

# A New Population of Mouse Lemurs (*Microcebus* sp.) from North-western Madagascar, with Population Size and Density Estimates

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**Abstract:** The destruction and degradation of forest habitats are the biggest drivers of primate population decline and extirpation. Enormous areas of what were once widespread and continuous tropical forest are today highly fragmented, and the populations of many primates are now isolated due to their inability to cross the large open spaces between forest patches. Although somewhat adaptable and resilient to forest degradation, the mouse lemurs (genus *Microcebus*) of Madagascar are particularly affected by this fragmentation and consequent isolation. The geographic distributions of many of the species of mouse lemurs remain poorly known, and such spatial data is needed to effectively conserve their populations. We conducted a survey of the lemurs in the Ankarafa forest of the Sahamalaza – Îles Radama National Park of north-west Madagascar and found there a previously unrecorded population of mouse lemurs. We used line transect Distance sampling to estimate its size and density. The Ankarafa *Microcebus* population density was significantly lower than that of the Anabohazo forest nearby which is much more extensive, and the population density in the Sahamalaza National Park appears to be lower than that of other mouse lemurs in other areas of Madagascar. Probably *M. sambiranensis*, our findings suggest large-scale regional variation in its population density. Further, our study demonstrates that populations of these small, cryptic primates remain to be discovered, and such data are urgently needed to safeguard their future, many of them being severely threatened with extinction.

## Introduction

The destruction and degradation of natural habitats and ecosystems is currently the biggest driver of global biodiversity decline and species extinction (Betts *et al.* 2017; Xu *et al.* 2021). Primates of the tropics are particularly threatened with extirpation because their forest habitat is disappearing at an alarmingly fast rate due to agricultural expansion and human population growth (Repetto 1990; Laurance 1999). Furthermore, much of their remaining tropical forest habitat is now heavily degraded and fragmented and few of the larger expanses of forest remnants are intact (Fahrig 2003; Estrada *et al.* 2017). Primates are generally entirely dependent on the forest for survival (Estrada *et al.* 2017) and for many it is a major challenge, if not impossible for them to cross large open spaces between separate forest tracts (Marsh 2013), resulting in the isolation of many primate populations. These small, isolated populations are at an increased risk of genetic bottle-necking, increased vulnerability to hunting and extreme weather events (Zhang *et al.* 2019; Bloomfield *et al.* 2020), and disease and elevated

stress levels due to lower resource availability in their poor-quality habitat (Gillespie and Chapman 2006; Martinez-Mota *et al.* 2007; Farias *et al.* 2015).

The lemurs of Madagascar are particularly threatened, with over 95% of species now listed as either Vulnerable, Endangered or Critically Endangered on IUCN's Red List (Schwitzer *et al.* 2013). Population declines in lemurs have been primarily caused by widespread deforestation and habitat fragmentation, leaving many species with highly restricted distributions (Gade 1996; Schwitzer *et al.* 2014). Conservation concerns for lemurs have also increased due to the increase in the number of species recognized over the recent decades, many of them newly described taxa restricted to small, few and far between, isolated forest fragments (Wilmé *et al.* 2006; Tattersall 2007; Andriatsitohaina *et al.* 2019). Survey efforts in Madagascar have increased in recent years, but many small, forested areas have yet to be surveyed, resulting in a poor understanding of the demography of many lemur species (Turner and Corlett 1996; Setash *et al.* 2017). Many of the less-charismatic lemurs are overlooked in studies of population density (Colléony

*et al.*, 2017) because of the financial limitations and time constraints that conservation biologists face (Muldoon and Goodman 2015; Setash *et al.* 2017). An understanding of lemur demographics is also vital to their conservation as they can provide valuable insights into how they respond to anthropogenic disturbance and habitat degradation (Herrera *et al.* 2011; Sawyer *et al.* 2017) and how they are affected by changes in habitat structure, climate and topography (Jolly *et al.* 2002; Hending *et al.* 2020).

