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"Programme Sahamalaza": New perspectives for the *in situ* and *ex situ* study and conservation of the blue-eyed black lemur (*Eulemur macaco flavifrons*) in a fragmented habitat

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Abstract

The critically endangered blue-eyed black lemur (*Eulemur macaco flavifrons*),which only occurs in a small area of sub-humid forest in northwest Madagascar, has been selected as the flagship species for all conservation efforts concerning the terrestrial part of the newly created protected area on the Sahamalaza peninsula. This paper provides a research and conservation scheme with regard to an ongoing programme for the study and conservation of *E. m. flavifrons*. It reviews the existing knowledge about the subspecies, including preliminary results from the current field work in Sahamalaza, and intends to help guiding further research activities. The issues addressed here are: distribution and status of the blue-eyed black lemur in the wild, general ecology and behaviour, nutritional ecology, genetics, parasitic status, the role of the captive population for conservation, as well as immediate in situ conservation measures and long-term perspectives. Whereas ongoing studies broach the issues of nutritional ecology, socioecology, parasitic status and habitat use of *E. m. flavifrons*, future work needs more detailed investigations on how the lemurs cope with the fragmentation of their habitat and which measures are necessary to increase the probability of persistence of the taxon in forest fragments. Important research questions are how matrix-tolerant *E. m. flavifrons* (and other species living in Sahamalaza) are, whether the animals suffer or benefit from possible edge effects, and if and to what extent dispersal between forest fragments takes place.

Key words: Fragmentation, ecology, behaviour, genetics, parasites, nutrition

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Programme Sahamalaza: Nouvelles perspectives pour l'étude et la protection *in situ* et *ex situ* du Lémur flavifrons (*Eulemur macaco flavifrons*) dans un habitat fragmenté

Résumé
Le Lémur flavifrons (*Eulemur macaco flavifrons*), espèce en danger critique qui n'est distribuée que dans une petite zone de forêt sub-humide au nord-ouest de Madagascar, a été retenu en tant qu'espèce porte-étendard de tous les efforts menés en matière de protection de la nature portant sur la portion terrestre de la nouvelle aire protégé créée sur la presqu'île de Sahamalaza. Nous présentons ici un plan de recherche et de protection de la nature basé sur un programme d'étude et de protection d'*E. m. flavifrons*. Nous reprenons ce qui est connu sur cette sous-espèce, y compris les résultats préliminaires du travail de terrain réalisé à Sahamalaza afin de mieux guider les futures activités de recherche. Les aspects abordés ici portent sur la distribution et le statut de Lémur flavifrons dans la nature, l'écologie générale et son comportement, l'écologie nutritionnelle, la génétique, la parasitologie, le rôle d'une population en captivité pour la conservation, ainsi que des mesures immédiates de protection de la nature et des perspectives à long terme. Alors que les études en cours abordent les questions d'écologie nutritionnelle, de socioécologie, de parasitologie et d'utilisation de l'habitat pour *E. m. flavifrons*, les travaux à mener dans l'avenir devront inclure des recherches plus détaillées pour comprendre comment les lémuriens tolèrent la fragmentation de leur habitat et quelles mesures doivent être prises afin d'augmenter les chances de maintenir ce taxon dans les fragments forestiers. Des questions de recherche importantes portent sur la tolérance d'*E. m. flavifrons* (et d'autres espèces vivant à Sahamalaza) à la matrice pour savoir si les animaux pâtissent ou profitent d'effets éventuels de lisière et si et dans quelle mesure la dispersion existe entre les fragments forestiers.

Mots-clés: Fragmentation, écologie, comportement, génétique, parasites, nutrition

Introduction

Due to its unique fauna and flora, the Sahamalaza region in northwest Madagascar has been in the focus of scientific and conservation interest since 1994 (WCS, 2001). The blue-eyed black lemur (*Eulemur macaco flavifrons*; fig. 1), exclusively occurring in the sub-humid forests of the Sahamalaza peninsula and in a small stretch of forest on the adjacent mainland, has been selected as the flagship species for all conservation efforts concerning the region. *E. m. flavifrons* is critically endangered because of its limited distribution area, fragmentation of its remaining habitat, and small total population size.

The Cologne Zoo has been involved in efforts to protect the last remaining habitat of the blue-eyed black lemur since the late 1980s, when it became one of the founding members of a Franco-German consortium for lemur research and conservation. This consortium has developed into the *Association Européenne pour l'Etude et la Conservation des Lémuriens* (AEECL) which, together with its American partners, the *Wildlife Conservation Society* (WCS), and with the Malagasy national parks authority (ANGAP) has since been working on the implementation of a UNESCO biosphere reserve and a national protected area on the Sahamalaza peninsula (fig. 2; see also Meier *et al.*, 1996; Rumpler *et al.*, 1996; Lernould, 1998, 2002; Moisson *et al.*, 1999). Scientists from AEECL, WCS and from the Universites of Antananarivo and Mahajanga have conducted a number of preliminary short-term observations in the area, mainly concentrating on population censuses of *E. m. flavifrons* and other species (e.g., Andriamanandratra, 1996; Meier *et al.*, 1996; Rakotondravony, 1996; Rakotondratsima, 1999). Moreover, studies were conducted on the genetic variability of the blue-eyed black lemur's subpopulations (e.g., Rabarivola *et al.*, 1998; Fausser *et al.*, 2000). There remained however large gaps in the information concerning population and social dynamics, habitat utilisation, nutritional ecology, and veterinary issues necessary for the development of comprehensive *in situ* and *ex situ* conservation and management plans for this critically endangered lemur.

