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# Prioritising Ex Situ Conservation for Malagasy Mammal Species in Line with IUCN's 'One Plan Approach to Conservation'

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**Abstract:** Madagascar, as one of the global biodiversity hotspots, hosts numerous unique terrestrial mammal species that need urgent protection. To identify priority species for conservation, an updated list of terrestrial Malagasy mammal species was compiled, including their threat status, distribution, endemism level, Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listing, and Evolutionarily Distinct and Globally Endangered (EDGE) score. An overview of these species kept in zoos worldwide was created using the Zoological Information Management System and Zootierliste to assess ex situ conservation efforts. Nearly 60% of the 212 native terrestrial mammal species are threatened with extinction, with 18% being regional endemics, 39% microendemics, and 42% endemics. The majority of these species (92%) occur within protected areas. About half of Madagascar's mammals are listed under CITES, and less than half have an EDGE score. Only 34 species are kept in zoos globally, with 26 Red-Listed as threatened. Nine out of seventeen families are not represented in zoos. A total of 1545 institutions, primarily in Europe and North America, keep Malagasy mammal species, with successful reproduction reported for 28 species in the last 12 months, 23 of them listed as threatened on the IUCN Red List. To maximize conservation, we recommend reallocating resources towards priority species and implementing concerted ex situ and in situ actions as proposed by the IUCN's One Plan Approach.

**Keywords:** conservation; ex situ; gap analysis; conservation breeding; protected area coverage; Madagascar



**Citation:** Rose, A.; Tuchtfeldt, M.; Lammers, R.; Rode-White, J.; Markolf, M.; Pagel, T.; Rödder, D.; Ziegler, T. Prioritising Ex Situ Conservation for Malagasy Mammal Species in Line with IUCN's 'One Plan Approach to Conservation'. *Diversity* **2024**, *16*, 456. https://doi.org/10.3390/d16080456

Academic Editor: Li Zhang

Received: 27 June 2024
Revised: 24 July 2024
Accepted: 26 July 2024
Published: 1 August 2024



## 1. Introduction

On a global scale, ongoing anthropogenic influence is currently promoting an extinction rate at least a hundred times higher than estimated during the previous 10 million years [1], with an estimated background extinction rate of 0.1 to 1 extinction per million species per year [2]. Such negative trends are especially concerning for biodiversity hotspots, which are defined by a high level of endemic species while at the same time experiencing a high degree of environmental degradation [3].

To safeguard and conserve endangered species, the International Union for Conservation of Nature's (IUCN) Conservation Planning Specialist Group (CPSG) introduced the One Plan Approach (OPA). This comprehensive conservation strategy combines both ex situ and in situ methods by uniting the knowledge and resources of zoological institutions and wildlife conservationists inside or outside the species' natural ranges to coordinate efforts for more effective conservation. The aim is to manage wild and held populations as one rather than treating them separately in order to ultimately ensure healthy and genetically diverse populations to counteract their risk of extinction [4,5]. This involves the management of breeding programs and incorporating tools such as studbooks, bringing

individuals into human care to ensure a diverse gene pool, as well as the successful reintroduction of individuals into their natural environment when required. Additionally, in situ conservation is achieved by assessing and addressing risks and threats to wild populations and protecting and restoring ecosystems and habitats. One key component of OPA is the consistent sharing of viable information and data between all stakeholders for collaborative decision-making processes and adaptive management [5]. Zoos have played a vital role in the past in conserving endangered species through breeding programs, especially when in situ methods are difficult due to habitat destruction or illegal human activities such as poaching [6]. With the intensifying threats to global biodiversity, zoos could become an even more important instrument as a reserve for species in the future [6,7].

Due to its long geographic isolation from the main African continent [8], Madagascar is known for its unique biodiversity and is described as one of the most important biodiversity hotspots [9,10], with an increase in newly discovered and described species in the last years [11,12]. The country is also one of the few that still has the potential to discover new mammal species [13,14]. A prominent example is the lemur genus *Microcebus*, the smallest primate in the world, with a growing number of newly described species [13,15].

A recent assessment estimated the overall rate of endemism in Malagasy land vertebrates at 84% with a high rate of endemism in mammal species at 95.5% [12]. Of all families described of extant terrestrial mammals in Madagascar, all nonvolant are endemic, namely Cheiroglaeidae, Daubentoniidae, Eupleridae, Indriidae, Lemuridae, Lepilemuridae, Nesomyidae, Soricidae, and Tenrecidae [16]. The most species-rich order is lemurs, a primate order unique to Madagascar [17]. Worldwide, mammals are among the most threatened vertebrate taxa, as 30% of terrestrial mammal species show population declines [18], and 26% of mammal species are threatened with extinction [19]. Madagascar is a region with a predicted high risk of extinction for mammals [20].

The island harbors seven main ecoregions: mangroves along the west coast, subhumid forest and ericoid thickets in the central parts, lowland forest in the eastern parts, dry deciduous forest in the west, succulent woodlands in the southeast, and spiny thickets in the southern region [21]. The highest species richness and levels of endemism can typically be found in the humid forest [11]. Despite growing conservation efforts in the last two decades, the establishment of numerous protected areas, and 10.4% of the island´s area being under protection [22,23], Madagascar´s natural forest decreased by 25% between 2001 and 2021 [24]. As most endemic vertebrates on the island are dependent on forests [22,25], deforestation and forest fragmentation pose another major risk to the survival of Malagasy species [26], including mammals [27]. Furthermore, species face a multitude of other threats, including overexploitation, destructive agriculture techniques, invasive species, and diseases [23], making the island one of the global conservation priorities [9,28–30]. Since undiscovered species in general, and mammals living in the tropics specifically, have an increased risk of extinction [31] and considering the continued threat for already described Malagasy mammal species, holistic conservation plans are needed [23].

In order to support further conservation measures for terrestrial Malagasy mammals, a comprehensive species list was compiled in order to provide input into conservation prioritization with respect to the One Plan Approach and give a guideline, especially for zoological institutions, to ensure the survival of highly threatened species. For this overview, we compiled data on whether animals are held and bred successfully in zoos, their threat and population status, legal protection, coverage by protected areas, and existing prioritization status according to their evolutionary distinctiveness.

## 2. Materials and Methods

### *2.1. Species List and Threat Status*

A list of terrestrial mammals in Madagascar was compiled according to the latest assessment of the IUCN Red List of Threatened Species [19]. The list was supplemented and reviewed according to the chapter 'Introduction to Mammals' in *The New History of*

*Madagascar* by Goodman (2022) [16]. Introduced species were excluded. Subspecies were not considered separately in the analysis.

Information acquisition regarding the threat status and population trends for each species was extracted from the IUCN Red List of Threatened Species. Species classified as Vulnerable (VU), Endangered (EN), and Critically Endangered (CR) were identified as 'threatened'. Population trends in the wild for each species were categorized into increasing population (↑), decreasing population (↓), stable population (-), and unknown (?) [19].

### 2.2. Distribution

A biogeographical map illustrating the various ecological regions of Madagascar was generated using shapefiles from the World Wildlife Fund [32] originating from the study by Olson et al. (2001) [21]. The open-source software QGIS version 3.22.8 LTR [33] was employed to determine the occurrences of terrestrial mammal species in the seven ecoregions of Madagascar based on distribution data of the species by the IUCN (2023) [19].

For categorizing species into microendemics, regional endemics, (national) endemics, or widespread, we compared IUCN distributions of all species with the center of endemism proposed by Wilmé et al. (2006) [34] (Figure 1). Microendemics were defined as species that overlap only with one center of endemism or which have an area of occurrence smaller than 1000 $km^2$. Regional endemics were defined as species that overlap with two centers of endemism. Endemics are restricted to Madagascar but overlap with three or more centers of endemism. Widespread species also occur outside of Madagascar.

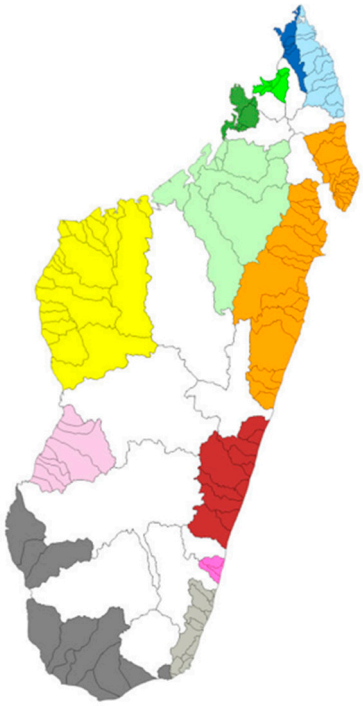

**Figure 1.** Centers of endemism in color. Regions without centers of endemism in white. Based on Wilmé et al. (2006) [34].

The information on distribution areas for the terrestrial Malagasy mammal species relies on data provided by the IUCN (2023) [19]. The shapefiles of the distribution for each terrestrial Malagasy mammal species were specified using ArcGIS Pro 3.0.0 [35] and the geographical data of the centers of endemism by Wilmé et al. (2006) [34].

### 2.3. ZIMS and "Zootierliste"

To assess Malagasy mammal species in zoological institutions, information was obtained from the Zoological Information Management System (ZIMS) database maintained

by Species360 [36]. The analysis of ZIMS encompassed the overall count of institutions per region, including the total number of males, females, and individuals of unspecified sex kept within each institution. Furthermore, the reproductive success of each species within the past 12 months, along with the corresponding number of participating institutions, was determined. Lastly, possible conservation breeding programs such as the European Studbook (ESB), the EAZA Ex situ Programme (EEP) of the European Association of Zoo and Aquaria, and the Species Survival Plan (SSP) of the Association of Zoos and Aquariums in North America were documented. To evaluate conservation gaps, the number of species kept in the past and present were identified. As a zoo is not obligated to participate in ZIMS, a 100% complete data collection is not available. To further complete the data set on terrestrial Malagasy mammals, information on former and present keeping was gathered from the website 'Zootierliste' (List of Zoo Animals, ZTL). ZTL provides data about vertebrate species in European zoos and other public and private animal institutions covering recent and past keepings. This information system is managed by zoos and private citizens and does not contain information about the number of individuals of each species and breeding successes [37]. The analysis of the ZIMS database was conducted on 16 February 2024 and of the ZTL platform on 17 February 2024.

### *2.4. CITES*

CITES is a United Nations convention to control legal wildlife trade better and to protect endangered species from extinction. The main source for compliance is the CITES appendices. Included species have been evaluated to determine whether international trade would pose a threat to their survival. The appendices include more than 40,000 species with different protection levels. Under Appendix I, species are listed which are prohibited from being traded internationally. Appendix II covers the trade of species that could become endangered unless controlled. Therefore, permits are needed for each step in the trade, ranging from export to import and transport. Finally, Appendix III records species that are protected in at least one member nation [38]. The CITES appendices were scanned on 18 February 2024 in order to determine the listings for each terrestrial Malagasy mammal species.

