Original Article

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A Population Estimate of Blue-Eyed Black Lemurs in Ankarafa Forest, Sahamalaza-Iles Radama National Park, Madagascar

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Key Words
Blue-eyed black lemur · Total count · *Eulemur flavifrons* · Madagascar · Population density · Sahamalaza Peninsula

Abstract
The critically endangered blue-eyed black lemur *(Eulemur flavifrons)* has one of the smallest distributions of any lemur, occurring only in the north-western forests of Madagascar. We report the results of a population estimate of this taxon in part of the Ankarafa Forest, Sahamalaza-Iles Radama National Park, a dry deciduous forest. We collected data between September 2007 and February 2008 using a total count method with marked individuals and known groups. 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 1.0 individual/ha or 97.3 individuals/km^2 for our study area, which is higher than previous estimates reported for Ankarafa and other sites within the Sahamalaza Peninsula. Our mean group size, however, was similar to those determined in previous studies. Both group size and density of the blue-eyed black lemur were higher within the National Park than in previous studies outside the Park.

Introduction

Estimating animal population densities and determining distributions are essential procedures for wildlife conservation and habitat management [Thomas, 1991; Kremen et al., 1994; Hoare, 2000; Southwood and Henderson, 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; Plumptre and Cox, 2006]. Den-

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sity 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 evidence of declining population densities [Cowlishaw and Dunbar, 2000]. The lemuriform 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; Mittermeier et al., 2010]. Since the arrival of humans 1,500–2,000 years ago in Madagascar, at least 17 lemuriform species have become extinct [Godfrey and Jungers, 2003; Mittermeier et al., 2006]. The habitats where lemurs occur are constantly being destroyed by slash-and-burn agriculture and erosion after deforestation, timber exploitation and charcoal production [Mittermeier et al., 2006, 2010]. Some lemur species are hunted for food [Nicoll and Langrand, 1989; Mittermeier et al., 1992, 2010], though the impact of these practices on population viability is not known. For the majority of lemur species, accurate population density and distribution estimates are still unavailable [Mittermeier et al., 2006, 2010].

To our knowledge, only 3 surveys of blue-eyed black lemur (*Eulemur flavifrons* [Gray, 1867]) populations have been conducted within the Sahamalaza Peninsula [Rakotondratsima, 1999; Randriatahina and Rabarivola, 2004; Volampeno, 2004]. Previously, *E. macaco* was classified as having 2 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 Scater's lemur [Mittermeier et al., 2008]. The blue-eyed black lemur is the least-studied member of the genus *Eulemur*, having been rediscovered only in the late twentieth century [Koenders et al., 1985]. It has one of the smallest geographic ranges of any lemur species [Mittermeier et al., 2006]. Most of its range falls within the Sahamalaza Peninsula. *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, 2010], and it is on the list of the world's most threatened primate species. The urgent need to conserve this lemur was a key factor in the establishment of Sahamalaza-Iles Radama National Park (SIRNP) in 2007.

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 is one such method, where observations are made of 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]. In the present study, individuals were marked from a previous study and groups known. It was assumed that marks were not lost, and that the capture and marking procedures did not affect the behaviour of the animals [Borchers et al., 2002; Greenwood and Robinson, 2006]. It was also assumed that all individuals were equally detectable, so as not to underestimate

population size [Borchers et al., 2002; Greenwood and Robinson, 2006]. Consequently in the present study, we used a total count method as some of the blue-eyed black lemur individuals in groups were marked, and the other groups known or recognizable over time. The total count was cumulative and asymptoted over the study period.

Our study aimed to determine the population size of the blue-eyed black lemur in Ankarafa Forest, Sahamalaza Peninsula, and so contribute to an update on the population's conservation status and the population's prospects for survival.

Methods

Study Site

The study was carried out in Ankarafa Forest (47°45′ E, 14°22′ S; 0–355 m above sea level), which is located in the western part of SIRNP and has an area of 234.23 ha [Volampeno, 2009] (fig. 1). The SIRNP is situated in north-western Madagascar in the province of Mahajanga. The vegetation is composed of degraded semi-deciduous forest. Volampeno [2009] describes the vegetation structure of Ankarafa Forest in detail. The study site is characterized by a subhumid climate with 2 distinct seasons: a hot and rainy season (December to April) and a dry season (May to November).