The smallest and most ubiquitous of all the lemurs are the small, nocturnal mouse lemurs (genus *Microcebus*) (Setash *et al.* 2017). Over the last thirty years, the genus has been the subject of intensive phylogenetic study resulting in taxonomic expansion, and it now has 25 extant species (Yoder *et al.* 2000; Hotaling *et al.* 2016; Schüßler *et al.* 2020). Due to their small size, the biogeography and distribution of mouse lemurs is often influenced and limited by major rivers, and species are often restricted to certain inter-river systems (Craul *et al.* 2007; Olivieri *et al.* 2007). In these inter-river systems, mouse lemurs have been recorded to live in a range of habitat types, including primary and secondary forest (Ganzhorn and Schmid 1998; Lehman *et al.* 2006a), disturbed forest (Herrera *et al.* 2011) and agricultural areas (Hending *et al.* 2018; Webber *et al.* 2020), both inside and outside of Madagascar's protected area network (Müller *et al.* 2000; Weidt *et al.* 2004; Hending 2021). Many mouse lemurs demonstrate some adaptability and resilience to habitat degradation and are therefore able to inhabit small patches of poor-quality forest (Knoop *et al.* 2017; Hending, 2021; but see Schäffler and Kappeler 2014). A recent increase in lemur survey efforts has resulted in the discovery of several new mouse lemur populations in remote forest fragments that were not previously known to harbor mouse lemurs. When new mouse lemur populations are found, however, it is often unclear as to which species they belong. This is due to cryptic species complexes within the genus (Zimmermann *et al.* 1998; Weisrock *et al.* 2010).

We conducted a population distribution and density assessment of *Microcebus* in the Sahamalaza-Îles Radama National Park (henceforward referred to as SIRNP) of north-west Madagascar. The Endangered Sambirano mouse lemur (*Microcebus sambiranensis*) (Blanco *et al.* 2020) was first described in a taxonomic revision of the genus by Rasoloarison *et al.* (2000). Its type locality is the Bekolosy Forest in the Manongarivo Special Reserve in the province of Mahajanga, but new populations of this species have since been located and genetically confirmed for the Ampasindava Peninsula and the Anabohazo forest of SIRNP (Randriatahina *et al.* 2014; Ratsavina *et al.* 2017). Whilst the confirmation of *M. sambiranensis* in the SIRNP was a significant geographic range increase for this species, it is somewhat surprising that these populations were not discovered before, considering the large number of biodiversity surveys that have been conducted in the area since its designation as a national park (G. H. Randriatahina, pers. comm.). As mouse lemurs are often present in areas of intact forest throughout Madagascar

(Mittermeier *et al.* 2010), our aim in this study was to survey for *Microcebus* in the remaining forest areas of SIRNP, and calculate the first population size and density estimates for these lemurs there.

