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Lemurs in a dying forest: Factors influencing lemur diversity and distribution in forest remnants of north-eastern Madagascar

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ABSTRACT

A majority of Madagascar's iconic lemurs (*Primates*, *Strepsirrhini*) is threatened with extinction due to anthropogenic activities like land use change (deforestation) and bushmeat hunting.

We used a multivariate approach combining land cover mapping, vegetation/degradation monitoring, the degree of anthropogenic disturbance and the status of forest protection by the local community to model their impact on lemur diversity, population densities and encounter rates within a rural area of lowland rain forest in north-eastern Madagascar.

High mean annual deforestation rates (2.4%) were calculated since 1990, resulting in a landscape of small and isolated forest fragments. A limited number of eight lemur species belonging to five lemur families were encountered. Diurnal species were absent, while cathemeral lemurs avoided human disturbance. Small and nocturnal species were relatively abundant. Overall lemur diversity was best explained by forest size and a combination of disturbance and hunting. Encounter rates of three nocturnal taxa were influenced by forest size and habitat degradation. Community-level forest protection had no effect on lemur diversity, but coincided with lower levels of habitat degradation. Lemur population sizes were relatively small and only few forests remain that offer suitable habitats for viable populations.

We highly recommend external conservation NGOs to support local forest management by improving the existing community-based approach. Actions should include expansion of protected habitats to increase population connectivity (reforestation) and to decrease lemur disturbance by villagers. Without external support, the last remaining forest habitats will be devastated within a few years resulting in the local extinction of most lemur populations.

1. Introduction

The island of Madagascar is widely known for its biodiversity with an outstanding high percentage of endemism (Myers et al., 2000; Goodman and Benstead, 2005). Although the iconic lemurs (*Primates*, *Strepsirrhini*) are the flagship species of the island, all taxa are declining in numbers. Anthropogenic activities, predominantly habitat loss and fragmentation through deforestation and excessive hunting for bushmeat, are the drivers pushing about nine out of ten lemur species towards the brink of extinction (Schwitzer et al., 2014; Estrada et al., 2017).

High deforestation rates during the last few decades have led to the complete devastation of forests in some regions and increasing fragmentation in others (Vieilledent et al., 2017). Forest size seems to act as a determinant for lemur diversity (Ganzhorn et al., 2000), whereas small-scale factors like habitat degradation (Ganzhorn et al., 1997; Herrera et al., 2011; Knoop et al., 2018) or edge effects (Harper et al., 2005; Lehman et al., 2006a, 2006b) can influence species abundances. Responses to anthropogenic disturbance are highly variable (Gardner, 2009; Irwin et al., 2010) and the knowledge on how lemurs are able to cope with altered habitats is still limited and requires further investigation (Irwin et al., 2010; Schwitzer et al., 2013).

Illegal bushmeat hunting of lemurs is the other main driver for pending extinctions (Schwitzer et al., 2014). With a Gross Domestic Product per capita of 449.7 US$ (World Bank, 2017), Madagascar is among the poorest countries worldwide, characterized by weak

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institutions, high annual population growth rates (approx. 2.8%), a low degree of urbanization (35.1%) and the majority of people living under extreme poverty (UNDP, 2016). Accordingly, poverty of a rural population, poor health conditions, child malnutrition and a general low food security were identified as main predictors for bushmeat hunting (Borgerson et al., 2016, 2017).

Long-term survival of lemurs therefore depends on poverty alleviation, protection and valuing of natural resources and biodiversity by rural communities (Schwitzer et al., 2013; Borgerson et al., 2016; Waeber et al., 2016) and species abilities to adapt to a changing environment (Schwitzer et al., 2013, 2014). These problems are primarily addressed with the expansion of community-based management approaches supported by non-governmental organizations (NGOs) and an international donor community (Gardner et al., 2018). About 63% of all protected areas in Madagascar are today based on these frameworks, whereas the remaining 37% are under governmental conservation (e.g., national parks; Gardner et al., 2018). Existing frameworks are evaluated and further improved from a socio-economic point of view, but the effects on habitat and species protection are poorly studied to date (Rasolofoson et al., 2015; Nopper et al., 2017).

We therefore aim to investigate the influence of forest size, forest degradation, direct anthropogenic disturbance and the status of forest protection by the community on lemur diversity, population density and abundance in a previously undocumented but anthropogenically affected area of north-eastern Madagascar. We predict that:

1. Decreasing forest size negatively influences lemur diversity and species abundance (Ganzhorn et al., 2000).
2. Low-level forest degradation may benefit lemur diversity and species abundance to some degree, but degradation acts as a negative predictor above that point (intermediate disturbance hypothesis, Connell, 1978; Ganzhorn, 1995; Ganzhorn et al., 1997; Herrera et al., 2011).
3. Direct anthropogenic disturbance (number of people in the forest per day) negatively affects lemur diversity as purposeful and opportunistic lemur hunting may be positively correlated with this parameter (Golden, 2009; Irwin et al., 2010; Borgerson et al., 2016).
4. The status of forest protection (by local community) positively influences lemur diversity and species abundance.

