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MADAGASCAR CONSERVATION & DEVELOPMENT

INVESTING IN A SUSTAINABLE NATURAL ENVIRONMENT FOR FUTURE GENERATIONS OF HUMANS, ANIMALS AND PLANTS OF MADAGASCAR

IN THIS ISSUE

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TABLE OF CONTENTS

EDITORIAL

SPOTLIGHTS

ARTICLE

SHORT NOTE

ESSAY

ADDENDA

EDITORIAL http://dx.doi.org/10.4314/mcd.v17i1.6

Time to adjust our lenses?

GOOD COPS OR BAD COPS?

Two CoPs or Conferences of Parties were held in November 2022—the United Nations Climate Change Conference or Conference of the Parties of the UNFCCC in Egypt and the CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Conference of Parties in Panama. With science having clarified that the window for decisive, effective climate action is steadily closing, one potentially encouraging outcome of the Climate Change CoP 27 is the agreement for the creation of a historic fund to compensate vulnerable nations for 'loss and damage' from climate-induced chaos. Many critics, however, have lambasted the Climate Change CoP 27 (Global Witness 2022) and it remains to be seen what assistance will be provided by the global north to countries such as Madagascar (Aljazeera 2022), where the island's semi-arid southern region has been suffering from what the UN (2022) refers to as possibly the "world's first climate change-induced famine". While the UN's World Food Programme and a bevy of smaller NGOs and charities have been hard at work to provide both immediate relief and longer-term preparations to help impacted communities cope with climate-induced shocks and other difficulties, now is the time for the government—in the spirit of the exquisite Malagasy concept of fihavanana (cf. Madaliving 2022)—to adopt a proactive stance when it comes to completing further work on pipelines to transport more water into the heart of the southern Malagasy sub-desert (Saholiarisoa 2019). The resources are there. It is also timely for the government to step up efforts directed at dealing with factors other than climate change that have contributed significantly to the scenario presented on international media during the past 4 years (World Weather Attribution 2021, see also video DW Documentary 2022).

Perhaps more pertinent to this post is the second of the two atrociously carbon emission- intensive CoPs, the CITES CoP in Panama. Discussed all-too-briefly at the event was the ongoing issue of Malagasy rosewood and ebony, including the fate of some 40,000 illegally sourced logs that have been held in Singapore, Sri Lanka, and Kenya since 2014 (Roberts 2022, Roberts et al. 2022). The consignment in Singapore—valued at US$ 50 million at the time it was identified—represents the largest ever seizure of illegally trafficked CITES-listed species. Unfortunately, the likelihood of the consignment being returned to the very people responsible for its illegal export is high.

Briefly, the outcome from the CITES conference thus far, is that stockpiled logs—illegally sourced—across the country, are ostensibly to be used 'domestically'. By this is meant that the timber will be used for construction, building restoration and for "sale to domestic tourists, with items weighing a maximum of 10kg (Roberts et al. 2022). With regards the latter, questions that go begging are (a) what kind of items are 'domestic tourists' going want to purchase; (b) considering the heavy, dense nature of both rosewood and ebony, is that weight limit realistic; and (c), who will measure and monitor all these items, given the controversial nature of the wood? Whatever the answers to these questions may transpire to be, the message being broadcasted to international criminal syndicates is disastrous: it undermines the credibility of CITES and reinforces the feeling among traffickers of any contraband wildlife and forest-derived products, that it is open season and that they can operate with even more impunity.

Two things transnational criminal rings tend to have in order to achieve their aims, are the necessary resources to wait out unfavourable conditions when it comes to trading specific products, and strategically placed political connections. The latter is known to be the case in Madagascar (Butler 2010). Given the deeply corrupting effects that illegal logging always has on society in supply countries, it is the sincerest hope of many concerned observers that Madagascar's (as yet unaudited) timber stockpiles will not end up being used either as a laundering mechanism, or to finance the 2023 political elections.

TRUTH

Annually, the international nature enthusiast community is mortified upon seeing images flashed on social media of Madagascar's forests going up in flames. This is particularly the case when such images are of fires battering protected areas. Perhaps now is an opportune occasion for some clarification when it comes to fires associated with swidden agriculture, as well as their management.

It is now acknowledged that Madagascar was in fact not originally covered in forest as was proclaimed to be the case by early explorers who lacked the appropriately sophisticated technology to qualify such assumptions. Professor Dame Alison Richard eloquently spelled it out in her 2022 masterpiece "The Sloth Lemur's Song", for which she drew from 50-odd years of research. One of the messages in Richard's revelatory 2022 zoom lecture to introduce the book to the Anglo-Malagasy Society, was that the western world now ought to refrain from pointing fingers at Malagasy pastoralists and should stop accusing them of having destroyed approximately 90% of the island's forests. In her seminal output, Richard outlined how recent, cutting-edge research revealed the falsity perpetuated by previous theories about the extent of Madagascar's original forest cover. While many of us who have published literature on Madagascar now have revisions to attend to, Prof Richard did warn that the frenzied rate of deforestation during the last 50-odd years is a momentous cause for concern.

Another instance surrounding the examination of data on forest destruction—and in this case also, its management in Madagascar—occurred during the course of 2022. On studying a paper in the journal Nature Sustainability by Eklund et al. (2021), a group of us raised concerns about the accuracy of information published. But our meticulously compiled rebuttal was persistently rejected. Now, one would expect of a reputable journal to give ear to—and to respectfully publish—corrections, when information it has showcased, is called to question (Andrianambinina et al. 2022). This is all the more the case when inaccuracies can cause distress to conservation professionals in the profiled country. Apart from

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demonstrating that the data contained errors, our argument conveyed how Madagascar National Parks (MNP) managed the threat of fires to the Protected Areas throughout the lockdown period by actually intensifying their efforts. The journal has, to date, not published an errata section. All is not lost, however: the rebuttal which Nature Sustainability repudiated is included in this month's edition of MCD.

"Whoever is careless with the truth in small matters cannot be trusted with important matters."
—Albert Einstein, physicist

SHINE ON, LITTLE LIGHT

Somewhere in the depths of the seemingly unceasing, dark tide of collective fear, ignorance and its incessant negative consequences, a delightful little light flickered. On 4 October 2022 I received word from author and wildlife tour leader Daniel Austin of two separate sightings of Madame Berthe's mouse lemur (Truscott 2022), a species which experts, notably DPZ/ German Primate Centre, had feared might be extinct after extensive searches had failed to find it (Vyawahare 2022). What makes these observations that much more meaningful, is that the Critically Endangered *Microcebus berthae* is Man's tiniest relative. Let's pause on that for a while. Our adorable, pint-sized cousin is certainly extremely scarce: as was the case with the DPZ researchers, my own efforts to locate it in Kirindy and Marofandilia Forests in October 2019, didn't bear fruit. But as this image shows, the species is still thriving right where it belongs. Its natural home, the Menabe Antimena Protected Area—which still provides a mind-blowing wildlife experience for eco-tourists—is desperately vulnerable and truly deserving of increased protection.

Online reviews reflect that the fortunate tour group mentioned, had the time of their lives in Madagascar, illustrating that high end, low volume, nature-based tourism has for the most part, enjoyed a successful post pandemic restart. The vast majority of eco-tourists, who patiently postponed travel through 2020 and 2021, have shared ebullient feedback, despite a catalogue of preventable hindrances. Some of these are being addressed, notably the marked reduction of domestic flights and maintenance of roads. Others, such as the cessation of direct flights between Johannesburg and Antananarivo, are apparently not. Worth mention is an announcement made recently by the incumbent president, who expressed that it is necessary for Madagascar to import East African herbivores such as Giraffes and Zebras (Caramel 2022), in order to boost tourist numbers to the island. This preposterous notion was met with a combination of outrage, disappointment among Malagasy commentators and rip-roaring laughter. The truth is, Madagascar has more than enough in terms of utterly fascinating, endemic animals and plants. Its scenic highlights are second to none. There are more than enough international eco-tourists yearning to explore the island's wild places; appreciate its

Critically Endangered Madame Berthe's mouse lemur *Microcebus berthae* is Man's tiniest relative. Photo courtesy of Mike Lowings.

endemic wildlife and flora and learn about Malagasy culture. There is nothing wrong with the existing supply of accommodation servicing the more accessible tourist locations. What could be incentivised is investment to revamp a number of properties standing partially derelict or closed down, but which have great potential. That, coupled with realistic, empathetic PR aimed at encouraging the right kind of travellers with a responsible ethic, could deliver the boost Madagascar's tourism industry needs. For the most part, the ingredients are already in place.