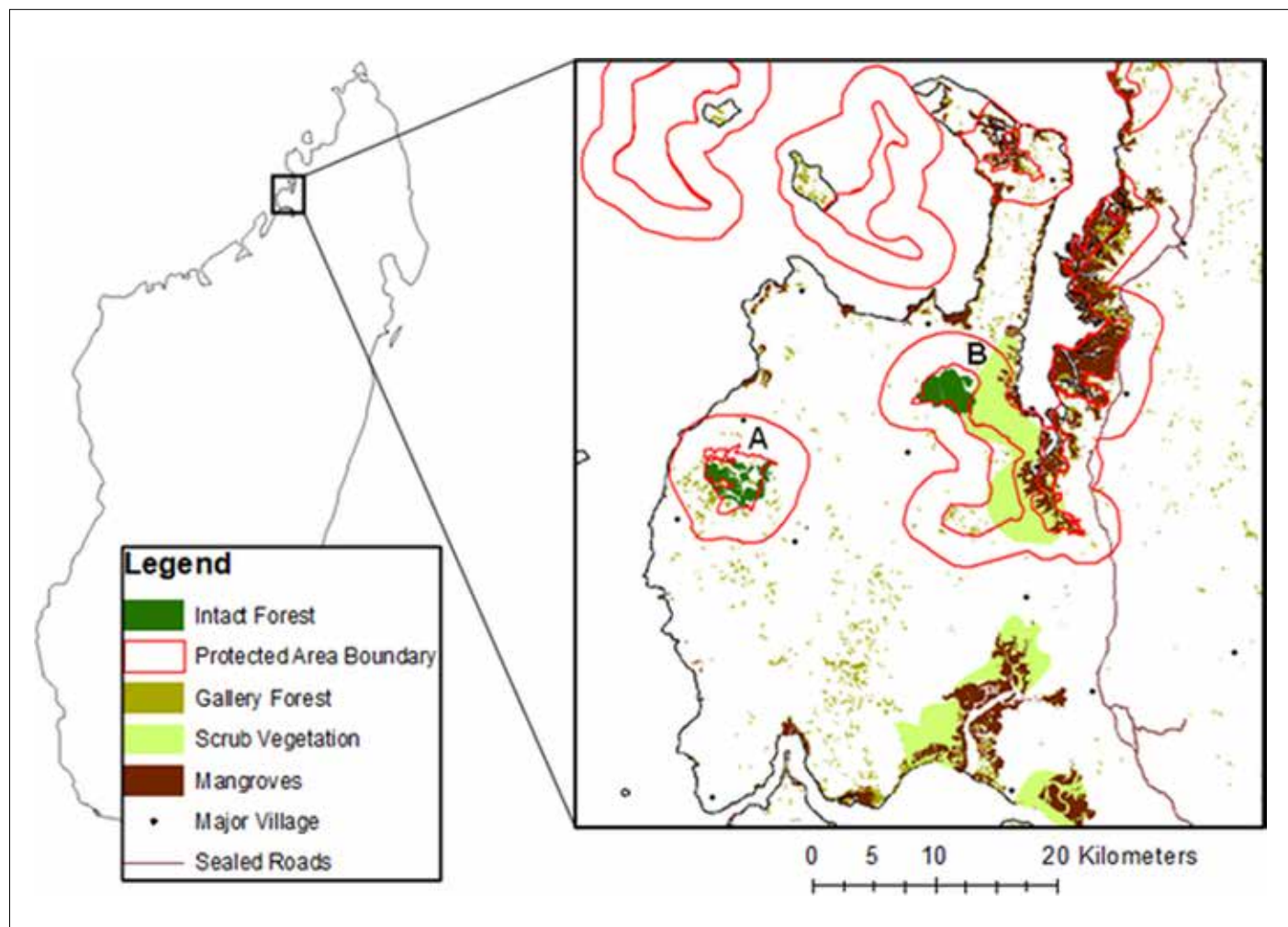
## Methods

### Study site

The 26,000-ha Sahamalaza – Îles Radama National Park is located on the Sahamalaza Peninsula in north-west Madagascar, between 14°04'S–14°37'S and 47°52'E–48°04'E (Volampeno 2009). It is also a UNESCO Biosphere Reserve and, although it has historically undergone heavy deforestation and habitat destruction (Seiler *et al.* 2014), two forests remain within the protected area. The first is the 1,169-ha Anabohazo forest, a continuous forest block located in the north-east of the protected area (Randriatahina *et al.*, 2014), and the highly fragmented 1,020-ha Ankarafa forest in the west of the national park (Volampeno *et al.* 2010) (Fig. 1). Anthropogenic grassland and savanna surround the two forests, although there are some matrices of gallery and scrub forest that intersect the isolated forest fragments (Volampeno *et al.* 2011). The SIRNP is located in Madagascar's Sambirano domain, an area of seasonal, sub-humid transitional forests. These forests are composed of a mixture of evergreen and deciduous species, many of which are endemic to the region (Du Puy and Moat 1996). Sahamalaza's climate is hot, sub-humid and seasonal, with a hot and wet dry season (November–April) and a cool dry season (May–October) (Mandl *et al.* 2018). The mean temperature range of the area is 20.6–32.0°C, with extreme temperature ranges of 13.2–39.1°C, and a mean annual precipitation of approximately 1,600 mm (Volampeno *et al.* 2011; Hending *et al.* 2017a). In the SIRNP, *Microcebus* occurs sympatrically with three other nocturnal species: *Cheirogaleus medius*, *Mirza zaza*, and *Lepilemur sahamalaza* (see Hending *et al.* 2017b).

