



# Living in tiny fragments: a glimpse at the ecology of Goodman's mouse lemurs (*Microcebus lehilahytsara*) in the relic forest of Ankafobe, Central Highlands, Madagascar

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## Abstract

Habitat fragmentation is one of the major types of anthropogenic change, though fragmented landscapes predate human intervention. At present, the Central Highlands of Madagascar are covered by extensive grasslands interspersed with small discrete forest patches of unknown antiquity. Ankafobe, an actively protected site, comprises two such fragments of 12 and 30 ha, respectively, known to harbor three lemur species and other endemic wildlife. At this location, we conducted a survey of resident Goodman's mouse lemurs, *Microcebus lehilahytsara*, to determine baseline behavioral and ecological conditions for this isolated population. By studying primates in forest fragments, investigators can characterize the effects of shrinking habitats and decreasing connectivity on species diversity and survival, thus providing a glimpse into the potential resilience of species in the face of anthropogenic disturbance. Investigating the behavioral ecology of Goodman's mouse lemurs across their geographic range could help us understand their metabolic and ecological flexibility and predict species long-term survival prospects. We conducted night transect walks, using capture techniques and telemetry, to track eight radio-collared individuals. Preliminary density estimates based on a limited number of sightings ( $n = 18$ ) were 2.19 ind/ha, and home range assessments ranged between 0.22 and 3.67 ha. Mouse lemurs traveled an average of 425 m nightly during the 5-h tracking periods and primarily fed on fruits of the mistletoe *Bakerella clavata*. The finding that Goodman's mouse lemurs apparently thrive in the seasonally cold and arid forest fragments in the Central Highlands indicates that they may be among the most tolerant and adaptable lemur species in Madagascar. These results point towards an exciting research program that focuses on ecological tolerance as a mechanism for long-term species survival.

**Keywords** Savannah · Cheirogaleid · Ecological flexibility · Radio collar · Tracking

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## Introduction

Primates worldwide are exposed to increasingly fragmented and degraded environments (Benchimol et al. 2014; Marsh and Chapman 2013; Marsh et al. 2016). Forest loss, structural degradation, and fragmentation are major threats for species survival around the world, though it is difficult to disentangle which of the factors related to fragmentation, such as fragment size, degree of isolation, or edge exposure, render species particularly vulnerable to local extirpations (Arroyo-Rodríguez et al. 2013; Razafindratsima et al. 2018; Steffens and Lehman 2018). Despite species-specific responses, there is general consensus that diminishing fragment area has a clear negative impact on species richness (Andriatsitohaina et al. 2019; Harcourt and Doherty 2005; Steffens and Lehman 2018). Reduced forest area and

increased edge exposure can affect floristic composition, microclimate, and species dynamics such as predator–prey interaction that may be detrimental for long-term species survival (Andriatsitohaina et al. 2020).

Madagascar is losing primary forests at a rapid pace despite efforts to increase environmental protection (Harper et al. 2007; Jones et al. 2019; Morelli et al. 2020). Virtually every native species is subjected to some level of habitat disturbance (Jones et al. 2019). For instance, more than 70% of described lemur species, the endemic primates of Madagascar, are listed as Endangered or Critically Endangered under the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN) (<https://www.iucnredlist.org/>). For many of these species, however, we still lack even the most basic information about geographic ranges, which are receding because of habitat loss (Steffens and Lehman 2018). Thus, understanding the effects of habitat degradation—including fragmentation—is imperative for conservation planning.

Mouse lemurs (genus *Microcebus*) are a speciose group of nocturnal lemurs that can be found in quite extreme environments, including small forest corridors, vanilla-cultivated forest fragments, and tree plantations (Ganzhorn 1987; Hending et al. 2018, Knoop et al. 2018). Notably, mouse lemurs in degraded habitats display behavioral and ecological flexibility that appears to protect them from changes in forest structure and resulting shifts in food availability (Knoop et al. 2018). For example, well-documented examples of dietary adjustments include greater reliance on fallback foods like gums and mistletoes, e.g., *Bakerella* (Atsalis 2008; Bohr et al. 2011). At Ranomafana National Park, a southeastern rainforest, mistletoe is a frequent staple in the diet of rufous mouse lemurs that allows them to accumulate fat deposits at the onset of the dry season which, in turn, is a precondition for prolonged torpor (Atsalis 1999; 2008). Notwithstanding evidence of ecological opportunism in mouse lemurs, there may be limits to their tolerance for disturbed environments. For example, Ganzhorn and Schmid (1998) found that annual survival was significantly reduced in mouse lemur populations in degraded habitat versus those in primary forest, perhaps suggesting that mouse lemurs in disturbed areas represent sink populations destined to perish.

