Chapter

Parks and Reserves in Madagascar: Managing Biodiversity for a Sustainable Future

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Abstract

Madagascar has an extended network of over 100 protected areas with various IUCN status covering more than 10% of terrestrial landscapes and seascapes. The location of these areas is to a high-degree congruent with remaining forests covering some 15% of the island. The definitions of forests are numerous, at global, national, and regional scales; here we emphasize the widespread system considering the percentage of tree cover canopy, to better define the eastern humid vs. western dry forests in Madagascar and to understand how best to protect the terrestrial biodiversity within parks and reserves. Forests are home to over 80% of Madagascar's biodiversity. These ecosystems are under high threat due to ongoing and rapid deforestation and degradation. We present the interlinkages and complexity of governing National Parks to safeguard Madagascar's unique biodiversity and ecosystem services.

Keywords: forests, endemism, forest governance, protected area management, deforestation

1. Introduction

Madagascar is a large island in the Southwest Indian Ocean located east of South Africa and Mozambique. After its independence from former colonial France (1890–1960), the country has experienced more than five political crises since the early 1990s. Madagascar fares among the poorest countries, where over 80% of its 26 million inhabitants, mainly living in rural areas, are depending on less than 2$ per day. The grand majority of rural people depend on agricultural production—mainly rice, and maize in the drier parts—mostly for subsistence and to lesser extent for local markets.

Madagascar is also widely renowned for its unique biodiversity. The fourth biggest island, separated from mainland Africa some 165 million years ago (Ma), assembles a high degree of endemism at species and higher taxonomic level. With few exceptions, its hundreds of species of amphibian and reptiles and 100% of lemurs are occurring in Madagascar only. There is also a high degree of endemism—over 82%—in the >12,000 native species of vascular plants [1]. Many of these species are also evolutionary ancient going back millions of years [2], and there still remain several hundreds of species to be discovered and scientifically described.

Goes one of these endemics extinct on the island, it translates into a loss at global level. This makes conservation so much more challenging and pressing. Madagascar has also been declared as one of the world's 200 global hot spots for biodiversity due to its endemism and threat status [3].

The rich and unique biodiversity has attracted a lot of research and conservation attention of global order, bringing to the scene relatively large donor institutions [4, 5], also translating into a quite large conservation network of protected areas. To date, some 8.5% of terrestrial landscapes are under formal protection, and some 6.2% of Madagascar territorial waters are protected seascapes.

In this book chapter, we aim to show the importance of Madagascar's protected area network, which consists of over 120 sites. In the first section, we provide an overview of the biological richness, more than 80% of which depends on forest ecosystems. Forests themselves come along in a range of different types: from humid forests in the east to dry forests in the west, to dry spiny forests in the southwest. In the next section, we give a detailed account of the protected area system, its IUCN categories and evolution through time to reflect global changes and expectations (cf. [6]), and its governance. The third section will focus on challenges and threats to protected areas and their biodiversity and governance based on three selected case studies. The final section constitutes an outlook, where we reflect upon ideas of the most imminent actions needed for safeguarding the PA system and its unique biodiversity in a poverty and corruption-stricken country.

2. Forests and biodiversity

The biodiversity of Madagascar is renown and characterized by several features: (i) a high rate of endemism in species and at higher taxonomical levels including genera, families, and suborders and/or orders; (ii) some radiations in endemic families or subfamilies; (iii) monospecific or paucispecific endemic families or subfamilies, and (iv) the absence of certain groups well represented in Africa or Asia.

Research in paleontology carried out in Madagascar revealed Cretaceous birds, amphibians, snakes, and mammals. The peculiar *Beelzebufo* from the Upper Cretaceous (100.5–66 Ma) of western Madagascar was a giant frog more closely related to extant frogs present in South America but absent from Madagascar [7]. The Mesozoic (251.902–66 Ma) snakes recovered in Madagascar belong to an extinct family [8], while the modern mammals currently occurring in Madagascar have no ancestors among the known paleontological records. In the current state of our knowledge, with a few exceptions, the vertebrates currently occurring on the island have ancestors who arrived in Madagascar after the K-Pg mass extinction 66 million years ago (Ma) [9, 10].

The records of mammals show some recently extinct taxa, especially large-bodied lemurs. These include the 160 kg Sloth lemur *Archaeoindris fontoynontii*, more than 20 times heavier than the current larger lemurs, the 6–7 kg *Indri indri* or *Propithecus diadema*, or >5000 times the size of the smallest primate on Earth, the Madame Berthe's mouse lemur *Microcebus berthae*. The lemurs exhibit all types of activity patterns with most of the smaller species being mainly nocturnal, the largest species in the Indridae family being diurnal, and many species, mostly in the Lemuridae family being cathemeral with activities occurring throughout the 24 hours [11–13]. Few species of lemurs have a diet with a high proportion of fruits; their diet is always complemented by leaves, which seems to be related with low levels of nitrogen in the Malagasy fruits [14]. All lemur species but one occur in the various forest types of the island. The exception is the narrow-ranged Alaotra gentle lemur *Hapalemur alaotrensis* endemic to the wetlands of Lake Alaotra [15].