LOOKING AHEAD

Madagascar's immense resources—minerals in particular—would make anyone wonder why the nation isn't prosperous. Author Nathaniel Adams delved into this frustrating conundrum in his recently published "The Tragedy of Madagascar" (Adams 2022). In an interview, Adams discussed elements preventing the country from flourishing, such as 'elite capture'. He described how the government is not doing what it should be, to address, for example, the state of the southern region where the combination of drought and the unsustainably high birth rate has been devastating. On seeing the recent documentary "Climate Change or Politics—Why Madagascar is Going Hungry" (DW Documentary 2022), veteran Africa journalist Duncan Guy, who covered the same story in 1992, expressed dismay at how much worse conditions appear to be in the 'Androy' the island's remarkable southern sub-desert.

Do things in Madagascar really have to be like a gigantic smash-up? That, only the Malagasy people can answer. It is their situation and exclusively theirs to resolve. Following on from thoughts expressed earlier, it is the most heartfelt hope of innumerable observers, that those currently holding political power, will honour the Malagasy nation by not forsaking the way of fihavanana, something precious which we can all learn from, and something which when observed personally, never fails to leave visitors feeling humbled and moved on a very deep level.

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SPOTLIGHTS http://dx.doi.org/10.4314/mcd.v17i1.2

CITES must urgently take the steps to save Madagascar's unique species of rosewood and ebony

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ABSTRACT

This contribution is an open letter to all CITES Management and Scientific Authorities, which is signed by all of the co-authors. As CITES convenes its 19th Conference of the Parties in November 2022, some of the largest seizures in history of illegally harvested CITES-listed species are poised to be handed back to the criminals who smuggled them out of Madagascar. Nearly 40,000 rosewood logs were illegally exported from the country in 2014, in clear violation of CITES and national embargos, as explicitly declared in Notices issued by the CITES Secretariat. The logs were seized by Singapore, Kenya, and Sri Lanka, but as a result of both passive and active interference from various Malagasy officials and aggressive use of these countries' national court and political systems, orders have now been issued for the logs to be returned to the smugglers. Release of this wood would have catastrophic consequences for the future sustainable management of Madagascar's remaining rosewood and ebony resources. We propose five essential steps that should be taken at the upcoming CITES CoP 19 in Panama to prevent this from happening.

RÉSUMÉ

Cette contribution est une lettre ouverte adressée à toutes les instances scientifiques et de gestion de la CITES, qui est signée par tous les co-auteurs. Alors que la CITES convoque sa 19e Conférence des Parties, en novembre 2022, plusieurs saisies importantes, les plus volumineuses de l'histoire dans un cas, d'espèces inscrites à la CITES et exploitées illégalement sont sur le point d'être rendues aux criminels qui les ont fait sortir clandestinement de Madagascar. Près de 40 000 rondins de bois de rose ont été sortis en contrebande de Madagascar en 2014, en violation flagrante de la CITES et des embargos nationaux, comme le déclarent explicitement les avis émis par le Secrétariat de la CITES. Ces rondins de bois de rose ont été saisis par les autorités douanières de Singapour, du Kenya et du Sri Lanka, mais suite à une ingérence active et passive de divers fonctionnaires du gouvernement de Madagascar et un usage agressif des systèmes judiciaires et politiques nationaux des pays dans lesquels les saisies ont eu lieu, l'ordre a maintenant été donné de restituer ces rondins aux contrebandiers. Nous énumérons ici cinq mesures essentielles qui doivent être prises lors de la prochaine CdP 19 à Panama pour empêcher que cela ne se produise.

THE LETTER

The illegally exported rosewood (*Dalbergia* spp.) and ebony (*Diospyros* spp.) logs harvested in Madagascar and seized by authorities in Kenya, Singapore, and Sri Lanka in 2014 (Butler 2014, CITES 2022a, EIA and TI 2022) highlight a major weakness in CITES enforcement and its ability to control trade that is detrimental to species (Figure 1). While arrests are up, the likelihood of confiscation or successful prosecution is limited. It is much less risky to traffic in rare and endangered species than to engage in gun, drug, or human trafficking (Nellemann et al. 2014, Interpol 2021). In order to be effective, CITES must ramp up the penalty provisions of its model legislation and regulations to significantly raise the stakes for the criminal syndicates that are undermining the Convention's effectiveness. The CITES Secretariat must be provided with both the mandate and resources to assist countries that have seized material of listed species so they can prosecute criminals engaged in illegal trafficking and ensure that the punishments are as severe as those for other international smuggling crimes (imposing meaningful periods of imprisonment and severe fines, along with confiscation of seized animals, plants, and/or their parts).

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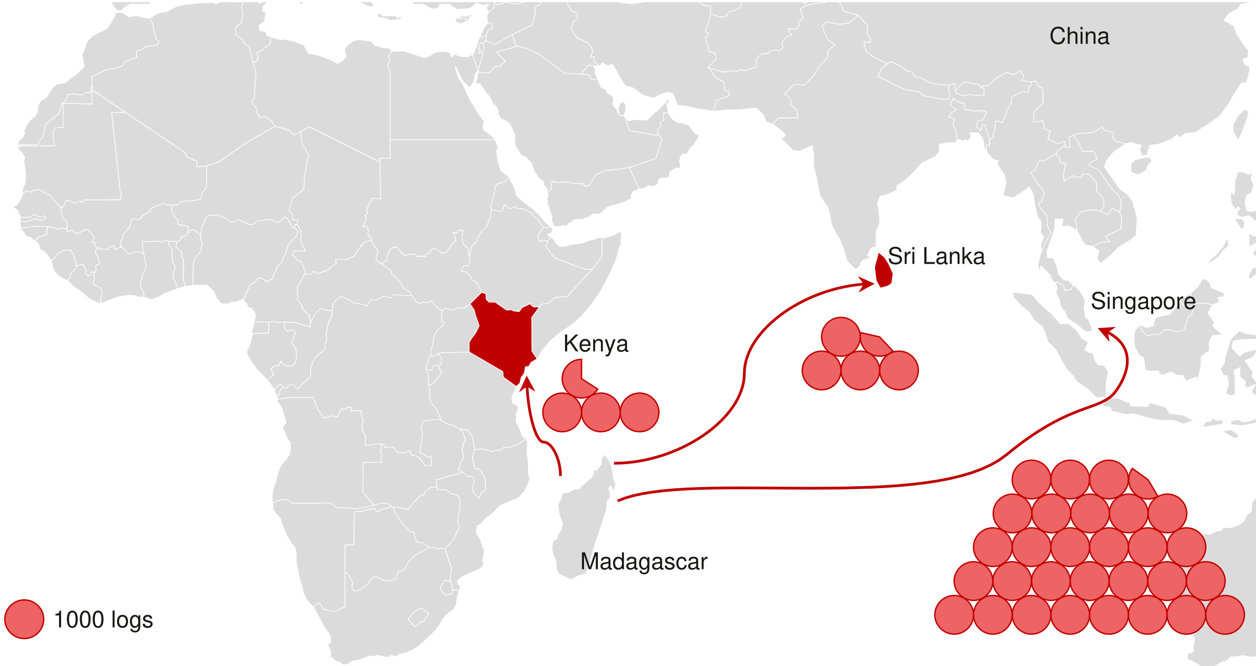

Figure 1. Rosewood stocks seized in 2014

In addition to the material seized in Kenya, Singapore, and Sri Lanka, Madagascar has proposed to take possession of the ca. 30,000 logs in the official stockpiles of rosewood and ebony still in the country, removing them from CITES jurisdiction based on the proposal that the wood will be used to restore public buildings and to make "handicrafts" weighing no more than 10 kg to be sold exclusively to domestic tourists (CITES 2017, Wilmé et al. 2020). But this plan contains no information on how wood supposedly designated for use in public buildings will be identified and tracked. Moreover, there is no clear plan on how the logs will be managed to prevent yet another wave of illegal trade being unleashed, as has happened time and again in the past (Randriamalala and Liu 2010, Wilmé et al. 2020). There is a very real risk that implementation of the proposed plan will reignite Madagascar's dormant laundering mechanisms, sealing a very different fate for the massive stockpiles of rosewood and ebony hidden in plain sight throughout the country.