### *2.5. EDGE Score*

EDGE species are animal species that are considered exceptional, distinct, and frequently neglected in conservation programs. The EDGE of Existence program recognizes species with an exclusive evolutionary pathway and a high risk of extinction and was established by the Zoological Society of London. Based on a phylogenetic analysis representing the Evolutionary Distinctiveness and the IUCN Red List Categories of the threat status, the EDGE score is calculated for each species. A high EDGE score indicates that the species has a limited number of closely related species and is threatened with extinction, therefore needing immediate conservation action. The program aims to conserve unique species and safeguard the world´s biodiversity by raising awareness, supporting conservation efforts, and providing educational knowledge [39]. The investigation of the EDGE score for eligible terrestrial Malagasy mammals was performed on 6 February 2024.

### *2.6. Prioritization*

To determine which species needs special attention in conservation measures a prioritization list was compiled. We first prioritized all terrestrial Malagasy mammal species that are not kept in zoos. The second prioritization criterion was the level of endemism with higher importance for species that are microendemic, followed by regional endemic and endemic. The least prioritized were widespread species i.e., occur outside of Madagascar. Thirdly, the IUCN Red List status was considered with higher prioritization as the threat level increased. Furthermore, the EDGE score was used from highest to lowest as the last criterion for the evaluation.

These prioritization criteria were chosen because they are globally accepted and approved by internationally recognized conservation authorities or organizations (such

as the IUCN). Furthermore, they are widely accessible to the conservation community. Weighting was considered, but we have decided against it due to the different scorings (e.g., numerical score vs. a small number of categories). A disadvantage of an index created by weighting is that details are lost that may be crucial for decisions. In conservation, decisions need to be taken on a participatory level, hence the weighting should happen on a strategic level, not a scientific level.

### *2.7. Protected Area and Key Biodiversity Area Coverage*

Based on our species list, we used the rredlist package for R [40] to extract detailed information on preferred habitats from the IUCN Red List, matching the identical classes of a habitat availability map with a spatial resolution of 100 m [41]. Preferred habitats of each species were intersected with general range estimates provided by the IUCN Red List, and the resulting presence–absence maps were further intersected with the protected area network obtained from www.protectedplanet.net (accessed on 20 July 2022) and key biodiversity areas (KBAs) [42]. KBAs are critically important sites for the global persistence of biodiversity, identified based on their significance for the conservation of species and ecosystems [43]. Species richness maps accounting for habitat availability were computed by stacking the single presence–absence maps. Following Crisp et al. (2001) [44], regions of high local endemism were identified using the corrected weighted endemism approach, which balances local species richness and the proportion of species occupying small geographic ranges.

## 3. Results

### *3.1. Species List and Threat Status*

Of the 212 native terrestrial Malagasy mammal species that were reported, a total of 127 were evaluated as threatened according to the IUCN: 39 Vulnerable, 55 Endangered, and 33 Critically Endangered. The number of non-threatened species was 72, including 70 Least Concern and 2 Near Threatened species. Approximately 6% (N = 13) of terrestrial mammals of Madagascar were Data Deficient [19] (Figure 2). The evaluation of the population status of terrestrial Malagasy mammals revealed that 142 species had declining populations, 8 species had stable populations, and only 1 species showed an increasing population trend. For the remaining 61 species, the population status was 'Unknown' [19].

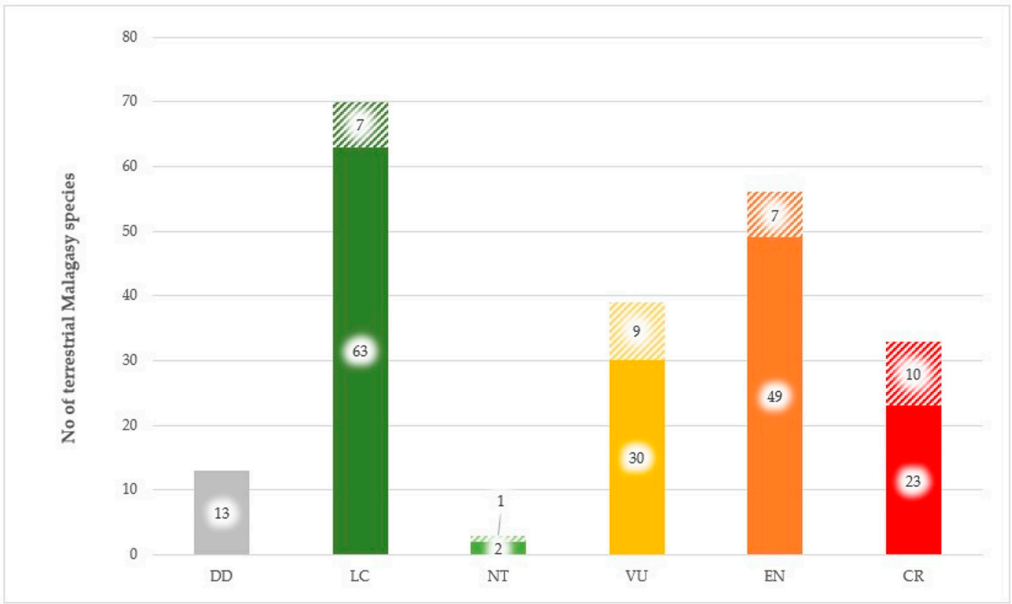


**Figure 2.** IUCN Red List status of terrestrial Malagasy mammals [19]. Species kept in zoos in stripes. DD = Data Deficient, LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered.

### 3.2. Distribution

The occurrences of terrestrial mammals in the seven biogeographical regions of Madagascar differed. Most of the species inhabited the subhumid forest (N = 149), followed by lowland forest (N = 134), dry deciduous forest (N = 112), ericoid thickets (N = 65), spiny thickets (N = 61), and succulent woodland (N = 50). The least number of terrestrial Malagasy mammal species were present in the mangroves along the west coast (N = 46) (Figure 3). With 78% (N = 165), the majority of the 212 species occurred in more than one, and only 5% (N = 12) lived in all seven biogeographical regions of Madagascar.

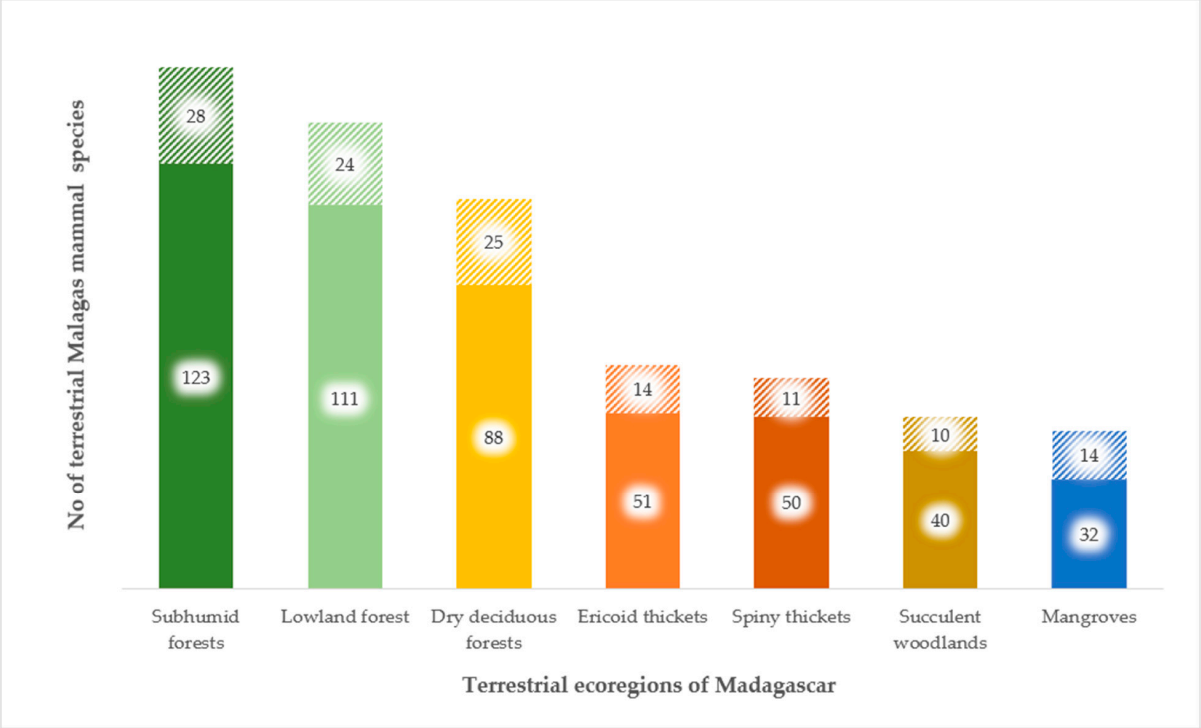


**Figure 3.** Occurrences of terrestrial Malagasy mammal species in different biogeographical regions of Madagascar. Species kept in zoos in stripes. Species may occur in more than one region.

The biogeographic analysis considering the level of endemism showed that only 4 of the 212 terrestrial Malagasy mammal species were also distributed outside of Madagascar and, therefore, evaluated as 'widespread'. All four were bat species, one species each of the family Hipposideridae and Molossidae, and two species of the family Miniopteridae. Most of the terrestrial mammal species of Madagascar occurred in more than two centers of endemism and are, therefore, endemic with 42% (N = 88). Microendemics with 39% (N = 82) inhabited only one center of endemism or had an area of occurrence under 1000 km$^2$, followed by regional endemic species with 18% (N = 38) living in two centers of endemism.

### 3.3. ZIMS and "Zootierliste"

All species that were listed in ZIMS except for two were also documented in ZTL. For 84 species, no records in either database were found. In total, 16% (N = 34) of the 212 terrestrial Malagasy mammal species from 8 different families are presently kept in zoos worldwide (Figures 4 and 5). Of the 127 threatened terrestrial mammal species of Madagascar, 20% (N = 26) and 9% (N = 8) of the 85 non-threatened species were held in zoos. According to IUCN, 28 of the 34 terrestrial Malagasy mammal species in captivity had a declining in situ population trend, while 3 species had a stable population in the wild. For the remaining three species kept in zoos, the population trend was assessed as unknown.