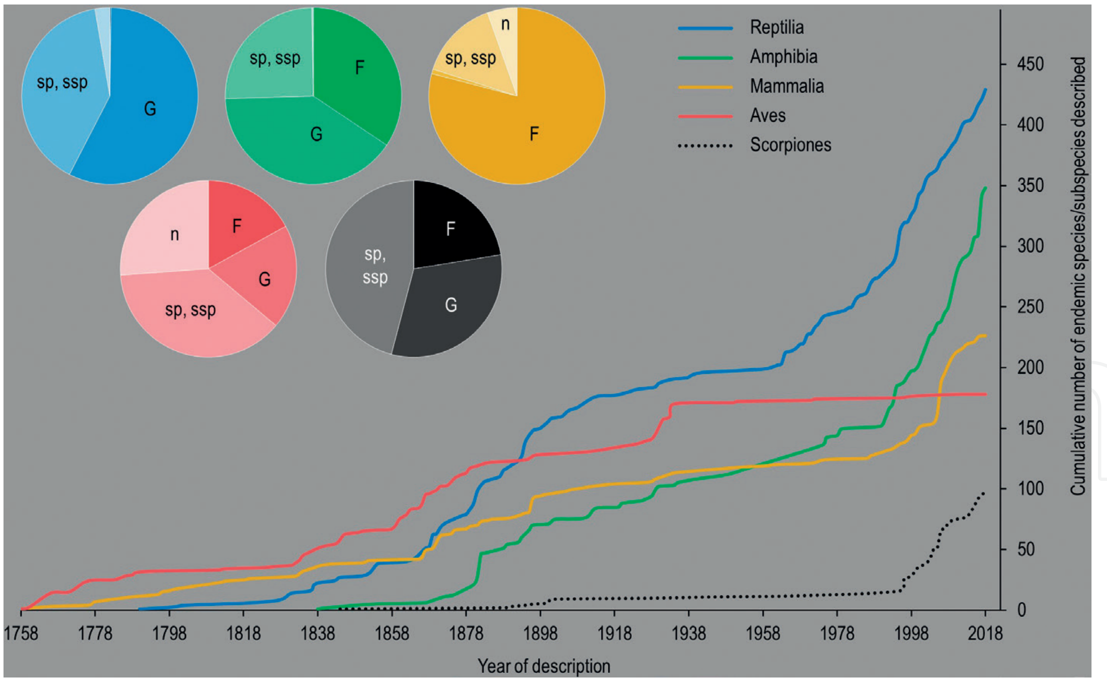

Figure 1.
Number of endemic species and subspecies described since 1758 and composition of the groups of scorpions, amphibians, reptiles, birds, and mammals in terms of level of endemism of the autochthonous species and subspecies found in Madagascar (F for species and subspecies belonging to an endemic family or subfamily, G for those belonging to an endemic genus; n for other native species and subspecies but not endemic).

The small terrestrial mammals of Madagascar are tenrecs and rodents. The tenrecs occur in all types of forest but have greater species richness in the humid forest. One species is solely encountered in rivers, the aquatic Web-footed tenrec *Limnogale mergulus*.

The humid forests encountered in the east and northwest harbor the highest richness of vertebrates, as compared to the western dry forests and the southern dry-spiny forest thickets. The endemic birds represent an exception; they are well represented in the driest forests of the west and the south [16]. The mammals, reptiles, and amphibians are represented by 191, 254, and 260 endemic species and subspecies, respectively; the birds have only 178 endemic species and subspecies (**Figure 1**, **Table 1**). These low numbers for birds are not fully understood, but recent research on the rich endemic scorpion fauna points toward a so-called "Neogrosphus rule" stipulating that "In a changing environment causing geographical barriers, the lower the species' dispersal ability, and the greater the niche breadth of the ancestor taxum, the higher the species richness" [17, 18].

The order of birds in Madagascar is thus both rich and poor: rich in endemic taxa with 178 endemic species and subspecies, but also one endemic order—or suborder according to authorities—three endemic families, one endemic subfamily, and 39 endemic genera. Several of these higher endemic taxa are rich and exhibit endemic radiations as the family Bernieridae or the subfamily Couinae with, respectively, 16 and 14 endemic species and subspecies [19–21]. The Malagasy avifauna can be considered as poor, because entire groups occurring in Africa are not represented in Madagascar or in extremely small numbers only. Small numbers can point toward recent colonization, as in the case of the Madagascar cisticola (*Cisticola cherina*), but not always. A great counterexample is the cuckoo-roller belonging to a monospecific family occurring in Madagascar and the Comoros only. There are very few endemic bird species linked to open grasslands: only one species of lark (*Eremopterix hova*) or a single species of cisticola, while about 50 species are known from continental Africa. Some 21 endemic species and subspecies (12.0%) are encountered in open

	Scorpiones	Amphibia	Reptilia	Aves	Mammalia
Order	—	—	—	1	—
Family	2	—	1	3	7
Subfamily	—	3	—	1	10
Genus	9	22	43	39	43
Subgenus	1	15	5	—	—
Species or subspecies	98	348	429	178	226
Nonendemic autochthonous species and subspecies	—	*1*	*12*	*63*	*13*
% of endemism of species and subspecies	100.0	99.7	97.3	73.9	94.6
Number of species or subspecies endemic at family or subfamily levels	22	120	1	41	189
Number of species or subspecies endemic at genus level	53	260	254	87	191
% of species and subspecies endemic at family or subfamily level	22.4	34.4	0.2	17.0	79.1
% of species and subspecies endemic at genus level	54.1	74.5	57.6	36.1	79.9

Table 1.
Number of endemic taxa in the order Scorpiones and four classes of vertebrates, namely amphibians, reptiles, birds, and mammals (nonendemic species and subspecies also indicated in italic for the purpose of calculations, numbers as of December 31, 2018, based on Noe4D [19]).