Data Collection

Whereas previous surveys [Rakotondratsima, 1999; Volampeno, 2004] of blue-eyed black lemur populations have used line transect techniques, we employed a total count method to estimate the population size and density of these lemurs given the limited size of Ankarafa Forest, and with known or marked individuals/groups that could be identified and monitored over an extended period. Most of the lemur groups were known and already habituated to the presence of researchers, as research has been conducted in the area since 2004. Four of the groups were marked by a previous researcher [G.H. Randriatahina, pers. commun.] 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.

We conducted censuses between September 2007 and February 2008. A pair of observers walked the existing 10 trails, which covered all appropriate forest types (table 1). Trails had been prepared by the local guides and ranged in length from 700 to 1,300 m, were an average of 683 ± 3.24 m apart, and covered 65% of Ankarafa Forest. The mean sighting distance was 4.5 ± 1.0 m. Trails were used occasionally by local people. Each trail was walked once a week from 6.00 to 10.00 h, when blue-eyed black lemurs were most active [Schwitzer et al., 2007]. Each trail was walked twice over 2 consecutive weeks. 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 and recorded together with locality and time. As mentioned, our method was based on repeated identification and confirmation of respective social groups. We identified and differentiated the free-ranging groups based on locality of the group, group size and group composition. During the repeated observations, if one group was encountered twice in the same place we recorded only the group with a maximum group size in order to avoid double counting. For example, during one census we found 3 groups, and then in a subsequent census we also found 3 groups with one being found at the same place as in the first census. If the size of this twice-encountered group was recorded as 6 individuals during the first census and 8 individuals during the second, then we took the size of this group to be 8 individuals.

In addition, we determined the age-sex classes of individuals within each group encountered. Distinguishing between adults and juveniles was difficult because of similarities in body size. Of the 29 groups counted, all but 6 were habituated to the presence of humans; however, these groups were known, and sexes of individuals could be determined from a distance. If we approached these unhabituated groups more closely to determine individual ages, they would