At their 2003 annual general meeting, AEECL identified the development of a comprehensive research programme for the remaining *E. m. flavifrons* meta-population as one of its priorities.

Fig. 1. Female blue-eyed black lemur (*Eulemur macaco flavifrons*). Photo: Nora Schwitzer

The first version of this scheme was published in early 2005 (Schwitzer & Kaumanns, 2005). The chapter at hand provides an updated second version. It reviews the existing knowledge about the subspecies, including preliminary results from the ongoing field work in Sahamalaza, and should help guiding further research activities. We have given precedence to those issues which are directly relevant to the conservation of the blue-eyed black lemur: distribution and status in the wild, general ecology and behaviour, nutritional ecology, genetics, parasitic status, the role of the captive population for conservation, as well as immediate *in situ* conservation measures and long-term perspectives. Our intention is to link *in situ* research and conservation efforts to corresponding *ex situ* studies wherever possible, as has been initiated already with regard to the nutritional ecology of the blue-eyed black lemur (Schwitzer, 2003; Polowinsky & Schwitzer, 2005; see also Singh & Kaumanns, 2005).

During the course of 2004 a field research station and a working group have been established by scientists of the Cologne Zoo and the Universities of Antananarivo and Mahajanga in the Ankarafa forest, situated within the UN Biosphere Reserve and proposed APMC (Aire Protégée Marine et Côtière) Sahamalaza - Iles Radama (Schwitzer & Lork, 2004). Ankarafa's forest fragments accommodate one of the largest connected populations of blue-eyed black lemurs still remaining. The reserve is part of the Province Autonome de Mahajanga, NW Madagascar, and extends between 13°52'S and 14°27'S latitudes and 47°38'E and 47°46'E longitudes (WCS/DEC, 2002). The first three long-term research projects, namely on the nutritional ecology, socioecology and parasitic status of *E. m. flavifrons* (see below), are currently being carried out within the framework of AEECL's Programme Sahamalaza. Other species that have been subject to studies and/or census work in Sahamalaza during the last years were *Mirza zaza* and *Lepilemur sahamalazaensis* (Olivieri *et al.*, this volume; M. Craul, pers. comm.) as well as birds (Razafindrajao, 2004; Schwitzer, 2005).

Distribution and status in the wild

The subspecies *E. m. flavifrons*, the taxonomic validity of which was recently confirmed independently by Rabarivola (1998) as well as Pastorini (2000), was rediscovered by science only in 1983 after more than a century of uncertainty about its existence (Koenders *et al.*, 1985; Meier *et al.*, 1996).