Because the official stockpiles have never been properly audited and secured, it will be an easy matter to claim that a significant portion were "discovered" in "undeclared" and "hidden" stockpiles. This will once again trigger a new rush to illegally harvest and export Malagasy rosewood and ebony species, including many that are already threatened with extinction. Even legal trade would put many species of *Dalbergia* and *Diospyros* at further risk of extinction (Lowry et al. 2022, Phillipson et al. 2022).

In conjunction with the placement of all Malagasy rosewood and ebony on CITES Appendix II in 2013, an Action Plan was adopted outlining the steps that would be needed to demonstrate that proposed trade of certain species would not be detrimental to their survival and to produce identification tools for monitoring and controlling trade (Mason et al. 2016). The CITES Intersessional Advisory Group has supported the implementation of the Action Plan, but it is far from being fully achieved. While significant progress has been made in clarifying species limits in both *Dalbergia* and *Diospyros* and in developing reliable tools to identify standing trees prior to harvest, methods for the identification of logs, cut wood, and finished products, critical for effective management and control, are still being developed (Waeber et al. 2019). Likewise, Madagascar's forestry sector has very limited experience with sustainable management practices, which will be required both to ensure that only limited quantities of appropriate species are harvested (and that threatened species are prohibited from exploitation) and that concessions are conserved and well managed for decades until the resource has been replenished—all of which will be essential if Madagascar is to achieve its stated goal of achieving sustainable and equitable exploitation of its precious woods.

At the upcoming CoP 19 (14–25 November 2022), CITES Parties, along with the Governments of Madagascar, Singapore, Kenya, and Sri Lanka, must do the following (Figure 2):

1. Prevent the approximately 40,000 logs of Malagasy rosewood (*Dalbergia* spp. Fabaceae) and ebony (*Diospyros* spp. Ebenaceae) seized in Singapore, Kenya, and Sri Lanka (Figure 1)—hereafter referred to as "precious wood"—from being returned to the smugglers who illegally exported them from Madagascar in 2014.

2. Fund and provide the expertise needed to implement all of the elements of the 2013 Madagascar Rosewood and Ebony Action Plan, including identifying species, auditing and securing all in-country stockpiles of rosewood and ebony, conducting non-detriment findings, and improving forest governance to protect the remaining rosewood and ebony trees.

3. Extend and expand the mandate of the Intersessional Advisory Group to aid in the full implementation of all of the elements of the 2013 Action Plan and to formulate disposal plans for the seized logs and stockpiles that will not be detrimental to the survival of the Malagasy species of rosewood and ebony.

4. Take immediate steps to halt ongoing illegal harvest of precious wood in Madagascar, which often goes unreported, in part due to the economic situation resulting from the COVID-19 pandemic and resulting enforcement vacuum.

5. Reject the Malagasy government's plan to use any stockpiles of rosewood and ebony logs, including those that are "officially controlled", for domestic purposes until the 2013 Action Plan

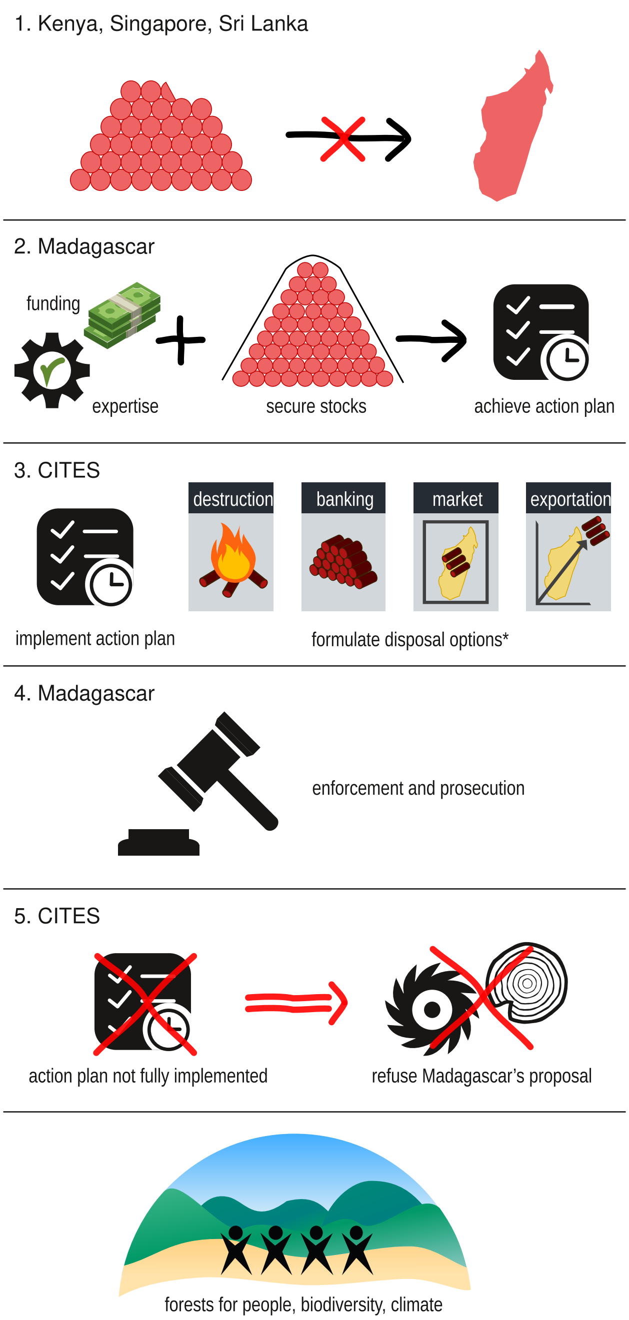

Figure 2. CITES Parties, and the Governments of Madagascar, Singapore, Kenya and Sri Lanka must fulfill their acts to stop illegal trafficking of rosewoods and ebonies. (* see Wilmé et al. 2020 for details)

has been fully implemented and any such use can be conducted in a manner that is demonstrably not detrimental to the survival of the Malagasy species of rosewood and ebony.

Madagascar is one of the planet's richest biodiversity hotspots, but while the world stands by idly, illegal and unsustainable logging of rosewood, ebony, and other sources of precious wood continues unabated in habitats that are critical for thousands of animal and plant species found nowhere else on Earth.

We ask for broad support to establish a CITES working group to address each of these issues, which should be empowered to amend the Draft Decisions (CITES 2022b,c) on Madagascar rosewoods (*Dalbergia* spp.) and ebonies (*Diospyros* spp.) so that all these actions are formally adopted.

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Aperçu sur la fragmentation de la forêt naturelle dans la Réserve Spéciale d'Ambohitantely et ses alentours entre 1949 et 2017, Hautes Terres Centrales

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RÉSUMÉ

Cette étude vise à caractériser la dynamique de la couverture forestière et la fragmentation de la forêt naturelle de la Réserve Spéciale d'Ambohitantely et les zones périphériques dans un rayon de 10 km de la limite de l'aire protégée entre 1949 et 2017. Au total, cinq images satellitaires pour les années 1989, 1995, 2002, 2010 et 2017, et 59 clichés de photographies aériennes prises en 1949 ont été utilisées. La télédétection et le système d'information géographique ont été utilisés pour la cartographie de l'occupation du sol pour les six périodes d'études, ainsi que pour l'analyse de la dynamique de la couverture forestière et l'estimation de la perte de surface forestière. Six métriques disponibles sur le logiciel FRAGSTATS ont été sélectionnées pour l'analyse de la fragmentation à l'échelle du paysage à savoir, le nombre de parcelles (NP), la densité de parcelles (PD), la variabilité de la taille des parcelles (AREA_SD), l'indice de la dimension fractale (FRAC_MN), l'indice de contiguïté (CONTIG_MN) et l'indice d'agrégation (AI). Après une classification supervisée, les classes d'occupation du sol ont été reclassées en forêt ou non-forêt. La dynamique de la couverture forestière dans la zone étudiée a montré qu'une vaste zone forestière a été convertie en zone non forestière. L'estimation de la perte de forêt indique que le taux annuel dans la réserve varie, et la plus importante estimée à 586,4 ha soit 4,05% par an a été enregistrée entre 1995 et 2002, et la plus faible est de 473,4 ha soit 0,41% par an, entre 1949 et 1989. Les résultats ont montré la diminution du nombre de fragments ainsi que la densité des fragments depuis 1989 à 2017, ce qui indique la disparition de fragments forestiers. En parallèle, la réduction de l'indice de la dimension fractale et de la variabilité de la taille des parcelles révèlent la simplification de la forme des fragments et la faible diversification de la superficie des différents fragments. L'augmentation de l'indice d'agrégation contre la diminution de l'indice de contiguïté confirme l'isolement des fragments.

