1989; Mittermeier *et al.* 2006). The Sahamalaza-Iles Radama National Park (SIRNP), situated within this range, is the main habitat of this lemur (Mittermeier *et al.* 2006). Due to habitat destruction from wood exploitation, uncontrolled fire and slash and burn agriculture the blue-eyed black lemur is classified as a critically endangered species (Mittermeier *et al.* 2006). The urgent need to conserve this lemur necessitated the establishment of SIRNP in 2007.

We aimed to develop a PVA as a modelling tool to evaluate the status of the population of the blue-eyed black lemur. Considering that the blue-eyed black lemur has a restricted distribution and is threatened due to habitat destruction, this study will help better understand the demographic dynamics of this lemur. This study allows us to provide some conservation strategies to ensure the survival of this critically endangered lemur and to make recommendations on its habitat.

Materials and methods

Study site

Ankarafa Forest (14° 22’ 64.2’’S lat, 47° 45’ 31.5’’E long) is situated in the western part of the SIRNP. The SIRNP is located in northwestern Madagascar in the province of Mahajanga, delimited by the Sahamalaza Bay in the east, the Mozambique Channel in the west and the Loza River in the south. The forest of SIRNP is fragmented, comprising several blocks of forest, and includes Ankarafa Forest. The vegetation of Ankarafa Forest is mainly dominated by *Mangifera indica, Garcinia pauciflora, Sorindeia madagascariensis, Grangeria porosa, Bambou* sp., and *Mascarenhasia arborescens,* and is disturbed by fire and human activities including logging, and slash and burn agriculture (Volampeno et al. in prep.).

PVA model

A computer software package, VORTEX version 9.50 (Lacy *et al.* 2005) was used to analyze the viability of the blue-eyed black lemur. This package is one of the most used for analysis of population viability for endangered populations (Lindenmayer *et al.* 1995). Demographic parameters used as input for the PVA model were obtained from field studies carried out in Ankarafa Forest, SIRNP and from other literature (Table 1). Simulations were run over 100 years using 100 iterations for one population of the blue-eyed black lemur.

The PVA model examined a series of simulation inputs including reproductive system, reproductive rates, mortality rates, catastrophes, mate monopolization, initial population size, and carrying capacity (Table 2). Six scenarios were performed for analysis. Because of the unavailability of some reproductive data including maximum age of reproduction and adult male and female reproduction rate we used a range between 50 and 100% for the breeding rate and range between 8 and 20 years for maximum age of reproduction for the six scenarios models (Table 2). The first age of reproduction is 3 years old and the lifespan of blue-eyed black lemur is about 27 years old (Volampeno 2009). All adult females in a group bred every year (Volampeno 2009). Environmental variation (EV) refers to annual variation in the reproduction probability due to environmental conditions including weather, abundance of prey or predators, and parasites loads (Lacy *et al.* 2005). If environmental variation is included, we assumed that the reproductive rate might decrease. We assumed that fire and logging were catastrophes affecting the blue-eyed black lemur in Ankarafa Forest, (pers. obs.). Based on the current population estimate of the blue-eyed black lemur in Ankarafa Forest which is 228 individuals (Volampeno 2009) we estimated that the carrying capacity of Ankarafa Forest is about 500 individuals. We defined extinction of the population as being if one sex was extinct. We did not encounter any deaths of both sexes for the ages between 1 to 2 years and 2 to 3 years in the wild while we twice found adult males and adult females dead in the forest (pers.obs.). Therefore, we estimated that adult mortality is about 2%.

Results

Data derived from the computer software package VORTEX included, population growth rate (r); deterministic growth rate (λ); net reproduction rate (Ro); probability of population extinction ; mean time to extinction and mean population size. These results ensured that the population of blue-eyed black lemur at Ankarafa Forest survived over a period of 100 years (Tables 3 and 4; Fig. 2).

All model scenarios showed that decreases of maximum age of reproduction and breeding rate resulted in the future extant population size declining from 1235 to 34 individuals (Table 4; Fig 2). The population of the blue-eyed black lemur showed sensitivity to the decreases of reproductive rate and maximum age of reproduction. When decreasing the breeding rate of adult females to 70%, and with 10 years for the maximum reproduction age, the VORTEX analysis predicted with an 1% of extinction probability within 40 years (scenario 4). If the adult female breeding dropped to 65% and maximum age of reproduction was eight years, the PVA model showed extinction probability of 18% within 64 years (scenario 5). Within 57 years the probability of an extinction increased dramatically up to 85% when only 50% of the adult female breed with eight years as maximum age of reproduction (scenario 6) (Fig. 3).

Discussion

Although the International Union for Conservation Nature (IUCN) Red List of threatened species reported that the population trend of the blue-eyed black lemur is decreasing (http://www.iucnredlist.org), our PVA model showed that the population is predicted to survive during the next 100 years. However, this analysis did not account for the effects of major habitat destruction and fragmentation. The SIRNP which is the main habitat of the blue-eyed black lemur is fragmented; SIRNP encompasses several blocks of forest including Ankarafa (Mittermeier *et al.* 2006). Several blue-eyed black lemur populations occurred in the entire SIRNP. We modelled only a single population as a starting point of the PVA of the blue-eyed black lemur.