Out of the 25 described mouse lemur species, Goodman's mouse lemurs (*Microcebus lehilahytsara*, Roos and Kappler 2005, family Cheirogaleidae) have been described as highland specialists, occupying cold and montane rainforests exclusively (Radespiel et al. 2012). This species was originally described from a population at Mantadia National Park, a montane rainforest, but in the last decade more localities have been identified at lower elevations and across the Central Highlands thus resulting in a considerable range expansion (Blanco et al. 2017; Schüßler et al. 2020). At Tsinjoarivo, a high-elevation rainforest, Goodman's

mouse lemurs were found in both primary and fragmented forests, where they fed on some of the same dietary items, such as fruits from different kinds of mistletoes, which were also used by sympatric dwarf lemurs and sifakas (Blanco 2010; Crowley et al. 2013; Irwin 2008). Little is known, however, about the behavioral ecology of Goodman's mouse lemur in the Central Highlands where they are subjected to more arid climates and, in some instances, extreme habitat fragmentation.

Ankafobe Forest, comprising two small forest fragments, represents the westernmost range of Goodman's mouse lemurs known to date (Schüßler et al. 2020). The degree to which Ankafobe was historically connected to other nearby fragments, and with larger forest blocks to the east, remains a subject of debate and is a critical piece of the puzzle relating to the geographic extent of grasslands in the Central Highlands prior to human colonization (e.g., Bond et al. 2008; Goodman and Jungers 2014; Mullin et al. 2021; Vorontsova et al. 2016). While many ecologists and botanists consider the vast grasslands of the Malagasy highlands to be primarily anthropogenic in origin, recently replacing a mosaic of woody vegetation types (e.g., Humbert 1927; Lowry et al. 1997; Perrier de la Bâthie 1936; Tiley et al. preprint), others consider these extensive grasslands to be ancient, predating human colonization (e.g., Bond et al. 2008; Vorontsova et al. 2016).

Today, the two disjunct fragments of Ankafobe Forest are surrounded and separated by grassland with occasional shrubs and rare trees. The distance between the two forest fragments is 200 m, and both are separated from the closest large forest block, Ambohitantely Special Reserve, by 10 km (Mullin et al. 2021). Previous surveys documented the presence of three lemur species at Ankafobe: the common brown lemur (*Eulemur fulvus*), the furry-eared dwarf lemur (*Cheirogaleus crossleyi*), and Goodman's mouse lemur (*Microcebus lehilahytsara*) (MBB, pers. obs.). *Eulemur fulvus* can move between fragments and regularly do so (AA and TVR, pers. obs.), but it is unknown to what extent small-bodied dwarf (300 g) or mouse lemurs (50 g) make this journey.

Here, we present the results of the first ecological survey of resident Goodman's mouse lemurs in the heart of the Malagasy Central Highlands. We specifically ask:

Is the distance between fragments an insurmountable barrier for mouse lemur dispersal? Are data on behaviors, sleeping sites, and home ranges from Ankafobe's mouse lemurs consistent with those of other mouse lemur populations occurring in larger and/or more continuous forests? And if so, how do Goodman's mouse lemurs manage to survive in tiny fragments?

