Population Assessment of the Crowned Lemur (*Eulemur coronatus*) in the Bobaomby Area, Northern Madagascar

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Abstract: We surveyed lemurs in the Bobaomby area in the far north of Madagascar from February to March 2018. The survey was part of a biodiversity inventory for the prospective creation of a new protected area. Five camp sites were visited, and distance sampling by transect surveying was used to assess the population density and abundance of the crowned lemur, *Eulemur coronatus*. At four of these sites, we surveyed three transects (each 1-km long) twice during the day and once at night. At the fifth site, Anjiabe, we surveyed four transects, also twice during the day and once at night. For each lemur we encountered, we recorded the perpendicular distance from the transect to the first individual detected. We also recorded group size. *Distance* software was used to estimate population density and abundance. In total, we surveyed 16 transects with a total effort of 31.5 km of daytime surveys. The crowned lemur, *Eulemur coronatus*, listed as Endangered on the IUCN Red List of Threatened Species, was the only lemur recorded for all sites. The density of *E. coronatus* was 277 individuals/km² and group size ranged from singletons to seven individuals. The recorded abundance at the five sites ranged from 1.5 to 6.2 individuals/km. Despite its similarity to other areas where *E. coronatus* occurs, we did not find any other lemur species at Bobaomby. The survey revealed the presence of many threatened species besides lemurs in the Bobaomby area. The main threats there are habitat loss due to selective logging, charcoal production and the conversion of the forest into agricultural land. The creation of a protected area will be important to protect the area's wildlife, and especially the crowned lemurs.

Key words: Lemurs, Bobaomby, Madagascar, new protected area, transect surveys, population density

Introduction

Madagascar is biogeographically diverse with a host of vegetation types supporting a rich lemur fauna (Axel and Maurer 2011). There are 112 species and subspecies of lemurs on Madagascar, all of them endemic (IUCN 2020). They are important as seed dispersers (Razafindratsima *et al.* 2014), pollinators (Kress *et al.* 1994), and as prey to the endemic predators (Goodman 2004; Karpanty, 2006), and are flagships for Madagascar's rich and endemic biodiversity (Dolins *et al.* 2010). They are considered one of the most threatened mammal groups in the world (Schwitzer *et al.* 2013)—97% of the lemur species and subspecies are now classified as threatened on the IUCN Red List (IUCN 2020). Slash-and-burn agriculture to create areas for subsistence, and forest clearing for cattle (zebu) pasture, with the associated habitat fragmentation are the major factors affecting Madagascar's natural forests (Green and Sussman, 1990; Irwin *et al.* 2010). Habitat loss reduces habitat availability, while habitat degradation increases the vulnerability of primate species to further anthropogenic pressures (Brooks *et al.* 2002; Fahrig 2003) such as hunting (Peres 2001; Laurance and Useche 2009). Faced with many pressures on lemur populations, accurate population estimates are needed to monitor population numbers and to inform targeted conservation action plans (Rylands *et al*. 2008; Murphy *et al.* 2016).

We conducted a biodiversity inventory in the Bobaomby area to assess its potential for the creation of a new protected area. It is located in the far north of Madagascar in the province of Antsiranana. Antsiranana is the main town near to the study site. Bobaomby is characterized by the existence of numerous sacred places, which play an important role in the traditional beliefs of the people there (Mannle and Ladle 2012). They maintain these places as sacrosanct and adhere to a set of rules that have been handed down from their ancestors (Mannle and Ladle 2012). Hunting or killing lemurs is taboo in the Bobaomby area.

A biological survey of the Ampombofofo forest, one of our study sites in Bobaomby, has resulted in the finding of six endemic amphibians, 37 endemic reptiles, 63 birds, two endemic small mammals, and one lemur, *Eulemur coronatus*, the object of this study (Mitchell *et al.* 2007). The crowned lemur, *E. coronatus*, occurs in extreme northern Madagascar and is listed as Endangered on the IUCN Red List of Threatened Species due to a continuing decline in area, extent and quality of habitat, as well as exploitation through unsustainable hunting (Reuter *et al.* 2020).

The high importance of the Bobaomby area in terms of traditional culture and species richness substantiates the need for its formal protection. Ampombofofo has received attention from researchers and is now listed as a Key Biodiversity Area due to the presence of three Critically Endangered, two Endangered and one Vulnerable species (Key Biodiversity Areas Partnership 2022). However, some sites in the Bobaomby area are poorly studied. We are carrying out surveys to provide abundance and density estimates for the crowned lemur in the lowland dry deciduous forest there to support the proposal of a new protected area of category V of the IUCN classification, and here we report on our findings.