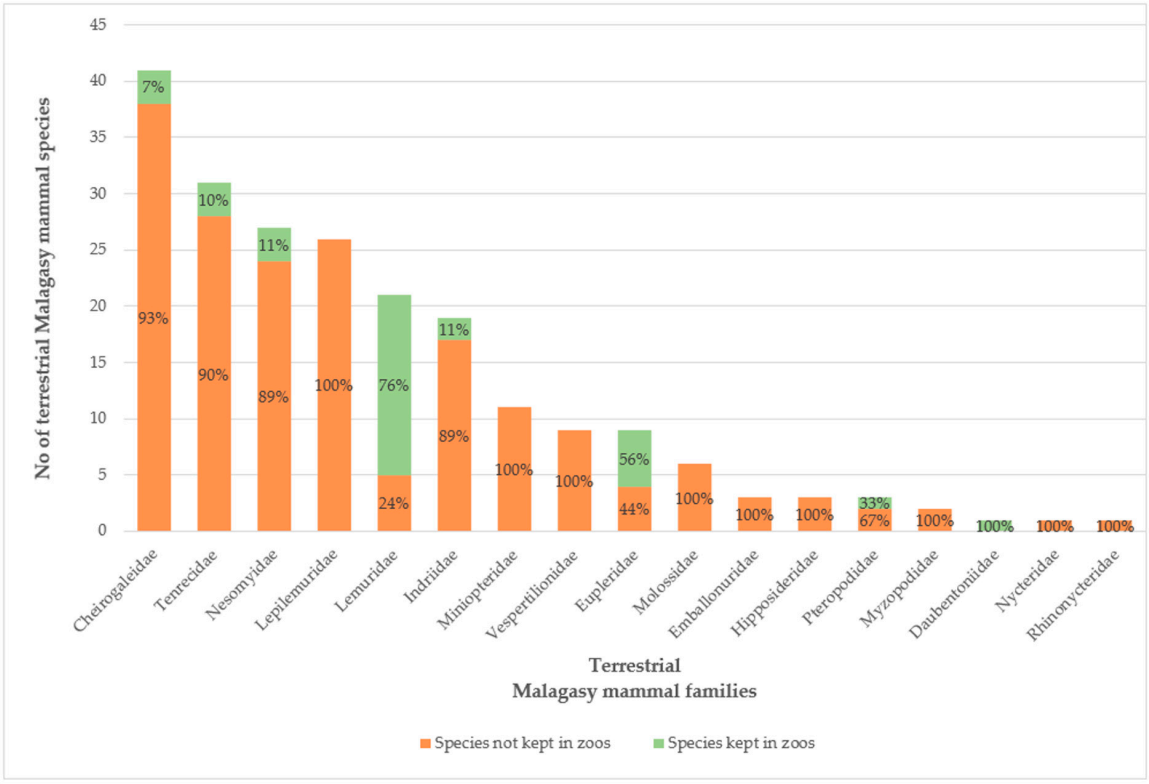


**Figure 4.** Percentage of terrestrial Malagasy species per family kept and not kept in zoos. Orange = percent of species per family not kept in zoos, Green = percent of species per family kept in zoos.

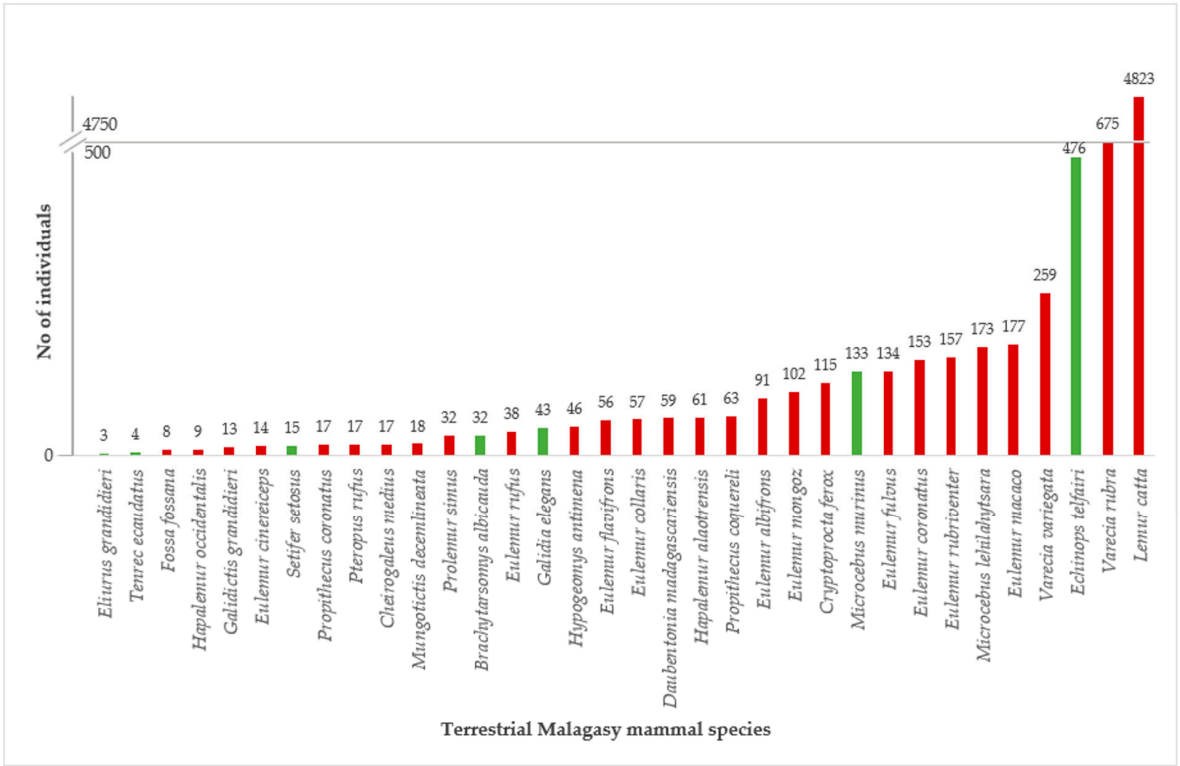


**Figure 5.** Population numbers of Malagasy mammal species registered in ZIMS (2024) [36] in zoological institutions worldwide. Red = threatened, Green = not threatened. Broken Y-axis between 500 and 4750 individuals.

The most represented family in zoos was Lemuridae, of which 76% (N = 16) of all 21 species were kept in zoos. This family also comprises the threatened species *Lemur catta*, which had the highest number of individuals (N = 4823), followed by *Varecia rubra* (N = 675) and *V. variegata* (N = 259). The family Eupleridae was the second most representative in zoos, with 56% (N = 5). The family Cheirogaleidae was the most diverse, including 40 species, of which only 8% (N = 3) were in zoos, followed by the family Tenrecidae, with 31 species, of which 10% (N = 3) were kept in zoos. The Tenrec *Echinops telfairi* was the non-threatened species with the largest ex situ population, with 476 individuals. The families Nesomyidae and Indriidae each had 11% of species per family (N = 3 and N = 2, respectively) in ex situ populations. The Critically Endangered Aye-aye (*Daubentonia madagascariensis*), which is the only species of the family Daubentoniidae, was represented by 56 individuals in zoos (Figures 4 and 5).

Wild lemurs' minimal viable population size is approximately 40 adult individuals [45]. Of 34 terrestrial Malagasy mammal species that were held, 13 species had less than 40 individuals distributed globally in zoos, including *Fossa fossana* (N = 8) and *Hapalemur occidentalis* (N = 9) with the least number of individuals. In total, 1545 institutions reported the keeping of terrestrial Malagasy mammal species, with the possibility of multiple counts, as not every zoo exclusively kept a single species. With 1335 of the 1545, the majority of the institutions held threatened species. With 953 institutions, Europe had the most institutions that held terrestrial Malagasy mammal species, followed by North America with 420, Asia with 111, Australia with 23, Africa with 18, and South America with 9 zoological institutions. A similar trend emerged with the number of species held on each continent, as Europe held all 34 terrestrial Malagasy mammal species that are kept worldwide in zoos, followed again by North America with 22, Asia with 13, Africa with 9, and South America with 3 species. The only terrestrial mammal species of Madagascar kept in zoos on the Australian continent was *Lemur catta*.

According to ZIMS and ZTL, the families Lepilemuridae, Miniopteridae, Vespertilioinidae, Molossidae, Emballonuridae, Hipposideridae, Myzopodidae, Nyteridae, and Rhinonycteridae were not represented in zoos (Figure 4). The analysis showed that another 26 terrestrial Malagasy mammal species were held in zoological institutions in the past, among them the Critically Endangered species *Hapalemur aureus*, *Indri indri*, *Lepi-lemur ruficaudatus*, *Propithecus diadema*, *Propithecus tattersalli*, and *Propithecus verreauxi*.

Based on the ZIMS database, 28 of the 34 terrestrial Malagasy mammal species in zoos reproduced successfully in the last 12 months. Of the 28 species with successful reproduction in zoos, 23 were threatened, including the 5 microendemic species *Hapalemur alaotrensis* with 6, *Eulemur flavifrons* with 7, *Hypogeomys antimena* with 8, *Propithecus coronatus* with 3, and *Propithecus coquereli* with 12 offspring in the last 12 months. In total, 233 breeding institutions were documented in ZIMS with several possible listings, as zoos might breed more than one species. The percentage of the 34 terrestrial mammal species of Madagascar kept in zoos that participated in breeding programs was 62% (N = 21), of which 6 species were included in the EEP, 5 in the SSP, and 10 species in both breeding programs. Furthermore, two species were recorded in the ESB.

The sex ratio of the 34 terrestrial Malagasy mammal species held in zoos was relatively proportional, with 45% females and 55% males (±12.55%). In general, the number of single-sex male individuals (N = 1039) kept in zoos was higher than those of females (N = 383).

Of all terrestrial Malagasy mammal species kept in zoos, 18% (N = 6) (Figure 6) were microendemics, which was only 8% of all microendemic mammal species of Madagascar. Furthermore, 23% (N = 9) of regional endemic terrestrial Malagasy mammals and 20% (N = 19) of the total amount of endemic mammal species of Madagascar were represented in zoos.

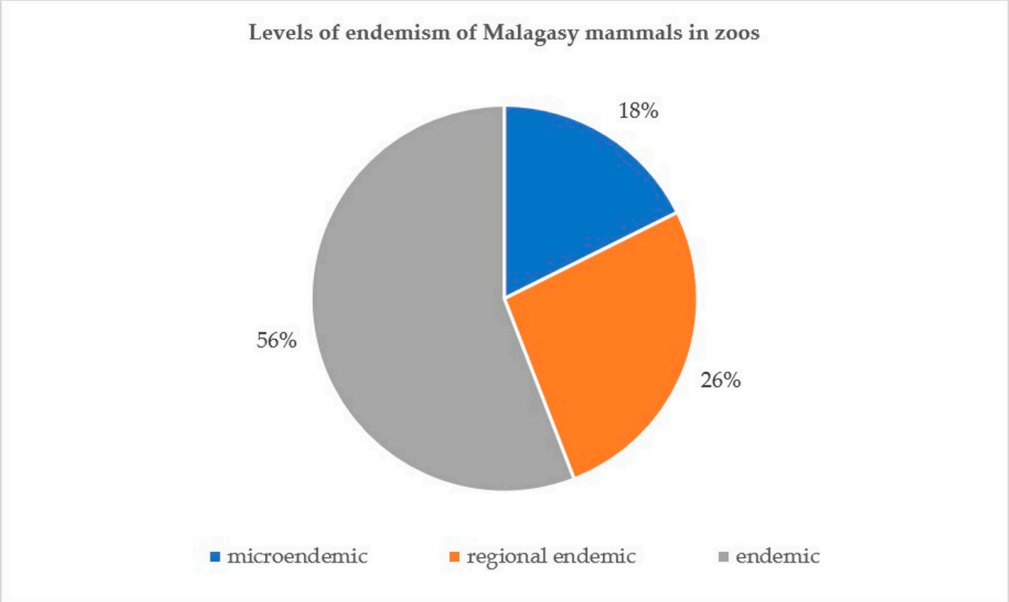


**Figure 6.** Distribution of endemism levels of terrestrial Malagasy mammals in zoos.

### *3.4. CITES*

According to CITES, 53% (N = 106) of the terrestrial Malagasy mammal species are listed under Appendix I, and 22 of the 106 species were held in zoos. Another 2% (N = 4) of Madagascar´s terrestrial mammal species are documented under Appendix II, of which 3 were kept in zoos. With 48% (102), nearly half of terrestrial Malagasy mammal species are not listed under CITES; however, 9 of the 102 species were held in zoological facilities. Additionally, 101 of the 106 terrestrial mammal species of Madagascar that were listed under Appendix I were also listed as threatened by the IUCN. Of the 102 terrestrial Malagasy mammal species that were not listed under CITES, 22 were threatened species, according to IUCN.