ABSTRACT

This study aims to characterize the dynamics of forest cover and fragmentation of the natural forest of the Ambohitantely Special Reserve between 1949 and 2017 and within a radius of 10 km of the boundary limit. Five different periods of satellite images were employed, specifically the years 1989, 1995, 2002, 2010, and 2017, as well as aerial photographs taken in 1949. Remote sensing and geographic information systems were used for land cover mapping for the six study periods, as well as for analyzing forest cover dynamics and estimating forest cover loss. Using the software FRAGSTATS, six different metrics were selected for the analysis of forest fragmentation at the landscape level: number of patches (NP), patch density (PD), patch size standard deviation (AREA_SD), mean patch fractal dimension (FRAC_MN), contiguity index (CONTIG_MN), and aggregation index (AI). Following a supervised classification, land cover classes were reclassified as forest or non-forest. The dynamics of forest cover at the site and over the study period indicated that considerable zones of forest were transformed to non-forested areas. The estimate of forest loss indicates that the annual rate in the reserve varies, and the largest estimated at 586.4 ha or 4.05% per year was recorded between 1995 and 2002, and the lowest is 473.4 ha or 0.41% between 1949 and 1989. The results indicate a decrease in the number of fragments as well as the density of fragments from 1989 to 2017 associated with the disappearance of forest. In parallel, the reduction of the mean patch fractal dimension and variability of the patch size denotes the simplification of the fragments' shapes and the slight diversification of the areas of the different fragments. An increase in the aggregation index as compared to a decrease in the contiguity index confirms the isolation of the fragments.

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INTRODUCTION

La Réserve Spéciale d'Ambohitantely est l'un des rares fragments de forêt indigène qui subsistent sur les Hautes Terres Centrales de Madagascar. Depuis plusieurs décennies, le feu dû au renouvellement des pâturages a causé les plus grands dommages à la forêt d'Ambohitantely et a contribué le plus à son changement (Bastian 1964, Goodman et al. 2018). Le problème de feu s'est beaucoup atténué grâce à l'installation de pare feu ; en 2016, cinq points de feu ont été détectés à l'intérieur de l'aire protégée, contre 46 points de feu dans un rayon de 5 km autour de la réserve. Cet écart est directement lié à l'utilité de pare-feu pour protéger ces blocs forestiers restants qui ont une grande importance pour la conservation (Goodman et al. 2018). Sous l'effet du feu, les conditions édaphiques se dégradent, favorisent le développement des espèces allochtones et réduisent la surface occupée par les espèces autochtones (Jacquin 2010, Ehrensperger et al. 2013). Ainsi, les lisières s'étendent et inversement la surface forestière diminue d'où l'isolement des fragments et la fragmentation des blocs forestiers. L'effet de la fragmentation agit comme une sorte de barrière qui réduit les possibilités de migration, de reproduction et de dispersion des espèces animales et végétales dépendant de la forêt (Murcia 1995, Andrén 1996, Fahrig 2017). Par exemple, pour les lémuriens, la perte significative de la diversité génétique allant jusqu'à la disparition de certaines populations dans les fragments de petites tailles et isolés suggèrent un effet néfaste de la fragmentation (Guschanski et al. 2007, Olivieri et al. 2008, Craul et al. 2009). En plus, le régime alimentaire des lémuriens et leur cohésion intra-groupe sont aussi fonction de l'aspect de la fragmentation et de la superficie du fragment forestier (Irwin 2007). Cependant, l'impact de la fragmentation de l'habitat, et de l'effet des lisières ne peuvent pas être généralisés, car ils varient selon les espèces concernées, le type de pression, la région phytogéographique et la saison d'étude (Lehtinen et al. 2003, Gardner 2009).

La plupart des études relatives à la fragmentation réalisées dans la Réserve Spéciale d'Ambohitantely sont concentrées sur l'effet de la fragmentation sur la distribution et la diversité des vertébrés ; tel le cas des oiseaux (Langrand et Wilmé 1997), des petits mammifères (Goodman et Rakotondravony 2000) et des amphibiens (Vallan 2000), et les paramètres les plus cités étaient la taille et la contigüité des fragments. A l'issue, une relation négative entre la richesse spécifique et la taille des fragments forestiers à Ambohitantely a été constatée (Ratsirarson et Goodman 2000). La majorité des données utilisées dans ces analyses ont été dérivées de l'interprétation des photographies aériennes prises en 1991 (Langrand et Wilmé 1997). Dans une perspective de conservation et de restauration du paysage, la compréhension de l'évolution de la fragmentation a une importance cruciale (Hervé et al. 2020). Cependant, les données disponibles sur la fragmentation de la forêt d'Ambohitantely restent non actualisées, avec la dernière analyse remontant à 1991 (Langrand 1995).

L'objectif principal de cette étude est de quantifier la tendance de la fragmentation de la forêt d'Ambohitantely et ses alentours entre 1949 et 2017. Les objectifs spécifiques sont les suivants : (i) Réaliser des cartes d'occupation du sol pour chaque année d'étude, (ii) Estimer les pertes de forêt entre chaque intervalle de temps, (iii) Détecter les changements au niveau de l'occupation du sol entre 1949 à 2017 et (iv) Quantifier les aspects de la fragmentation dans la zone d'étude. L'hypothèse émise dans cette recherche est que les données de différentes périodes et les approches adoptées révèleraient la tendance spatio-temporelle de la réduction de la superficie et la fragmentation de la forêt d'Ambohitantely et de ses alentours.

MÉTHODOLOGIE

MILIEU D'ÉTUDE. La zone d'étude couvre une superficie de 75 893 ha. Elle englobe la Réserve Spéciale d'Ambohitantely et s'étend dans les zones périphériques comprises à une distance de 10 km aux alentours de la limite de l'aire protégée. La réserve est située dans l'ex-province d'Antananarivo, région d'Analamanga et district d'Ankazobe. Elle est accessible suivant la RN4 reliant Antananarivo et Mahajanga, à environ 30 km au nord de la ville d'Ankazobe. La réserve a été créée selon le décret n° 82-078 du 12 février 1982, et elle est gérée par Madagascar National Parks (MNP).

Concernant le type de bioclimat, la zone d'étude appartient à « l'étage subhumide, sous étage à saison sèche atténuée par des brouillards » (Cornet 1974). Elle est marquée par une saison froide et sèche entre juin et août, avec une température moyenne minimale de 5,7°C, alternée avec une saison chaude et pluvieuse entre décembre et février avec une température moyenne maximale de 29,3°C (Goodman et al. 2018). La moyenne des précipitations annuelles est de 1461 mm. La zone d'étude est constituée par une mosaïque de forêt dense humide sempervirente de moyenne altitude (végétation climacique) et de prairie secondaire (Gautier et al. 2018).

DONNÉES UTILISÉES.

Photographies aériennes : Des photographies aériennes prises en 1949 couvrant la Réserve Spéciale d'Ambohitantely et toutes les zones dans les 10 km aux alentours ont été collectées auprès de la Foibe Taotsaritanin'i Madagasikara (FTM). Au total 59 clichés ont été compilés dont les détails importants sont donnés sur le Tableau 1.

Images satellites : Les images satellites fournies par Landsat TM (Thematic Mapper) de 1989, 1995, 2002 avec 8 bandes spectrales de 30 m de résolution spatiale et OLI-TIRS Landsat 8 de 2010 et 2017 contenants 11 bandes spectrales de 30 m de résolution spatiale couvrant la zone d'étude ont été téléchargées sur le site de l'USGS (http://earthexplorer.usgs.gov/). Les images ayant moins de 20% de couverture nuageuse ont été priorisées pour les analyses. Le Tableau 2 résume les principales caractéristiques des images satellites utilisées.

Table 1. Caractéristiques des photographies aériennes utilisées dans cette étude.