The VORTEX analysis concluded that there was no risk of extinction of the blue-eyed black lemur population unless the maximum reproduction age was below 12 years and female reproductive rate was less than 70%. The PVA model predicted high probability of extinction within 55 years when only 50% of adult females bred with a low maximum age of reproduction of about eight years. We suggest that it is reasonable to presume that it will not be the case because of blue-eyed black lemur reproductive behaviour (Volampeno 2009) and another long-term study on the blue-eyed black lemur (Randriatahina in prep.) confirmed that all adult females in a group reproduced annually. The estimated lifespan of the blue-eyed black lemur is 27 years and first age of reproduction is about 3 years (Volampeno 2009). Consequently, we assume that eight years is too young a maximum age of reproduction for this lemur. We suggest that the blue-eyed black lemur should reproduce until 15 years of age.

For all scenarios we added catastrophes (e.g. fire and logging) but in low frequencies; under such conditions the PVA model predicted survival of the blue-eyed black lemur population. We propose that if the habitat destruction including deforestation and fire become severe, the habitat of this lemur will dramatically decrease in size thus it will be unable to maintain a viable population as further reduction of habitat area will affect food availability and reproductive rate of the blue-eyed black lemur. Unless the forest habitat of this lemur is conserved, we predict that habitat destruction will be a major factor resulting in the decline of the population which will increase the risk of extinction of this species.

This study was a preliminary analysis on population viability for the blue-eyed black lemur. Some demographic data were unavailable for the PVA modelling. Therefore, this is not intended to be a complete analysis. However, this study revealed useful information of the future of the blue-eyed black lemur population over the next 100 years.

Conservation implications

Our PVA model predicted a survival of the blue-eyed black lemur population in Ankarafa Forest for the next 100 years. However the VORTEX analysis determined that the probability of extinction is high if the breeding rate drops to 50% and maximum of age of reproduction is below about 10 years. We believe that habitat destruction, unless stopped, will be a serious threat affecting the demographic parameters of the lemur which will increase the extinction risk of the blue-eyed black lemur population. Conservation strategies for the blue-eyed black lemur and its habitat are urgently needed. We propose three strategies for the blue-eyed black lemur and its habitat conservation.

The first strategy is to continue long-term research on behaviour, ecology and demography of the blue-eyed black lemur for further PVA. These data will provide information to assist park managers and decisions makers in monitoring the population trends and conservation status of the blue-eyed black lemur and to implement suitable and sustainable conservation actions. In particular, ongoing studies of the blue-eyed black lemur are also needed to determine population density variation; to evaluate the habitat requirements, and to track the prospects for the species' survival.

The second strategy is one of habitat restoration. Since 2005 the AEECL (Association Européenne pour l'Etude et la Conservation des Lémuriens), a consortium of European zoos for lemur research and conservation, has been involved in reforestation program in the SIRNP every year (http://www.aeecl.org). We suggest that indigenous tree species should be reforested in order to ensure food and shelter of the blue-eyed black lemur. They also provide medicinal plants materials of construction for the local population (pers. obs.). Reforestation that utilized indigenous plants would help to increase the forest size and connectivity between fragments of forests.

The third strategy is one of environmental education programmes for the inhabitants of the SIRNP. Protected areas represent an important approach to biodiversity conservation (Abbot and Thomas 2001; Ormsby and Kaplin 2005). It is no doubt that the local communities living in or near of protected areas have lived there for thousands of year thus they depend on forest resources. Therefore, they should be educated to be aware about the costs of deforestation; the benefits of the forest use, and the importance of biodiversity conservation. The inhabitants of the SIRNP have been trained on different types of modern rice growing (Randriatahaina pers. comm). However, some of villagers still employ slash and burn agriculture for rice growing (Volampeno et al. in prep.). Thus, there is a need to raise the local community awareness about the use of modern technology in rice growing in the entire of SRNP.

In conclusion, this study modelled the possible future population size of the blue-eyed black lemur and predicted probability of extinction through a population viability analysis. Conservation strategies cited above are urgently needed for the long-term survival of the blue-eyed black lemur and for its habitat protection despite the generally positive scenarios of the PVA.

Acknowledgements

This research was supported by grants from Association Européene pour l 'Etude et la Conservation des Lemuriens (AEECL), Conservation International (CI) and the Third World Organization for Women in Sciences (TWOWS). We wish to thank the School of Biological and Conservation Sciences, University of KwaZulu-Natal, South Africa, IdeaWild and Wildlife Conservation Society Madagascar Program. We would also thank the Madagascar National Parks for giving us permission to conduct our research in Sahamalaza-Iles Radama National Park. Special thanks are due to our local assistants Tombomisy, Zafihita, Yvess, Florent Adeline and Marlyne.

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Figure legends

Fig 1: Mean extant population of the blue-eyed black lemur in Ankarafa Forest.

Fig 2: Mean probability of extinction of the blue-eyed black lemur in Ankarafa Forest.

Table 1. Summary of the natural history data of the blue-eyed black lemur.