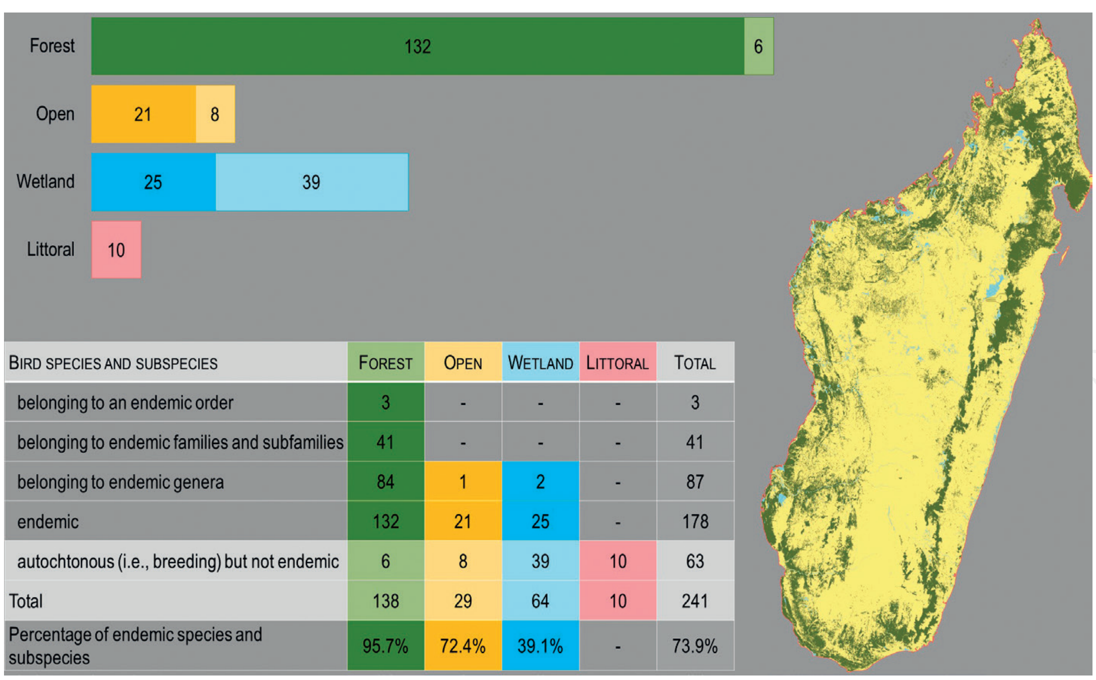

Figure 2.
Distribution of the endemic and nonendemic species and subspecies of birds according to the main type of habitat in which they occur (Madagascar simplified land cover based on [22]).

grasslands including the Madagascar partridge in the monospecific endemic genus *Margaroperdix madagarensis*, which is the only open grassland bird in a higher endemic taxon. Wetland birds are represented by 39 species and subspecies including 25 endemics (**Figure 2**). The paucity of endemic species in grasslands, some species encountered in wetlands, and the majority of species occurring in the different types of forests [22] fits the global pattern for the endemic vertebrates and invertebrates observed in Madagascar.

The largest bird in the World has been "made in Madagascar" and was much larger than the New Zealand Moas [23]. New Zealand and Madagascar, now >11,500 km apart, have some common geological history. Both islands were part of the Gondwana—separation from mainland Africa occurred at approximately 165 Ma, from Antarctica (and, indirectly, South America and Australia, linked with New Zealand) at approximately 115–112 Ma, and from the Indian subcontinent at approximately 88 Ma [10, 24]. These two large islands also share more recent avian history facts with the ratites. They were both home to giant birds that have disappeared in the last three to six centuries: the elephant birds in Madagascar and the Moas in New Zealand. It is widely reported that the elephant bird could have survived until the seventeenth century given that Etienne de Flacourt refers to it in his 1658 book [25]. Flacourt is also cited to refer to giant lemurs (e.g., [26]), on p. 154 of his book, thus encouraging some authors to give credit to the recent existence of these animals during the last centuries. The iconic New Zealand kiwis are also linked to Madagascar because they share a common ancestor with the elephant birds [27, 28]. Studies in New Zealand have revealed that humans were responsible for the extinction of the Moas some six centuries ago [29], but such firm conclusions have not been reached for the elephant birds or for the lemurs—contradicting views are still debated (e.g., [30, 31]). *Æpyornis titan* was described in 1894 [32] and later considered as a synonym of *Æ. maximus*. Hansford and Turvey [33] resurrected the species on the basis of new material recently collected in a cave of Isalo and transferred the species to a new genus Vorombe (Malagasy Vorona = bird and "be" = big). *Vorombe titan* is the largest bird that ever existed in the world. These giants weighing up to 860 kg were therefore seven to eight times heavier than the current ostriches of Africa. Recent studies have found that some elephant birds were vegetarian and nocturnal, a common trait shared with the New Zealand kiwis [34].

The elephant birds have also revealed the earliest known human presence in Madagascar [35]. In the oldest archeological site—the trading port Mahilaka in the northwest, established in the 10th century [36, 37]—human presence has more recently been depicted on animals with butchery marks on bones. For example, dwarf hippos, extinct giant lemurs, or elephants birds dated 2000 years before present BP [38, 39], or on a pigmy hippo bone dated 4000 BP [40]. Chicken bones are often used to date archeological sites (e.g., [41]); the chickens encountered in Madagascar are related to populations present in Indonesia and Africa [42]. A fossil Guinea fowl bone has been dated 10,000 years BP [43]; though Guinea fowl has better flight abilities than a chicken, it still cannot cross the >500 km distance separating Madagascar from Africa.

Box 1. *Elephant birds.*

The Central African forests are structured in such a way that a few dominant species and the large trees can explain the forests [44]. The tropical forests of western and central Africa are home to some 15,000 species of vascular plants (with an endemism estimated at 30%) of which 3000 are trees [45]. The countries from western and central Africa with tropical forests cover an area 12 times the size of Madagascar, which has nevertheless a comparative incredible richness of vascular plants, that is, more than 12,000 native plant species (82% are endemic to Madagascar), including more than 3000 native species of trees [1]. When compared to central Africa, Madagascar is peculiar due to the diversity of the types of vegetation encountered on the island.