### *3.5. EDGE of Existence Programme*

Based on the EDGE of Existence Programme, 84 (40%) of the 212 terrestrial Malagasy mammal species had an EDGE score. *Daubentonia madagascariensis* had the highest EDGE score of 20.13 and was ranked in the second place of all mammal species worldwide on the EDGE list. Three other terrestrial mammal species of Madagascar had an EDGE score over ten, namely *Varecia rubra* (11.31), *Varecia variegata* (11.29), and *Indri indri* (10.44). *Eulemur rufus* had the lowest EDGE score of Malagasy mammals, with 3.55. Of the 84 terrestrial Malagasy mammal species ranked on the EDGE list, 23 were kept in zoos.

### *3.6. Prioritization*

The results presented in Table 1 show the top 10 of all 212 terrestrial Malagasy mammal species that need priority conservation attention. All ten species are microendemic, Critically Endangered according to the IUCN, and have an EDGE score of $\leq$4.45. With six species, the family Indriidae has the highest number of species in the prioritization list, followed by Cheirogaleidae with two species. The families Lepilemuridae and Lemuridae each have one species included in the list. All families in the top ten priority list belong to the lemur order (Table 1). A comprehensive overview of prioritization within each Malagasy mammal family is provided in Appendix B.

**Table 1.** Top ten priority species of terrestrial Malagasy mammals.

| Species | Family | Endemism Level | IUCN Status | EDGE Score |
|---|---|---|---|---|
| *Hapalemur aureus* | Lemuridae | microendemic | CR | 5.41 |
| *Propithecus tattersalli* | Indriidae | microendemic | CR | 5.31 |
| *Propithecus candidus* | Indriidae | microendemic | CR | 5.25 |
| *Propithecus perrieri* | Indriidae | microendemic | CR | 5.21 |
| *Microcebus gerpi* | Cheirogaleidae | microendemic | CR | 5.14 |
| *Lepilemur septentrionalis* | Lepilemuridae | microendemic | CR | 4.96 |
| *Avahi cleesei* | Indriidae | microendemic | CR | 4.63 |
| *Avahi unicolor* | Indriidae | microendemic | CR | 4.63 |
| *Propithecus deckenii* | Indriidae | microendemic | CR | 4.50 |
| *Microcebus berthae* | Cheirogaleidae | microendemic | CR | 4.45 |

### *3.7. Protected Area and Key Biodiversity Area Coverage*

Both species richness of Malagasy mammal species and species richness of threatened Malagasy mammal species are high in PAs. High values in endemism occur both outside and inside PAs. The numbers of species and numbers of threatened Malagasy mammal species differ between the PAs in Madagascar and are highest in the east of the country with its subhumid and lowland forests.

Of the 212 terrestrial Malagasy mammal species, 8% (N = 17) are not covered by PAs, of which 13 species are threatened with extinction. Furthermore, *Propithecus perrieri* and *Lepilemur septentrionalis* are listed in the top ten priority list (Table 1) and show no coverage by PAs. Most of the terrestrial Malagasy mammals´ habitats, with 96% (N = 203), are located within key biodiversity areas. The results show regions in Madagascar with a high number of mammal species occurring in KBAs that are not included in protected areas (Figure 7).

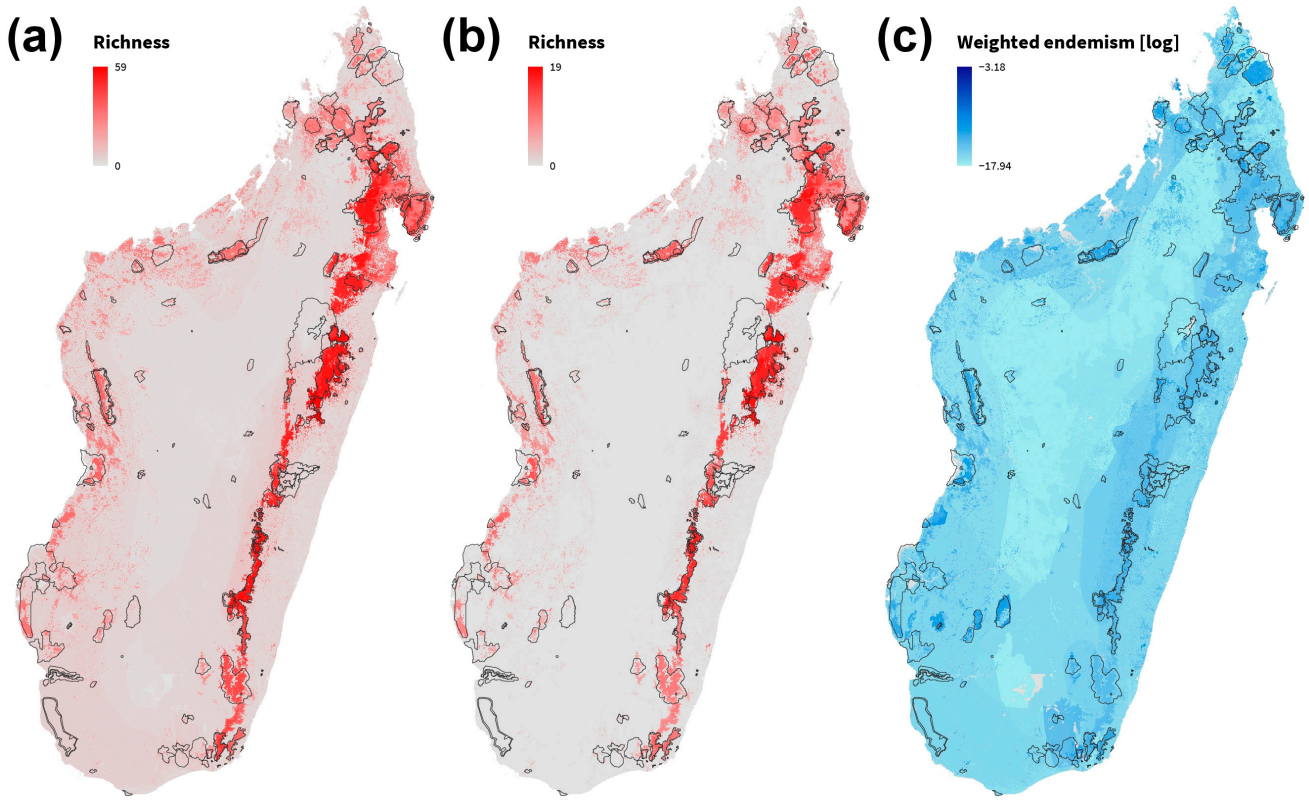


**Figure 7.** *Cont.*

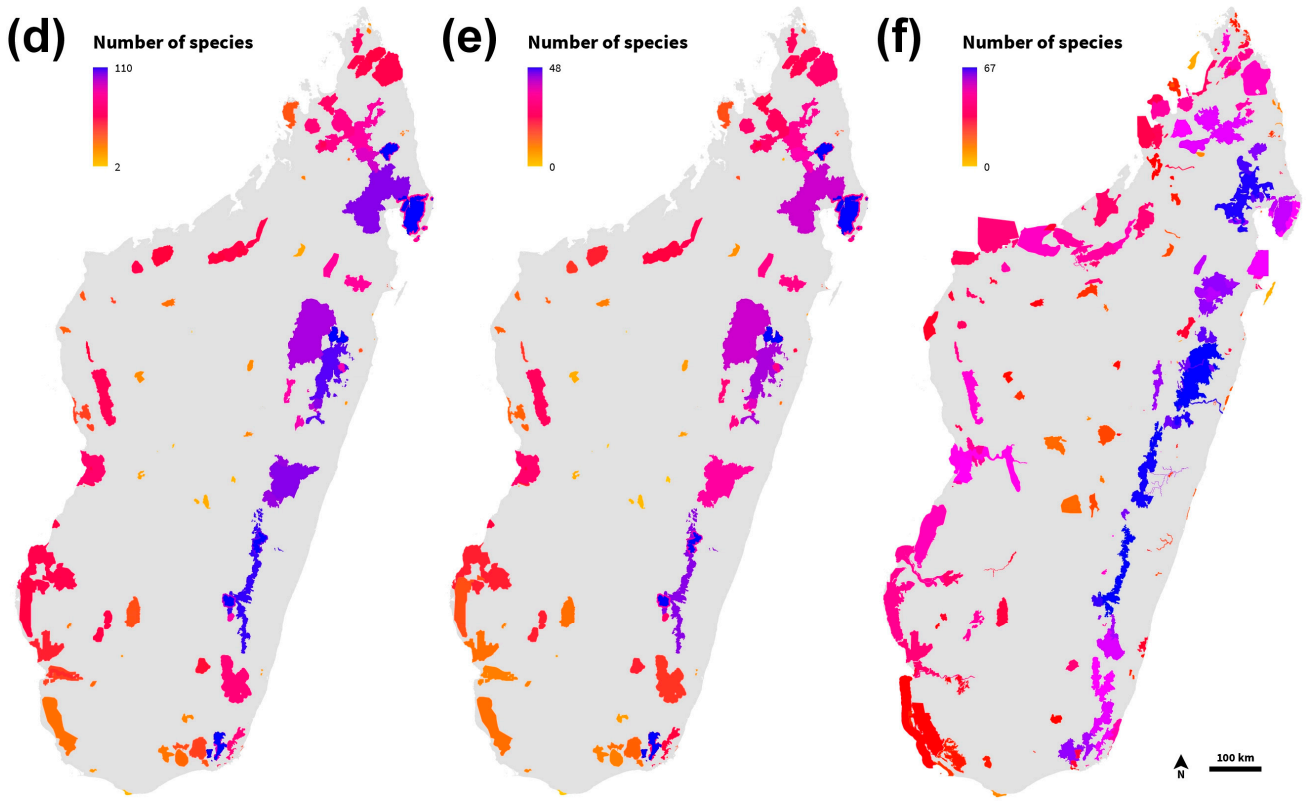


**Figure 7.** Spatial patterns of species richness, endemism, protected area coverage, and key biodiversity area coverage of terrestrial mammal species in Madagascar. (**a**) Richness of all species, (**b**) richness of threatened species, (**c**) weighted endemism, (**d**) number of species per PA, (**e**) number of threatened species per PA, (**f**) number of species per KBA. Darker colors indicate higher values. PAs are outlined in black.