## Methods

### Study species

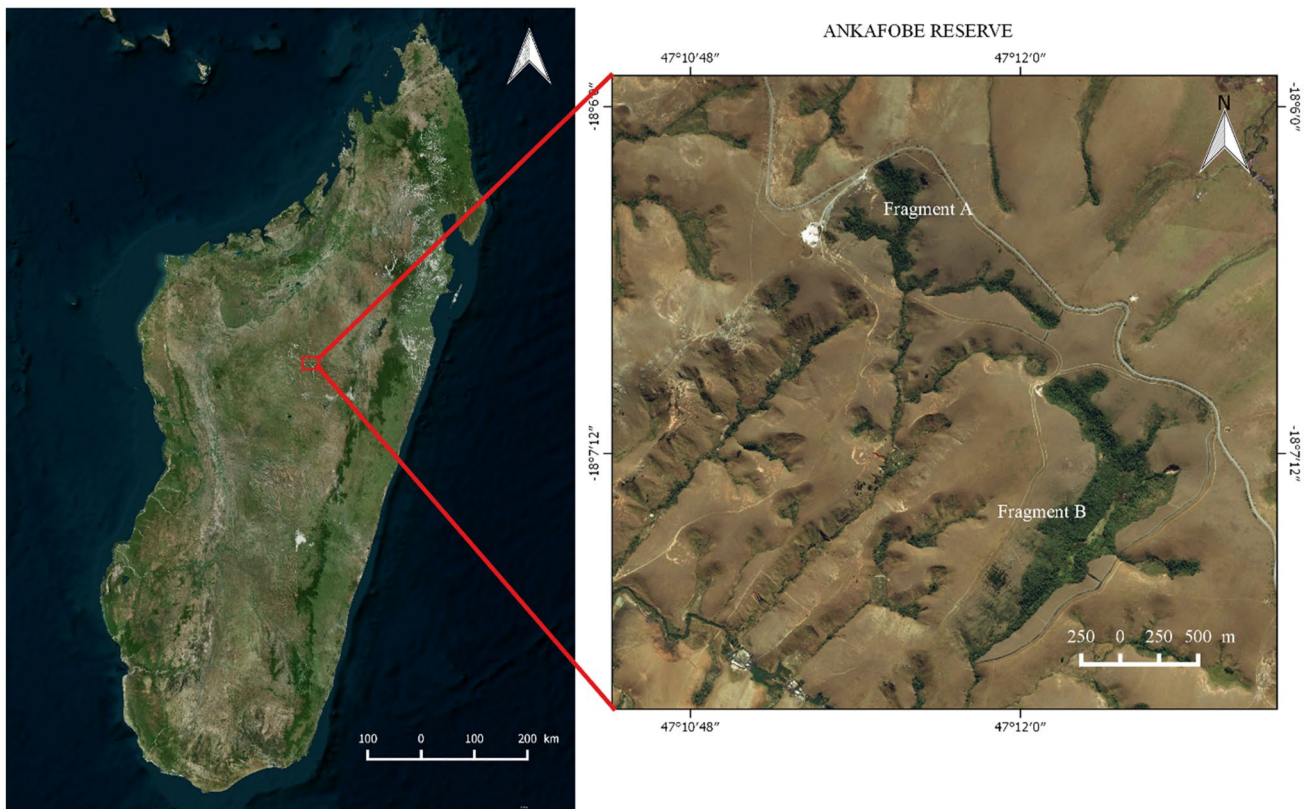
Mouse lemurs at Ankafobe were genetically confirmed as *Microcebus lehilahytsara* (Yoder et al. 2016). Recently, Poelstra et al. (2020) proposed that *M. mittermeieri*, a mouse lemur species occupying rainforests sites in NE Madagascar, should be synonymized with *M. lehilahytsara*. If this taxonomic amendment holds, Goodman's

mouse lemurs will become one of the most broadly distributed species of mouse lemur (Poelstra et al. 2020).

### Study sites

We conducted our study in two forest fragments in Ankafobe Forest (S18.10643 E47.18701, 1472 m), a protected area managed by a local community association VOI-Sohisika with the support of Missouri Botanical Garden's Madagascar Research and Conservation Program. Forest fragment A is 12 ha, and forest fragment B is 30 ha (Figs. 1, 2). The climate at Ankafobe Forest can be classified as subhumid with

**Fig. 1** Panoramic (left) and close-up (right) views of fragment A at Ankafobe



**Fig. 2** Map showing Ankafobe Forest fragments in the heart of the Central Highlands of Madagascar



mists (Cornet 1974). Two distinct seasons occur: wet and hot between December and April, and dry and cool between May and November. A local weather station adjacent to the Ankafobe Forest recorded total annual precipitation of 1671 and 1405 mm in 2019 and 2020 respectively, with 90% and 92% falling during the wet season. The highest average monthly temperature (24.2 °C) occurs in November, and the lowest (16.8 °C) in June.