Contrary to the Central African forests and other tropical forests in the World, the Malagasy forests are not renowned for their timber species with a few exceptions: the valuable timber species including the rosewood (*Dalbergia* spp.) and the ebony (*Diospyros* spp.) infamous for the traffic they are subject to [46, 47]. The high diversity encountered in the Malagasy flora is best explained by the diversity of vegetation types. Forests are ranging from humid forests in the east and the north where mean annual rainfall can reach 4000 mm to the southwestern spiny forest thickets in an extremely variable environment where mean annual rainfall can be below 500 mm [22, 48]. The central Menabe dry forests are structured with a few dominant species: the baobabs. The dry forests of western and southern Madagascar harbor six endemic species of baobabs (only one species occurs in Africa and one in Australia) [49].

Whether forests once covered all or almost the entire surface of the island remains controversial (e.g., [50]); however, it is certain that Madagascar has experienced major changes including during the recent Quaternary with its paleoclimatic oscillations. These oscillations and their effects on the abiotic factors, especially the numerous rivers with their watersheds, have allowed to propose

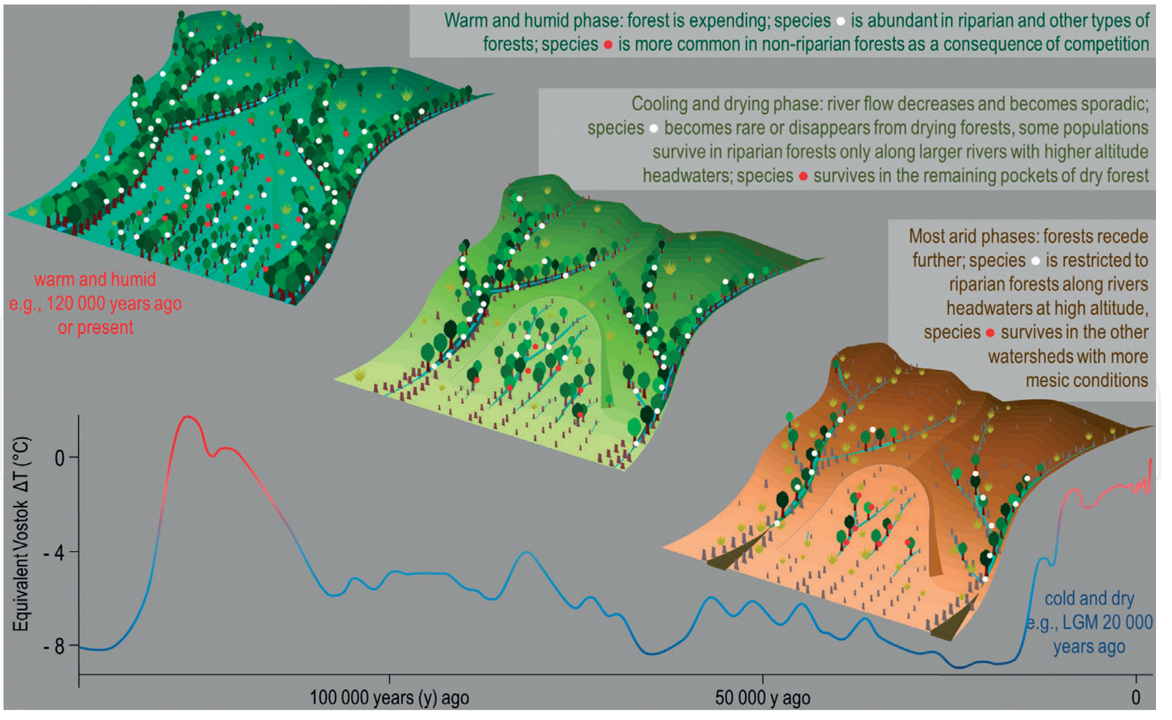

Figure 3.
Evolution of the abiotic factors, including the rivers and the slope, and biotic features, including the riparian forest and two faunal forest species, during paleoclimate oscillations (figure modified from [53], according to the Creative commons attribution 3.0 Unported license).

a model explaining the current distribution of some elements of the endemic forest biodiversity, more particularly the current range of some bird species, but especially those of many lemur species [51–54]. During the dry phases of the paleoclimate oscillations, the range of many populations were reduced to refugia, that is, places where water would still be available, therefore allowing the survival of a forest (vs. under high latitudes refugia are typically places free of ice). Finding out where these refugia could have occurred is part of the key to understand where the plants and animals were best in coping with the dry periods with decreasing rainfall (**Figure 3**).

3. Protected area system

Madagascar's high species richness and uniqueness has led to the creation of the first parks and reserves at the beginning of the twentieth century around the same time when the first protected areas were created on continental Africa [55]. The French administration established 10 Strict Nature Reserves at the end of 1927. By 1997, 46 protected areas (PA) covering almost 1.8 million hectares—with a clear focus on biodiversity conservation and research—were designated, including Strict Nature Reserve (IUCN Category I), National Parks (IUCN Category II), and Special Reserves (IUCN Category IV) [56–59] (**Figure 4**).

In the 1990s and 2000s, an important phase of internationally driven policy changes has been implemented in Madagascar. A suite of international conventions were signed and ratified laying ground for national legislative adaptation to better safeguard the biological and cultural patrimony and embed it in a global context [60]. The Convention on Biological Diversity CBD was ratified in 1995 (Law 1995-013 and Decree 1995-695); Ramsar Convention on Wetlands (Law 1998-003 and Decree 1998-261) was ratified in 1998; the Convention on the Conservation of Migratory Species of Wild Animals CMS was ratified in 2007. Madagascar was the