## 4. Discussion

In total, 98% of the 212 terrestrial mammal species in Madagascar are endemic and, therefore, occur nowhere else in the world, making Madagascar one of the most important mammalian diversity hotspots in the world [46]. Our findings reveal that among the 208 endemic species, 38 are regional endemics, while 82 are microendemics. Since there are various categories of endemism and no universally recognized method to measure endemism levels [47], the number of microendemics and regional endemics among terrestrial Malagasy mammal species may be even higher, depending on the concept applied. The discovery of many cryptic *Microcebus* species over the past decades [13], along with recent molecular studies of the bat genera *Hipposideros* [48] and *Miniopterus* [49], further suggest an increasing number of terrestrial Malagasy mammal species. Given the heightened risk of extinction for undiscovered mammal species [31], the continuous deforestation in Madagascar [23], and the vast area of endemism centers throughout the country [34], on-site conservation should be one of the substantial pillars of conserving terrestrial mammal species in Madagascar. Since a high number of terrestrial Malagasy mammal species was documented for subhumid forests (N = 149), lowland forests (N = 134), and dry deciduous forests (N = 113), in situ mammal conservation should be emphasized in these ecoregions. Mangroves are the ecoregion with the least amount of terrestrial Malagasy mammal species, which could be due to the ecoregion´s small overall area.

Only 53% of the terrestrial Malagasy mammal species are listed under CITES Appendix I and are, therefore, banned from international commercial trading. Overexploitation and illegal wildlife trade are two of the biggest threats to biodiversity [23]. More significant than international trade, despite nationwide prohibition, is bushmeat hunting. This practice is widely used across the country, especially in rural and poor regions, to ensure food

security [50]. Bushmeat hunting and related national trade remain a major concern for Malagasy mammals, particularly for lemur species [51].

Our research showed that 60% (N = 127) of terrestrial Malagasy mammal species are threatened with extinction. For the 13 species that are classified by the IUCN as Data Deficient, further research is required in order to assign another Red List category since 64% of Data Deficient terrestrial mammal species are predicted to have a risk of extinction [52]. Despite the growing number of Madagascar´s national parks and reserves, habitat destruction persists outside and inside protected areas [53]. Furthermore, the ongoing deforestation in Madagascar poses a threat of inbreeding due to habitat fragmentation, especially in humid forests [23]. Consequently, the survival of terrestrial mammal species of Madagascar cannot only rely on in situ conservation. Ex situ efforts in zoological institutions have to be increased for the conservation of threatened Malagasy mammal species and the effective implementation of the One Plan Approach, viz. to save species from extinction and to buy time, when conservation measures on site cannot be conducted in time.

This analysis does not consider terrestrial Malagasy mammal species that are held in private ownership or other institutions such as universities or museums. Additionally, data entries in the ZIMS or ZTL database may change on a regular basis, and zoological institutions are not obligated to transmit or update their information. However, based on our sources, only 16% of terrestrial mammal species of Madagascar are in ex situ populations, of which 74% are threatened under IUCN. Over half of the terrestrial Malagasy mammal species in zoos are lemur species (Appendix A). Possible reasons for this overrepresentation could be their popularity among visitors [54], given that some lemur species are present in numerous zoos worldwide (e.g., *Lemur catta*, *Varecia rubra*, *Varecia variegata*). These species are mainly diurnal and have noticeable color patterns and a relatively large body size, making it easy for visitors to see them [54]. Here, zoo facilities could be better used in the sense of the One Plan Approach, viz. acting as a modern ark. Species that are nocturnal and small could be emphasized for the public through special display and awareness of their uniqueness, e.g., the Aye-aye with its characteristic appearance that is the only representative of the family Daubentoniidae.

Out of the nine families of terrestrial Malagasy mammal species that are not represented in zoos, eight belong to chiropteran families, including Myzopodidae, which is the only bat family endemic to the island [55]. Furthermore, the endemic lemur family Lepilemuridae has no representation in zoological facilities but encompasses 25 species that are all threatened with extinction [19]. Two of the species were kept in the past (*L. ruficaudatus*, *L. mustelinus*); however, no kept individual has been reported for the last 30 years (Figure 4, Appendix A Table A1).

Given the biodiversity crises and the limited time, budget, and resources for conserving threatened species, the discussion on prioritizing species to ensure their survival is not new [56]. The EDGE of Existence program ranks species according to their evolutionary distinctiveness and threat status [39]. We found that 60% of terrestrial Malagasy mammal species had no allocated EDGE Score; furthermore, 43 species are threatened with extinction (Appendix B). Due to the overall high endemism level in mammalian species of Madagascar [12], we distinguished between three endemism levels to further prioritize species. Since microendemics only occur in restricted areas, their risk of extinction is highest, particularly for those already assigned a threatened status. Thus, zoological institutions, especially those with limited financial or spacious capacity, should focus on keeping and breeding priority species as our list proposes.

According to our prioritization list, special conservation attention should be focused on terrestrial Malagasy mammal species that are not kept in zoos, are microendemic, have a high risk of extinction, and have a high EDGE score. The top ten priority species can be found in Table 1. Furthermore, species within each Malagasy mammal family were also prioritized. One of the families with the highest overall priority score is Indriidae. Given their slow reproduction rate, particularly in comparison with other lemurs and primates [57] and, therefore, their higher risk of extinction [58], establishing ex situ populations could

buy time for threatened wild populations [6]. Another family with a high prioritization is Cheirogaleidae, primarily species of the genus *Microcebus* with restricted geographic ranges [59]. A focus should also be drawn to the lemur family Lepilemuridae as 88% of its species are microendemic, all species are threatened according to the IUCN, and none are currently kept in zoos. The main limitation of the prioritization list was the missing data on the EDGE score of more than half of the terrestrial Malagasy mammal species (Appendix B Table A2).

Of the 34 terrestrial Malagasy mammal species held in zoos, 13 species include less than 40 individuals (Appendix A Table A1). As the minimal viable population size for lemurs in the wild is considered to be around 40 adult individuals [45], it is vital to increase the number of individuals of these species in ex situ populations, especially for threatened and microendemic species with a declining population such as *Propithecus coronatus*.

To ensure the suitability and effectiveness of the establishment of ex situ populations, a considered management plan is necessary, as proposed in the IUCN guidelines on ex situ management for conservation. This tool supports the decision-making process on crucial steps such as the evaluation of risks, the acquisition of resources, and the attributes of the ex situ population. Well-managed ex situ populations can ultimately help to prevent the extinction of wild populations and secure their long-term survival [60].

For a more prioritized keeping and breeding program to take place, zoos should consider reducing the number of individuals of non-threatened terrestrial Malagasy mammal species with a high number of individuals held, such as *Echinops telfairi* with 476 specimens or even the threatened species *Lemur catta* with currently 4823 specimens worldwide (Appendix A Table A1). This way, zoos could reallocate their resources towards ensuring 'insurance populations' [6] for highly threatened and prioritized terrestrial mammal species of Madagascar that have small or no ex situ populations.

The majority of terrestrial Malagasy mammal species in zoos (62%) are in breeding programs. The reproductive success in the last 12 months of these species was 100%. On the contrary, all terrestrial mammal species of Madagascar in zoos that did not have successful reproductions in the last 12 months are simultaneously not registered in breeding initiatives, according to ZIMS (Appendix A Table A1). This highlights the importance of the maintenance of studbooks, the exchange of individuals, and the research and monitoring of reproductive individuals. Currently, the main focus on kept terrestrial Malagasy mammals lies in Europe and North America, with only a few zoological institutions keeping species in Africa and Oceania. For more diverse breeding programs and for establishing secure ex situ populations, an overall expansion of conservation breeding networks is needed.

Zoos also play a crucial role in filling the data gap for terrestrial Malagasy mammal species that lack life history information to allow for better keeping and breeding success. One prominent example is the review of the crowned sifaka (*Propithecus coronatus*) that draws from 25 years of captive management experience in an EEP [61]. In North America, the Duke Lemur Center provides life history data of 19 lemur species throughout its 50 years of existence, being involved in multiple SSPs while also supporting in situ conservation in Madagascar [62].

For many species, it makes sense to have a broader distribution of ex situ populations worldwide. That helps to minimize the risk of losing animals through diseases kept only at one institution. One example is *Propithecus coquereli*. This species was mainly managed at the Duke Lemur Center and other zoos in the US. Recently, we have established a population in Europe. Zoos in Berlin, Chester, and Cologne participate in the European Studbook, which is run by Tierpark Berlin. For this and many other species, we need to expand our ex situ management to be more effective. Additionally, more holders lead to more experience in the captivity of the managed species, which again improves the ex situ efforts.

Despite the growing number of protected areas in Madagascar [23], not all terrestrial Malagasy mammal species can be effectively protected within these areas. Global analysis shows that an average of 14% of threatened mammals and their habitat are not covered by

PAs [63,64]. Our results reveal that only 8% of terrestrial Malagasy mammal species are not found in PAs, yet most of these species are threatened with extinction. Especially terrestrial mammal species in Madagascar that do not benefit from PA coverage can be supported by ex situ populations.

The majority of terrestrial Malagasy mammal species (96%) occur within key biodiversity areas. However, we also found regions, e.g., along the west coast (Figure 7), that are KBAs with a high number of mammal species but without protected area coverage. For the further expansion of Madagascar's protected area network, these sites should be prioritized.

It must be acknowledged that range estimates and preferred habitat assessments currently listed by IUCN are based on expert opinion and, hence, represent current knowledge. Both may be refined and updated as soon as new information becomes available. This may introduce some uncertainty in our analyses as especially rare and poorly understood species may either occupy habitat types currently not listed by IUCN or occur beyond their currently assumed extent of occurrence or area of occupancy as indicated by the IUCN range polygons.

Several conservation and breeding centers are located in Madagascar such as the Parc Botanique et Zoologique de Tsimbazaza in Antananarivo or the Ivoloina Parc Zoologique in Toamasina [65]. To ensure the survival of terrestrial Malagasy mammal species and to promote healthy and genetically diverse populations as the OPA advocates [4], it is vital to support existing ex situ conversation programs in Madagascar. These facilities can furthermore contribute to educational and research purposes and facilitate the reintroduction of terrestrial Malagasy mammal species born in human care [65].

The prioritization list does not consider species that have a low prioritization but are easily kept and bred with minimal effort and resources or show similarities with species that have been held successfully. The tenrec species *Geogale aurita* presents potential for keeping due to its comparable life history traits with *Echinops telfairi*, a species widely held in zoological collections globally. Both tenrec species are nocturnal, inhabit dry deciduous forests, and are insectivores [57].

Given the persistent threat of habitat loss and hunting [23], low-priority species could become endangered in the near future. From a global view, prominent examples of the past are the passenger pigeon (*Ectopistes migratorius*), which went extinct within a few decades despite high abundances [66], and the long-tailed macaque (*Macaca fascicularis*), whose IUCN threat status increased from Least Concern to Endangered in less than 15 years [67]. These cases illustrate that the persistent monitoring of now low-priority species is needed to ensure fast conservation actions.

In order to conserve the unique terrestrial mammal diversity of Madagascar, improving and expanding in situ measures as well as effective ex situ conservation planning are required. Through this study, we aim to provide a guideline for zoos to prioritize ex situ conservation for threatened terrestrial Malagasy mammal species.