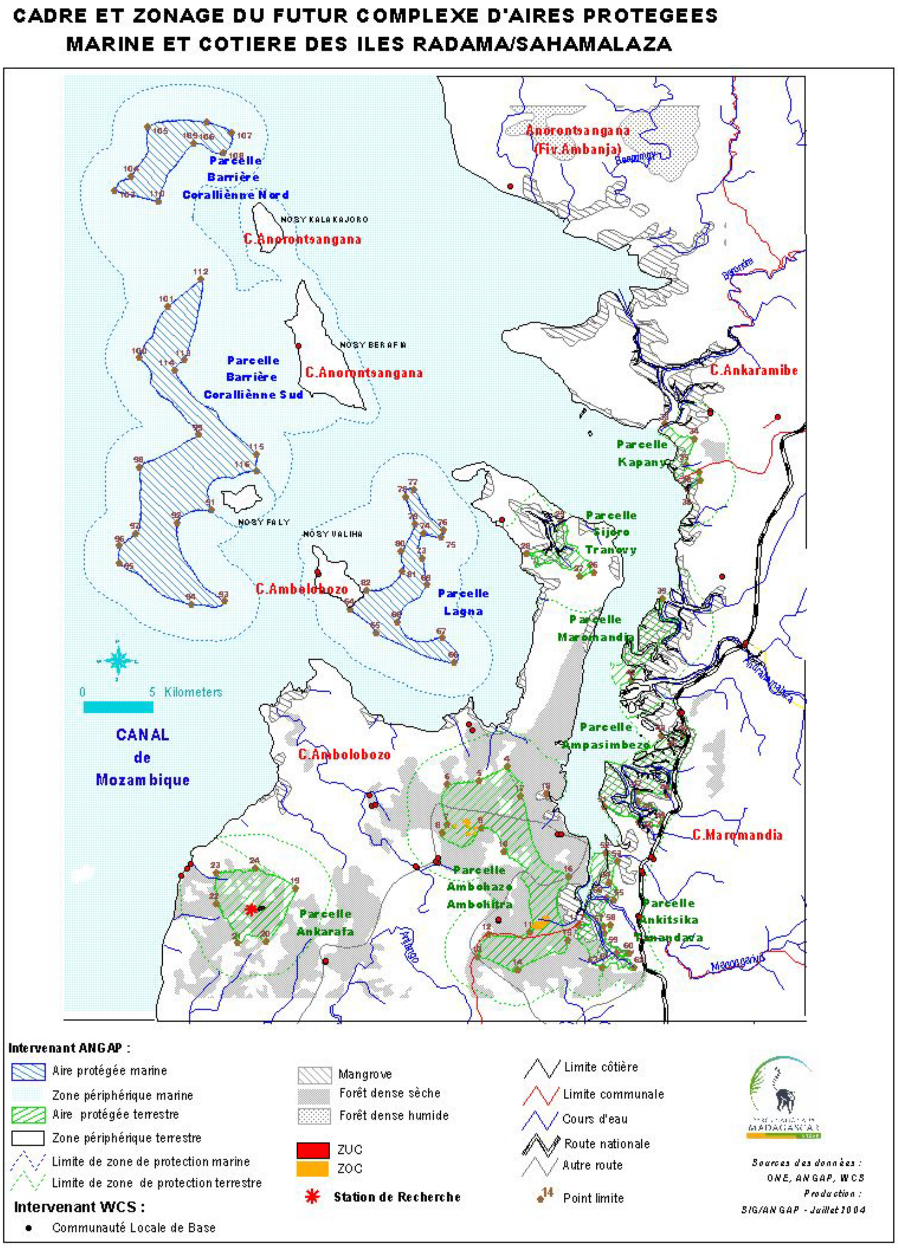

Fig. 2. Sahamalaza peninsula, northwest Madagascar, the largest connected distribution area of *Eulemur macaco flavifrons*, UNESCO Biosphere Reserve since 2001 (©ANGAP & WCS Madagascar, with kind permission).

It is therefore one of the least-studied of all lemur taxa. The taxon exclusively occurs in northwest Madagascar in a very small area of about 2700 km^2 south of the Andranomalaza, north of the Maevarano, and west of the Sandrakota rivers, where it inhabits primary and secondary forests and forest fragments (Koenders *et al.*, 1985; Meyers *et al.*, 1989; Rabarivola *et al.*, 1991; Mittermeier *et al.*, 1994). The area of repartition of *E. m. flavifrons* lies within a transition zone between the Sambirano region in the north and the western dry deciduous forest region in the south, harbouring semi-humid forests with tree heights of up to 30 m on ferruginous alkalescent and alkaline soils based on sandstone, basalt or clay (IRNT, 1991a). Average annual precipitation is around 1600 mm (IRNT, 1991b).

The blue-eyed black lemur seems to hybridise with the nominate subspecies of *E. macaco*, the black lemur (*E. m. macaco*), in the border region of the two distribution areas (Meyers *et al.*, 1989; Rabarivola *et al.*, 1991; Andrianjakarivelo, 2004). Based on a few specimens they captured in the region of Ambodivoahangy as well as east of the village of Beraty, Meyers *et al.* (1989) suggest that a zone of intergradation between the two forms occurs over the entire Manongarivo Mountain range and foothills. They further suggest that there exists a geographical cline in subspecific traits in this area. However, lemurs which look very similar to the "hybrids" depicted by Meyers *et al.* (1989) and Rabarivola *et al.* (1991) also occur at the western border of the *E. macaco* distribution area, around the village of Kapany, about 12 km north of Maromandia (Schwitzer, 2004). The main part of the Kapany forest is situated on the mountainsides of the 405 m high Ankitsiky mountain. Because the mountain is steep and it is privately owned and not accessible without permission, large parts of the original primary forest are still intact. The Kapany lemurs resemble *E. m. macaco* in some, but not all characteristics. The eartufts of both sexes are not as pronounced as in the *E. m. macaco* shown in Koenders *et al.* (1985) and Meyers *et al.* (1989), and in the females the head is, except for the black face, completely white. These animals are homogeneous in colouration across groups and forest fragments. It is therefore unlikely that they represent subspecies hybrids. The actual distribution area of these individuals is currently not known. Information on distribution would help to clarify their taxonomic status.