Caractéristiques	Descriptions
Missions	013/400/1949 et 023/400/1949
Dates	06 Juin 1949, 23 Juillet 1949 et 09 Septembre 1949
Type de jeu de photos	Noir et blanc
Echelle de la photographie aérienne	1/40000e
Taux de recouvrement de la photographie aérienne	65 à 75% (recouvrement frontal) dans l'axe du vol et 20 à 45% (recouvrement latéral) dans l'autre axe
Dimension	25 cm x 25 cm

Tableau 2. Caractéristiques des images Landsat utilisées dans l'analyse.

Années de référence	Date de prise de vue	Références	Résolution spatiale
1989	19 Mars 1989	LT05_L1TP_159073_19890319_20170204_01_T1	30 m
1995	20 Mars 1995	LT05_L1TP_159073_19950320_20170109_01_T1	30 m
2002	26 Nov. 2002	LE07_L1TP_159073_20021126_20170127_01_T1	30 m
2010	30 Avril 2010	LT05_L1TP_159073_20100430_20161015_01_T1	30 m
2017	03 Nov. 2017	LE07_L1TP_159073_20171103_20171129_01_T1	30 m

TRAITEMENT DES IMAGES SATELLITES. Le prétraitement des données a pour finalité d'améliorer et de géoréférencer les images satellites. Le logiciel ArcGIS version 10.1 a été utilisé pour la totalité des analyses comprenant : la correction géométrique, la correction radiométrique, la correction atmosphérique et le géoréférencement qui a consisté à projeter les images satellites dans le système de projection WGS 84—UTM zone 38 Sud. Ensuite, les phases de traitement et de classification des images ont permis d'extraire des informations à partir des images prétraitées. L'ensemble des bandes constituant les images pour chaque année d'étude ont été importées dans ArcGIS, pour créer la composition colorée qui s'avère efficace pour distinguer les différentes classes d'occupation de sols. Sous ArcGIS, une zone tampon défini à partir d'une distance de 10 km autour de la Réserve Spéciale d'Ambohitantely a été générée afin de délimiter la zone d'étude.

La méthode de classification supervisée basée sur l'algorithme de maximum de vraisemblance a été appliquée pour élaborer la classification de l'utilisation du sol. Ainsi, il est nécessaire de générer des sites d'entrainement pour calibrer l'algorithme de classification. Ceci permet de s'assurer que les classes spectrales constituant chaque catégorie d'utilisation du sol étaient suffisamment représentées dans la statistique d'entraînement. Les données d'entrainement ont été recueillies à partir de l'interprétation visuelle de l'image Landsat, l'examen de la texture et structure des imageries plus précises de Google Earth et l'observation de 34 points de vérification sur terrain (Figure 1). Ce processus a été effectué pour toutes les six classes et enregistré sous un fichier de signature sous ArcGIS, qui est

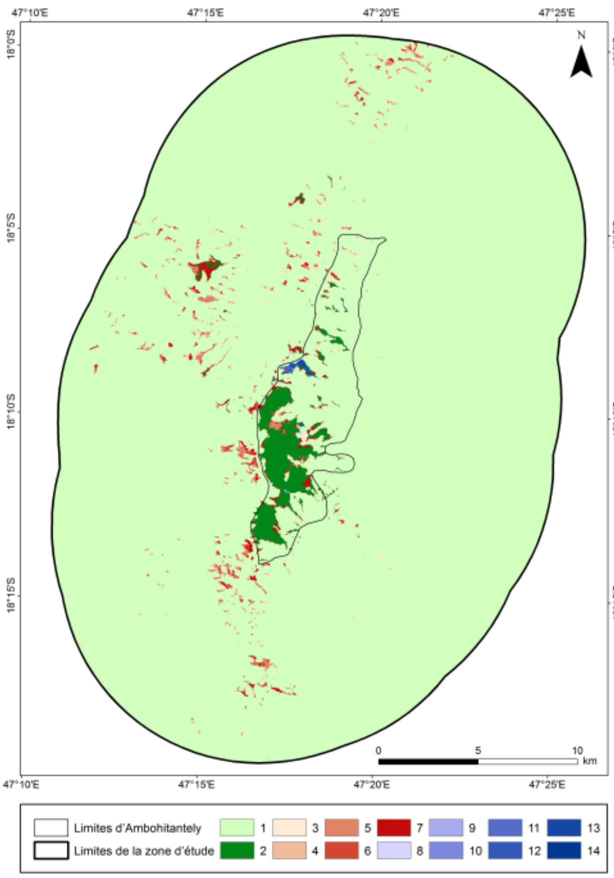

Figure 1. Cartographie de l'occupation du sol (d'après l'image Landsat (2017) ; les blocs forestiers utilisés dans des études antérieures sur l'impact de la fragmentation forestière des vertébrés à savoir Langrand et Wilmé (1997), Goodman et Rakotondravony (2000), et Vallan (2000) ont également été indiqués).

nécessaire pour la classification supervisée. L'indice de végétation par différence normalisé ou IVDN a été également créé pour affiner la classification. Une descente sur terrain mi-novembre 2018 a été menée dans le but de collecter des données sur les zones douteuses et autres formes de vérification sur place. Cette descente sur terrain a permis de comprendre l'état de la végétation d'Ambohitantely et de définir les différentes formations végétales pour affiner la cartographie de l'occupation du sol de 2017. A partir des données de la vérification sur terrain, les zones mal classées ont été corrigées à l'aide de l'outil de reclassification dans ArcGIS. Le coefficient Kappa a été utilisé pour évaluer la précision de la carte thématique produite. Les six classes de végétation et d'occupation des sols suivantes ont été retenues : forêt dense humide sempervirente de moyenne altitude et autres formations, savane arborée, forêt dégradée, savane herbeuse (ici prairie herbeuse) et végétation rupicole (Rajeriarison et Faramalala 1999).

INTERPRÉTATIONS DES PHOTOGRAPHIES AÉRIENNES. Les protocoles de photo-interprétations adoptés dans cette étude ont été adaptés à partir de ceux utilisés par Muraz et al. (1999) et Piney (2010). Les traitements ont été réalisés avec le logiciel ArcGIS version 10.1. Les 59 clichés aériens ont été numérisés avec une résolution de 400 dpi puis rectifiés orthogonalement en images raster. Ces derniers ont été géoréférencés en utilisant la carte topographique produite par FTM 1960 et les images satellites prétraitées comme carte de base. L'intersection des rivières, les routes ou d'autres éléments ont été utilisés comme points de contrôle. Les paramètres d'orientation et d'étalonnage ont été déduits à partir de la carte d'assemblage fournie par la FTM. Les images géoréférencées et mosaïquées ont été projetées dans le système de coordonnées géographiques UTM zone 38 Sud. L'échelle de 1/80000e a été la meilleure pour distinguer les forêts des autres éléments. Une cartographie d'occupation du sol comprenant deux classes, forêt ou non-forêt a été obtenue à l'issue de la photo-interprétation.

ESTIMATION DES TAUX DE RÉDUCTION FORESTIÈRE. Avant d'aborder le calcul des taux de réduction forestière, la définition des termes forêts, zones non-forêt et perte de couverture forestière s'avère importante. Selon la FAO et JRC (2012), la forêt est caractérisée par une canopée fermée à plus de 60% constituée par des arbres de plus de 5 m de hauteur. Sur les photographies aériennes et les images satellitaires Landsat, elle apparait sous une couleur plus sombre et de texture grossière couvrant au moins une surface de 1 ha. La déforestation est la conversion de la forêt à d'autres utilisations des terres (FAO et JRC 2012). Ici, la perte de la couverture forestière dénote l'apparition de zone non-forêt définie par une couverture de la canopée de moins de 30%, avec des arbres inférieurs à 5 m de hauteur (FAO et JRC 2012). Sur les photographies aériennes et les images satellitaires Landsat, elle est différenciée par une couleur assez sombre à claire et de texture moins dense à fine. Les taux de réduction forestière peuvent être exprimés en tant que superficie déboisée sur une période donnée par rapport à la superficie forestière initiale (Puyravaud 2003). Cependant, l'intervalle de temps entre les dates des images satellites et les photos aériennes prises dans cette étude sont variables, allant de 6 à 40 ans. Pour atténuer cette différence, le calcul du taux de perte de forêt (Puyravaud 2003) résumé dans l'équation 1 a été adopté.

$$R = \frac{1}{T2 - T1} \ln \frac{A2}{A1}$$

Avec R le taux de la perte de forêt entre la date initiale ou T1 et la date finale ou T2 ; A1 la superficie de la forêt à la date T1 et A2 la superficie de la forêt à la date T2.