Parameter	Description/value	Reference
Identification	Male: black; female: reddish-orange	1
Locomotion	Quadrupedal, leaping	1
Social organisation	Mutimale-multifemale, female dominant	2, 3
Mean group size	7.9+ 1.8	3
Mean home range size	5.28+5.23ha	4
Diet	Frugivore	2, 3
Behaviour and ecology	Arboreal, cathemeral	1, 5
Mating system	Polygynous	Randriatahina pers. comm
Male first age of reproduction	3 years	Randriatahina pers. comm
Female first age of reproduction	3 years	6
Gestation duration	120 days	Randriatahina pers.comm
Female reproductive rate	100%	6
Birth season	Sept-Oct	6
Birth rate	1.04+0.06	6
Litter size	1	6
Adult sex-ratio	1.43	Randriatahina in prep.
Infant sex-ratio	1.62	6
Infant mortality	22.70%	6
Initial population size (Ankarafa forest)	39	7
Population density (Ankarafa forest)	97.3ind/km2	3
Current population (Ankarafa forest)	228	3
Lifespan	27 years	Digby pers.comm
Distribution	Northwestern forests of Madagascar	1, 8
Habitat	Dry deciduous forest	1
Habitat disturbance	Human activities, fire	3
Predation	*Cryptoprocta ferox, Polyboroides radiatus*	9

1: Mittermeier et al. 2006; 2: Randriatahina in prep.; 3, 4 Volampeno 2009; 5: S chwitzer et al. 2007; 6: Volampeno 2009; 7: Randriatahina and Rabarivola 2004; 8: : Meyers et al. 1989; 9: Randriatahina and Volampeno in press

Table 2. VORTEX input data per scenario (changes in successive scenarios are indicated in bold text)

Scenario	**1**	**2**	**3**	**4**	**5**	**6**
Female first age reproduction (year)	3	3	3	3	3	3
Male first age reproduction (year)	3	3	3	3	3	3
Maximum reproduction age (senescence)	**20**	**15**	**12**	**10**	**8**	**8**
Mean Birth rate	1.04	1.04	1.04	1.04	1.04	1.04
Maximum number of progeny	**2**	**1**	**1**	**1**	**1**	**1**
Sex-ratio at birth	1.62	1.62	1.62	1.62	1.62	1.62
Adult female breeding (%)	**100**	**85**	**80**	**70**	**65**	**50**
Adult female in breeding with EV (%)	**80**	**70**	**60**	**50**	**40**	**40**
Males in breeding (%)	**100**	**85**	**80**	**70**	**65**	**50**
Female mortality age 0 to 1 (%)	4.54	4.54	4.54	4.54	4.54	4.54
Female mortality age 1 to 2						
Female mortality age 2 to 3						
Female mortality after age 3 (%)	2	2	2	2	2	2
Male mortality age 0 to 1 (%)	18.18	18.18	18.18	18.18	18.18	18.18
Male mortality age 1 to 2						
Male mortality age 2 to 3						
Male mortality after age 3 (%)	2	2	2	2	2	2
Catastrophe type 1: fire						
Frequency (%)	2	2	2	2	2	2
Catastrophe type 2: logging						
Frequency (%)	1	1	1	1	1	1
Initial population size	39	39	39	39	39	39
Carrying capacity	500	500	500	500	500	500
Increase in carrying capacity (%)	**3**	**2**	**1**	**1**	**2**	**1**
Extinction definition	1 sex remains	1 sex remains	1 sex remains	1 sex remains	1 sex remains	1 sex remains

Table 3. Deterministic projections for the blue-eyed black lemur population of Ankarafa forest

Scenario		**1**	**2**	**3**	**4**	**5**	**6**
Population growth rate	r	0.189	0.150	0.130	0.210	0.040	-0.003
Deterministic growth rate	lambda (ג)	1.200	1.170	1.140	1.220	1.040	0.997
Net reproductive rate	Ro	5.03	3.29	2.48	3.41	1.27	0.98
Female and male generation time	T bar	8.56	7.58	6.73	5.82	5.32	5.43

Deterministic projections assure no stochastic fluctuations, no inbreeding depression, no limitation of mates, no harvest, and no supplementation.

Table 4. Results from VORTEX under 6 scenarios at 100 years.

Scenario at 100 years		**1**	**2**	**3**	**4**	**5**	**6**
N[Extinct]		0	0	0	1	18	84
P[E]		0	0	0	0.01	0.18	0.84
N[Surviving]		100	100	100	99	82	16
P[S]		1	1	1	0.99	0.82	0.16
Mean size (all populations)		1235	988	736	719	388	5
SE		5.34	3.72	3.51	8.3	38.39	2.04
SD		53.39	37.19	35.1	83	383.89	20.38
Means across extant populations only	Population size	1235	988	736	727	473.29	34
	SE	5.34	3.72	3.51	4.06	41.22	10.15
	SD	53.39	37.19	35.1	40.4	373.24	40.59
Number of simulations that went extinct at least once		0	0	0	1	18	84
Mean time in years to first extinction					40	64	55
Mean growth rate across all years prior to carrying capacity truncation		0.19	0.15	0.15	0.19	0.02	-0.03