There is only a small total population remaining of *E. m. flavifrons*, the largest part of it living in forest fragments on and adjacent to the Sahamalaza peninsula (Mouton, 1999; see fig. 1). Rakotondratsima (1999) estimates the population of the Sahamalaza peninsula to count 450-2300 individuals and to have shown a decline of 35.3% in three years (see also Andriamanandratra, 1996), whereas Mittermeier *et al.* (1992) assume that there are only 100-1000 animals left overall. Andrianjakarivelo (2004) found the mean density of *E. m. flavifrons* in eight inventoried forest fragments to be 24 individuals per km^2 (range: 4-85 ind./km^2). A total count in two different fragments of the Ankarafa forest on the Sahamalaza peninsula yielded a density of 60 individuals per km^2 (Schwitzer *et al.*, in prep.). However, the density of the subspecies in Ankarafa seems to be higher than in any other forest of the *E. m. flavifrons* distribution area (Randriatahina & Rabarivola, 2004). Extrapolating the two density estimates of Andrianjakarivelo (2004) and Schwitzer *et al.* (in prep.) to the total surface of the terrestrial core zones of the future protected area "Sahamalaza - Iles Radama" (which harbour the only forest fragments remaining in the park) yields a remaining population of 2780-6950 blue-eyed black lemurs. The subspecies is threatened by hunting, trapping, and forest destruction, and is classified as "critically endangered" by the IUCN (Mittermeier *et al.*, 1994; Gerson, 1995; Rakotondratsima, 1999; Andrianjakarivelo, 2004).

Although there is a reasonable estimate of the *E. m. flavifrons* population in the Sahamalaza protected area, there is no information on the number of groups and the size of the forest fragments they are living in. Knowledge of these issues would provide a basis for conservation measures to be carried out. It would furthermore constitute a first step of a larger study on the effects of habitat fragmentation on the blue-eyed black lemurs.

General ecology and behaviour

The ecology and behaviour of blue-eyed black lemurs has only recently become subject of extensive long-term studies in the wild, and the existing knowledge is still rudimentary. In addition, only two captive studies on these issues have yet been carried out (Digby & Kahlenberg, 2002; Schwitzer, 2003).

According to most authors, blue-eyed black lemurs live in groups of an average five to seven individuals, ranging from 2 to 13 (Rakotondratsima, 1999; Andrianjakarivelo, 2004; Randriatahina & Rabarivola, 2004). However, our recent long-term observations (Schwitzer *et al.*, in prep.) revealed that *E. m. flavifrons* form communities of around 15-25 individuals which split into subgroups (1-7 individuals) during most of the daytime and assemble in "sleeping areas" (groups of three or four neighbouring trees) at dusk. A similar pattern was described for the closely related *E. m. macaco*, where group (=community) size was however lower (mean: 9.9 ind.; range: 5-14; n=4 (Colquhoun, 1993, 1997)). In our studies of *E. m. flavifrons*, two or more females constituted the core of

a subgroup, whereas males were transient and only loosely associated with the female cores (Schwitzer *et al.*, in prep.). Other than Rakotondratsima (1999) we did not find communities of *E. m. flavifrons* to be larger in disturbed habitat than in primary forest (Schwitzer *et al.*, in prep.; see also Andrianjakarivelo, 2004). Also, we could not observe units of 40 or more blue-eyed black lemurs assembling close to freshwater sources during the dry season, as Andriamanandratra (1996) did (see also Meier *et al.*, 1996).
Based on a number of observations of isolated males or unisex groups of two males, Rakotondratsima (1999) speculated that in *E. m. flavifrons* females are philopatric and males disperse. Our observations showed, however, that males frequently diverge from and reassociate with female subgroup cores during the day, which may have been misleadingly interpreted as dispersal events (Schwitzer *et al.*, in prep.). This pattern may also explain the converse evidence with regard to a male bias in the sex ratio of blue-eyed black lemur communities (e.g., Rakotondratsima, 1999; Randriatahina & Rabarivola, 2004; Andrianjakarivelo, 2004). The sex ratio in the European captive population is balanced (1 male to 1.05 females (AEECL, 2002)).

Preliminary results of our own studies show that *E. m. flavifrons* exhibits a cathemeral activity pattern in the wild (Schwitzer *et al.*, 2005; Marsh, 2005). The degree of nocturnality shown by the studied animals was variable and seemed to be linked to moonlight intensity. Activity peaked during the early morning and late afternoon hours. Home range size appeared to be larger in secondary than in primary forest. Schwitzer (2003), who carried out a pilot study of captive *E. m. flavifrons* in two different zoos, found that the animals spent between 53% and 58% of daytime hours (9.00-18.00 h) and 64% of nighttime hours (18.00-9.00 h) resting/sleeping or sitting, either alone or in huddle groups. The studied individuals fed and foraged during 12-14% of daytime and 10% of nighttime hours. A core time of inactivity existed between 23.30 h and 5.00 h in the morning. In captivity *E. m. flavifrons* thus seems to show a degree of cathemerality similar to that in the wild.