Ankafobe Forest is species-diverse, and located within a number of adjacent, steep-sided valleys. The structure and flora of the forest are different in the valley bottoms compared to the upper slopes. Frequent woody plants in the valley bottom include *Suregada gaultherifolia* (Euphorbiaceae), *Syzygium parkeri* (Myrtaceae), *Ixora regalis* (Rubiaceae), *Grewia speciosa* (Malvaceae), and *Stephanodaphne germinata* (Thymelaeaceae), whereas frequent species on the upper slopes include *Baronia taratana* (Anacardiaceae), *Tambourissa purpurea* (Monimiaceae), *Ficus soreciodes* (Moraceae), *Dracaena reflexa* (Asparagaceae), and *Macaranga alnifolia* (Euphorbiaceae) (see Ankafobe plots here [https://www.mobot.mg/conservation/permanent\\_plot/](https://www.mobot.mg/conservation/permanent_plot/)). The grassland surrounding this forest is fire-prone and dominated by the grass *Loudetia simplex* (Miandrimanana et al. 2018). The forest is relatively sheltered from the strong winds that stoke these fires and, provided the canopy is intact, resists burning.

### Capture protocols, night walks, and density estimates

We conducted three nocturnal walks between September 30 and October 2, 2015, following different trails inside and around fragment A. This time of the year is ideal for conducting transect walks and sampling because mouse lemurs are active, i.e., this time marks the beginning of the reproductive season (Schüßler et al. 2020).

We walked the transects at a pace of 0.5–1 km/h. We calculated density of mouse lemurs based on encounter rates. We collected GPS coordinates of mouse lemur sightings and estimated perpendicular distance, in meters, between each sighted individual and the trail. The average of these individual distances represented the “detection distance” for mouse lemurs. We used a general formula  $d = n/2wL$ , where  $d$  = density as number of individuals/km<sup>2</sup>,  $n$  = number of sightings,  $w$  = mean lateral detection distance,  $L$  = total length of the transect (km) (Ganzhorn and Kappeler 1996).

During the second mission to Ankafobe in February 2016, we set up to 19 Sherman traps in forest fragment A and 10 traps in fragment B between February 5 and 13, 2016, for a total of 243 trap nights. Traps were set in pairs on each side of pre-existing trails every 15–20 m, and they were tied with double strings to horizontal branches 1–2 m high. Traps were baited with small pieces of banana and

opened around 16:00 and checked the following morning at 5:00. We captured a total of eight mouse lemurs, six in fragment A and two in fragment B. All captured mouse lemurs were brought back to the main campsite, where they were briefly anesthetized with ketamine (10 mg/kg) injected with microchips (Trovan®), weighed, and measured following the protocols in Blanco et al. (2017). All individuals were monitored until fully recovered from anesthesia, given clean water, and safely placed in cloth bags in a shaded area until release at the capture site later the same day. Animal handling protocols followed International Primatological Society Guidelines for the Ethical Treatment of Non-human Primates.

### Telemetry, behavioral ecology, and sleeping site usage

To conduct nocturnal follows and identify sleeping site locations, we fitted small radio collars (1 g, M1420 Advanced Telemetry Systems, Isanti, MN, USA) to captured mouse lemurs. Between February 8 and 26, we conducted a total of 12 nocturnal trackings from 18:30 to 23:45, on eight mouse lemurs (males,  $n=4$ , females,  $n=4$ ). A single radio-collared mouse lemur was selected as the focal individual each night. We employed a three-person tracking team: one of us carried the receiver and antenna, another member carried a GPS device (Garmin® GPSMAP 64st), and a third member carried a notebook and recorded observations.

We conducted 2-min scan sampling (Altmann 1974) and recorded behavioral data: grooming, sleeping, resting, moving, feeding (including food item, e.g., unripe or ripe fruit, insect). We recorded out of sight (OOS) if the focal individual could not be seen. When calculating activity budgets, however, we removed OOS observations and focused on recorded behaviors. Feeding scans were combined when continuous. For example, if feeding was reported at 19:02; 19:04, 19:06, 19:08 on a single night, those scans were grouped as one single feeding bout that lasted 6 min. The 2-min sampling was implemented to minimize disturbance on the focal mouse lemur that could result from continuous exposure to a bright white light during the tracking. The alternative to use red lights was dismissed: forest structure and dense canopy made red lights unsuitable for night follows. Instead, we directed a white light towards the focal lemur to record behavior, turned off the light for 2 min, and turned it on again to record another behavioral observation. We collected location information using a GPS unit every time the individual moved by a minimum of 4 m. If the individual was not seen but the radio signal was strong (1 bar in the gain setting of the receiver, indicating 5–10 m distance), we also collected GPS coordinates that we used to calculate nightly distances and to estimate the areas of the home ranges. This protocol was implemented to preserve spatial

data that would be lost if we only relied on direct visual observations of focal lemurs.