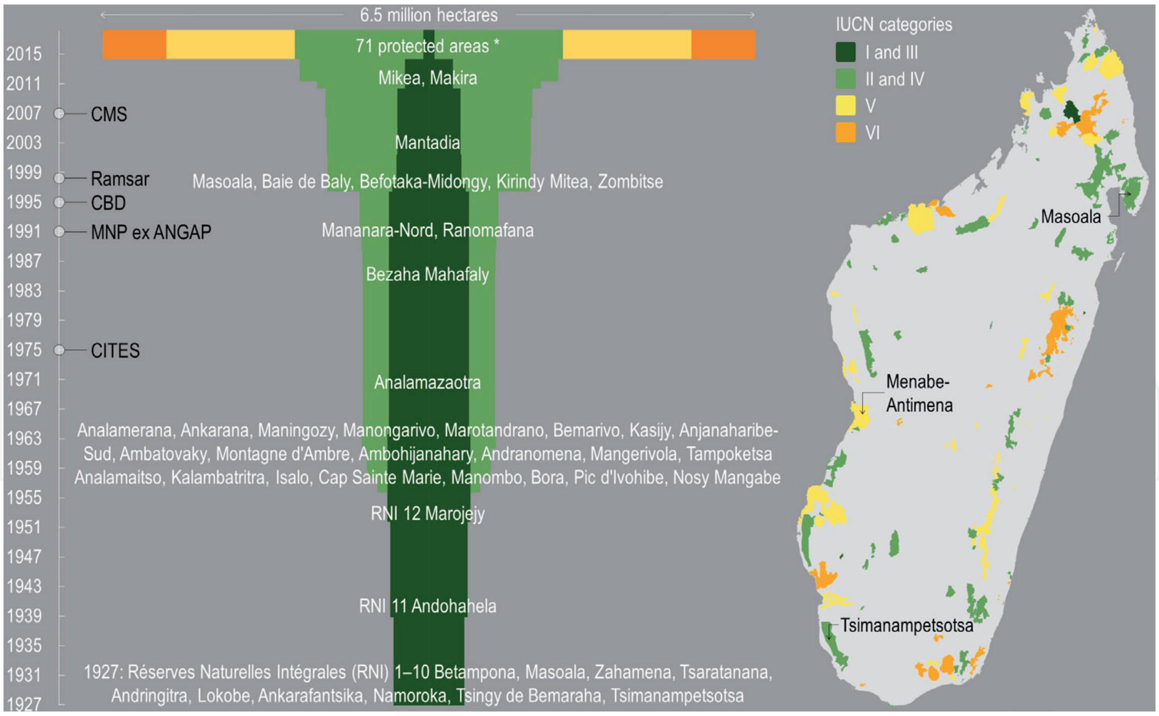

Figure 4.
*Protected areas and IUCN categories. Evolution of terrestrial protected areas in Madagascar (left), and distribution of the protected areas in 2018 (right). (*Agnakatrika, Agnalazaha, Alandraza Analavelo, Allée des Baobabs, Ambararata Londa, Ambatoatsinanana, Ambatofotsy, Ambatotsirongorongo, Ambodivahibe, Ambohidray, Ambondrombe, Ambositra-Vondrozo, Amoron'i Onilahy, Ampanangandehibe-Behasina, Ampasindava, Ampotaka-Ankorabe, Analabe Betanatanana, Analalava, Andrafiamena Andavakoera, Andreba, Angavo, Anjozorobe-Angavo, Ankarabolava, Ankarea, Ankeniheny-Zahamena, Ankivonjy, Ankodida, Antrema, Beanka, Behara Tranomaro, Bemanevika, Bombetoka Beloboka, Bongolava, COMATSA Nord, COMATSA Sud, Galoko-Kalobinono, Ibity, Itremo, Lac Alaotra, Loky Manambato, Mahavavy Kinkony, Mahialambo, Mahimborondro, Makirovana Tsihomanaomby, Mandena, Mandrozo, Mangabe-Ranomena-Sahasarotra, Mangoky Ihotry, Manjakatompo Ankaratra, Marolambo, Maromizaha, Menabe Antimena, Montagne des Français, Nord-Ifotaka, Nosy Antsoha, Oronjia, Petriky, Pointe à Larrée, Ranobe bay, Ranobe PK32, Rivière Nosivolo, Sahafina, Soariake, Sud-Ouest Ifotaky, Torotorofotsy, Tsimembo Manambolomaty, Tsinjoriake, Tsitongambarika, Velondriake, Vohidava-Betsimalaho, Vohidefo; CMS = Convention on the Conservation of Migratory Species of Wild Animals, Ramsar = Ramsar Convention on Wetlands, CBD = Convention on Biological Diversity, MNP = Madagascar National Parks, CITES = Convention on International Trade in Endangered Species of Wild Fauna and Flora).*

first country to develop and implement a roadmap for conservation and development. The New Environmental Action Plan (NEAP) brought about a decentralization in governance of natural resources management [61]. The GELOSE policy (Gestion Locale Sécurisée, secure local management) regulates the transfer of property rights from the State to local communities (Law 97-107 and Decree 97-1200); it is applicable to forests, pastures, water, and wildlife. Specifically, the protected area legislation Code des Aires Protégées (N. 848-05/N. 2001/05) legalized in 2003, and revisions related to the law of hunting (2006-098) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora CITES (ratified in 1975) were undertaken to control the exploitation of wild animals and regulating in situ conservation (Decree 2006-400) (**Figure 4**). After the crisis years 2009–2013, the PA legislation code has been revised in 2015 under the Refonte du Code des Aires Protégées (N. 2015-005) and supplemented with an updated environmental charter, Charte de l'Environnement Malagasy actualisée (N. 2015-003).

During the fifth World Parks Congress 2003 (Durban, South Africa), President Marc Ravalomanana declared to triple the terrestrial surface under protection in Madagascar up to 6 million hectares under the so-called Durban Vision [62]. The new System of Protected Areas of Madagascar (SAPM)—established in 2002—including both, the management of the original PAs and new protected areas

(NPAs), is responsible for the safeguarding of biodiversity and cultural heritage and sustainably managing resources for the people of Madagascar (Commission SAPM, 2006). Until the early 2000s, the State through the parastatal organization ANGAP (created in 1991, now MNP, Madagascar National Parks) governed parks. Since the SAPM, management has become more diverse and complex, reflecting global trends toward protected area for people and biodiversity [63]. The NPAs follow a shared governance model by the regional government and local communities, accompanied by a legally recognized promoter (usually an international NGO, sometimes national NGO, universities, or even mining companies) [64, 65]. There are now 116 sites covering an area of 6.5 million hectares for the terrestrial protected areas alone (**Figure 4**).