### Transect sampling

We conducted fieldwork between February 2019 and May 2022, covering both the wet and dry seasons. To assess *Microcebus* presence and population density, we established a system of line transects in both forests—Anabohazo and Ankarafa. We created seven transects in Anabohazo (mean length = 857 m; range = 500–1,000 m) and ten transects in Ankarafa (mean length = 995 m; range = 850–1,100 m). The ten Ankarafa transects were in ten separate forest fragments (mean fragment size = 92.7 ha, range = 18.3–247.2 ha) that were separated by grassland (one transect per fragment). During our transect walks, a team of three observers walked at a pace of 1 km/h, starting at approximately 19:00 when it was dark enough for the lemurs to begin moving and feeding. The same team of observers undertook all of the transect walks to avoid observational bias among different participants (Buckland *et al.* 2001), and we spread our survey effort evenly throughout the study period to control for seasonal variations in mouse lemur activity and



**Figure 1.** The Sahamalaza-Îles Radama National Park and the location of Ankarafa forest (A) and Anabohazo forest (B). Figure created in ArcMap, with a scale of 1:7,000,000 for Madagascar and a scale of 1:350,000 for the zoomed panel. The two red lines surrounding protected areas represent the protected area (inner) and a 3-km buffer zone (outer).

detectability. We recorded the position of any *Microcebus* individuals that were sighted during transect walks using a handheld GPS (eTrex 30, Garmin, Olathe, Kansas, USA) and measured the perpendicular distance from the transect to the tree in which they were positioned using a laser range-finder (80 m, XCSOURCE, San Francisco CA, USA). We used high-lumen headlamps (Tikka+, Petzl, Crolles, France) and hand-torches (EC20, Nitecore, Guangzhou, China) to spot the lemurs.

#### Population density and size estimates

We used our *Microcebus* observation data, our transect length data and perpendicular distance data (i.e., estimated strip width – ESW) to compute estimates of population density and size for our study area in the ‘Distance v7.3’ software (Thomas *et al.* 2010). Although several methods are available to compute primate population sizes and densities (Meyler *et al.* 2012), we opted to use the Buckland method (Buckland *et al.* 2001) as it accounts for the decreasing probability of observing an animal as its perpendicular distance from the transect line increases. Furthermore, it has been

used successfully in the study of other primate species (for example, Quémère *et al.* 2010; Quinten *et al.* 2010; Axel and Maurer 2011; Sawyer *et al.* 2017; Miller *et al.* 2018; Roberts *et al.* 2021; Wuesthoff *et al.* 2021). We specifically chose the Buckland method over the widely used King method (for example, Norscia *et al.* 2006; Gardner *et al.* 2009), as this method often produces overestimates; many *Microcebus* species such as *M. sambiranensis* are threatened with extinction, and overestimates of their population sizes would jeopardize their conservation. We used instance detection functions in our model, and we truncated our datasets with a 5% threshold to remove very distant observations. This was an approach we adopted to ensure accurate model fitting, based on Buckland *et al.* (2001) and the methodologies used in similar studies (Miller *et al.* 2018; Martin *et al.* 2021; Roberts *et al.* 2021).

#### Data analysis

We performed statistical analyses in the RStudio software (R. Studio, Inc., Boston, USA) with an  $\alpha$ -level of 0.05. To analyse population density, we used a population density

dataset comprised of mean encounter rates per transect ( $N$ /km) for both Anabohazo and Ankarafa. To test the normality of our population density dataset, we used a Shapiro-Wilk test. The dataset was of non-normal distribution, was highly skewed, and zero-heavy, so we performed  $\log(x+1)$  transformation. The resulting dataset was still of non-normal distribution, so we compared population density between forests using a Mann-Whitney U test.