In their study of captive groups of blue-eyed black lemurs at the Duke University Primate Center, Digby & Kahlenberg (1999, 2002) found that females were dominant over males, which is unusual among mammals but has been described for a number of lemur species (e.g., Jolly, 1966; Colquhoun, 1997, for *E. m. macaco*; for an overview see Wright, 1999). Older females in this study were dominant over younger females, and younger males received less aggression from females than did older males. The authors state however that these data need to be confirmed by studies on wild *E. m. flavifrons*.

In situ
A field study on the socioecology of the blue-eyed black lemur is currently ongoing. At this stage it would moreover be necessary to investigate in more detail how community structure and home range size is influenced by habitat structure. It also needs to be studied how well the lemurs are able to utilise the matrix surrounding the forest fragments (matrix-tolerant species; Laurance & Bierregaard, 1997) and to disperse between these fragments. Data need to be collected in additional forest fragments with differing degrees of human utilisation (e.g., primary forest, secondary forest, forest-agricultural mosaic). The studies should include both the dry season as well as the rainy season to investigate seasonal variation. Knowledge of these issues facilitates the adequate design of conservation activities such as e.g., the assignment of protection status for certain forest fragments outside the core areas of the future protected area or the planting of tree corridors between such fragments. It also helps to predict the carrying capacity of the remaining habitat in Sahamalaza, prerequisite to a population and habitat viability analysis to be carried out for *E. m. flavifrons*.

Ex situ
As of January 1st, 2002 there were 35 blue-eyed black lemurs living in European zoos (AEECL, 2002). The European captive population of the subspecies is being managed in a European Endangered species Programme (EEP). This population could be used for the

study of behavioural aspects that would be difficult to observe in the wild, such as details of social relationships among individuals, which could shed light on the social system of *E. m. flavifrons*.

Nutritional ecology

Until recently, almost nothing was known about the nutritional ecology of the blue-eyed black lemur in the wild, and the existing knowledge was based on anecdotal evidence. Ralimanana & Ranaivojaona (1999) for instance presented a list of 28 plant species or genera which they believed could serve as food resources for *E. m. flavifrons*.
Preliminary results of our own ongoing studies show that the blue-eyed black lemurs in Sahamalaza exploited a total of 78 different plant species and fed on 94 different food items altogether during the course of one year (Schwitzer *et al.*, in prep.). *E. m. flavifrons* is a generalist feeder, exploiting different resources during different times of year according to their availability. Other than feeding on fruits and leaves the lemurs were observed preying on insects, licking insect exudates and consuming fungi, buds, flowers, the pith of woody stems as well as soil. Feeding and foraging amounted to between 13% and 32% of 24h activity. The length and distribution over the day of feeding bouts differed between months. In general feeding and foraging was concentrated on the early morning and late afternoon hours. Data will be presented elsewhere (Schwitzer *et al.*, in prep.).

A first detailed study on aspects of *E. m. flavifrons* feeding ecology in captivity was recently completed (Schwitzer, 2003). A study on seasonal variation in intake levels and on the digestibility of macronutrients is currently being carried out on captive blue-eyed black lemurs in different European zoos. The results of these captive studies will serve to complement the data obtained in the wild and help to draw a more complete picture of the subspecies' feeding ecology. Regarding *E. m. flavifrons*, such information can be useful to evaluate the remaining lemur habitat within and adjacent to the prospective Sahamalaza protected area, to effectively plan possible reintroduction and translocation measures, and to optimise diets for the individuals kept in the *ex situ* breeding programme.

In Zoos, lemurs apparently are susceptible to obesity. Pereira & Pond (1995) suggested a high incidence of obesity in captive lemurs (see also Schaaf & Stuart, 1983), a thesis which was supported by personal quantitative observations in European zoos (Schwitzer & Kaumanns, 2001; Schwitzer, 2003). The blue-eyed black lemur seems to be an extreme case in this respect. In their quantitative study on body weights of wild and captive lemurs, Terranova & Coffman (1997) found an obesity rate of 95% for *E. m. flavifrons* (20 out of 21 individuals), this being the highest rate for any of the studied species. In the same study *E. m. flavifrons* showed a significant difference in body weights between wild and captive individuals. Similar results were obtained by Schwitzer (2003), with 80% of captive individuals being obese.
It is not known whether the high susceptibility to obesity in this taxon is solely related to an over-provision of food, or whether it may also relate to a comparatively low energy expenditure (low basal metabolic rate) and thus to a high efficiency of energy utilisation, a feature that has been found in other lemur species (McCormick, 1981; Müller, 1983; Daniels, 1984; Richard & Nicoll, 1987; Schmid & Ganzhorn, 1996; Drack *et al.*, 1999). Low energy expenditure could possibly be looked at as an adaptation to a habitat which may provide only few food resources during certain times of the year (for an overview see Wright, 1999). Regarding the extremely high obesity rate in captive blue-eyed black lemurs, it may be speculated that the subspecies exhibits an even lower BMR than other lemur species and thus possibly one of the lowest of any primate taxon. This would explain a relatively high tolerance for disturbed habitats which has been reported for blue-eyed black lemurs (Andrianjakarivelo, 2004; Randriatahina & Rabarivola, 2004). Information about the metabolic rate of *E. m. flavifrons* can therefore be of high value to the ongoing conservation efforts for these animals on the Sahamalaza peninsula.