DÉTECTION DU CHANGEMENT AU NIVEAU DE LA COUVERTURE VÉGÉTALE. L'état de la couverture forestière à une date T2 a été évalué en superposant l'occupation du sol à la date T2 avec celle de la date T1 (année antérieure). En procédant à l'analyse, les possibilités suivantes ont été attendues : (i) Aucun signe de changement, si la zone forêt au temps T1 reste forêt au temps T2 ou encore la zone non-forêt au temps T1 est toujours non-forêt au temps T2. (ii) Déforestation, si la zone forêt au temps T1 devient zone non-forêt au temps T2. (iii) Régénération forestière, si la zone non-forêt au temps T1 devient zone forêt au temps T2. Enfin, les résultats des changements au niveau de la couverture végétale pour tous les six intervalles de temps sont représentés sur la carte d'occupation du sol de 2017.

QUANTIFICATION DE LA FRAGMENTATION DU SITE D'ÉTUDE. Le logiciel FRAGSTATS version 4.2 (McGarigal et Marks 1995) a été utilisé pour le calcul de diverses métriques permettant de caractériser la fragmentation dans la zone d'étude. Du point de vue pratique, le terme « paysage » dans FRAGSTATS exprime une échelle à laquelle les parcelles sont considérées dans son ensemble. Dans cette étude, les parcelles représentent chaque fragment forestier ou blocs forestiers. Le choix des métriques à retenir dans les analyses s'appuie sur les données disponibles issues du traitement d'image. Six types de formations végétales ont été distingués dans la zone d'étude, mais pour simplifier les analyses, l'occupation du sol a été classée seulement en deux catégories dont les forêts naturelles et les non-forêts. La classe des forêts naturelles représente les forêts denses humides sempervirentes de moyenne altitude, et la classe des non-forêts comprennent les savanes arbustives, les prairies herbeuses, les formations rupicoles, la plantation d'*Eucalyptus* et les zones défrichées. Les analyses ont été paramétrées à l'échelle du paysage et six métriques basées sur la taille, la forme, l'agencement et la distribution spatiale des fragments (McGarigal et Marks 1995) ont été sélectionnées : (i) le nombre de parcelles (NP) permet de compter tous les fragments présents et apporte ainsi de l'indication concernant le degré de morcellement. Plus le nombre de fragments est élevé, plus le morcellement est important ; (ii) la densité des parcelles (PD) mesure le nombre des fragments par unité de surface. Une densité de parcelles plus élevée indique qu'il y a plus de fragment donc considéré comme beaucoup plus fragmenté ; (iii) l'indice de la taille des fragments (AREA_SD) donne des informations sur la variabilité de la taille des fragments. Plus la valeur de l'AREA_SD est élevée, plus la taille des fragments est variée ; (iv) l'indice de la dimension fractale (FRAC_MN) mesure la complexité des formes d'un paysage. Cet indice est faible (voisin de 1,0) quand le paysage est constitué de fragments de formes géométriques simples. Au contraire, il est élevé quand les fragments constituants le paysage sont de formes tortueuses et compliquées ; (v) l'indice de contiguïté (CONTIG_MN) mesure l'agrégation des fragments au niveau du paysage en tenant compte de la connectivité spatiale des cellules dans chaque fragment. L'indice prend une valeur entre 0 et 1. Plus, l'indice est élevé, plus il y a connectivité ; et (vi) l'indice d'agrégation (AI) informe sur la distribution spatiale des fragments dans un paysage. Un faible indice d'agrégation signifie que le paysage est très fragmenté, inversement si cet indice est élevé alors les fragments du paysage sont plus agrégés.

Pour calculer les métriques de paysage, les fichiers rastérisés de la zone d'étude des six années étudiées 1949, 1989, 1995, 2002, 2010 et 2017 ont été importés dans FRAGSTATS. Le résultat issu de l'analyse avec ce logiciel est fourni sous forme de tableau, mais pour bien suivre la tendance de l'évolution de la fragmentation de la forêt d'Ambohitantely sur une longue période de 1949 à 2017, la présentation des résultats sous forme de courbe a été adoptée.

RÉSULTATS

STATUT DE L'OCCUPATION DU SOL DE 1949 À 2017. Après la classification de l'image Landsat 2017 basée sur les réponses spectrales et les investigations sur terrain de 2018, six classes d'occupation du sol ont été créées à savoir : forêt dense humide sempervirente de moyenne altitude, savane arbustive à *Erica* (Ericaceae) et *Pteridium* (Dennstaedtiaceae), prairie herbeuse, formation rupicole, plantation d'*Eucalyptus* (Myrtaceae) et une zone récemment défrichée. La représentation cartographique de l'occupation du sol en 2017 a été préparée à l'échelle 1/80000e (Figure 1). Un total de 1302,4 ha de forêt naturelle a été estimé en 2017 pour l'ensemble de la Réserve Spéciale d'Ambohitantely et les zones dans les 10 km de sa périphérie. La carte sur la Figure 1 a également été utilisée comme référence pour l'identification des changements dans les catégories d'occupation du sol. Les cartes d'occupation du sol pour les périodes de 1949 à 2010 sont présentées dans le matériel supplémentaire.

Le résultat de l'étude a montré un changement d'occupation de sol dans la plupart des types de végétation pendant la période d'étude c'est-à-dire une diminution de la superficie de la forêt dense humide sempervirente de moyenne altitude (Tableau 3). Due à l'effet des pressions sur la réserve, il est important de noter la réduction progressive de la forêt et inversement l'accroissement de la superficie des zones non-forêts depuis 1949 à 2017.

ANALYSE DE LA DYNAMIQUE DE LA COUVERTURE VÉGÉTALE. La superposition des cartes de répartition de la couverture végétale dans la Réserve Spéciale d'Ambohitantely et dans les rayons de 10 km pour les années entre 1949 et 2017 a produit la carte de la dynamique forestière (Figure 2). Cette carte comporte au total 14 classes. Pour mieux comprendre les dynamiques intervenues entre chaque intervalle de temps, un résumé des changements nets est rapporté dans le Tableau SM1. L'analyse associée a permis de soulever les trois cas suivants (Figure 2, Tableau SM1).

Légère transformation : la classe 1 représente les zones non-forêts d'une superficie de ca. 180. 000 ha qui sont toujours restées non-forêt depuis 1949 jusqu'à 2017. La Figure 2 montre aussi à quel point, la plupart des zones forestières d'une superficie de 1241,5 ha ont été relativement stables depuis 1949

Tableau 3. La superficie des classes de forêt et autres classes de végétation (non-forêt) pendant les périodes d'études de 1949 à 2017.

	1949	1989	1995	2002	2010	2017
Superficie forêt (ha)	3011,4	2626,5	2351,4	1776,7	1692,4	1302,4
Superficie non-forêt (ha)	72.881,9	73.266,8	73.541,9	74.116,6	74.201,0	74.590,9

jusqu'à 2017. En particulier, ce sont les grands blocs situés à l'intérieur de l'aire protégée.

Perte de forêt : La perte de forêt ou conversion des zones forestières en zones non-forêt constitue la majorité des changements observés. Les classes 3, 4, 5, 6 et 7 sont des zones qui ont été affectées par la déforestation. La plupart de ces zones qui ont subi des perturbations sont remplacées par des savanes arbustives et prairies regroupées ici dans la zone non-forêt. La plupart des zones touchées par la perte de forêt sont réparties en dehors de l'aire protégée, tandis que les zones entre le bloc A et le bloc B (voir Figure 1) et surtout leurs lisières sont non plus à l'abri des pressions.

Alternance entre la perte de forêt et la régénération forestière : ceci regroupe les classes 8 à 14. Les classes 8 et 9 dans le bloc A montrent les forêts en 1949, et qui ont été dégradées entre 1989 et 2002 (Figure 2). Sur la base de ces analyses, nous avons des témoins de la régénération de ces deux classes de forêts dans des zones auparavant fortement perturbées (Tableau SM1). Les classes 10 à 14 sont des zones non-forêts en 1949 et au cours de plusieurs décennies ont montré différents schémas de perturbation de l'habitat et de régénération. Par contre les classes 13 et 14 respectivement 0,45 ha et 0,63 ha sur la partie nord ont disparu en 2017, malgré la régénération forestière entre 1989 et 2002.