Between February 5 and March 9, in the morning hours, we tracked radio collar signals to identify sleeping site locations and recorded their GPS coordinates. The details of sleeping sites are documented elsewhere (Blanco et al. 2017).

### Assessment of nightly distances and home ranges

In order to delineate the perimeter of the two forest fragments needed for the spatial analysis, two of us (AA and TVR) walked along the external boundary of fragments A and B, with a handheld GPS unit (Garmin eTrex) to record location coordinates every 100 m. These coordinates were then entered in QGIS 2.8.2 (<http://www.qgis.org/fr/site>), the software used for all GIS analysis. We used the Points to Line tool and used the Convert Line to Polygon tool to generate polygons for each fragment.

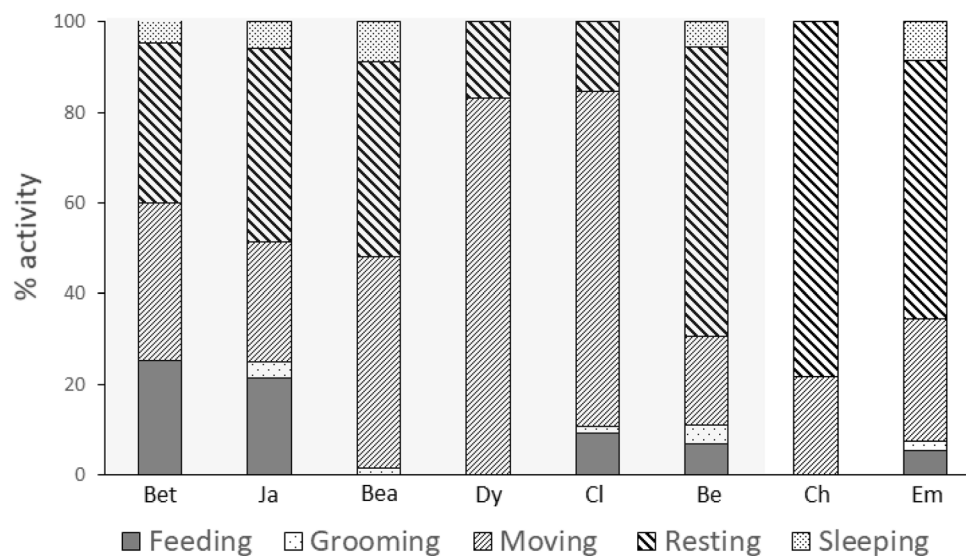
We estimated nightly distances using the Points to Line tool. This tool allowed us to calculate distances, in meters, by connecting GPS coordinates in the order they were collected during the nocturnal tracking. To assess home ranges, we used the Convex Hull tool to construct minimum convex polygons based on nocturnal movements and location of sleeping sites. When the polygons included areas outside of the forest fragment (i.e., including surrounding grasslands) we removed the non-forested areas using the Clip tool.

## Results

In 2015, we surveyed fragment A (Fig. 1) and sighted six mouse lemurs nightly for a period of three nights. Transect length ranged between 1.1 and 1.3 km and the average density estimate across nights was 2.19 ind/ha (using a lateral detection distance of 15 m,  $SD=6$ ), which yields a mean estimate of 26 mouse lemurs populating the fragment. In 2016, we radio-collared and followed eight mouse lemurs (six in fragment A, two in fragment B) for a total of 12 nights and 58 h. For 8 out of the 12 nights, we observed mouse lemurs a minimum of 48% of the tracking time (OOS 52% or less). Mouse lemurs spent a great portion of the tracking period alternating between resting and moving (Fig. 3). Feeding events were recorded during seven nights for five different individuals. We recorded a total of 23 feeding events, ranging from 1 to 16 min duration each. Three events involved feeding on insects (by two different individuals), and 20 events (87%) involved eating fruits (ripe,  $n=15$ ; unripe,  $n=5$ ) of the hemiparasitic epiphyte mistletoe *Bakerella clavata*.