In situ
Studies on several aspects of the nutritional ecology of *E. m. flavifrons* in the wild have been or are currently being carried out. These include the nature and quantity as well as the spatio-temporal distribution of food consumed by lemurs living in two different forest fragments over the course of one year, feeding behaviour, and the distribution of feeding and foraging over the lemurs' active time. Now it is necessary to look in more detail into individual food intake through measuring bite rates and counting pick-ups of focal animals. Moreover it would be interesting to collect similar data in even more disturbed forest fragments to investigate how the animals cope with the destruction of their original food resources and how well they are able to exploit new resources such as second growth plant species generated through edge effects. This needs to be done for the other lemur species occurring in Sahamalaza as well, and the results be used to guide reforestation measures and the planting of corridors between forest fragments.

Ex situ
The study on the nutritional ecology of *E. m. flavifrons* in the wild will be complemented with the results of an analysis of different physiological parameters, which can only be accomplished by studying captive individuals of the subspecies in European zoos. This study is currently being carried out. It includes digestibility trials under controlled conditions in several zoos (to be compared with approximated digestibilities obtained in the wild) and during different times of the year, using the double-meal technique and total faecal collection. Body weights of all *E. m. flavifrons* kept in one collection are being measured over the course of one year. At the next stage the basal metabolic rate of captive blue-eyed black lemurs should be measured, either with a metabolic chamber or by using doubly-labelled water ($^{2}H_2{}^{18}O$). This will also help to design appropriate diets for the captive reserve population.

Genetics
Small populations of animals living in fragments of their original habitat without access to neighbouring populations may be subject to adverse genetic effects such as genetic drift. Therefore, in order to investigate the long-term viability of such population fragments before applying conservation measures, the genetic status of the (sub)populations must be known. This is especially the case for subpopulations living on islands or peninsulas, as is the case for the blue-eyed black lemur.

A first study on the genetic variability of different subpopulations of *E. m. flavifrons* on the Sahamalaza peninsula as well as at the peninsula's base has been carried out by Fausser *et al.* (2000). The authors found no significant differences in homozygosity between the sample of individuals caught at Marozavavy and Maromanjo (on the peninsula) and that caught at Madiorano, Andohaomby and Ambolobozo (at the base of the peninsula). From these results they conclude that nucleotide diversity within the population is large enough for the latter to be viable over the long term without the introduction of additional animals into the future reserve. As yet, the studies of Rabarivola (1998) and Fausser *et al.* (2000) remain the only genetic works referring to the blue-eyed black lemur. Studies on the genetic variability of the nominate subspecies, *E. m. macaco*, have been undertaken by Rabarivola *et al.* (1996, 1998).

With regard to *E. m. flavifrons* it is now necessary to investigate as to what extent the subpopulations living in the eastern part of the subspecies' distribution area, described by Meyers *et al.* (1989) to be "generally similar to *E. m. flavifrons* except for several subspecific characteristics", differ genetically from those subpopulations living within the proposed protected area. In this respect it would also be of interest to clarify the taxonomic status of the *E. macaco* variant occurring north-west of Maromandia (see Schwitzer, 2004).
Currently, blood samples are being collected from *E. m. flavifrons* subpopulations in the forest of Ankarafa and examined for genetic variability. This goes along with a

socioecological study on the relatedness of individuals within and across groups. Samples should also be collected in the forests of Anabohazo and Ambohitra in the future.

All former subspecies of *Eulemur fulvus* (*albifrons*, *albocollaris*, *collaris*, *fulvus*, *rufus*, *sanfordi*) were recently elevated to full species status (Groves, 2001; Mittermeier *et al.*, in press; but see Pastorini *et al.*, 2000; Yoder, 2003). Taking this into account it seems questionable to keep referring to *Eulemur macaco flavifrons* and *E. m. macaco* as subspecies of a single species, as pairwise genetic distances between them (68-72 bp) are in the same range as between the former *E. fulvus* subspecies (29-90 bp) (Pastorini, 2000). We therefore suggest to reconsider the systematics of *E. macaco*, including genetic analyses of a larger sample of subpopulations than has previously been the case.

Parasitic status

The parasites of the Malagasy lemurs have so far not attracted too many researchers, and except for a few more recent publications (Landau *et al.*, 1989; Rabetafika, 1995; Randriamiadamanana *et al.*, 1998; Dutton *et al.*, 2003; Schad *et al.*, 2005) all existing literature dates back to the early 1980s or before (e.g., Chabaud & Petter, 1958, 1959; Uilenberg, 1970; Garnham & Uilenberg, 1975; Coulanges *et al.*, 1978a,b; Fain, 1982).