4. Deforestation is emptying the protected areas

4.1 Drivers of land cover change

Madagascar's land cover has undergone big changes over the past decades. Many of the main drivers of change affecting forests are man-made in Madagascar. Agriculture is the number one promoter of change causing deforestation. In the tropics, agriculture is mainly characterized by family-based productions, operating in a dynamic mosaic of open landscapes dominated by grassy areas, slash, and burn shifting cultivation and land clearings [66]. In Madagascar, over 80% of the population lives in rural areas with some 78% of the active population engaging in agricultural activities [67].

Energy demand is another big driver across the island. Access to electricity is still poor, where some 15% of the total population—cities (37%) vs. rural inhabitants (4%)—benefit from it [68]. A grand majority of the 26 million inhabitants are still highly dependent on wood biomass for domestic energy supply (charcoal, firewood). An energy diagnostics conducted by WWF in 2012 revealed that more than 90% of rural inhabitants are still using fuel wood as main energy supply [69]. It is unknown to what extent the charcoal production is affecting natural forests within protected areas. While firewood collection affects any forests, charcoal production can take place in pine or eucalyptus plantations—which usually are grown on former forested lands, which is the case in many parts of the highlands—or it has been produced within natural forests. For example, in the southwest, production takes place mainly in the natural dry and spiny forests [70].

In contrast to other tropical countries, extractive industries such as oil and mining are of minor importance in Madagascar. While there is a number of prospecting projects ongoing, mainly on the western escarpment of the country—here lie the main natural geologically interesting layers (cf. [71])—there are only two large-scale mining operations installed. Small-scale artisanal (illegal) mining is much wider spread and oftentimes coincides with protected areas and forests. However, its impacts are far below the ones of agricultural expansion and energy needs. In contrast to some central African countries, there is no big-scale industrial logging.

4.2 Case studies

In the following, we present three protected areas from dense humid forests in the east, the National Park of Masoala, the western dry forest of the reserve of Menabe Antimena, to the southwestern dry spiny forest thicket of the National Park of Tsimanampetsotsa (**Figures 4** and **5**). We briefly depict its conspicuous biogeographic and ecological elements and summarize the main threats affecting these three sites.

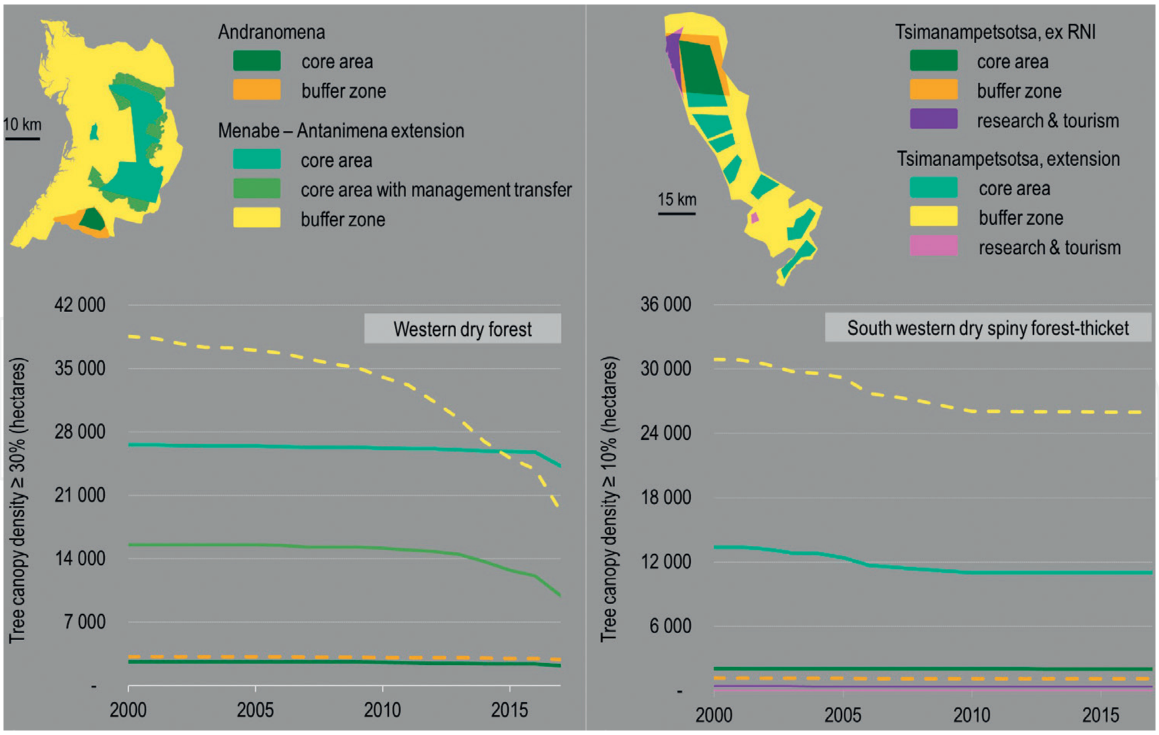

Figure 5.
Forest loss in Andranomena (left) and Tsimanampetsotsa (right) based on the different zoning of respective protected areas.

Case 1: The *Masoala National Park* with a total area of 212,000 hectares for its terrestrial portion alone is the largest National Park of Madagascar. It covers almost entirely the Masoala peninsula as well as the Center of endemism of Masoala [52]. The red ruffed lemur has its range limited to this center of endemism. The Strict Nature Reserve of Cap Masoala covering some 27,800 ha—created in 1927—has been degazetted in September 1964. The NP Masoala created in 1997 is unrelated to the previous RNI and protects the largest continuous humid forests of eastern Madagascar [72].