Mouse lemurs shared and reused sleeping sites frequently, forming small groups of a single female plus one or two males. All sleeping locations were nest-like structures, including small crevices in monocaul trees (most prominently *Pandanus*) and mixed structures made of dead dry leaves and entangled liana branches. On many occasions, up to three radio-collared mouse lemurs were found to share the same nest on any given day, though on one occasion, the same nest was used by different mouse lemurs at different times in a single 24-h period (Table 1). Females tended to share nests more often than males, but there were exceptions: some females (e.g., “Bet”) were sometimes

**Fig. 3** Activity budgets of single nights for eight radio-collared mouse lemurs. Individuals from fragment A are inside gray box



**Table 1** Frequency of sleeping site (SS) usage by Goodman’s mouse lemurs

SS #	Used by	Tree species	Times used	% usage	Max # ind. shared at once	Max # ind. shared total
1	“Bet”	<i>Dalbergia emirnenensis</i>	2	2.15	1	1
2	“Bea,” “Cl,” “Be,” “Dy”	<i>Trema orientalis</i>	7	7.53	3	4
3	“Bea,” “Cl,” “Be”	<i>Dombeya</i> sp.	4	4.30	3	3
4	“Be,” “Cl,” “Bet”	<i>Antidesma madagascariense</i>	9	9.68	3	3
5	“Be,” “Cl,” “Bet,” “Ja”	<i>Pandanus spinifer</i>	17	18.28	3	4
6	“Dy”	<i>Pandanus spinifer</i>	3	3.23	1	1
7	“Cl”	<i>Dracaena reflexa</i>	2	2.15	1	1
8	“Cl”	<i>Dracaena reflexa</i>	1	1.08	1	1
9	“Bea,” “Be”	<i>Homalium</i> sp.	7	7.53	1	2
10	“Be,” “Cl”	<i>Filicium decipiens</i>	2	2.15	2	2
11	“Be”	<i>Pandanus spinifer</i>	4	4.30	1	2
12	“Ch”	<i>Oldeania itremoensis</i>	9	9.68	1	1
13	“Dy”	<i>Oldeania itremoensis</i>	3	3.23	1	1
14	“Em”	<i>Oldeania itremoensis</i>	12	12.90	1	1
15	“Ja”	<i>Brachylaena merana</i>	1	1.08	1	1
16	“Dy”	<i>Pandanus spinifer</i>	1	1.08	1	1
17	“Dy”	<i>Pandanus spinifer</i>	5	5.38	1	1
18	“Dy”	<i>Pandanus spinifer</i>	3	3.23	1	1
19	“Ja”	<i>Polyscias ornifolia</i>	1	1.08	1	1

found alone in their nests, whereas some males (“Cl” and “Be”) were frequently found sharing nests with each other. Importantly, there was no evidence that individuals moved between forest fragments.

We calculated nightly ranging distances for eight mouse lemurs. The distances that they covered were between 110 and 662 m, with an average of 425 m per 5 h nocturnal observations. Home range estimates across individuals varied greatly between 0.22 and 3.67 ha, with a mean value of 1.44 ha and a median of 1.3 ha. Male mouse lemurs generally displayed greater ranges than females, though small sample sizes prevent statistical testing (Table 2; Fig. 4).