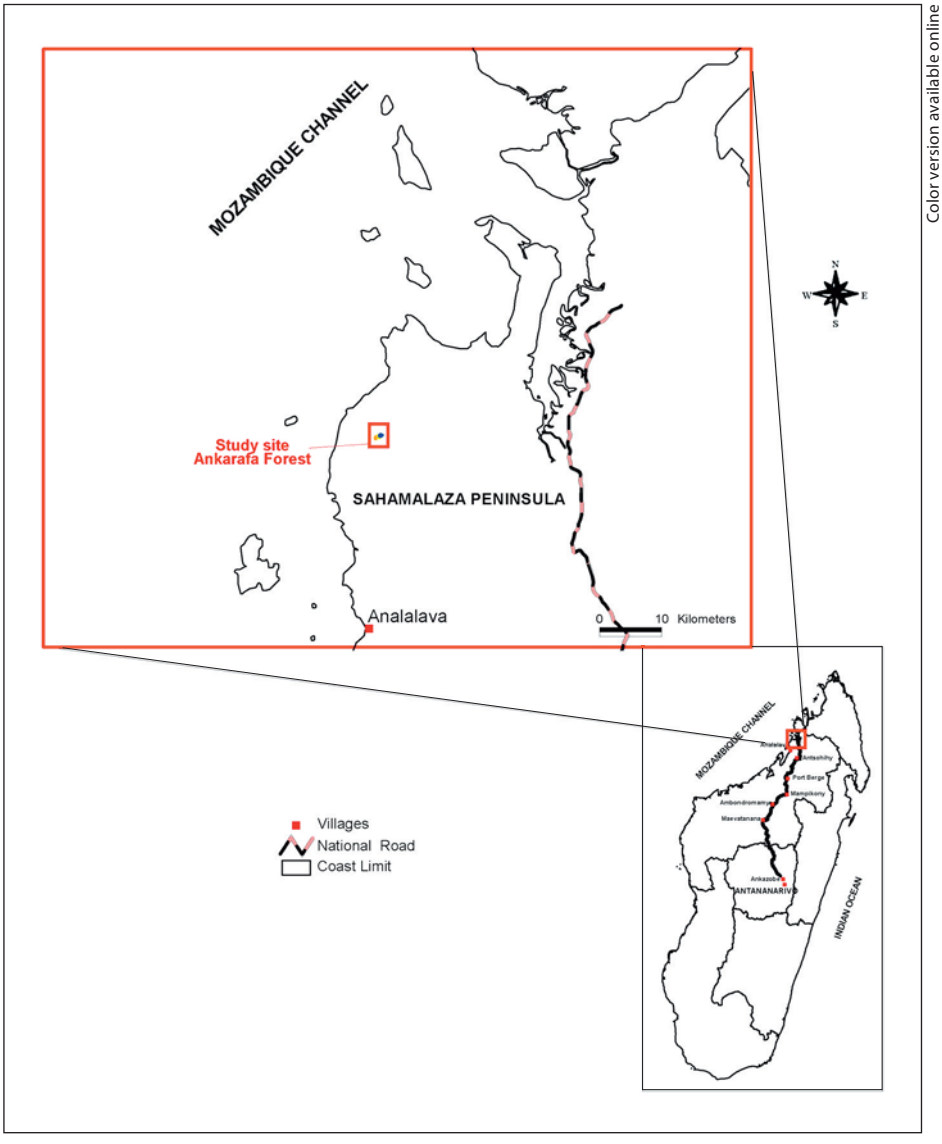

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Fig. 1. Location of the Sahamalaza-Iles Radama National Park, Madagascar.

flee. Consequently we grouped adult with 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 density was calculated by dividing the number of individuals recorded by the total area of the study area of forest covered during the survey. A Global Positioning System device (E-Trex Garmin Inc., Olathe, Kans. USA) was used to record the study site borders and to determine the total area of Ankarafa Forest in the Geographical Information

Table 1. Description of each census trail in this study

Trail	Description
1	About 80% burned due to man-made uncontrolled fire Many dead trees, cutting down of trees including bamboo groves Tall trees still alive including mango trees and *Canarium madagascariensis*
2	Near a paddy field and a former hamlet
3	Near a hamlet, close to areas cleared for agriculture by slash and burn
4	Presence of a stream and of bamboo groves Lemurs were seen sometimes to drink water from the stream
5	Presence of a stream, raffia plantation Clearing for a former paddy field and former hamlet Many mango trees, few cashew nut trees, coconut trees and lemon trees
6	Dominated by *Soreindeia madagascariensis* trees Evidence of trees blown down during a cyclone in February 2007
7	Dense vegetation with tall trees
8	Presence of bamboo groves and mango trees
9	A part of this area was burnt in October 2006 Few dead trees, cut-down trees Dominated by mango trees
10	Presence of mango trees, cashew nut trees, bamboo groves Many young trees

System ArcView 3.2 (Environment System Research Institute Inc., Redlands, Calif., USA). In addition, all locations of lemur groups were shown on a detailed accurate map of the area using ArcView.

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 = $\pm$1.8; table 2). Five of the 29 groups encountered did not have infants. The population density of blue-eyed black lemurs for the study area (65% of the total Ankarafa Forest) was estimated to be 1.0 individual/ha or 97.3 individuals/km^2 with 0.1 groups/ha or 12.4 groups/km^2 (table 3).

Age-Sex Classes and Sex Ratios

Differentiation of the blue-eyed black lemur population 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 an expected ratio of 1:1 ($\chi^2 = 5.19$, $p < 0.05$). The infant sex ratio did not deviate significantly from 1:1 ($\chi^2 = 0.042$, $p > 0.05$). Including all animals of known sex, the sex ratio was male biased (1.43) and deviated significantly from 1:1 ($\chi^2 = 4.3$, $p < 0.05$).