TAUX DE PERTE DE FORÊT DE 1949 À 2017. Le taux annuel de perte de forêt dans la zone d'étude varie au cours des 68 années d'études et les détails sur l'évolution sont présentés dans le Tableau 4. De tailles variables de zones de forêt sont perdues

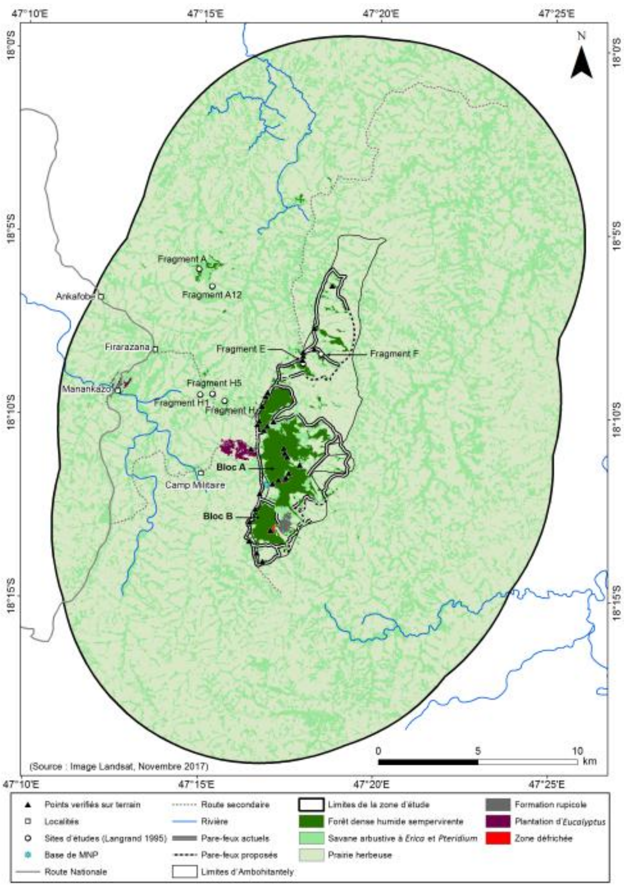

Figure 2. Cartographie de la dynamique du couvert végétal dans la Réserve Spéciale d'Ambohitantely entre 1949 et 2017. Vert clair = non-forêt ; vert foncé = forêt ; taches rougeâtres = zones défrichées ; les classes 8 à 14 sont des forêts régénérées à un moment donné (voir les détails dans le Tableau SM1).

chaque année. De 1989 à 1995, la déforestation a affecté 281,5 ha de couverture forestière. La perte maximale de surface forestière estimée à 586,4 ha soit 4,05% par an s'est produite au cours de la troisième période de 1995-2002. Entre 2010 à 2017, l'ampleur de la déforestation a significativement augmenté avec un taux de perte de 3,99% par an équivalent à 414,4 ha de forêt perdue. Le long de la période d'étude de 1949 à 2017, la régénération n'était presque pas mesurable. La tendance à la baisse de la perte de forêt était légèrement ralentie entre 1949 et 1989 avec un taux de 0,41% par an soit 473,4 ha de surface forestière perdue, et de 0,63% par an entre 2002 à 2010 soit 88,2 ha de perte de forêt.

APERÇU DE LA TENDANCE DE LA FRAGMENTATION À L'ÉCHELLE DU PAYSAGE. L'évolution des métriques de la fragmentation entre 1949 à 2017 dans la zone d'étude est présentée sur la Figure 3. En 1949, les fragments recensés étaient au nombre de 436 (Figure 3A) et la densité des parcelles égale à 0,57 (Figure 3B) et la superficie de la forêt était encore importante 3011,4 ha (voir Tableau 4). Les valeurs élevées de l'indice de la taille des parcelles (66,22) sur la Figure 3C et l'indice de dimension fractale (1,093) sur la Figure 3D informent qu'en 1949, les fragments avaient eu des formes très variées et irrégulières. L'indice de contigüité très élevée (0,488) associée avec le plus faible indice d'agrégation (85,11) reflète la contigüité entre les fragments. Entre 1989 et 1995, le nombre et la densité des parcelles ont augmenté allant respectivement de 512 à 525, et de 0,67 à 0,69, alors que la perte de forêt semble faible (281,5 ha) (voir Tableau 4). Ce gain en nombre et densité de fragment face à un faible taux de perte de forêt révèle un cas de morcellement des fragments. La diminution de la variabilité de la taille des parcelles (de 54,76 à 52,52), de l'indice de la dimension fractale (de 1,071 à 1,068) et de l'indice de contigüité (de 0,386 à 0,361) démontrent que la zone d'étude est caractérisée par des fragments de formes simples, moins variées et plus isolés entre eux. Depuis 1995 jusqu'à 2017, il y a eu une diminution du nombre et de la densité des parcelles (Figure 3A et 3B) et durant la même période le taux de perte de forêt a augmenté (voir Tableau 4) ce qui confirme un cas de disparition de certains fragments. Une légère augmentation de la variabilité de la taille des fragments entre cette période signifie que la forme des fragments est devenue plus tortueuse. L'important indice d'agrégation observé en 2017 montre que les fragments restants sont beaucoup plus agrégés, tel le cas des blocs forestiers A et B (Figure 1).

DISCUSSIONS

ÉVOLUTION DE LA DÉFORESTATION DANS LA ZONE D'ÉTUDE. Dans la plupart des études sur la déforestation et la fragmentation de la forêt à Madagascar (Harper et al. 2007, Grinand et al. 2013, Rakotomalala et al. 2015, Vieilledent et al. 2018), les périodes d'études ont été subdivisées en un intervalle de temps allant de 3 à 20 années, ce qui permet de bien saisir l'évolution à long terme. Dans notre étude, les cinq intervalles de temps variaient de 6 à 40 années. Les taux de perte de forêt les plus importants ont été observés entre 1995-2002 (4,05%) et entre 2010-2017 (3,99%). Ces périodes coïncident avec les deux

Tableau 4. Superficies et taux de perte de forêt pour les cinq périodes observées entre 1949 et 2017.

	1949-1989	1989-1995	1995-2002	2002-2010	2010-2017	1949-2017
Superficie de forêt perdue (en ha)	473.4	281.5	586.4	88.2	414.4	1843.9
% de perte de forêt/an	0.41	1.86	4.05	0.63	3.99	1.31