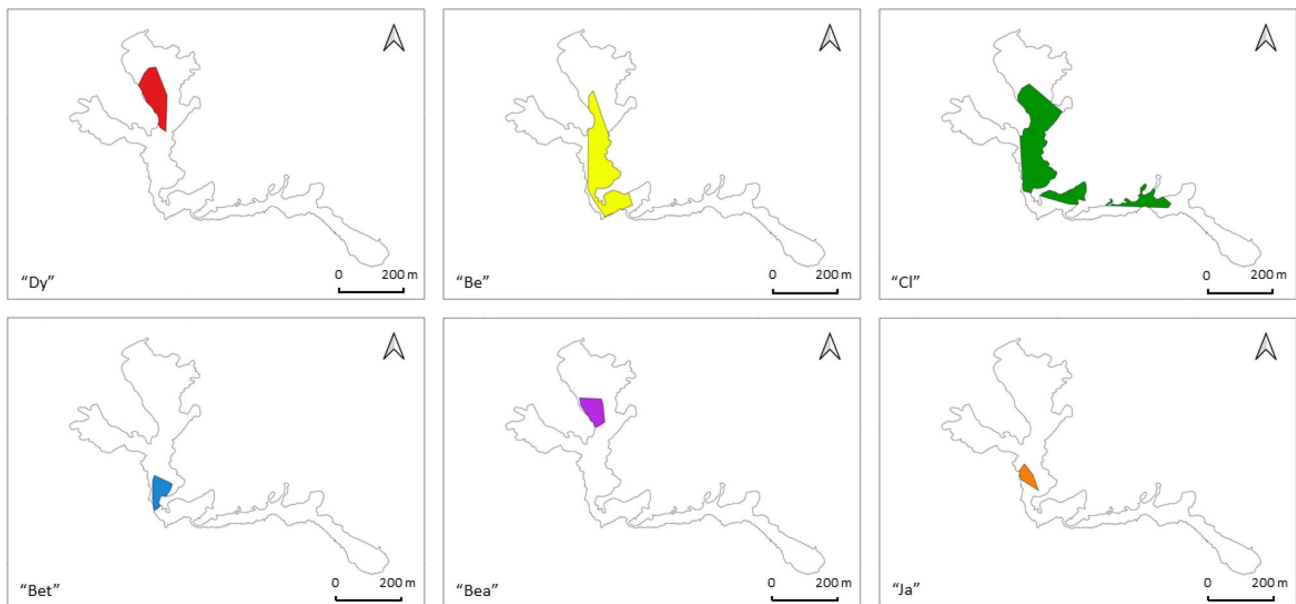
## Discussion

Our preliminary surveys at Ankafobe did not find evidence that mouse lemurs disperse between fragments and that traveling the 200 m distance across open grasslands may be rare. A glimpse at the behavioral ecology of Goodman’s mouse lemurs (*M. lehilahytsara*) in the micro-forests of Ankafobe, shows similarities with data from mouse lemurs inhabiting rain, subhumid, and dry forests. Like rufous mouse lemurs (*M. rufus*) at Ranomafana, golden-brown mouse lemurs (*M. ravelobensis*) at Ankarafantsika,

**Table 2** Nightly distances by individual mouse lemurs and estimated home ranges

Id	Sex	Nightly distance (m)	HR estimation (ha)	Duration of observations (h)	# GPS points night	#GPS points SS
“Cl”	Male	110	3.67	4.5	14	11
“Dy”	Male	604	0.97	5.0	31	7
“Ja”	Female	251	0.22	5.0	22	3
“Bea”	Female	662	0.48	5.0	42	3
“Be”	Male	375	2.30	4.5	12	9
“Bet”	Female	295	0.39	5.25	25	6
“Em”	Male	645	1.87	5.0	23	2
“Ch”	Female	461	1.62	5.2	21	1

GPS coordinates were recorded during night observations (night) or during sleeping site surveys (SS)  
HR home range



**Fig. 4** Estimated home ranges for six mouse lemurs from fragment A: top males, bottom: females

Berthe’s mouse lemurs (*M. berthae*) at Kirindy, and Sambirano mouse lemurs (*M. sambiranensis*) from Sahamalaza, Goodman’s mouse lemurs at Ankafoabe slept in mixed-sex groups that varied in composition and sleeping site fidelity (Atsalis 2008; Hending et al. 2017; Radespiel et al. 2003). Moreover, nest-like structures were commonly used, though tree hole usage may increase during the dry season for mouse lemurs that use prolonged torpor (Blanco et al. 2017; Karanewsky and Wright 2015). Nightly distances for Ankafoabe mouse lemurs were slightly greater than those for Sambirano mouse lemurs, but home ranges were similar in size, with differential overlap, constituting what Hending et al. (2017) called “social neighborhoods.” Although our data are preliminary, the finding that mouse lemur males at Ankafoabe showed larger home ranges than females suggests that neighborhood boundaries, if they exist, may be permeable for males.