## 5. Recommendations

Based on our findings, we recommend prioritizing threatened Malagasy mammal species for collaborative conservation breeding programs according to the provided list. The prioritization process should involve the following considerations.

1. Include overlooked threatened taxa into breeding programs, such as small-bodied and nocturnal species, e.g., Nesomyidae, *Cheirogaleus* spp., *Lepilemur* spp. This is easiest for threatened species where historic expertise exists (e.g., *Mirza coquereli*, *Phaner furcifer*) or where similar, often closely related, less threatened species are kept in zoos but could be exchanged with their threatened counterparts (e.g., *Echinops telfairi* with threatened members of Tenrecidae).

2. Aim to increase the number of individuals for threatened species that are prioritized for breeding but currently kept in very small populations. Examples are *Prolemur simus*, *Eulemur mongoz*, and many other lemur species.
3. Reduce the number of non-threatened species or the number of individuals of commonly kept threatened species. Examples of the latter are *Lemur catta* and *Varecia rubra*.

In order to achieve this successfully, conservation breeding networks should be expanded to different locations, including in-country conservation breeding programs. Following the One Plan Approach, breeding programs should connect and cooperate with existing on-site conservation programs in Madagascar. Finally, zoological institutions should highlight species of conservation value that are inconspicuous because of their appearance or lifestyle and, thus, easily overlooked by story-telling to raise conservation awareness for visitors.

## 6. Conclusions

The findings of our study highlight the critical need for integrating in situ and ex situ conservation initiatives for terrestrial Malagasy mammal species following the One Plan Approach. While protected areas play a crucial role in safeguarding habitats, complementary efforts within zoological institutions are vital for the survival of threatened terrestrial mammal species of Madagascar. Our study proposes a prioritization framework to guide ex situ conservation efforts, emphasizing the importance of focusing resources on species most at risk of extinction. Successful ex situ measures require strategic management of populations in human hands, including the reallocation of resources from abundant or non-threatened terrestrial Malagasy mammal species to those of a higher prioritization, such as highly threatened microendemic species. Moreover, collaborative breeding programs and data sharing among institutions are essential for maximizing reproductive success and genetic diversity to ensure the long-term survival of Madagascar's terrestrial mammal species.

**Author Contributions:** Conceptualization, D.R. and T.Z.; methodology, D.R., M.M., J.R.-W. and T.Z.; software, D.R., R.L. and A.R.; formal analysis, D.R. and A.R.; investigation, R.L., M.T. and A.R.; resources, M.M.; writing—original draft preparation, R.L., M.T. and A.R.; writing—review and editing, M.M., D.R., T.P., J.R.-W. and T.Z.; visualization, A.R.; supervision, D.R., J.R.-W. and T.Z.; project administration, D.R. and T.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Data Availability Statement:** The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

**Acknowledgments:** We would like to thank Lucienne Wilmé and Jörg U. Ganzhorn for providing the shapefiles for the centers of endemism.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Appendix A

**Table A1.** Terrestrial Malagasy mammals currently or formerly kept in zoological institutions. Threat status and population trend according to the IUCN Red List of Threatened Species (2023). DD = Data Deficient, LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered. ↓ = decreasing, ↑ = increasing, – = stable, ? = unknown. Tot. Ind. = total number of individuals kept, Tot. M = total number of males kept, Tot. F = total number of females kept, Tot. O = total number of individuals without determined sex, Tot. Inst = total number of zoological institutions keeping individuals, No. of Births = number of births in the past 12 months, Tot. Breeding Inst. = total number of breeding institutions, EEP = European Endangered Species Program, ESB = European Studbook, SSP = Species Survival Plan, ZIMS = Zoological Information Management Software, ZTL = Zootierliste, CITES = Appendices listing.

| Family<br>*Species* | Threat Status | Population Trend | Tot. Ind. | Tot.M | Tot.F | Tot. O | Tot. Inst. | No. of Births | Tot. Breeding Inst. | EEP/ ESB/ SSP | Species Kept | From (year) | Until (year) | ZIMS/ ZTL | EDGE | EDGE Rank | CITES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cheirogaleoidae** | | | | | | | | | | | | | | | | | |
| *Allocebus trichotis* | EN | ↓ | | | | | | | | | past | 1991 | 2002 | ZIMS | 4.31 | 307 | I |
| *Cheirogaleus crossleyi* | VU | ↓ | | | | | | | | | past | 1967 | 1971 | ZIMS | | | I |
| *Cheirogaleus major* | VU | ↓ | | | | | | | | | past | 1978 | 1993 | ZIMS | | | I |
| *Cheirogaleus medius* | VU | ↓ | 17 | 5 | 2 | 10 | 1 | 3 | 1 | | today | 1965 | | ZIMS | | | I |
| *Microcebus lehilahytsara* | NT | ↓ | 173 | 89 | 83 | 1 | 7 | 28 | 2 | EEP | today | 2005 | | ZIMS | 3.75 | 452 | I |
| *Microcebus murinus* | LC | ↓ | 133 | 65 | 65 | 3 | 28 | 21 | 4 | EEP/SSP | today | 1967 | | ZIMS | | | I |
| *Microcebus myoxinus* | VU | ↓ | | | | | | | | | past | 1910 | 1911 | ZIMS | 3.7 | 471 | I |
| *Microcebus rufus* | VU | ↓ | | | | | | | | | past | 1973 | 2005 | ZIMS | 3.79 | 441 | I |
| *Mirza coquereli* | EN | ↓ | | | | | | | | | past | 1986 | 2012 | ZIMS | 5.11 | 101 | I |
| *Mirza zaza* | VU | ↓ | | | | | | | | | past | 1982 | 2012 | ZIMS | | | I |
| *Phaner furcifer* | EN | ↓ | | | | | | | | | past | 1986 | 1996 | ZIMS | 4.01 | 394 | I |
| **Daubentoniidae** | | | | | | | | | | | | | | | | | I |
| *Daubentonia madagascariensis* | EN | ↓ | 59 | 28 | 29 | 2 | 15 | 4 | 4 | EEP/SSP | today | 1862 | | ZIMS | 20.13 | 2 | I |

**Table A1.** *Cont.*

| Family<br>*Species* | Threat Status | Population Trend | Tot. Ind. | Tot.M | Tot.F | Tot. O | Tot. Inst. | No. of Births | Tot. Breeding Inst. | EEP/ ESB/ SSP | Species Kept | From (year) | Until (year) | ZIMS/ ZTL | EDGE | EDGE Rank | CITES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Eupleridae** | | | | | | | | | | | | | | | | | |
| *Cryptoprocta ferox* | VU | ↓ | 115 | 64 | 51 | 0 | 55 | 13 | 4 | EEP/SSP | today | 1954 | | ZIMS | 4.93 | 143 | II |
| *Fossa fossana* | VU | ↓ | 8 | 6 | 2 | 0 | 3 | 2 | 2 | | today | 1966 | | ZIMS | 4.61 | 198 | II |
| *Galidia elegans* | LC | ↓ | 43 | 20 | 20 | 3 | 13 | 8 | 4 | ESB | today | 1966 | | ZIMS | | | |
| *Galidictis fasciata* | VU | ↓ | | | | | | | | | past | 1905 | 1963 | ZTL | 4.2 | 366 | |
| *Galidictis grandidieri* | EN | ↓ | 13 | 8 | 5 | 0 | 4 | 0 | 0 | | today | 2017 | | ZIMS | 4.89 | 149 | |
| *Mungotictis decemlineata* | EN | ↓ | 18 | 7 | 11 | 0 | 9 | 1 | 1 | ESB | today | 1997 | | ZIMS | 4.89 | 151 | |
| *Salanoia concolor* | VU | ↓ | | | | | | | | | past | 1902 | 1913 | ZTL | 4.22 | 364 | |
| **Indriidae** | | | | | | | | | | | | | | | | | |
| *Indri indri* | CR | ↓ | | | | | | | | | past | 1965 | 1965 | ZIMS | 10.44 | 16 | I |
| *Propithecus coquereli* | CR | ↓ | 63 | 29 | 33 | 1 | 15 | 12 | 4 | EEP/SSP | today | 1962 | | ZIMS | 4.52 | 218 | I |
| *Propithecus coronatus* | CR | ↓ | 17 | 12 | 5 | 0 | 6 | 3 | 3 | EEP | today | 1987 | | ZIMS | 4.56 | 208 | I |
| *Propithecus diadema* | CR | ↓ | | | | | | | | | past | 1993 | 2012 | ZIMS | 5.23 | 72 | I |
| *Propithecus tattersalli* | CR | ↓ | | | | | | | | | past | 1987 | 2008 | ZIMS | 5.31 | 58 | I |
| *Propithecus verreauxi* | CR | ↓ | | | | | | | | | past | 1984 | 2002 | ZIMS | 4.50 | 225 | I |
| **Lemuridae** | | | | | | | | | | | | | | | | | |
| *Eulemur albifrons* | VU | ↓ | 91 | 48 | 39 | 4 | 31 | 5 | 2 | SSP | today | 1969 | | ZIMS | 4.23 | 354 | I |
| *Eulemur cinereiceps* | CR | ↓ | 14 | 7 | 7 | 0 | 5 | 0 | 0 | | today | 2002 | | ZIMS | | | I |
| *Eulemur collaris* | EN | ↓ | 57 | 30 | 26 | 1 | 21 | 3 | 3 | SSP | today | 1962 | | ZIMS | 4.23 | 355 | I |
| *Eulemur coronatus* | EN | ↓ | 153 | 82 | 69 | 2 | 50 | 10 | 7 | EEP/SSP | today | 1955 | | ZIMS | 4.42 | 265 | I |
| *Eulemur flavifrons* | CR | ↓ | 56 | 28 | 28 | 0 | 20 | 7 | 4 | EEP/SSP | today | 1985 | | ZIMS | 5.00 | 124 | I |
| *Eulemur fulvus* | VU | ↓ | 134 | 71 | 60 | 3 | 45 | 3 | 3 | SSP | today | 1972 | | ZIMS | | | I |