## Results

### Population size and density estimates

In total, we conducted 120 transect walks, 70 of which were in Anabohazo (10 walks per transect) and 50 of which were in Ankarafa (five per transect). We recorded 49 *Microcebus* individuals over a total survey effort of 109.8 km during this study (Table 1). *Microcebus* was present in both Anabohazo (0.84 individuals/km) and Ankarafa (0.09 individuals/km). Our dataset of transect population density values was of non-normal distribution ( $W = 0.66$ ,  $P < 0.001$ ). Estimated population density was significantly higher in Anabohazo in comparison to Ankarafa ( $U = 60.0$ ,  $P = 0.008$ ). The number of *Microcebus* individuals sighted in Ankarafa was too low to estimate population size (abundance) for that forest (Buckland *et al.* 2001). In general, the estimated population densities of *Microcebus* appear to be low in the SIRNP in comparison to other mouse lemur species reported in the literature (Table 2).

## Discussion

### New *Microcebus sambiranensis* population

The confirmation of *Microcebus* in the Ankarafa forest is a noteworthy finding, as mouse lemurs had never been recorded there prior to this investigation. As the distributions of mouse lemur species in northern Madagascar are known to be complex, with considerable inter-species range overlap (Sgarlata *et al.* 2019), without genetic confirmation, it is not possible to say with 100% certainty to which species this new population belongs. Its very small size (even for mouse lemurs) and the pelage coloration of the Ankarafa mouse lemurs match that described for *M. sambiranensis* in the Anabohazo forest and the Manongarivo Reserve (Rasoalison *et al.* 2000; Hending *et al.* 2017b), and we therefore strongly predict this new population to be *M. sambiranensis*. Although the discovery of this new population (if it is indeed *M. sambiranensis*) represents only a small geographic range increase of approximately 20 km westwards, our observations imply that the potential area of occupancy of *M. sambiranensis* in the SIRNP is in fact double that currently described in the literature, as the geographic area of Ankarafa is similar in size to that of Anabohazo (Randriatahina *et al.* 2014). This is encouraging for the conservation of this species. It is somewhat surprising that *Microcebus* had not previously been observed in Ankarafa, due to the considerable survey effort and large number of scientific studies

**Table 1.** *Microcebus sambiranensis* population size and density estimates for the forests of Sahamalaza-Îles Radama National Park, using data collected from February 2019 – May 2020. N – number of *Microcebus* observed; ESW – estimated strip width; D – estimated population density; A – estimated population size. Estimates were computed using Distance v7.3 (Thomas *et al.* 2010).

Measure	Anabohazo	Ankarafa	Total
Area (ha)	1,169	1,020	2,189
Survey effort (km)	60.0	49.8	109.8
$N$	44	5	49
$N$ /km	0.84	0.10	0.41
ESW	7.07	17.15	7.54
D ( $N$ /km <sup>2</sup> )	51.87	2.93	29.60
	(17.70–151.96)	(0.55–15.50)	(12.24–71.56)
A	606	-	648
	(207–1,776)		(268–1,566)

previously undertaken in the Ankarafa forest (for example, Volampeno 2009; Seiler *et al.* 2014; Mandl *et al.* 2018). We only observed five individuals, however, during this investigation (Table 1), which suggests that the low population density of the Ankarafa mouse lemurs may well explain why this population remained undetected for so long.

### Population density

Our observations of *Microcebus* activity in both the wet and dry seasons suggest that mouse lemurs in the SIRNP may not undergo prolonged torpor. The possibility of long-term torpor cannot be entirely excluded, however, as species that undergo torpor may be occasionally detected during periods of environmental hardship (Schmid 2000). Population densities of *Microcebus* are low compared to the population densities of other mouse lemur species (Table 2), especially species that inhabit the dry deciduous forest areas of Madagascar's western and southern regions (for example, *M. murinus*: Müller *et al.* 2000; *M. griseorufus*: Ralison 2006; *M. berthae*: Schäffler and Kappeler 2014). In contrast, our population densities are analogous to those of rainforest species (*M. mittermeieri*: Sterling and McFadden 2000; *M. rufus*, Herrera *et al.* 2011) and transitional forest species (*M. tavaratra*: Hawkins *et al.* 1990). This is not surprising considering that the Sambirano domain is characterised by transitional forest. When compared with the population density data for other mouse lemurs, our *Microcebus* data supports the theory of large-scale regional variation in mouse lemur population densities that result from habitat-specific community assemblages (Ganzhorn *et al.* 1997; Muldoon and Goodman 2015; Setash *et al.* 2017). However, these differences in densities may simply be due to variations in survey method and study design (Murphy *et al.* 2016).