Main issues: The threats to the natural habitats and biodiversity of Masoala are deforestation and the permanent transformation of the habitat through slash and burn practices, the fragmentation of the habitat, and the overexploitation of some timber species, especially rosewood and ebony since the late 2000s [46, 72], and in places some overexploitation of tuber and animals [73].

Case 2: The *Menabe-Antimena reserve* with a total area of some 194,000 ha covers almost entirely the center of endemism of the Menabe between the large Mangoky River to the south and the Tsiribihina River to the north. The Menabe is a topography inclining toward the Mozambique Channel of hemicircular shape of about 200 km from north to south and 150 km from east to west. The Menabe is a kind of small sedimentary basin with three levels of cuestas that has emerged since the Miocene. The region experiences temperatures of 23–26°C, annual rainfall of 740 mm in Morondava, which increase inward and with altitude. The irregularity of the precipitations associated with a very strong evapotranspiration creates a hydrological deficit. All of the rivers within the Menabe are dry for several months a year between April and September. The most remarkable endemic species of the Menabe is probably the 2 kg giant jumping rat *Hypogeomys antimena* active at night, herbivorous and frugivorous, and monogamous [74, 75]. The forests of Madagascar are characterized by their biodiversity, including for the plants; if most forests cannot be seen through their large trees as in some parts of Africa, the Menabe forests are the exception with the baobabs (*Adansonia* spp.) dominating the canopy. The dry forests of Menabe-Antimena have a “natural” protection against fire: a natural fire would not enter deep into the forest layers.

Main issues: As for the majority of the western dry forests of Madagascar, the main threat encountered in the Menabe-Antimena is the destruction of the forest through slash and burn cultivation (**Figure 5**); especially in the past year, these forests have been burning as never seen before. Since the late 2000s, an intensification of the extraction of precious hardwood has been further adding pressures to the forest system [16].

Case 3: *The National Park of Tsimanampetsotsa* (also spelled Tsimanampesotse or Tsimanampetsotse) lies in the Center of endemism of the Karimbola in the driest region of Madagascar. As early as 1927, a Strict Nature Reserve of 17,520 hectares protected the Lake Tsimanampetsotsa and the spiny forest on its eastern bank toward the Mahafaly Plateau. The reserve was extended to an area of 43,200 hectares in June 1966 before encompassing a large proportion of the Mahafaly Plateau and the full diversity of its ecosystems in 2007, totaling an area of 203,400 hectares. The park lies in a region with the lowest annual rainfall of the country (<500 mm) with no organized river network, perched water table, and sink holes where blind gobies (*Typhleotris* spp.) inhabiting the subterraneous water system can be seen [76]. The park protects a narrow ranged endemic carnivore *Galidictis grandidieri*, two species of land tortoises, several species of lemurs and birds, and a dry spiny forest thicket with a high level of endemism.

Main issues: The Park of Tsimanampetsotsa is threatened by human activities, including overexploitation of natural resources such as increased cutting of natural forests (**Figure 5**) and trafficking of the radiated tortoises *Astrochelys radiata* [77, 78].

A common feature of threat from the two western sites is that the buffer zones are suffering most deforestation; also, the new core zones are more affected by anthropogenic activities. Interestingly, the old core zones and buffers experienced almost no deforestation. It seems that people are respecting the old boundaries. The newly added areas are more under pressure of agricultural needs from the adjacent riverine human populations as it seems less clear, which zones are exactly under what management regime. These confusions represent an important loophole in the governance system of the parks in Madagascar, which comes to the detriment of forests and biodiversity. Nevertheless, the forests in Madagascar would be very likely much more degraded and deforested without any formal and real protection; thus, these case studies can report at least some success in conservation and management efforts.

4.3 Methodology

For Madagascar’s biodiversity analyses, we used the Noe4D database [19] comprising ca. 11,000 references and 52,800 georeferenced samples primarily documenting the endemic vertebrate fauna. We applied the layers provided in the Atlas of the vegetation of Madagascar [22] and the tree cover density Hansen/UMD/Google/USGS/NASA to evaluate forest cover and rates of deforestation on these three types of vegetation [79]. Data cleaning was conducted on the protected areas data sets, and the geometry was repaired due to self-intersections on each parcel of the data. Similar processing was done on the zonation of each protected areas, in addition to reprojection to similar coordinate system/projection. Vegetation data of Moat and Smith [22] and tree cover 2000 of Hansen [79] were clipped to the specified protected areas of interest, and both data sets were merged to get the type of vegetation per each pixel of the tree cover. The protected area zonation was then added to the merged data sets. Once the preparation of the data was completed, the tree loss data for the period 2001–2017 and the tree loss per each defined protected area zonation were calculated. Degraded humid forests on Masoala are significantly different from humid forests when a tree canopy density is higher than 90%. When we added the southwestern dry spiny forest-thicket layer on the tree cover density, we had to consider a tree cover density as low as 10% given that a tree cover density at 30% and higher did not reveal any forest cover; when choosing a tree cover density of 10% and above, the degraded southwestern dry spiny forest was also revealed (36.4% vs. 53.9%). The dry tropical forests are globally underestimated [80]. As shown in our case studies, the drier a forest, the higher the resulting underestimation of canopy cover. The southern and southwestern formations, because of their low stature and estimated low above ground carbon stocks, are of little interest for REDD+, which partly explains their low representativeness in the tree cover density's calculations. Nevertheless, these forests are extremely important in terms of endemic biodiversity, and we propose that a tree cover density of 10% be retained for this type of forest. Degraded dry forests cannot be distinguished from the intact dry forests [22]. Our analyses of the Menabe-Antimena suggest that a tree cover density not higher than 50% should be considered to evaluate the extent and quality of the Madagascar western dry forest.