**Table A1.** *Cont.*

| Family *Species* | Threat Status | Population Trend | Tot. Ind. | Tot.M | Tot.F | Tot. O | Tot. Inst. | No. of Births | Tot. Breeding Inst. | EEP/ ESB/ SSP | Species Kept | From (year) | Until (year) | ZIMS/ ZTL | EDGE | EDGE Rank | CITES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Eulemur macaco* | EN | ↓ | 177 | 89 | 87 | 1 | 67 | 16 | 13 | EEP | today | 1904 | | ZIMS | 3.70 | 469 | I |
| *Eulemur mongoz* | CR | ↓ | 102 | 60 | 39 | 3 | 33 | 12 | 9 | EEP/SSP | today | 1898 | | ZIMS | 5.07 | 110 | I |
| *Eulemur rubriventer* | VU | ↓ | 157 | 85 | 70 | 2 | 53 | 4 | 4 | EEP | today | 1925 | | ZIMS | 3.68 | 478 | I |
| *Eulemur rufus* | VU | ↓ | 62 | 29 | 31 | 2 | 28 | 5 | 3 | SSP | today | 1963 | | ZIMS | 3.55 | 551 | I |
| *Eulemur sanfordi* | EN | ↓ | | | | | | | | | past | 1969 | 2015 | ZIMS | 4.25 | 346 | I |
| *Hapalemur alaotrensis* | CR | ↓ | 61 | 34 | 24 | 3 | 16 | 6 | 3 | EEP | today | 1985 | | ZIMS | 5.38 | 48 | I |
| *Hapalemur aureus* | CR | ↓ | | | | | | | | | past | 1988 | 1995 | ZIMS | 5.41 | 47 | I |
| *Hapalemur griseus* | VU | ↓ | | | | | | | | | past | 1962 | 2022 | ZIMS | 3.99 | 399 | I |
| *Hapalemur occidentalis* | VU | ↓ | 9 | 6 | 3 | 0 | 4 | 1 | 1 | | today | 1991 | | ZIMS | 3.99 | 401 | I |
| *Lemur catta* | EN | ↓ | 4823 | 2415 | 2023 | 385 | 555 | 369 | 113 | EEP/SSP | today | 1961 | | ZIMS | 4.76 | 167 | I |
| *Prolemur simus* | CR | ↓ | 32 | 10 | 20 | 2 | 10 | 3 | 2 | EEP | today | 1987 | | ZIMS | 5.33 | 54 | I |
| *Varecia rubra* | CR | ↓ | 675 | 358 | 307 | 10 | 191 | 32 | 15 | EEP/SSP | today | 1983 | | ZIMS | 11.31 | 13 | I |
| *Varecia variegata* | CR | ↓ | 259 | 133 | 95 | 14 | 82 | 11 | 5 | EEP/SSP | today | 1989 | | ZIMS | 11.29 | 14 | I |
| **Lepilemuridae** | | | | | | | | | | | | | | | | | |
| *Lepilemur mustelinus* | VU | ↓ | | | | | | | | | past | 1969 | 1973 | ZIMS | | | I |
| *Lepilemur ruficaudatus* | CR | ↓ | | | | | | | | | past | 1986 | 1993 | ZIMS | | | I |
| **Nesomyidae** | | | | | | | | | | | | | | | | | |
| *Brachytarsomys albicauda* | LC | ? | 32 | 9 | 13 | 10 | 6 | 17 | 3 | | today | 2018 | | ZIMS | | | |
| *Eliurus grandidieri* | LC | ? | 3 | 1 | 2 | 0 | 1 | 0 | 0 | | today | 2008 | | ZIMS | | | |
| *Eliurus myoxinus* | LC | ? | | | | | | | | | past | 1967 | 1967 | ZIMS | | | |
| *Hypogeomys antimena* | CR | ? | 46 | 21 | 23 | 2 | 15 | 8 | 5 | | today | 1990 | | ZIMS | 4.94 | 139 | |

**Table A1.** *Cont.*

| Family<br>*Species* | Threat Status | Population Trend | Tot. Ind. | Tot.M | Tot.F | Tot. O | Tot. Inst. | No. of Births | Tot. Breeding Inst. | EEP/ ESB/ SSP | Species Kept | From (year) | Until (year) | ZIMS/ ZTL | EDGE | EDGE Rank | CITES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pteropodidae** | | | | | | | | | | | | | | | | | |
| *Pteropus rufus* | VU | ↓ | 17 | 5 | 2 | 10 | 1 | 3 | 1 | | today | 2020 | | ZIMS | | | II |
| **Tenrecidae** | | | | | | | | | | | | | | | | | |
| *Echinops telfairi* | LC | – | 476 | 198 | 187 | 91 | 143 | 42 | 9 | SSP | today | 1975 | | ZIMS | | | |
| *Hemicentetes nigriceps* | LC | ? | | | | | | | | | past | 1966 | 2022 | ZIMS | | | |
| *Hemicentetes semispinosus* | LC | ? | | | | | | | | | past | 1965 | 2003 | ZIMS | | | |
| *Microgale dobsoni* | LC | ↓ | | | | | | | | | past | 1966 | 1970 | ZIMS | | | |
| *Microgale talazaci* | LC | ↓ | | | | | | | | | past | 1966 | 1978 | ZIMS | | | |
| *Microgale thomasi* | LC | ↓ | | | | | | | | | past | 1966 | 1969 | ZIMS | | | |
| *Setifer setosus* | LC | – | 15 | 6 | 4 | 5 | 8 | 0 | 0 | | today | 1966 | | ZIMS | | | |
| *Tenrec ecaudatus* | LC | – | 4 | 4 | 0 | 0 | 4 | 0 | 0 | | today | 1900 | | ZIMS | | | |

## Appendix B

**Table A2.** Prioritization list of terrestrial Malagasy mammal species sorted by families. Threat status according to the IUCN Red List of Threatened Species (2023). DD = Data Deficient, LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered.

| Family<br>*Species* | Species Kept | Endemism | IUCN | EDGE Score |
|---|---|---|---|---|
| **Cheirogaleidae** | | | | |
| *Microcebus gerpi* | no | microendemic | CR | 5.14 |
| *Microcebus berthae* | no | microendemic | CR | 4.45 |
| *Microcebus manitatra* | no | microendemic | CR | 0.00 |
| *Microcebus mamiratra* | no | microendemic | EN | 5.14 |
| *Phaner parienti* | no | microendemic | EN | 4.73 |
| *Microcebus bongolavensis* | no | microendemic | EN | 4.45 |
| *Microcebus jollyae* | no | microendemic | EN | 4.45 |
| *Microcebus margotmarshae* | no | microendemic | EN | 4.45 |
| *Microcebus sambiranensis* | no | microendemic | EN | 4.45 |
| *Microcebus simmonsi* | no | microendemic | EN | 4.45 |
| *Cheirogaleus lavasoensis* | no | microendemic | EN | 0.00 |
| *Cheirogaleus thomasi* | no | microendemic | EN | 0.00 |
| *Microcebus ganzhorni* | no | microendemic | EN | 0.00 |
| *Microcebus jonahi* | no | microendemic | EN | 0.00 |
| *Microcebus tanosi* | no | microendemic | EN | 0.00 |
| *Cheirogaleus andysabini* | no | microendemic | EN | 0.00 |
| *Microcebus danfossi* | no | microendemic | VU | 4.45 |
| *Microcebus ravelobensis* | no | microendemic | VU | 4.45 |
| *Microcebus rufus* | no | microendemic | VU | 3.79 |
| *Microcebus myoxinus* | no | microendemic | VU | 3.70 |
| *Microcebus griseorufus* | no | microendemic | LC | 0.00 |
| *Cheirogaleus grovesi* | no | microendemic | DD | 0.00 |
| *Microcebus boraha* | no | microendemic | DD | 0.00 |
| *Cheirogaleus sibreei* | no | regional endemic | CR | 5.68 |
| *Phaner electromontis* | no | regional endemic | EN | 4.70 |
| *Allocebus trichotis* | no | regional endemic | EN | 4.31 |
| *Phaner furcifer* | no | regional endemic | EN | 4.01 |
| *Cheirogaleus shethi* | no | regional endemic | EN | 0.00 |
| *Microcebus tavaratra* | no | regional endemic | VU | 3.75 |
| *Cheirogaleus crossleyi* | no | regional endemic | VU | 0.00 |
| *Cheirogaleus major* | no | regional endemic | VU | 0.00 |
| *Microcebus marohita* | no | endemic | CR | 5.14 |
| *Mirza coquereli* | no | endemic | EN | 5.11 |
| *Phaner pallescens* | no | endemic | EN | 4.72 |
| *Microcebus macarthurii* | no | endemic | EN | 4.45 |

**Table A2.** *Cont.*

| Family<br>*Species* | Species Kept | Endemism | IUCN | EDGE Score |
|---|---|---|---|---|
| *Microcebus arnholdi* | no | endemic | VU | 4.45 |
| *Mirza zaza* | no | endemic | VU | 0.00 |
| *Microcebus lehilahytsara* | yes | regional endemic | NT | 3.75 |
| *Cheirogaleus medius* | yes | endemic | VU | 0.00 |
| *Microcebus murinus* | yes | endemic | LC | 0.00 |
| **Daubentoniidae** | | | | |
| *Daubentonia madagascariensis* | yes | endemic | EN | 20.13 |
| **Emballonuridae** | | | | |
| *Paremballonura atrata* | no | endemic | LC | 0.00 |
| *Paremballonura tiavato* | no | endemic | LC | 0.00 |
| *Coleura kibomalandy* | no | endemic | DD | 0.00 |
| **Eupleridae** | | | | |
| *Salanoia concolor* | no | microendemic | VU | 4.22 |
| *Eupleres major* | no | endemic | EN | 5.30 |
| *Eupleres goudotii* | no | endemic | VU | 4.61 |
| *Galidictis fasciata* | no | endemic | VU | 4.20 |
| *Galidictis grandidieri* | yes | microendemic | EN | 4.89 |
| *Mungotictis decemlineata* | yes | regional endemic | EN | 4.89 |
| *Cryptoprocta ferox* | yes | endemic | VU | 4.93 |
| *Fossa fossana* | yes | endemic | VU | 4.61 |
| *Galidia elegans* | yes | endemic | LC | 0.00 |
| **Hipposideridae** | | | | |
| *Paratriaenops auritus* | no | regional endemic | VU | 4.08 |
| *Macronycteris commersoni* | no | endemic | NT | 0.00 |
| *Paratriaenops furcula* | no | widespread | LC | 0.00 |
| **Indriidae** | | | | |
| *Propithecus tattersalli* | no | microendemic | CR | 5.31 |
| *Propithecus candidus* | no | microendemic | CR | 5.25 |
| *Propithecus perrieri* | no | microendemic | CR | 5.21 |
| *Avahi cleesei* | no | microendemic | CR | 4.63 |
| *Avahi unicolor* | no | microendemic | CR | 4.63 |
| *Propithecus deckenii* | no | microendemic | CR | 4.50 |
| *Avahi betsileo* | no | microendemic | EN | 4.63 |
| *Avahi mooreorum* | no | microendemic | EN | 4.63 |
| *Propithecus edwardsi* | no | microendemic | EN | 4.54 |
| *Avahi occidentalis* | no | microendemic | VU | 4.60 |
| *Avahi peyrierasi* | no | microendemic | VU | 3.94 |
| *Indri Indri* | no | regional endemic | CR | 10.44 |
| *Propithecus diadema* | no | regional endemic | CR | 5.23 |
| *Propithecus verreauxi* | no | regional endemic | CR | 4.50 |