Table 2. Number of blue-eyed black lemurs recorded along each trail in Ankarafa Forest, Sahamalaza Peninsula, using the direct count method

	Trail										Total
	1	2	3	4	5	6	7	8	9	10	
Length, km	1	0.7	1.2	1	1.1	1.3	0.8	1	0.9	1.2	
Individuals, n	30	25	23	9	28	36	34	7	15	21	228
Groups, n	4	3	3	1	3	5	4	1	2	3	29
Range in size	4–9	6–11	7–9	9	8–10	5–9	6–11	7	7–8	4–11	
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	

Ten trails were walked and each trail was walked twice. Groups found along one trail were different from those seen on other trails.

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

Site	Sex ratio	Area surveyed ha	Density individuals/km	Total individuals	Total number of groups	Mean group size (± SE or SD)	Method	Source
Ankarafa (Sahamalaza)	1.42	234	97	228	29	8 ± 1.8	direct count	this study
Ankarafa (Sahamalaza)	1.43	not known	not determined	39	5	7.8 ± 1.9	line transect	Randriatahina and Rabarivola [2004]
Other sites (Sahamalaza)	0.71	57.8	129.76	77	13	5.2 ± 4.5 to 6 ± 3.7	line transect	Rakotondratsima [1999]
Ten sites outside Sahamalaza	1.03	417	24	112	17	4.7 ± 2.9	line transect	Andrianjakarivelo [2004]

Discussion

Social Group Size and Sex Ratio

The social group sizes we recorded in Ankarafa Forest were consistent with previous studies conducted at the same site, ranging from 4 to 11 individuals (mean ± SD, 8 ± 1.8). Randriatahina and Rabarivola [2004] reported 7–11 individuals/group (mean ± SD, 7.8 ± 1.9), while a study conducted from 2004 to 2007 [G.H. Randriatahina, pers. commun.] found that group size ranged from 6 to 11 individuals (mean ± SD, 8.6 ± 1.1). In comparison, at 3 other forest sites (Anabohazo, Analavory and Ambohitra), Rakotondratsima [1999] found mean values ± SD from 5.2 ± 4.5 to 6 ± 3.7 individuals/group, which is lower than the average group size in Ankarafa. This may be a consequence of several factors, including forest habitat area and quality, due to an increase in the amount of exploitation and illegal hunting in these forest fragments. These factors may affect resource availability, reproduction and birth rates in lemurs, reducing group size. Rakotondratsima [1999] reported a high incidence of lemur traps in the forests he surveyed, and observed villagers returning with

blue-eyed black lemurs that had been hunted in the forest. Outside the Sahamalaza Peninsula, Andriajakarivelo [2004] estimated 112 individuals in 17 groups distributed in 10 sites, with a mean group size of 4.7 (±2.9) individuals, which is again lower than the average in our study.

In the closely related taxon *E. macaco*, the black lemur, investigators have reported groups ranging 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 [Mittermeier et al., 2006].

We had difficulty distinguishing the age classes of each sex, and pooled data for adults and juveniles. We found a male-biased sex ratio for the adult/juvenile classes. An adult male-biased sex ratio was also reported for *E. rufus* [Ostner and Kappeler, 2004]. Our results support those found by G.H. Randriatahina [pers. commun.] and Rakotondratsima [1999]. According to G.H. Randriatahina, males usually outnumber females in social groups, and the number of adult females does not exceed 3/group. Similarly a male-biased sex ratio has been observed in *E. macaco* [Bayart and Simmen, 2005]. In non-human primate species, explanations of sex ratio bias are still ambiguous and remain problematic. However, Ostner and Kappeler [2004] suggested that a male-biased adult sex ratio may result from delayed male dispersal or female transfer. Further studies may elucidate the reasons and dynamics of the male-biased sex ratio found in blue-eyed black lemurs.

Numbers of Blue-Eyed Black Lemurs

Our estimate of numbers of blue-eyed black lemurs in Ankarafa Forest was higher (228 individuals) than in previous studies. Randriatahina and Rabarivola [2004] counted 39 individuals while Volampeno [2004] estimated 145. Several factors may have influenced this increased estimate, including the method used, the survey period and duration, and the habitat conditions. Previous surveys were conducted using the line transect method, while we performed total counts. Our survey was conducted over a period of 6 months, while previous surveys were of much shorter duration. Finally, our survey coincided with the birth season and did not include the individual migration period, while previous studies were carried out before the birth season. According to G.H. Randriatahina [pers. commun.], female migration takes place before the birth season while male migration coincides with the mating period (March to April), thus previous surveys coincided with both female and male migration. In comparison with the present study in Ankarafa Forest, Rakotondratsima's [1999] brief survey of blue-eyed black lemurs at 3 additional sites on the Sahamalaza Peninsula found only 77 individuals.