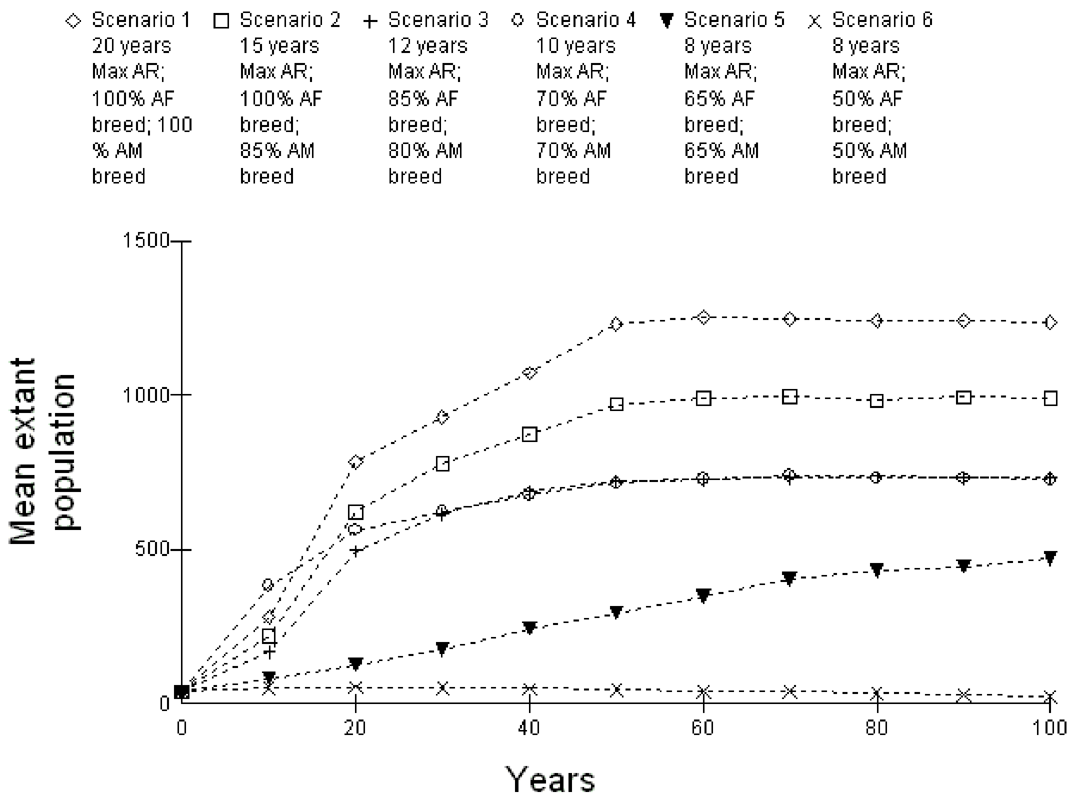

Figure 1. Mean extant population of the blue-eyed black lemur in Ankarafa Forest.

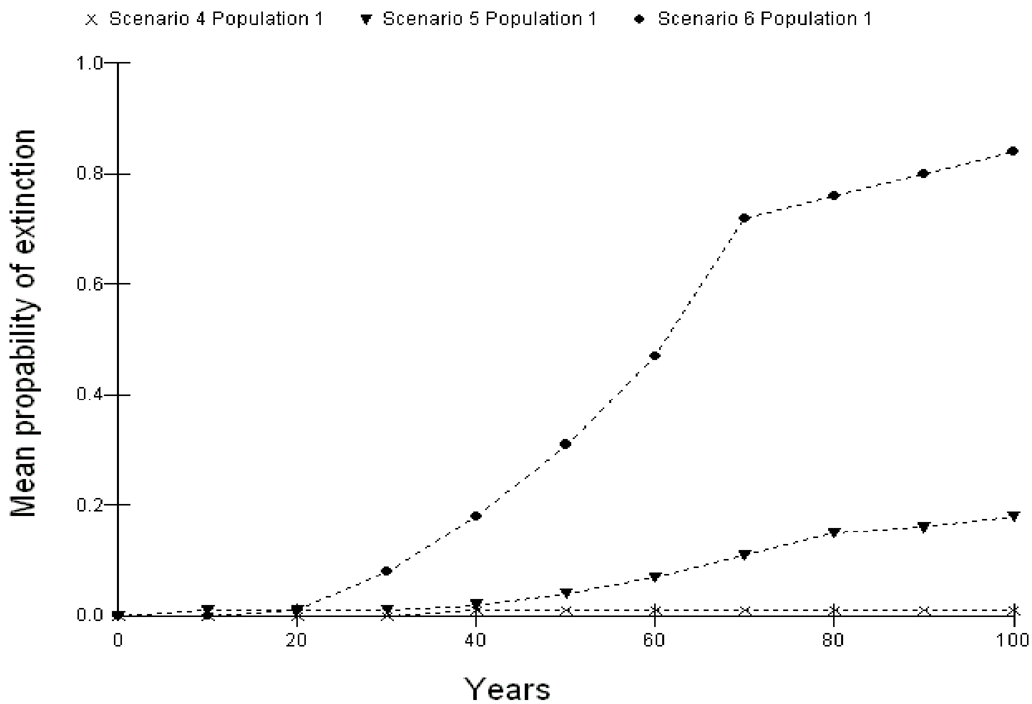

Figure 2. Mean probability of extinction of the blue-eyed black lemur in Ankarafa Forest.

Chapter 7

Involving local communities in conservation: An example involving blue-eyed black lemurs (*Eulemur flavifrons*)[6]

Abstract

Involving local communities and gaining their active support is crucial for the success of programs aimed at conserving endemic biodiversity. We aimed to increase local population awareness of the necessity to conserve the critically endangered species *Eulemur flavifrons* and its habitat. We describe environmental education activities including song and play performances at an annual lemur festival, and the distribution of T-shirts in the Sahamalaza-Iles Radama National Park, which contains the major part of this lemur's distribution. We questioned people from different villages inside the Sahamalaza-Iles Radama National Park about their impressions of our performance at the festival. In general, the local community was positive towards lemur and forest conservation. Environmental education projects, even simple ones as described here, may assist conservation efforts to save threatened wildlife.