**Table A2.** *Cont.*

| Family<br>*Species* | Species Kept | Endemism | IUCN | EDGE Score |
|---|---|---|---|---|
| *Avahi meridionalis* | no | regional endemic | EN | 4.63 |
| *Avahi ramanantsoavanai* | no | regional endemic | VU | 3.94 |
| *Avahi laniger* | no | endemic | VU | 3.94 |
| *Propithecus coronatus* | yes | microendemic | CR | 4.56 |
| *Propithecus coquereli* | yes | microendemic | CR | 4.52 |
| **Lemuridae** | | | | |
| *Hapalemur aureus* | no | microendemic | CR | 5.41 |
| *Eulemur sanfordi* | no | regional endemic | EN | 4.25 |
| *Hapalemur meridionalis* | no | endemic | VU | 4.01 |
| *Hapalemur griseus* | no | endemic | VU | 3.99 |
| *Eulemur rufifrons* | no | endemic | VU | 0.00 |
| *Hapalemur alaotrensis* | yes | microendemic | CR | 5.38 |
| *Eulemur flavifrons* | yes | microendemic | CR | 5.00 |
| *Varecia rubra* | yes | regional endemic | CR | 11.31 |
| *Prolemur simus* | yes | regional endemic | CR | 5.33 |
| *Eulemur mongoz* | yes | regional endemic | CR | 5.07 |
| *Eulemur coronatus* | yes | regional endemic | EN | 4.42 |
| *Eulemur collaris* | yes | regional endemic | EN | 4.23 |
| *Eulemur macaco* | yes | regional endemic | EN | 3.70 |
| *Eulemur rufus* | yes | regional endemic | VU | 3.55 |
| *Varecia variegata* | yes | endemic | CR | 11.29 |
| *Eulemur cinereiceps* | yes | endemic | CR | 0.00 |
| *Lemur catta* | yes | endemic | EN | 4.76 |
| *Eulemur albifrons* | yes | endemic | VU | 4.23 |
| *Hapalemur occidentalis* | yes | endemic | VU | 3.99 |
| *Eulemur rubriventer* | yes | endemic | VU | 3.68 |
| *Eulemur fulvus* | yes | endemic | VU | 0.00 |
| **Lepilemuridae** | | | | |
| *Lepilemur septentrionalis* | no | microendemic | CR | 4.96 |
| *Lepilemur ahmansoni* | no | microendemic | CR | 0.00 |
| *Lepilemur grewcockorum* | no | microendemic | CR | 0.00 |
| *Lepilemur hollandorum* | no | microendemic | CR | 0.00 |
| *Lepilemur jamesorum* | no | microendemic | CR | 0.00 |
| *Lepilemur ruficaudatus* | no | microendemic | CR | 0.00 |
| *Lepilemur sahamalaza* | no | microendemic | CR | 0.00 |
| *Lepilemur tymerlachsoni* | no | microendemic | CR | 0.00 |
| *Lepilemur aeeclis* | no | microendemic | EN | 0.00 |
| *Lepilemur betsileo* | no | microendemic | EN | 0.00 |
| *Lepilemur dorsalis* | no | microendemic | EN | 0.00 |

**Table A2.** *Cont.*

| Family<br>*Species* | Species Kept | Endemism | IUCN | EDGE Score |
|---|---|---|---|---|
| *Lepilemur edwardsi* | no | microendemic | EN | 0.00 |
| *Lepilemur fleuretae* | no | microendemic | EN | 0.00 |
| *Lepilemur hubbardorum* | no | microendemic | EN | 0.00 |
| *Lepilemur leucopus* | no | microendemic | EN | 0.00 |
| *Lepilemur microdon* | no | microendemic | EN | 0.00 |
| *Lepilemur otto* | no | microendemic | EN | 0.00 |
| *Lepilemur petteri* | no | microendemic | EN | 0.00 |
| *Lepilemur randrianasoloi* | no | microendemic | EN | 0.00 |
| *Lepilemur scottorum* | no | microendemic | EN | 0.00 |
| *Lepilemur wrightae* | no | microendemic | EN | 0.00 |
| *Lepilemur mustelinus* | no | microendemic | VU | 0.00 |
| *Lepilemur ankaranensis* | no | regional endemic | EN | 4.25 |
| *Lepilemur milanoii* | no | regional endemic | EN | 0.00 |
| *Lepilemur seali* | no | regional endemic | VU | 0.00 |
| **Miniopteridae** | | | | |
| *Miniopterus ambohitrensis* | no | microendemic | LC | 0.00 |
| *Miniopterus griffithsi* | no | microendemic | DD | 0.00 |
| *Miniopterus egeri* | no | regional endemic | LC | 0.00 |
| *Miniopterus mahafaliensis* | no | regional endemic | LC | 0.00 |
| *Miniopterus petersoni* | no | regional endemic | DD | 0.00 |
| *Miniopterus brachytragos* | no | endemic | LC | 0.00 |
| *Miniopterus gleni* | no | endemic | LC | 0.00 |
| *Miniopterus majori* | no | endemic | LC | 0.00 |
| *Miniopterus sororculus* | no | endemic | LC | 0.00 |
| *Miniopterus aelleni* | no | widespread | LC | 0.00 |
| *Miniopterus manavi* | no | widespread | LC | 0.00 |
| **Molossidae** | | | | |
| *Mops atsinanana* | no | endemic | LC | 0.00 |
| *Mops jobimena* | no | endemic | LC | 0.00 |
| *Mops leucostigma* | no | endemic | LC | 0.00 |
| *Mormopterus jugularis* | no | endemic | LC | 0.00 |
| *Otomops madagascariensis* | no | endemic | LC | 0.00 |
| *Mops leucogaster* | no | widespread | LC | 0.00 |
| **Myzopodidae** | | | | |
| *Myzopoda schliemanni* | no | regional endemic | LC | 0.00 |
| *Myzopoda aurita* | no | endemic | LC | 0.00 |
| **Nesomyidae** | | | | |
| *Macrotarsomys ingens* | no | microendemic | EN | 4.76 |
| *Voalavo antsahabensis* | no | microendemic | EN | 4.69 |
| *Nesomys lambertoni* | no | microendemic | EN | 4.66 |

**Table A2.** *Cont.*

| Family<br>*Species* | Species Kept | Endemism | IUCN | EDGE Score |
|---|---|---|---|---|
| *Eliurus penicillatus* | no | microendemic | EN | 0.00 |
| *Eliurus petteri* | no | microendemic | EN | 0.00 |
| *Eliurus danieli* | no | microendemic | LC | 0.00 |
| *Eliurus antsingy* | no | microendemic | DD | 0.00 |
| *Eliurus ellermani* | no | microendemic | DD | 0.00 |
| *Macrotarsomys petteri* | no | microendemic | DD | 0.00 |
| *Eliurus carletoni* | no | regional endemic | LC | 0.00 |
| *Brachytarsomys villosa* | no | endemic | VU | 4.01 |
| *Brachyuromys betsileoensis* | no | endemic | LC | 0.00 |
| *Brachyuromys ramirohitra* | no | endemic | LC | 0.00 |
| *Eliurus majori* | no | endemic | LC | 0.00 |
| *Eliurus minor* | no | endemic | LC | 0.00 |
| *Eliurus myoxinus* | no | endemic | LC | 0.00 |
| *Eliurus tanala* | no | endemic | LC | 0.00 |
| *Eliurus webbi* | no | endemic | LC | 0.00 |
| *Gymnuromys roberti* | no | endemic | LC | 0.00 |
| *Macrotarsomys bastardi* | no | endemic | LC | 0.00 |
| *Monticolomys koopmani* | no | endemic | LC | 0.00 |
| *Nesomys audeberti* | no | endemic | LC | 0.00 |
| *Nesomys rufus* | no | endemic | LC | 0.00 |
| *Voalavo gymnocaudus* | no | endemic | LC | 0.00 |
| *Hypogeomys antimena* | yes | microendemic | CR | 4.94 |
| *Brachytarsomys albicauda* | yes | endemic | LC | 0.00 |
| *Eliurus grandidieri* | yes | endemic | LC | 0.00 |
| **Nycteridae**<br>*Nycteris madagascariensis* | no | endemic | DD | 0.00 |
| **Pteropodidae**<br>*Eidolon dupreanum* | no | endemic | VU | 0.00 |
| *Rousettus madagascariensis* | no | endemic | VU | 0.00 |
| *Pteropus rufus* | yes | endemic | VU | 0.00 |
| Rhinonycteridae<br>*Triaenops menamena* | no | endemic | LC | 0.00 |
| **Tenrecidae**<br>*Microgale jenkinsae* | no | microendemic | EN | 4.46 |
| *Microgale jobihely* | no | microendemic | EN | 4.46 |
| *Microgale monticola* | no | microendemic | VU | 3.77 |
| *Oryzorictes tetradactylus* | no | microendemic | DD | 0.00 |
| *Limnogale mergulus* | no | regional endemic | VU | 4.47 |
| *Microgale nasoloi* | no | regional endemic | VU | 3.77 |
| *Microgale dryas* | no | regional endemic | VU | 3.66 |

**Table A2.** *Cont.*

| Family<br>*Species* | Species Kept | Endemism | IUCN | EDGE Score |
|---|---|---|---|---|
| *Hemicentetes nigriceps* | no | regional endemic | LC | 0.00 |
| *Microgale longicaudata* | no | regional endemic | LC | 0.00 |
| *Geogale aurita* | no | endemic | LC | 0.00 |
| *Hemicentetes semispinosus* | no | endemic | LC | 0.00 |
| *Microgale brevicaudata* | no | endemic | LC | 0.00 |
| *Microgale cowani* | no | endemic | LC | 0.00 |
| *Microgale dobsoni* | no | endemic | LC | 0.00 |
| *Microgale drouhardi* | no | endemic | LC | 0.00 |
| *Microgale fotsifotsy* | no | endemic | LC | 0.00 |
| *Microgale gracilis* | no | endemic | LC | 0.00 |
| *Microgale grandidieri* | no | endemic | LC | 0.00 |
| *Microgale gymnorhyncha* | no | endemic | LC | 0.00 |
| *Microgale majori* | no | endemic | LC | 0.00 |
| *Microgale parvula* | no | endemic | LC | 0.00 |
| *Microgale principula* | no | endemic | LC | 0.00 |
| *Microgale pusilla* | no | endemic | LC | 0.00 |
| *Microgale soricoides* | no | endemic | LC | 0.00 |
| *Microgale taiva* | no | endemic | LC | 0.00 |
| *Microgale talazaci* | no | endemic | LC | 0.00 |
| *Microgale thomasi* | no | endemic | LC | 0.00 |
| *Oryzorictes hova* | no | endemic | LC | 0.00 |
| *Echinops telfairi* | yes | endemic | LC | 0.00 |
| *Setifer setosus* | yes | endemic | LC | 0.00 |
| *Tenrec ecaudatus* | yes | endemic | LC | 0.00 |
| **Vespertilionidae** | | | | |
| *Neoromicia malagasyensis* | no | microendemic | VU | 4.23 |
| *Hypsugo bemainty* | no | microendemic | LC | 0.00 |
| *Neoromicia robertsi* | no | microendemic | DD | 0.00 |
| *Neoromicia matroka* | no | regional endemic | LC | 0.00 |
| *Myotis goudoti* | no | endemic | LC | 0.00 |
| *Scotophilus marovaza* | no | endemic | LC | 0.00 |
| *Scotophilus robustus* | no | endemic | LC | 0.00 |
| *Pipistrellus raceyi* | no | endemic | DD | 0.00 |
| *Scotophilus tandrefana* | no | endemic | DD | 0.00 |

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