On the local scale for the SIRNP, our results correspond to the Island Biogeography Theory (MacArthur and Wilson 1967; Steffens and Lehman 2016); *Microcebus* population density is lower in fragmented and degraded forest

**Table 2.** Overview of mouse lemur (*Microcebus* spp.) population densities from the literature in comparison to those of *Microcebus* in the Sahamalaza-Îles Radama National Park. The table is a modified version of Table 1 from Hending (2021). See Hending (2021) for references.

Scientific name	Common name	Mean Population Density (N/Ha)	Population Density Range (N/Ha)	Density Estimates in Literature (N)
<i>Microcebus</i> sp.	SIRNP Mouse Lemur	0.30	-	-
<i>Microcebus</i> sp.	Unidentified Mouse Lemur	1.35	0.37–2.32	2
<i>Microcebus arnholdi</i>	Arnhold’s Mouse Lemur	N/A	N/A	0
<i>Microcebus berthae</i>	Madama Berthe’s Mouse Lemur	2.49	0.34–12.72	13
<i>Microcebus bongolavensis</i>	Bongolava Mouse Lemur	N/A	N/A	0
<i>Microcebus boraha</i>	Boraha Mouse Lemur	N/A	N/A	0
<i>Microcebus danfossi</i>	Danfoss’s Mouse Lemur	3.78	2.20–5.27	15
<i>Microcebus ganzhorni</i>	Ganzhorn’s Mouse Lemur	3.16	1.41–6.80	5
<i>Microcebus gerpi</i>	GERP’s Mouse Lemur	N/A	N/A	0
<i>Microcebus griseorufus</i>	Reddish-grey Mouse Lemur	6.69	2.20–25.60	27
<i>Microcebus jollyae</i>	Jolly’s Mouse Lemur	N/A	N/A	0
<i>Microcebus jonahi</i>	Jonah’s Mouse Lemur	N/A	N/A	0
<i>Microcebus lehilahytsara</i>	Goodman’s Mouse Lemur	0.58	0.05–1.10	2
<i>Microcebus macarthurii</i>	Macarthur’s Mouse Lemur	0.34	0.041.06	12
<i>Microcebus mampiratra</i>	Claire’s Mouse Lemur	N/A	N/A	0
<i>Microcebus manitatra</i>	Manitatra Mouse Lemur	N/A	N/A	0
<i>Microcebus margotmarshae</i>	Margot Marsh’s Mouse Lemur	N/A	N/A	0
<i>Microcebus marohita</i>	Marohita Mouse Lemur	N/A	N/A	0
<i>Microcebus mittermeieri</i>	Mittermeier’s Mouse Lemur	0.52	0.06–0.97	2
<i>Microcebus murinus</i>	Gray Mouse Lemur	3.38	0.29–12.72	42
<i>Microcebus myoxinus</i>	Pygmy Mouse Lemur	3.25	0.57–6.67	5
<i>Microcebus ravelobensis</i>	Golden-brown Mouse Lemur	3.35	0.08–9.38	18
<i>Microcebus rufus</i>	Brown Mouse Lemur	0.79	0.06–3.90	11
<i>Microcebus sambiranensis</i>	Sambirano Mouse Lemur	1.25	1.25–1.25	1
<i>Microcebus simmonsii</i>	Simmons’ Mouse Lemur	1.93	0.62–3.75	4
<i>Microcebus tanosi</i>	Anosy Mouse Lemur	1.35	0.20–3.20	4
<i>Microcebus tavaratra</i>	Northern Rufous Mouse Lemur	1.58	0.29–3.25	12