Key words: *Eulemur flavifrons,* education, conservation, local communities

Introduction

Conservation areas often have local communities living in or near them. During the creation of protected areas local communities have often been disregarded by institutions and organizations involved in establishing conservation areas (West and Brechin, 1991; Western and Wright, 1994; Stevens, 1997). Consequently, conflicts may arise between wildlife managers and local communities when the use of natural resources becomes restricted, because local communities' livelihoods depend on the forest (Hough, 1988; Hales, 1989; Rodgers, 1989; Gadgil, 1990; Mishra *et al.,* 1992). Protected areas should make allowance for the maintenance of the livelihoods of local communities (McNeely, 1995; Ghimire and Pimbert, 1997).

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[6] Revised for to the *Lemur News* : Maria S. N. Volampeno and Colleen T.Downs, Involving local communities : An example involving blue-eyed black lemurs (*Eulemur flavifrons*)

Over the last decade, involving local populations in conservation activities has become a priority of conservation policy (Adams and Hulme, 1998; Agrawal and Gibson, 1999). Several studies have documented that participation and support from local communities is an effective method for sustainable conservation (Heinen, 1993; Durbin and Ralambo, 1994; Fiallo and Jacobson, 1995). For example, sustainable forest management requires that the people living in the forest should learn how to use the forest resources without depleting them in the long term (Brookfield, 1988).

The major objectives of environmental education are to provide local people with the knowledge they need to protect and improve their environment, and to assist them in assessing the impacts of resource use so that they can modify their behaviour to ameliorate environmental problems as they arise (Palmer, 1998). Here we report on our contribution to environmental education of the local community in the Sahamalaza-Iles Radama National Park (SIRNP), which contains the major part of the range of the blue-eyed black lemur (*Eulemur flavifrons*). Our objectives were to increase local population awareness of the necessity for conservation of the blue-eyed black lemur and its habitat, and to shift local attitudes away from deforestation to sustainable management of natural resources.

The SIRNP is located in north-western Madagascar in the province of Mahajanga (between 14° 04' and 14° 37' S and 47° 52' and 48° 04' E) with altitudes varying from 0 to 355 m. The peninsula covers an area of approximately 26,000 ha, limited by the Sahamalaza Bay in the east, the Mozambique Channel in the west and the Loza River in the south (see Volampeno, 2009).

Why protect the blue-eyed black lemur?

Because of the presence of the critically endangered blue-eyed black lemur in the SIRNP, the area has been the focus of scientific and conservation interest by the Association Européenne pour l'Etude et la Conservation des Lémuriens (AEECL), which is a consortium of European zoos engaged in lemur research and conservation (http://www.aeecl.org). The blue-eyed black lemur can be considered one of their "flagship" species because it represents all conservation efforts in the SIRNP. This lemur is among the most distinctive lemurs, with its bright blue eyes and strong sexual dichromatism; the males are completely black and the females reddish-orange (Mittermeier *et al.,* 2006). It ranks also among the least studied of the diurnal lemurs and was rediscovered relatively recently (Koenders *et al.,* 1985).

The distribution of this lemur is restricted to a small area of forest in north-western Madagascar, most of which occurs within the SIRNP (Mittermeier *et al.,* 2006). The species is classified as critically endangered because of continued habitat destruction for wood exploitation, uncontrolled fire, and slash and burn agriculture (Mittermeier *et al.,* 2006; pers. obs.).

Blue-eyed black lemurs are arboreal and frugivorous, and thus totally dependent on the forest. Several studies have demonstrated that many frugivorous primates, including lemurs, play an important role in seed dispersal for forest trees and the pollination of some forest canopy flowers (e.g. Kress *et al.,* 1994; Birkinshaw and Colquhoun, 1998; Lambert, 1998; Ganzhorn *et al.,* 1999; Oliveira and Ferrari, 2000; Fedigan and Jack, 2001; Lambert, 2001; Koné *et al.,* 2008). The frugivorous nature of blue-eyed black lemurs indicates that it probably plays a role in seed dispersal and forest regeneration.

Why involve the local population?

Habitation of the forest by people goes back more than a thousand years, and the local communities have a good practical knowledge of the forest, and the skills to manage and develop their environment (Palmer, 1998). Members of the Sakalava ethnic group constitute the majority of the population found on the SIRNP, but migrants from the Tsimihety ethnic group also inhabit in this region (Andrianantenaina, 1996). In the SIRNP, the majority of the villages are situated along the eastern and western coastal areas, with only a few settlements scattered in the interior of the peninsula (Andrianantenaina, 1996). Rice is the main crop cultivated. This agricultural practice consists of cutting and burning forested zones of one to two acres for paddy fields. After one or two years of production, the soil is exhausted, and the farmers abandon the site and search for new site (pers. obs.). Subsistence fishing is also practiced, but on a small scale due to the difficulty of obtaining fishing equipment (Andrianantenaina, 1996). Most of the households on the peninsula have free-ranging cattle. Consequently the local population has burned grasslands near the forest savannahs to encourage the growth of young grasses for livestock pastures (Rakotondratsima, 1999). This practice results in uncontrolled fire on the peninsula. In addition, the villagers practice logging inside the forest for private sale.

If the forest continues to decline at its present rate, the blue-eyed black lemur will face extinction and the local populations will lose the benefits of the forest. My rationale was that, if the local community was made more aware of the consequences of degrading their environment, they could be convinced to take responsibility for conserving and managing the natural resources in their vicinity.