5. Protected areas are gaining in importance

Deforestation in Madagascar has increased substantially in the past years [15]. Forests across Madagascar are being replaced for agricultural production, mainly through slash-burning, which does not halt at protected area boundaries. Fertility of freshly cleared forests yields production for few years only [81]. These lands are changing into grassland-dominated areas. This means that terrestrial biodiversity is increasingly restricted to protected areas, where some intact forests remain. The more the nonprotected areas are being denuded of their original vegetation cover, the more the protected areas are gaining importance for the survival of biodiversity.

The recent increase in the total area of protected areas in Madagascar (**Figure 4**) is clearly in line with the desire to protect Madagascar's biodiversity. The first stage of the process was completed in 2015 with the legalization of the status of these protected areas making the large expansion of the system. While Henri Humbert did not underestimate the complexity of protecting the natural wealth of Madagascar in 1946 [55], the current situation has certainly become more complex. To date, more threats are looming with a steadily and fast-growing human population in need of survival. Adding to the complexity is human-caused climate change, its impacts on biodiversity and ecosystem services are still to be researched in the case of Madagascar.

Several parks and reserves in Madagascar have been and are being researched with the aim to better understand how to protect the endemic biodiversity while resolving conflicts with the human populations relying on its ecosystem services for a livelihood. The parks and reserves selected in our case studies are the subject of research in this direction (e.g., SuLaMa in Tsimanampetsotsa, research by Harvard on Masoala, research by Durrell in Menabe).

The potential effects of anthropogenic climate change for Madagascar's biodiversity may likely be unparalleled in its recent geological history. As shown, the endemic biodiversity has experienced multiple paleoclimatic oscillations and other events that have shaped its biogeography. During the dry periods of recent paleoclimatic oscillations, there is no doubt that many taxa survived in refugia, typically places where vegetation and animals still had access to water. Populations of entire species have likely experienced some negative or positive fluctuations depending on their ability to cope with and adapt to dry conditions, as well as their ability to compete for scarce resources. The protected areas play an important role to ensure resilience of its biodiversity in the context of anthropogenic climate change. For this, a better understanding of how geomorphology, reliefs, watersheds, and paleo-refugia influenced the distribution of the endemic biodiversity is crucial.

5.1 Complexity bears challenges

The new protected areas phase has increased the structural complexity of governance, which came at the cost of efficiency and efficacy. Many authors have identified and listed factors that impact forest and protected area governance efficiency, such as financial and human resources constraints, or the remoteness and accessibility of protected areas or forests [4, 82–84]. Many of these aspects are of "technical" nature: (i) developing better management plans based on evidence rather than political or marketing reasons to attract further funding (e.g., [85]) that can lead to (ii) improved and more efficient implementation; (iii) capacity building of staff would, inter alia, also allow for (iv) a better optimization of the use of scarce financial and human resources. According to Mauvais, Coordinator of the IUCN Program on African protected areas, [86] "(…) improving governance will have an infinitely greater impact than just working on what we are doing or trying to do in the field," referring to the abovementioned, where technical hurdles are much easier to overcome, especially with the most recent developments in monitoring and in-time reporting of forest and park infractions (e.g., [87]). Tools like SMART (smart-conservationtools.org/) or novel ones like the GLAD alerts (https://glad.umd.edu/alerts), for example, allow the anticipation of forest fires, thus guiding management actions to address potential deforestation. The recording of forest soundscapes is also a promising and novel tool for monitoring biodiversity for conservation [88].

5.2 Implementing new policies

During the NEAP period in the 1990s, the international community spearheaded by the World Bank pushed the Malagasy government to implement forest governance devolution, that is, to better engage with riverine populations and have them engaged in the decision-making process and management of forests and protected areas. In rather a short time and with little evidence of success, more than 450 so-called transfers of management have been installed across Madagascar [89]. To date, it remains still unclear whether this comanagement has been fruitful [90, 91]. Main problems lie in the noncommunication between park agents and village representatives and the mutual nontrust in working together among other reasons (see [83] for an example of governance perceptions around the Zahamena National Park). As shown in our case study examples from the Tsimanampetsotsa or Menabe protected areas, core areas of the original parks (with higher restrictions) show much slower deforestation than areas under a comanagement agreement.

Before rushing into new policy implementations to mirror global trends, utmost caution needs to rule to best assess potential risks. The CBD's (Convention on Biological Diversity) Aichi-Targets (target 11) require that by 2020, "at least 17% terrestrial and inland water areas and 10% of coastal and marine areas, (…) are conserved." While the protected area approach is globally still the most powerful conservation tool to safeguard biodiversity (e.g., [92, 93]), a problem in Madagascar with increasing the protected area surfaces, both on land and sea, is that there is no automatic guarantee of increased protection. Rather, this will increase the already gargantuan task of governing and managing protected areas and its forests and biodiversity. Currently, there are over 1 million ha of protected areas (26 sites) of so-called "paper parks," that is, not managed at all [61]. One looming factor, regardless of governance and management, is the financing of these parks. If the international community is interested in safeguarding the unique biodiversity, which represents both, a national and global patrimony, then it should ensure the proper funding of it. Madagascar alone cannot stem the financial burden of the protected areas network [61].

6. Conclusions

The area of protected areas has been greatly increased over the past years. The protected areas represent last vestiges for intact forests, as fragmentation and degradation are advancing at fast pace mainly outside their borders. Governance has now the gargantuan task to ensure that the parks and reserves are fulfilling their role of protecting the endemic biodiversity of Madagascar. The endemic biodiversity is still far from being known, research needs to be maintained to document but also to adapt the network of protected areas to allow that the entire biodiversity can benefit from protection, as well as find adequate and necessary means to carry out this task (viz., conservation and management tools, and funds, to list but the most important once). The endemic biodiversity of Madagascar is an inestimable heritage for the generations of Madagascar and the world, and the parks and reserves are its best chance for the future.

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Conflict of interest

We declare no conflict of interests.

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