2. Material and methods

2.1. Study site

The study site is located in the Mananara Nord district (Analanjirofo region) in north-eastern Madagascar. This region is characterized by a humid climate, high rainfall throughout the year and rain forest vegetation (Cornet, 1974; Kottek et al., 2006). The study region (about 180 km^2, Fig. 1) was covered with the last remaining patch of lowland rain forest (220–450 m a.s.l.) between the Mananara and Fahambahy Rivers in 1990. The actual study area is situated in the north-eastern quarter of the 1990 rain forest continuum (ca. 19 km^2, Fig. 1). A total of 24 different forest fragments within the area were surveyed during this study. According to our assessment of historic satellite pictures, the study area is representative for the forest patches that resulted from the fragmentation of the 1990 forest continuum. Landscape characteristics, e.g. infrastructure, forest decline, occurrence of rural villages and population, do not differ between our study area and the larger study region (Fig. 1).

A total of 14 lemur species could potentially occur in the study area (Table 1; Mittermeier et al., 2010; Schüßler & Radespiel, unpubl. data). Two species of *Microcebus* were identified, *M. mittermeieri* and *M.* sp. #3 (Louis and Lei, 2016; Schüßler & Radespiel unpubl. data) whereas species affiliation of *Cheirogaleus* sp. was uncertain. Observed individuals were rather uniformly grayish than grayish-brown like *C. major* that may potentially occur in the study area (Groeneveld et al., 2009; Lei et al., 2014).

Half of the forest patches included in our survey are protected by the local community under the GELOSE/GCF legislation. This transfers governance of forest management from regional authorities to local community associations, so called "Communités de Base" (COBA; Pollini and Lassoie, 2011; Cullman, 2015). Data was collected in September 2017 near the villages of Ambavala and Madera (S 16°12′, E 49°36′).

2.2. Estimation of lemur abundance

Lemur populations were surveyed using line transects and distance sampling (Buckland et al., 2001). We installed 9 transects crossing all 24 forest fragments with varying lengths between 1.0 and 3.0 km totaling 13.0 km. Transect length was determined by landscape characteristics and the presence of accessible pathways through the forest. Each transect was surveyed 3–4 times, both during day (10–16 h) and night (18–22 h), resulting in a search effort of 41.7 km and 41.0 km, respectively. Same transects were surveyed with at least two days in between to minimize observer disturbance (Buckland et al., 2001).

All sightings of lemurs were noted taking data of transect ID, position in transect (accurate to 25 m), date and time, species, estimated perpendicular distance and number of individuals. During night surveys, lemurs were detected with forehead lamps by eye reflections and subsequently confirmed with a powerful hand torch taking into account the inter-orbital distance, movements (e.g. quadrupedally/leaping), size, color or vocalization resulting in 168 encounters. Survey teams consisted of the first author and an assistant (both previously trained in lemur discrimination during a pilot survey) and two local guides. While walking slowly (ca. $1\ km * h^{-1}$), the observer team regularly checked all vegetation heights to the front and both sides for lemurs to minimize missed out sightings. Perpendicular distances were estimated to an accuracy of 0.5 m by the first author who was trained before (Buckland et al., 2001).

Population abundances were analyzed in two different ways. First, we estimated population densities for *Microcebus* spp., *Cheirogaleus* sp. and *Avahi laniger* (see Buckland et al., 2001) in R (R Core Development Team, 2013) using the "distance" package (Miller, 2017; Miller et al. in press) with data truncated at 5% (Meyler et al., 2012). *Microcebus* spp. density was separately estimated for forest habitats and for forest combined with secondary habitats. Detection functions for each species were modeled and selected according to the lowest AIC value (Burnham and Anderson, 2002; Miller et al. in press). The fit of the detection function was checked via visual interpretation of quantile-quantile plots and χ^2-goodness-of-fit tests (Buckland et al., 2001; Miller et al. in press).

Secondly, mean encounter rates per km of transect (MER) for *Microcebus* spp., *Cheirogaleus* sp. and *Avahi laniger* were calculated. These estimates of MERs were then used as response variables for the statistical modeling as described below.

2.3. Dataset on forest ecology and human disturbances

Each of the 24 forest fragments can be characterized by the following variables: forest size (continuous variable, in km^2) vegetation degradation (categorical as a score from 1 to 14), direct human disturbance (continuous, daily mean of humans per 1 km of transect) and the status of protection by the COBA (categorical, protected or not).

2.3.1. Forest size and deforestation rate

In order to reconstruct forest size and deforestation rates, we acquired satellite images from four different time stages from the USGS archive (http://earthexplorer.usgs.gov/) to produce land cover maps. We used cloudless, level 1 terrain corrected and georeferenced products from 19.06.1990, 26.09.1997, 08.03.2005 (Landsat 5 TM; path 158, row 071) and 09.11.2017 (Sentinel-2; tile T39LUC). All scenes were