Materials and methods

Song and sketch performance

The AEECL/WCS consortium helped the the local communities to establish conservation association "VOLAMAINTSO" and other local associations in order to help them manage their natural resources sustainably (Schwitzer, 2006; Schwitzer *et al*. 2006) established. Since 2005, VOLAMAINTSO has organized an annual "lemur festival" for three days each September. The main goal of this festival is to increase the local population's awareness of the biodiversity, and especially of the need for lemur conservation. During the festival villages living within the SIRNP participate in devising songs and dances and in sports events. The songs are presented as part of a competition, and the village which performs the best song receives a prize from the AEECL. The lyrics of the songs must relate to conservation.

Since 2006 M.S.N.V has been a lemur festival organizer, and in 2007 my local research assistants and she participated in the festival, which took place in Antafiabe, a village inside the SIRNP. They performed a song and a play about the blue-eyed black lemur (Figure 1). They practiced every night for a period of a month before the lemur festival. M.S.N.V. wrote the song lyrics and play script and an assistant translated it into the local language "Sakalava" so the public could understand our message. The performance was both educational and entertaining and could be understood by all age/sex classes. The lyrics of the song were about the importance and benefits of biodiversity protection and the disadvantages of deforestation and slash and burn agriculture. The title of the play was ***"Protect the blue-eyed black lemur to protect the forest"***. All the research assistants acting in the play wore costumes that matched that of the actor playing the blue-eyed black lemur and imitating its vocalization and movement. They were taught to act naturally during the show in order to keep the full attention of the public. The play illustrated how the local population benefits from blue-eyed black lemurs and the forest, and showed that the presence of the lemurs in the SIRNP provides advantages for the local population in the form of tourism and jobs, and contributes to forest regeneration. It also demonstrated that the needs of the local people (e.g. wild fruits, medicinal plants, fuelwood, construction materials) depend on the survival of the forest. The play ended with a strong message: “Protecting this lemur will help forest protection”.

The song was performed for about 10 min on the first day of the festival, while the play lasted 30 min and was performed on the second day. Both were performed once at the festival.

Distribution of T-shirts

Conservation International (CI) agreed to provide 50 cotton T-shirts to promote lemur conservation as a contribution to M.S.N.V. PhD research support. The AEECL programme coordinator (Guy Randritahina) and M.S.V. designed the logo for the T-shirt, which was drawn by Stephen Nash. The T-shirt is illustrated in Figure 2. A conservation message was written on both sides in the local language. On the front was a colour picture of the Sahamalaza sportive lemur *(Lepilemur sahamalazensis*), a recently described species (Andriaholinirina *et al.,* 2006), and the text message: “***Stop fire, deforestation and lemur hunting”***. On the back were colour pictures of a male and female blue-eyed black lemur with the text message: “***Protect biodiversity”***.

The T-shirts were distributed in September 2008. The number of shirts was insufficient for all villagers in the SIRNP, and so they were distributed to our research assistants, teachers at primary schools and village chiefs. We arranged meetings with the respective teachers and village chiefs during which we explained our reasons for protecting blue-eyed black lemurs and the consequences of deforestation. We included research assistants in the programme because they have made observations of blue-eyed black lemurs and know the importance of protecting the species and its habitat. The village chiefs have frequent contact with the local population, and are decision makers whose words carry authority (pers. obs.). During classes, teachers have the opportunity to discuss conservation with pupils, and also have contact with the pupils’ parents. We encouraged them to pass on the conservation message whenever possible, such as at village meetings or environmental events like Environment Day, Tree-planting Day and the lemur festival.

Local community perceptions

After our performance we asked about 30 people (excluding children) from different villages a series of questions relating to their comprehension of the play contents and lessons learned from our performance. Of these 64% were female and 36% male, and all had watched the performance. Of these 50% highlighted that they had enjoyed the performance, 23% highlighted leanring about the behaviour of blue-eyed black lemurs including aspects of their vocalizations and movements, 17% highlighted learning the advantages of the presence of this lemur e.g tourism, while while 10% highlighted learning the costs of deforestation. In addition, after the event the local conservation association (which is the main organizer of the lemur festival) and the village chiefs conducted an evaluation of the festival. Overall, the local communities enjoyed the performances, gained knowledge of behaviour of the blue-eyed black lemurs (e.g. vocalization, movement), and were more aware of the costs of deforestation and advantages accruing from the presence of blue-eyed black lemurs. The village chiefs and teachers were highly motivated to encourage a change of attitude towards lemur hunting and deforestation among the local population, and decided to wear the T-shirts during meetings and environmental events. Many people asked us for more T-shirts. Our play was the first to be performed since the initiation of the annual lemur festival in the SIRNP. In 2008 we were asked about a new play, as the people had enjoyed the previous one.

Discussions and conclusion

Our contribution was not the only conservation education measures that have been/are being carried out in Sahamalaza-Iles Radama National Park (e.g.distribution of educational booklets, participation in JME and local fares) (Schwitzer, 2006; Schwitzer *et al.* 2006). Our environmental education was a basic step towards practical blue-eyed black lemur conservation. It received a positive response from the local population. Further projects, such as the production of leaflets, T-shirts, posters, handbooks for schools, and documentaries, are necessary to increase public awareness of the need for sustainable conservation of the blue-eyed black lemur and its habitat. Communities have lived in the forest for thousands of years and depend on forest wildlife and resources. Through programmes like ours, they can be encouraged to take ownership of and responsibility for the management and protection of the forest and its resident lemur species.