The fragmentation of forests can lead to the alteration of habitat use by primates (Singh *et al.*, 2001) and to increased primate densities in smaller home ranges (e.g. Rakotondratsima, 1999). These factors lead to an increased risk of parasitological infections for the individual primate. Small forest fragments can furthermore force primates to develop new behavioural strategies, like e.g. foraging on the ground. In fragmented forests primates, humans and domestic animals often live in close proximity to each other. Such overlap of habitats makes mutual infections between domestic and wild animals and between humans and wild animals more likely and can thus cause serious health problems for both a primate and a human population (Gilbert, 1994; Cruz *et al.*, 2000; Nizeyi *et al.*, 2002).
The blue-eyed black lemur today only occurs in small stretches of forest which are already highly fragmented. It is not known if the fragmentation of their habitat has resulted in different patterns of habitat use in blue eyed black lemurs. An ongoing study is however comparing habitat use in two differently sized fragments of the Ankarafa forest on the Sahamalaza peninsula with a different degree of human exploitation (Peters *et al.*, 2004; Schwitzer *et al.*, in prep.). This needs to be extended to more different forest fragments in the future. It is moreover not known if the pressure through humans and domestic animals has an effect on the prevalence and status of parasites in the *E. m. flavifrons* population. Since the lemurs seem to frequently use plantations as food resources and come close to villages, a mutual infection with parasites between humans, domestic animals and lemurs seems likely. There may be a seasonal variation in parasite load of humans and lemurs which may be related to seasonally varying resource use of the lemur groups. Information about the prevalence, diversity, and load of parasites of both humans and lemurs (and possibly also domestic animals) can thus be important for the AEECL/WCS community-based *in situ* conservation programme for the blue-eyed black lemur in Sahamalaza (see also Dutton *et al.*, 2003). Faecal samples from four different groups of *E. m. flavifrons* living in forest fragments with a different extent of degradation as well as from humans and domestic animals frequenting the forest fragments have been collected over the course of one year and are currently being analysed for the presence of intestinal parasites (Schwitzer *et al.*, in prep.). Blood smears have also been collected and are analysed for blood parasites. In a second step, this study needs to be extended to more different forest fragments.

It would moreover be interesting to carry out a more detailed biomedical evaluation of the blue-eyed black lemur population on the Sahamalaza peninsula, not the least to gain reference values (e.g., Dutton *et al.*, 2003).

The role of the captive population for conservation

Since 1984 an *ex situ* population of blue-eyed black lemurs exists in Europe and in the USA. The European population consisted of 35 individuals as of January 1st, 2002 (AEECL, 2002), and ISIS lists 34 individuals in US institutions altogether (www.isis.org). Both of these subpopulations are managed in co-ordinated breeding programmes (Porton & Wilson, 1997), which have been set up in order to build up and maintain self-sustaining reserve populations in captivity. Such reserve populations may in the future be used as reservoirs for reintroduction measures, as happened with captive-born black-and-white ruffed lemurs (*Varecia v. variegata*) at Betampona National Park (e.g., Britt *et al.*, 2004). Moreover, the indivdiuals living in zoos can be regarded as ambassadors of the endangered wild populations and therefore play a major role in conservation education. The third main function of *ex situ* populations of endangered species is to function as substitutes and models of the respective *in situ* populations for conservation-oriented research activities.

Captive blue-eyed black lemurs have so far been subject to only a few studies. Female and juvenile dominance has been investigated in the subspecies at the Duke University Primate Center (DUPC) (Digby & Kahlenberg, 1999, 2002; Archie & Digby, 1999; Combes, 2003). In the same institution the phenomenon of targeting aggression in *E. m. flavifrons* has been addressed (Digby, 1999). Terranova & Coffman (1997) included the blue-eyed black lemur in their study on lemur body weights, which was also conducted at the DUPC.

In European zoos the behavioural development of new-born *E. m. flavifrons* was studied (De Michelis *et al.*, 1999) as well as the subspecific divergence in the vocal repertoires of *E. m. macaco* and *E. m. flavifrons* (Gamba & Giacoma, 2002). Moreover, *E. m. flavifrons* was included in a study on energy intake and obesity in captive lemurs (Schwitzer, 2003).

Research on captive blue-eyed black lemurs should now focus on those studies which would be difficult to carry out on wild groups of the subspecies. Some of these issues have already been addressed in other chapters, such as digestibility studies, measurement of metabolic rates, or studies on social relationships. These works can complement the respective *in situ* research activities and can also help to optimise captive propagation programmes and thus contribute to the conservation of the subspecies.

Furthermore, the captive individuals can be regarded as a special case of a highly fragmented population. Captive groups, which usually are small and provide only limited possibilities of dispersal and exchange, especially with regard to the community structure which the taxon seems to exhibit in the wild (Schwitzer *et al.*, in prep.), may be looked at as models for the study of consequences of fragmentation and physical and spatial proximity.