Methods

Sites

The Bobaomby area includes part or all of the municipalities of Antsahampano, Mangaoka and Andravondronina, and Antsiranana II District in the Diana Region of extreme north and northwestern Madagascar (Fig. 1; Table 1). It is part of the western ecoregion (Humbert 1955), and is dominated by savanna with patches of western dry forest (Moat and Smith 2007). The soil is characterized by a layer of limestone and sand (Besairie 1965). We selected five sites in the area, based on their repartition, altitude and vegetation.

Data collection and field sampling

The lemur surveys were conducted from 3 February to 20 March 2018. Distance sampling along transect lines was

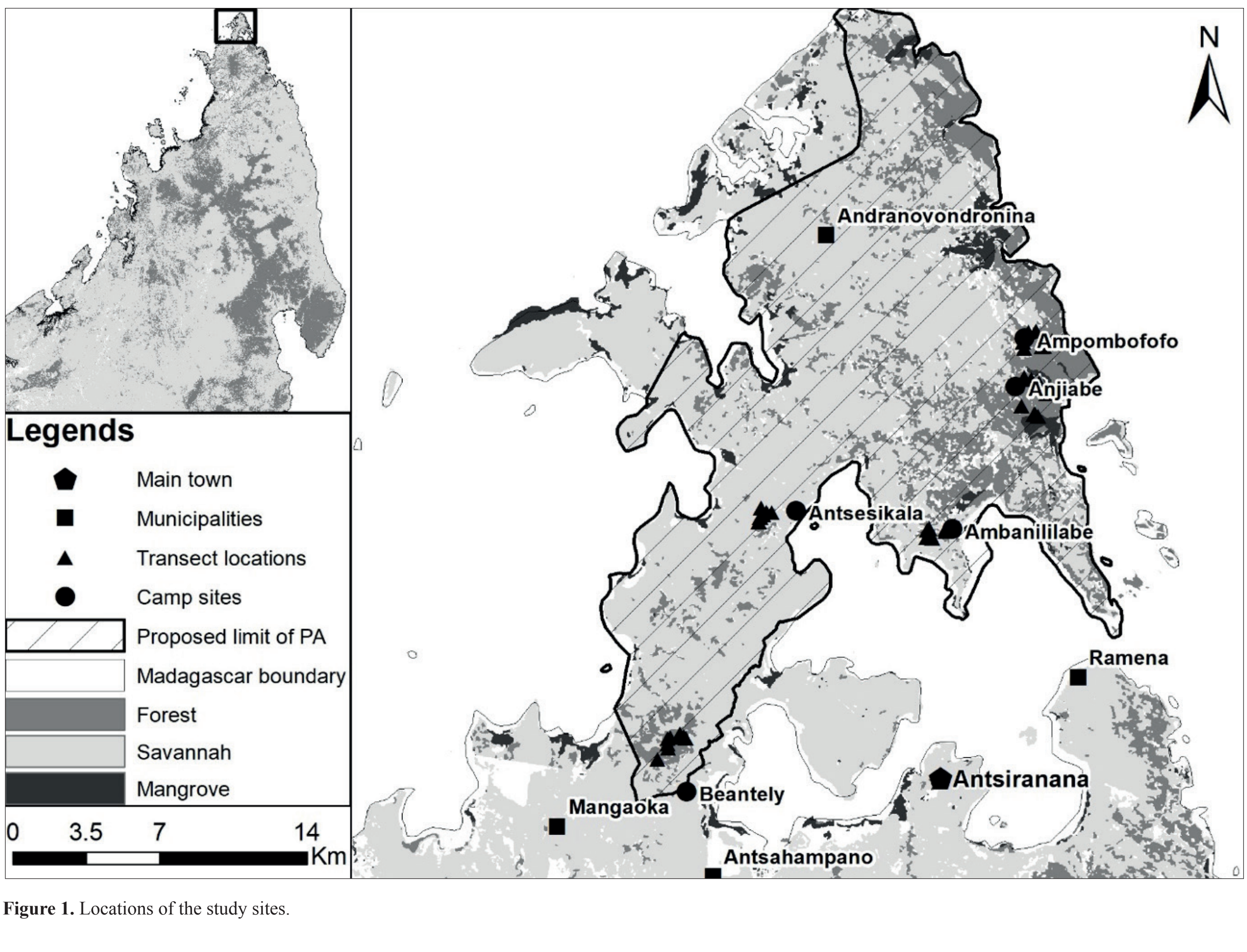

Figure 1. Locations of the study sites.

Table 1. Information on each transect surveyed.