Acknowledgements

This research was supported by grants from Association Européene pour l 'Etude et la Conservation des Lemuriens (AEECL), Conservation International (CI), and the Third

World Organization for Women in Sciences (TWOWS). M.S.N.V. wishes to thank the School of Biological and Conservation Sciences, University of KwaZulu-Natal, South Africa, IdeaWild and Wildlife Conservation Society for support, and the Madagascar National Parks for giving me permission to conduct my research in Sahamalaza-Iles Radama National Park. M.S.N.V is grateful to Russell Mittermeier and Stephen Nash for their help with the T-shirts. Special thanks are due to Guy Randriatahina, the local assistants and the local communities in the Sahamalaza-Iles Radama National Park.

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Figure legends

Figure 1: Enactment of the play during the Lemur Festival September 2007, Antafiabe Village, Madagascar.

Figure 2: Design of the T-shirt for conservation awareness of lemurs showing a) the front and b) the rear of the t-shirt.

Figure 1. Enactment of the play during the Lemur Festival September 2007, Antafiabe Village, Madagascar.

a) b)

Figure 2. Design of the T-shirt for conservation awareness of lemurs showing a) the front and b) the rear of the t-shirt.

Chapter 8

Summary and conclusions

Madagascar ranks as one of the world's biodiversity hotspots because of the high endemicity of floral and faunal species (Myers et al. 2000; Mittermeier et al. 2006). The island is facing major threats to its biodiversity. Today, anthropogenic activities and forest fragmentation are the major causes of the decline of plants and animals species including lemurs (Godfrey et al. 1997; Hume 2007). Fragmentation is one of the main threats to the lemurs (Mittermeier et al. 2006).

The blue-eyed black lemur is one of the least-studied day-active lemurs because of its recent rediscovery and limited distribution (Koenders et al. 1985, Meyers et al. 1998, Mittermeier et al. 2006). The Sahamalaza- Iles Radama National Park is the main habitat of this lemur (Mittermeier et al. 2006) and is also one of Madagascar's most recently declared protected areas. Due to habitat destruction, the blue-eyed black lemur is classified as a critically endangered species (Mittermeier et al. 2006). Given that little is known about the life history of the blue-eyed black lemur and that its habitat is restricted and threatened, the chief purpose of this study was to gather fundamental data on the natural history of the blue-eyed black lemur. I also provide information regarding a programme aimed at involving local communities in the conservation of the blue-eyed black lemur and its habitat and provide conservation strategies for the human population in Sahamalaza-Iles Radama National Park.

The study site was described by using a plot sampling method both along the forest edges and forest cores (Chapter 2). Ankarafa Forest is dominated mainly by the *Mangifera indica*, *Garcinia pauciflora*, *Sorindeia madagascariensis, Grangeria porosa, Mascarenhasia arborescens* and *Bambou* sp species. Forest edges contained fewer living trees and more dead trees than the forest cores areas. Seventy-eight percent of the tree species recorded produce fruits. It is concluded that the Ankarafa Forest should be classified as disturbed because of evidence of human activities including clearing and logging (Chapter 2).

The direct count method was used to estimate the population size and density of the blue-eyed black lemur in Ankarafa Forest (Chapter 3). The blue-eyed black lemur population size in Ankarafa Forest was estimated to be 228 individuals comprising 29 groups with group size ranging from 4 to 11 individuals (mean: 8 ± 1.8). The population density was estimated to stand at 97.3 individuals km^{-2}. My study provides the most up- to-date data on the Ankarafa Forest blue-eyed black lemur population. It also showed the effectiveness of the direct count method for estimating population size of day-active primates living in a relatively small area. Consequently, I suggested that a broader census of the blue-eyed black lemur population across the Sahamalaza-Iles Radama National Park, the main habitat of this lemur, be conducted using the same method (Chapter 3).

Home range use by the blue-eyed black lemur was studied in particular to assess the variation between dry and wet seasons at Ankarafa Forest (Chapter 4). The results supported the hypothesis that home range size varies seasonally as a consequence of the effect of rainfall on fruit availability. Blue-eyed black lemurs occupy larger home ranges in the dry season than in the wet season. This result is similar to those documented in *Papio ursinus* (Gwenzi et al. 2007) and *Trachypithecus francoisi* (Zhou et al. 2007). I suggested that food resource availability may be the factor affecting home range variation in the blue-eyed black lemur. Previous studies have demonstrated that in primate species changes in home range size result from changes in food distribution and availability (Takasaki 1984; Rylands 1986; Kirkpatrick et al. 1998; Su et al. 1998). The average total home range of the blue-eyed black lemur was estimated to be 5.3 ± 5.2 ha. This concurred with home range sizes reported by Overdorff and Johnson (2003) and supports the interpretation home ranges of most *Eulemur* species are relatively small, about 10ha (Chapter 4).