(Ankarafa) than in continuous forest (Anabohazo). Whilst the low population densities for *Microcebus* may be due to forest habitat type (Setash *et al.* 2017), it is highly unlikely that they are due to the ongoing habitat degradation and fragmentation in the SIRNP alone (Seiler *et al.* 2010, 2013). This is because many mouse lemurs demonstrate high levels of adaptability to changes in habitat quality and structure (Radespiel 2006; Knoop *et al.* 2017; Hending 2021) and have been observed to be tolerant to habitat degradation and edge habitats (Lehman *et al.* 2006a, 2006b). Furthermore, *M. sambiranensis* is known to occur in both core and edge forest habitat (Hending *et al.* 2017a). Low *Microcebus* population densities may be due to inter-species competition with the sympatric *Lepilemur sahalalaza*, *Mirza zaza* and *Cheirogaleus medius* (Schäffler *et al.* 2015, 2021). According to

the niche concept, they may therefore be restricted to certain areas or niches in the forest due to competitive exclusion (Schwab and Ganzhorn 2004; Rakotondranary and Ganzhorn 2011). Also, the omnivorous diet of *Microcebus* is highly similar to that of *M. zaza* and *C. medius* (Hladik *et al.* 1980; Fietz and Ganzhorn 1999; Hending *et al.* 2018b), and competition for food resources may limit population density for all three species at the study site. Competition for suitable sleeping sites is, however, unlikely to affect *M. sambiranensis* population density, as all four sympatric species have different sleeping micro-habitat preferences (Seiler *et al.* 2013; Rode-Margono *et al.* 2016; Hending *et al.* 2017b).

Our estimated population density and population size values provide a useful overview into the demography and conservation status of *M. sambiranensis* (Dobson and Lyles

1989), but our results should be treated as preliminary, as the low sample size of our dataset may compromise the robustness of our estimates (Buckland *et al.* 1993, 2001). Also, our sample size in this investigation was too low to estimate the population size for Ankarafa; further survey effort is now needed to increase sample sizes there, which will allow computation of an estimated population size. Our estimated total population size values should, therefore, be regarded tentatively, as they are almost certainly a considerable underestimate.

#### Next steps and conservation

Whilst we strongly predict that the Ankarafa mouse lemurs are *M. sambiranensis*, this needs to be confirmed with genetic analyses. Tissue samples of Ankarafa's mouse lemurs should consequently be collected to confirm the identity of this species and to gain insight into the genetic structure and demographic history of the species (Sgarlata *et al.* 2019). Additionally, the gallery forest in the SIRNP should be surveyed for *Microcebus*, as individuals have been sited in the matrix of trees between the core forest areas (Hending and Randrianarison, pers. obs.). A comprehensive dataset for the entire SIRNP would allow for reliable estimation of population density and total size and a reliable overview of the conservation status of this species, and would provide the means to assess how mouse lemur population density correlates with habitat type, forest fragmentation and degradation.

#### Acknowledgments

We thank our field guides Raumiald, Mahatsara, Avit-sara, Hervé, Aristide and Jacques, and our cooks Klariny, Klarice and Marceline for all their help and enthusiasm during our time together in the field. We also express our sincere gratitude to the people of Ambinda, Betsimpoaka, Marovato, Maropapango, Antanandava, Antanambao Manambaro, Antafiabe, Maromandia and Amboloboza for their logistical assistance. We are grateful to MICET and MNP for their facilitation services and for kindly allowing us to conduct research in the Sahamalaza-Îles Radama National Park (permit numbers 245/19 and 124/22 - MEEF/SG/DGGE/DAPRNE/SCBE.Re). Finally, we thank the National Geographic Society, Re:wild, Primate Conservation Incorporated, La Vallée des Singes, Idea Wild, the Primate Society of Great Britain, AEECL, the University of Bristol, Bristol Zoological Society and many private donors for kindly funding this fieldwork. Two anonymous reviewers kindly provided excellent suggestions to improve our original submission.

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*Received for publication:* 10 July 2022

*Revised:* 31 October 2022