Social flexibility, i.e., variable nest occupancy, is accompanied by feeding opportunism with a heavy reliance on the staple food, mistletoe. This is consistent with findings from Tsinjoarivo forest, where *Bakerella* seeds were frequently found in Goodman’s mouse lemur feces (Blanco 2010). Mistletoes have been considered a keystone resource for several lemur species living in disturbed ecosystems in Madagascar (Crowley et al. 2013; Godfrey et al. 2008) as well as for bird and insect species worldwide (Shaw et al. 2004; Watson and Herring 2012). The basis of mistletoe’s significance as a critical resource can be summarized as follows: (i) availability: due to an extended phenology, *Bakerella*’s fruiting season almost overlaps with the following flowering season, leaving a short window of time when no reproductive parts are

produced (Irwin 2008); (ii) fruits have high energy content: for example, *Bakerella clavata* has high lipid content, which makes it an energy-packed food source (Atsalis 1999, 2008); (iii) it is sun-loving and tolerant to arid conditions, with mistletoe being photophilic and especially abundant in open-forest areas including forest edges (Irwin 2008). They are also resistant to droughts, as they can obtain critical nutrients, including water, from their host plants (Atsalis 1999).

In turn, mouse lemurs can promote the abundance of mistletoes in the forest by facilitating their regeneration. Specifically, mouse (and dwarf) lemurs are known to be important seed dispersers; for example, *Bakerella* seeds have a greater probability of germinating if passed through the digestive system of mouse lemur and excreted as fecal matter (Ramananjato et al. 2020). They may even be responsible for the evolution and diversification of mistletoes in Madagascar (Génin and Rambeloarivony 2018). Additionally, mouse lemurs are arboreal and can disperse seeds, either stuck to their fur or excreted through feces, high in the canopy where exposure to the sun may be more conducive to germination. Taken as a whole, we contend that Goodman’s mouse lemurs make the best out of their settings: they have discrete but permeable territories, they rely on fallback foods whose growth they facilitate, and they avoid energetic challenges by using torpor when affordable (Andriambeloson et al. 2020; Blanco et al. 2017).

At a minimum, this study highlights behavioral flexibility (sensu Nowack and Lees 2013) of Goodman’s mouse lemur, adding new insights to the growing literature on mouse lemur survival in degraded environments. Although different species may respond differently to disturbance,



mouse lemurs can be regarded as exemplars of ecological opportunism, switching feeding and metabolic strategies depending on seasons or settings (Knoop et al. 2018; Schülke and Ostner 2007).

While metabolic and ecological research on Goodman's mouse lemurs in forest relics like Ankafoabe and across the Central Highlands can most immediately help us predict survivability in fragmented and/or degraded environments, phylogeographic studies can also contribute to understanding past patterns and processes. If Goodman's mouse lemurs are, as seems likely, found in additional tiny forest fragments across the Central Highlands, these subpopulations will preserve traces of historic connectivity in their genomes. And indeed, recent genetic analysis of Goodman's mouse lemurs from Ankafoabe showed unusually large genetic diversity for a small subpopulation presumably living in isolation (Yoder et al. 2016). As one possible explanation, this genetic pattern could be explained by sporadic connectivity through time among mouse lemur subpopulations from different fragments, allowing for punctuated gene flow events. This scenario assumes that fragment connectivity and isolation resulted from climate-induced expansion and contraction of forest and other woody vegetation types, with existing populations serving as "museums" of genetic diversity (Yoder et al. 2016).

We show that Goodman's mouse lemurs at Ankafoabe persist despite spatial confinement, cold, and seasonally arid conditions, which makes them ideal candidates for studying metabolic extremes in primates. Thus, answering the questions "Are Goodman's mouse lemurs occupying other tiny fragments across the Central Highlands? And if so, are they relying on the same resources for survival (e.g., mistletoes)?" becomes imperative for a larger understanding of ecological and metabolic resilience in primates. And at even larger scales, increased understanding of their geographic distribution can offer insight into our understanding of natural landscape transformation across the central plateau of Madagascar prior to human colonization.

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**Author contributions** MBB, ADY designed study; JBA, AA, TVR, MBB collected field data; MBB, JBA, NW analyzed data; JBA, MBB, CB, ADY wrote the paper.

## Declarations

**Conflict of interest** The authors declare no conflict of interest.

**Ethical approval** Our research adhered to the legal requirements of the Government of Madagascar, under Research Permit N°225/15/MEEF/SG/DGF/DAPT/SCBT, reissued by the Ministry of Environment, Ecology and Forests (current MEDD), and our research protocols complied with the Duke Institutional Animal Care and Use Committee (IACUC) under protocol A263-17–12. In addition, prior to beginning research, we informed local state representatives (Ankazobe) of the proposed work and asked them to validate our research permit, and also informed local communities through VOL-Sohisika so as to avoid misunderstandings concerning our work at this site.

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