My study is also the first study on the life history traits, maternal behaviour and infant development of the blue-eyed black lemur was conducted over two successive birth seasons (Chapter 5). I showed that the births are seasonal, occurring at the end of the dry season (late August- October). The age of first reproduction is about 3 years and female gives birth to a single offspring. The mean birth interval is about 358 ± 24.81 days and the birth rate was estimated to be 1.0 infant per female per year. Lactating females appeared dominant over males, supporting the general observation of female dominance in Malagasy lemur species (Richard 1987; White et al. 2007). Infant blue-eyed black lemurs spent the first three weeks of life in close contact with their mothers. Environmental exploration started at week 6. At week 10, ingestion of solid food and independent locomotion began. The behavioural development stages of infant blue-eyed black lemurs covered the three general stages stated by Poirier (1972) and Fragaszy and Mitchell (1974). Mothers were the primary caretakers of infants although other group members provided alloparental care to infants including carrying, grooming and playing. Infant mortality over the study period was 22.7%. Predation and sickness were observed as the causes of infant mortality over this period. Using life history parameters of several primates the prediction regarding relationships between life history parameters and body size was supported. My result conforms view of in front of mammalian life history patterns being distributed along a “fast-slow continuum “(Promislow & Harvey 1990) and supported Harvey and Clutton-Brock ‘s (1985) conclusion that, in primate species, life history traits correlate highly with body size. I showed that the blue-eyed black lemurs reproduced at a relatively early age, and have high birth rate compared with other species of primates (Chapter 5).

Preliminary analysis of the viability of the blue-eyed black lemur population in Sahamalaza-Iles Radama National Park using the computer software package VORTEX showed that the population is projected to survive for the next 100 years (Chapter 6). The simulations yielded that the probability of extinction depends on the female reproductive rate and maximum age of reproduction. When only half of the adult females breed at 8 years as the maximum age of reproduction, the probability of extinction increased up to 85% within 57 years. This showed that the population of the blue-eyed black lemur is sensitive to the reproduction rate parameters. Conservation strategies were proposed for sustainable protection of the blue-eyed black lemur and its habitat. It is suggested that severe habitat destruction may affect the reproduction which increases the risk of population extinction. It appears that habitat destruction is one the major threats of Malagasy lemurs (Chapter 6).

The preventon of habitat destruction, conserving forests and the fauna found there are essential if the biodiversity of Madagascar’s forests is to be maintained. Consequently the local communities living in areas surrounding the Sahamalaza-Iles Radama National Park were involved in activities that highlighted blue-eyed black lemur conservation (Chapter 7). These activities included a play with songs performed, and distributing T-shirts carrying a conservation message. These all generated a positive response among the local inhabitants towards lemur and forest conservation. The local community became aware of about the various costs of deforestation and the need for blue-eyed black lemur conservation. Local decision-makers (e.g. chiefs of villages and public school teachers) were also involved and were role models in increasing local awareness of changing attitude towards lemur hunting and forest over-exploitation (Chapter 7).

In conclusion, the study has provided essential data to the understanding of the natural history of the blue-eyed black lemur and highlighted conservation needs and approaches both for species and its habitat. Following this study, I have the following recommendations that may be appropriate for a sustainable conservation of the blue-eyed black lemur and for management of its habitat in the long-term.

Mapping the entire habitat of the blue-eyed black lemur via satellite imagery and Geographical Information Systems (GIS) should be a priority for areas both in the national park and outside it. Using this information the vegetation types, shape and exact size of the remaining forest fragments would be determined. New maps should be used in combination with old ones to examine the history of forest fragmentation and the deforestation rate. It is important to evaluate the rate and extent of forest loss to help the park managers to protect the remaining forest both in the national park and outside. Creation of buffer zones around the park may be necessary to prevent people from exploiting wood illegally and to limit the practice of slash and burn agriculture inside the forest.

Habitat characteristics of several sites other than Ankarafa Forest need to be described to provide comparative data on the forest characteristics including species diversity, tree heights and tree diameters and the extent of forest disturbance.

Ongoing population surveys across the entire habitat of this species need to be conducted. These surveys will allow changes in the distribution, abundance, status and social structure of the blue-eyed black lemur population to be described and monitored. These surveys should be conducted annually so that trends in population numbers, especially whether they are increasing or declining, can be determined. Long-term monitoring of populations is essential since the species is endangered and their habitat is under threat. To further determine the dynamics of the population reproductive parameters, the present study will be continued to yield longer term information regarding reproductive, birth and mortality rate.

Studies at several sites need to be conducted to estimate the spatial requirements and to examine the effect of habitat on the home range size in blue-eyed black lemurs. Study of the habituated lemur groups in Ankarafa Forest should be continued to investigate the dynamics of the groups, including migration, birth, death and predation.

Genetic studies are also needed to assess genetic variability and kinship patterns in social groups. These longer-term studies cited above are needed to understand more completely the life history of the blue-eyed black lemur and are necessary for a complete Population Habitat and Viability Analysis (PHVA).

Environmental education programmes are also crucial for the protection of both the blue-eyed black lemurs and the remaining forests providing habitats for several floral species. Local people surrounding the Sahamalaza-Iles Radama National Park should be educated about the importance of protecting the environment where they live. An environmental education curriculum could be comprised of several resources (e.g. posters, leaflets, school handbooks, show performances, films and documentaries) so that all age/sex classes understand the message. On any occasion relating to environmental issues (e.g. environment day, reforestation day and the lemur festival) and regional and national events or celebrations (e.g. Independence Day; the regional fair and school open days) posters and leaflets could be distributed, films and documentaries could be broadcast and show performance could be continued. Local schools should be provided with environmental handbooks so that pupils are made aware about of the importance of the forest and wildlife conservation. Pupils should be encouraged to participate in local and international celebrations (e.g. environment day, reforestation day, the lemur festival).

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