Immediate *in situ* conservation measures and long-term perspectives

The *in situ* conservation measures which are required at this stage with regard to the remaining population of blue-eyed black lemurs and the Sahamalaza region as a whole have been described in detail elsewhere (e.g., WCS/DEC, 2002; Andriamampianina & Randriamahazo, 2003).

The most prominent threat to the *E. m. flavifrons* population is habitat destruction due to slash-and-burn agriculture, and the resulting fragmentation of the population. Therefore two major conservation issues would have to be addressed immediately: it must be ensured that further fragmentation of the remaining lemur habitat in Sahamalaza will not take place, and the negative effects of the isolation of small subpopulations have to be minimised. To halt the ongoing habitat destruction in the region, WCS and AEECL have implemented a community-based natural resource management programme (CBNRM) in December 2000. Two objectives of this programme were identified: to maintain and strengthen natural processes and the condition of terrestrial and marine ecosystems; and to improve natural resource use techniques in order to improve the standard of living of the local human populations. An action plan was proposed and is currently being implemented. The local people must moreover benefit directly from the conservation measures to be implemented, e.g. through ecotourism, as park rangers or field guides. On the other hand, a strict and effective protection of the core zones of the protected area must be ensured immediately through ANGAP.

To minimise the effects of already existing habitat fragmentation, a long-term management plan could involve interconnecting forest fragments which maintain *E. m. flavifrons* subpopulations too small to be viable by corridors of trees. This would allow dispersal to take place and would therefore enable gene flow between formerly isolated populations. Such corridors could consist of fast-growing fruit tree species, the fruits of which could also be exploited by the local human population. However, it must be ensured that these corridors will also be suitable for the dispersal of other wildlife living in the area, such as *Lepilemur*, *Mirza*, *Cryptoprocta* and *Eupleres* (Schwitzer, 2005). In addition to corridors, buffer zones could be created around forest fragments to absorb edge effects (Marsh, 2003). Lemur populations remaining in very isolated habitat fragments too small to support a viable population size could be translocated, either into areas free of anthropogenic factors, or into captivity to increase the gene pool of the *ex situ* breeding programme.

Further issues

Lemur populations in heavily fragmented habitats are more susceptible to devastation by climate factors such as drought or cyclones, as they cannot retreat into larger forested areas (Pope, 1996; Wright, 1999). Because lemurs are strongly seasonal breeders, the populations may be unable to recover from decreased food availability and/or increased mortality (Wright, 1999). These issues need to be studied over the long term, covering a period of at least ten years. Data need to be collected on births, deaths, immigrations and emigrations as well as on life history variables such as age of weaning, age of sexual maturity, infants per female lifetime etc., from groups living in small forest fragments and others inhabiting larger complexes of forest. Such data could be used to develop effective population management plans, both for *in situ* and *ex situ* populations. They can further provide a model for population management of diurnal lemurs in general.

With regard to long-term data on life history variables of *E. m. flavifrons* it would be of interest to investigate the extent of infant mortality in the wild population of the subspecies. According to Wright (1999) there is some evidence that in certain lemur species infant mortality rates may be twice as high as in anthropoid primates. The author suggests that lemurs living in an unpredictable, harsh climate may opt for a strategy of low investment in infants. This being the case, *E. m. flavifrons*, living in sub-humid forests of the southern Sambirano with a prolonged dry season of almost eight months, should also show a high rate of infant mortality. In captive lemur populations however infant mortality is not higher than in new-world monkeys, old-world monkeys or apes (Kaumanns *et al.*, 2000).

Conclusions

The research and conservation issues discussed above are part of a long-term action plan for the conservation of the blue-eyed black lemur in the Sahamalaza region. Part of this plan, to establish a field research station in the Ankarafa forest which can be used by both researchers and conservationists concerned with *E. m. flavifrons* or other projects in the area, has already been realised. AEECL, a consortium of European zoological gardens, in cooperation with the University of Mahajanga, ANGAP and the Wildlife Conservation Society, currently functions as coordinating body for the research and conservation activities concerning the blue-eyed black lemur population within the future protected area. To enable the exchange of students and researchers between Europe and Madagascar, two member institutions of AEECL have signed agreements of cooperation with the University of Mahajanga. The research activities involving the European captive population of blue-eyed black lemurs are also being coordinated by AEECL.
We think that the further realisation of the points described above will on the one hand lead to an increase in knowledge about the blue-eyed black lemur and its habitat, on the other hand to an increase in awareness of the fragility of the ecosystems in Sahamalaza, both in the local human population as well as in the Malagasy authorities. In addition to the

study and conservation of the blue-eyed black lemur as a flagship species for the region, as outlined in the document at hand, active habitat preservation and research into community ecology must also be vital parts of a broadly-based approach to preserve Sahamalaza and its inhabitants.

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