The population density of blue-eyed black lemurs in Ankarafa Forest was higher than outside the Sahamalaza Peninsula, where the estimated population density was 24 individuals/km^2 [Andrianjakarivelo, 2004]. Again, this may be a consequence of forest habitat area and quality (including fruit availability), as well as the intensity of illegal hunting. For instance, Andriajakarivelo [2004] reported relatively high levels of illegal hunting and counted 88 lemur traps in the 10 sites he visited. This indicates that hunting is likely to be a major threat to blue-eyed black lemurs. In addition, forests outside the SIRNP are not yet protected, and human pressure continues to be a problem.

Since the establishment of the research camp in the Ankarafa Forest in 2004, we have found no lemur traps in this forest. Further, establishment of the SIRNP in 2007 has led to a decline in anthropogenic disturbance in the forest, particularly with respect to slash-and-burn agriculture, field establishment inside the forest and forest exploitation [Volampeno, 2009]. Nevertheless, villagers still practise some logging inside the forest. During our surveys, we found a rosewood tree (*Dalbergia* sp.) that had been cut down and transformed into a beam.

We could make reliable predictions of blue-eyed black lemur population size in only a section of Ankarafa Forest, not in the entire SIRNP. The SIRNP forest is fragmented, comprising several forest blocks including Ankarafa, Anabohazo, Analavory and Ambohitra. The forest blocks are widely separated and not connected to one another by treed corridors. In addition, blue-eyed black lemurs may be locally extinct in Analavory Forest because of an uncontrolled man-made fire in 2004 that burnt almost the entire block. If the total area of SIRNP (summation of the forest fragment areas) is used to extrapolate the population size, this results in a highly erroneous estimate of abundance of 25,308 individuals for the total forest area. As mentioned above, many of the forest fragments are more degraded than those in our study site and likely to have fewer individuals within them. It is possible that the study area is a refugium within SIRNP for blue-eyed black lemurs, so numbers are more concentrated here than in the more transformed areas. Additionally, SIRNP contains the major 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 for this species.

Method Used

We used the total count method with marked or known individuals and groups to estimate the blue-eyed black lemur population size in Ankarafa Forest. According to our knowledge, this is the first published account estimating lemur population densities using this method. Such direct total counts are feasible in restricted areas like Ankarafa Forest, and in areas where individuals/groups are known and recognizable. Over time we saw the groups repeatedly, and precise details of group size and composition were obtained, yielding a total count that was cumulative and reached an asymptote to give an accurate and precise estimate of population size and density for the study area. The direct total count has been used successfully for other primate species such as the mountain gorilla *(Gorilla beringei)* in the Virunga Volcanoes and Bwindi Impenetrable National Park [Harcourt and Fossey, 1981; Harcourt et al., 1983; Mcneilage et al., 1998]. It appears to be a reliable estimator, particularly when groups are known.

Conclusions

Our study shows the value of using the total count method with marked or known individuals and groups to estimate the size and density of primate populations living in restricted areas. We think this a particularly reliable method when the species are diurnal or cathemeral with peaks of activity in the morning, as is characteristic of the genus *Eulemur* [Johnson and Overdorff, 1999; Overdorff and Johnson, 2003] and has been reported in *E. flavifrons* [Schwitzer et al., 2007], as repeated sightings are possible under ideal light conditions. Transect methods may either under- or overestimate numbers. Our results provide the most recent update on the

number of blue-eyed black lemurs in Ankarafa Forest. However, as the habitat is restricted, the population should be monitored regularly in order to detect population changes and monitor the population's prospects for survival. Assessing the population status of such a 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 Peninsula. 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 in the SIRNP.

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