Site	Total transect surveyed	Total effort (km)	GPS coordinates	Elevation range (m)
Beantely	3	6	12.267457S, 49.180112E	128–275
			12.272323S, 49.167592E	
Antsisikala	3	5.5	12.174800S, 49.212875E	55–159
			12.170343S, 49.211026E	
Ambanililabe	3	6	12.177900S, 49.292060E	17–69
			12.158605S, 49.301543E	
Anjiabe	4	8	12.119355S, 49.336674E	10–47
			12.120866S, 49.330476E	
Ampombofofo	3	6	12.094134S, 49.339971E	11–52
			12.090132S, 49.329391E	

used for detecting them. This method is used for studying abundance or density of primate populations from different countries (Buckland *et al.* 2010) including Madagascar (Meyler *et al.* 2012). We surveyed 1-km transects, as already used in other lemur surveys (Rasoloharijaona *et al.* 2005; Ralantoharijaona *et al.* 2014). Three transects were surveyed for each camp site except in Anjiabe where we had four. Transect lines were spaced at least 2 km apart to avoid double counting. We used pre-existing trails inside the forest and marked every 20 m with flagging tape for reference during the surveys (Olivieri *et al.* 2005; Ralantoharijaona *et al.* 2014). Each transect was surveyed three times—two diurnal walks and one nocturnal. Repeat surveys on each transect were spaced by 48 hours to avoid disturbing the animals and to keep each survey independent. For all sites, the transect surveys were conducted by the same three people, experienced in detecting lemurs and in the survey protocols. The transects were walked at speeds of about 0.5 km/hour. Diurnal surveys were done between 8:30 and 11:30 and 15:00 and 17:00—periods covering peak lemur activity (Randriatahina and Rabarivola 2004; Ralison 2007; Dammhahn *et al.* 2013). Diurnal surveys were carried out twice (on different days) on each of the 16 transects, giving a total effort of 31.5 km. Nocturnal surveys were done between 18:30 and 21:00, but we used only the data from diurnal observations for density estimation because our target species is most active during the day (Wilson *et al.* 1989). For each sighting, we measured the perpendicular distance of the first individual detected to the transect line (Schmid and Smolker 1998; Hassel-Finnegan *et al.* 2008) using a tape measure. We also determined the group size by rapidly assessing the location of individuals on the periphery, visually determining group spread, and then counting the number of individuals. Their calls were used as indicators of the presence of the species. Visible evidence of threats to the species habitat was recorded during the surveys.

We also conducted interviews (13:00–14:00) to gain a comprehensive understanding on the lemur species in the Bobaomby area. Participants were asked for their consent before being interviewed. Those interviewed were local guides, villagers, decision-makers and local authorities. We asked open-ended questions on lemur species found in the area. We aimed for 15 questionnaires for each site.

Data analysis: density estimation

We conducted a cluster analysis using the Conventional Distance Sampling (CDS) engine in *Distance* software version 7.1 (Buckland *et al.* 2001; Thomas *et al.* 2010). Lemur population densities were estimated based on the measured perpendicular distances between the detected groups and the transect (Buckland *et al*. 2004), which provides a detection function for the observed distances (Thomas *et al*. 2002). The target species lives in groups, which we term clusters. With repeated surveys of the same transect, the total effort is calculated as transect length multiplied by the number of surveys (Buckland *et al.* 2010). We used a combination of four key functions and adjustments suggested by Thomas and his collaborator (2010). Based on the detection distances curve, we set the truncation at 30 m from the transect line, which corresponds to the exclusion of about 5% of all observations (Buckland *et al.* 2001). The *Distance* software estimates the density of groups and animals (by multiplying density of the group with the mean of group size; Buckland *et al.* 2015). We did not estimate the lemur population density at each site because there were too few sightings at any of them (Whitesides *et al.* 1988).

Data analysis: Kilometric Abundance Index

The Kilometric Abundance Index (KAI) is a commonly used measure that allows for a straightforward comparison of species abundance at different sites (Vincent *et al.* 1991; Buckland *et al.* 1993; Schmid and Smolker 1998; Ralantoharijaona *et al.* 2014). It is the ratio of the total number of individuals recorded along a transect divided by the total transect length (km) covered at each site (Preatoni *et al.* 2012).

Results

Eulemur coronatus was the only lemur recorded at the five sites in the Bobaomby area. It is common in all the five sites we surveyed. The sites ranged from 11 to 275 m above sea level (Table 1). The 75 interviews of members of the local communities in the five sites (15 interviews at each) all confirmed that *E. coronatus* was the only lemur species present.

Density of Eulemur coronatus

We encountered 30 groups, ranging from single individuals (we counted as a group) to seven. The Hazard-rate with Hermite polynomial adjustment was selected by the *Distance* software as the model best fitting the data. Over the five sites combined, the cluster (group) density was estimated at 71 per km² and, again covering the five sites combined, population density was estimated to be 277 individuals/km² (Table 2).

Kilometric Abundance Index

The Kilometric Abundance Index (KAI) varied among sites (Table 3). Anjiabe had the highest KAI. with 6.2 ind./ per km, and Ampombofofo had the lowest, with 1.5 ind./ km. The mean group size at each site ranged from two to four individuals.

Threats and pressures

During our surveys, we identified the main threats and pressures across sites as selective logging, charcoal production and the conversion of forest into agricultural land.

Table 2. Density estimates of *Eulemur coronatus* in the Bobaomby.

Parameter	Value	CV (%)	CI at 95%	
DS (groups/km²)	71.7	35.1	35.9	143
D (ind./km²)	277.4	36.4	136.3	564.3

CV: coefficient of variation; CI: confidence interval, DS: density of groups, D: density of animals

Table 3. Kilometric Abundance Index per site.

Site	Distance walked (km)	Number of individual	Mean group size	KAI (ind./km)
Beantely	6	26	2.8	4.3
Antsisikala	5.5	24	3.8	4.3
Ambanililabe	6	10	3.3	1.6
Anjiabe	8	50	4.5	6.2
Ampombofofo	6	9	4.5	1.5

Discussion

Lemurs of the Bobaomby area

Despite the variation in area and quality of the habitat across our study areas, *Eulemur coronatus* was the only lemur species detected at all study sites. A previous study in the Ampombofofo forest, one of our study sites, also reported the lack of any lemurs other than *E. coronatus* (Mitchell *et al.* 2007).

Population density of Eulemur coronatus

Our density estimate of 277 individuals/km² is high compared to previous studies from other areas where *E. coronatus* occurs. We are the first to assess the populations from the five sites in the Bobaomby area, and our result indicates a large 95% confidence interval, which is related to our coefficient of variation of more than 30%. In this case, we considered the lower value of the confidence interval as a more realistic density of 136 individuals per km². A previous study indicated that the density of *E. coronatus* differs depending on different sites and their habitat quality (Gudiel *et al.* 2017). Population densities are low outside protected areas and much higher in and around protected areas (Reuter *et al.* 2020). The population density estimated in the Ankarana National Park ranged from 105 to 276 individuals/km²—the highest density was recorded in secondary forest (Gudiel *et al.* 2017). Densities of 18 to 50 individuals/km² were recorded for forest fragments in northern Madagascar (Banks 2013). Lemur population densities have been found to be most influenced by patterns of resource availability and quality as well as interactive effects at the community level (Banks 2013). The higher density estimate from this study might be explained by the absence of competition for food and territory. In addition, people from this region still respect the local traditional taboo on hunting or killing lemurs and this is strictly obeyed by all village members (Mitchell *et al.* 2007; Mannle and Ladle 2012). Edge effects related to food quality and predation may also be influencing their abundances (Lehman *et al.* 2006). *Eulemur coronatus* is otherwise known to be negatively impacted by habitat fragmentation (Eppley *et al.* 2020).

Regarding the high coefficient of variation in population density, it is probably linked to our low number of sightings. Although the recommended number of independent sightings is 60 (Buckland *et al*. 1993), there is no fixed rule about a sufficient sample size, and smaller sample sizes can produce robust density estimates if treated carefully (Peres 1999). During this study, we have carefully followed all survey protocols as described in Buckland *et al.* (1993, 2001) and maximum detection rates.

Considering the interval of confidence, the density of *E. coronatus* from the Bobaomby could be also considered as 136 individuals/km², which is lower than of the Ankarana National Park: 208 individuals/km² in the primary forest and 276 individuals/km² in the secondary forest (Gudiel *et al.* 2017).

Regarding the group sizes that we recorded, they do vary across sites, but the average group size is lower than has been found in past studies (Wilson *et al.* 1989; Hawkins *et al*. 1990; Freed 1996; Mittermeier et *al.* 2010). According to Mittermeier *et al.* (2014), the largest groups recorded for *E. coronatus* number 15 individuals.

Kilometric Abundance Index

The KAI varied between sites. Anjiabe had the highest (6.2 ind./km) and Ambanililabe (1.6 ind./km) and Ampombofofo (1.5 ind./km) the lowest. This variation might be due to the quality of habitat (floristic composition) and resource availability (seasonality and dispersion). During our surveys, we identified several threats. For all study sites, they were habitat loss due to selective logging for various uses, charcoal production and conversion of forest into agricultural land. The remaining forest habitat should be prioritized for conservation. *Eulemur coronatus* contributes to forest regeneration as it is a pollinator and seed disperser for many of the endemic plant species (Chen *et al.* 2015).

Conclusion

This study has indicated healthy populations of the Endangered *Eulemur coronatus* and this, along with the lack of hunting, makes these sites in the Bobaomby area of great value for its conservation. The species is threatened by selective logging, charcoal production and the conversion of the forest into agricultural land, and a protected area would allow for their management. We recommend the inclusion of Anjiabe as the core area of the future new protected area. A protected area could support long-term scientific research not only on the crowned lemur, but also the highly endemic fauna and flora of Bobaomby, of such significance that it has been identified as a Key Biodiversity Area. Ecotourism initiatives could benefit the livelihoods of the local communities there.

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