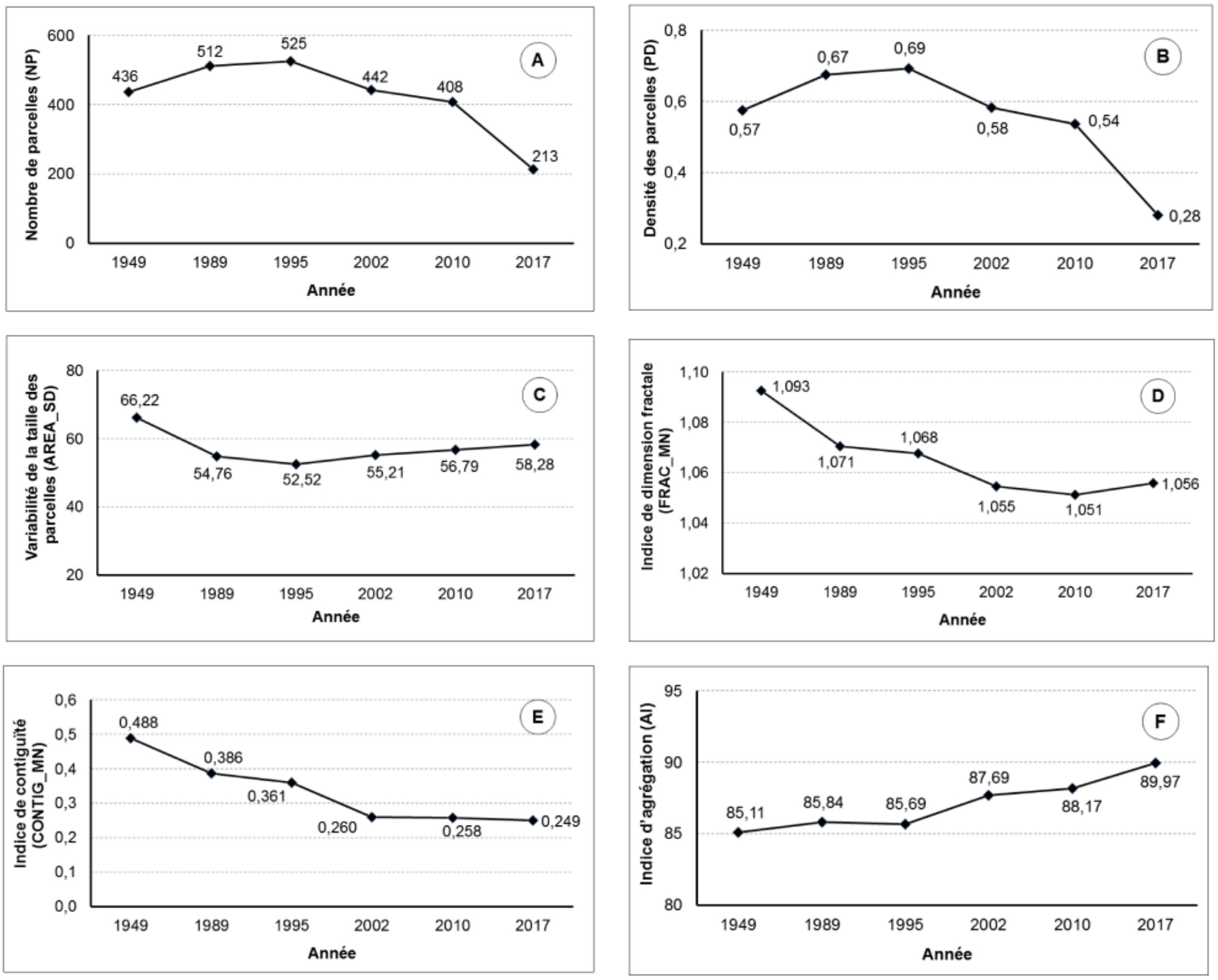

Figure 3. Aperçu sur la variation temporelle du nombre et de la distribution spatiale des fragments le long de la période d'étude.

évènements d'instabilité politique à Madagascar, ceux de 2002 et de 2009-2010. Cette constatation rejoigne les conclusions de Kull (2002) qui rapporte les crises politiques comme des facteurs de propagation des feux, et d'Alvarado (2012) dans le cas des feux de forêt dans le massif d'Ibity. Les zones les plus affectées par la déforestation sont situés en dehors de la Réserve Spéciale d'Ambohitantely, ce qui souligne l'importance de la conservation dans les aires protégées (Eklund et al. 2016). L'étude la plus récente relative à la déforestation et la fragmentation à Madagascar est celle de Vieilledent et al. (2018), dont les principaux résultats sont accessibles en ligne. Vu que nos données et celles de Vieilledent et al. (2018) ont les mêmes dates (2017) et les mêmes résolutions spatiales (30 m au sol), les cartes d'occupation du sol générées peuvent être comparables. Cependant, notre étude a été paramétrée à l'échelle du paysage alors que celle de Vieilledent et al. (2018) s'étendait à l'échelle de Madagascar, ce qui a un effet sur l'échantillonnage et la classification de la couverture végétale. En plus, le calcul du taux de perte de forêt et de la quantification de la fragmentation sont sensibles à des différences minimes, ce qui rend la comparaison difficile.

REVUE DE LA MÉTHODOLOGIE, SYNTHÈSE DES RÉSULTATS ET RETOUR À L'HYPOTHÈSE. Du point de vue représentation spatiale, la cartographie de la dynamique du couvert végétal illustre clairement les zones stables, les zones touchées par l'alternance de la régénération-déforestation. Elle évoque aussi la tendance de la fragmentation, qui s'étend des zones périphériques vers l'intérieur de le Réserve Spéciale d'Ambohitantely. Du point de vue temporel, les différences entre les valeurs des tailles des parcelles ou fragments, de forme et de contiguïté entre les fragments pour chaque année d'étude sont bien évidentes. Ces constats valident la pertinence de l'utilisation des données de différentes périodes analysées avec la technologie de télédétection, SIG et FRAGSTATS pour la mise à jour des données sur la fragmentation de la forêt d'Ambohitantely et ses alentours.

CARACTÉRISATION DE LA FRAGMENTATION DANS LA ZONE D'ÉTUDE. Les résultats révèlent une nette tendance de la fragmentation. En 1949, le paysage était constitué par de nombreux fragments avec des tailles variées et de formes hétérogènes. Au fil du temps, il y eu une augmentation du nombre de fragments mais réduits en taille et de formes simplifiées. Sous l'effet d'une fragmentation encore plus intense, certains fragments ont disparus. A titre indicatif, certains fragments forestiers utilisés par différents groupes de recherche dans les années 1990 pour les études de l'effet de la fragmentation chez certains groupes des vertébrés (Langrand et Wilmé 1997, Goodman et Rakotondravony 2000, Vallan 2000) sont nettement réduits en superficie et ont même disparus. Les métriques utilisées dans cette étude ont déjà été appliquées par Ravonjimalala et al. (2017) pour le suivi de l'évolution spatio-temporelle de la fragmentation de la forêt dense sèche des Mikea. Leur analyse a montré que la perte de fragments est aléatoire et affecte toutes les classes de taille. Le processus de fragmentation dans la forêt des Mikea réduit les grands fragments en parcelles forestières plus petites et plus isolées, qui deviendront finalement des zones non forestières. Une grande similarité au niveau de la tendance de fragmentation de la forêt a été constatée entre notre étude et celle de Ravonjimalala et al. (2017). En comparaison, dans d'autres sites avec des blocs forestiers isolés, notamment dans la région de Loky-Manambato, les données génétiques montrent un goulot d'étranglement qui peut expliquer la séquence d'événements qui ont conduit à des blocs forestiers séparés spatialement et géographiquement proches (Quéméré et al. 2012).

Ces dernières années, il y a eu beaucoup de discussions dans la littérature sur la question si les vastes formations herbeuses dans certaines parties de Madagascar, y compris les Hautes Terres Centrales, sont au moins des portions des formations végétales naturelles (Klein et al. 2007, Bond et al. 2008, Solofondranohatra et al. 2018). Bien qu'ici nous n'ayons pas l'intention d'évaluer ces différentes données et hypothèses associées, nous voudrions simplement souligner que dans le cas d'Ambohitantely au cours des dernières décennies la perte de forêt et la fragmentation de l'habitat ont pu être quantifiées (Hansson 2002). Elles sont clairement liées aux activités humaines, à savoir l'invasion du feu dans les zones forestières entraînant une réduction de la couverture de végétation ligneuse native. Si la matrice de formations herbeuses présente entre les blocs forestiers isolés, qui ont évolué de manière dynamique au cours du siècle dernier (Réau et al. 2003), est au moins en partie une formation naturelle, des travaux supplémentaires sont nécessaires pour connaitre les forêts naturelles existantes dans la région et les paramètres biotiques et abiotiques à l'origine de ces modèles.

INTÉRÊT POUR LA CONSERVATION. La première étape a consisté à créer des cartes d'occupation du sol pour chaque année d'étude. La superposition entre deux cartes d'occupation du sol pour deux années d'études successives a permis d'estimer le taux de perte de forêt et de détecter les changements au niveau de la couverture végétale. D'autre part, les métriques utilisées pour quantifier la fragmentation ont été calculées à base des données d'occupation du sol. Les résultats obtenus à l'issue de ces séries d'analyses ont permis de valider l'hypothèse de recherche stipulant que les données de différentes périodes ainsi que les différentes approches proposées mettraient en exergue les tendances de la fragmentation. La tendance de la fragmentation a bien été définie.

La connaissance de la dynamique forestière et de la fragmentation du paysage est cruciale pour la planification de la conservation et de la gestion durable (Laurance et al. 2000). Le résultat de l'analyse de la fragmentation de la forêt a montré que la grande superficie et la forme compliquée du grand bloc forestier de la Réserve Spéciale d'Ambohitantely dénotent son intérêt pour la conservation. Malgré les simplifications de la forme de paysage, l'isolement de certains fragments et la diminution de la taille des fragments, le grand bloc forestier de la Réserve Spéciale d'Ambohitantely présente encore toutes les potentialités pour la conservation de la faune et flore qu'il abrite. A part la taille de la réserve, les qualités de l'habitat associées aux différents types de végétation et le faible effet de bord contribuent considérablement à la conservation des espèces à grande échelle (Harrison et Bruna 1999). Toutefois, une recherche plus poussée apportera des réponses concernant le débat sur l'efficacité de la conservation et de l'importance de la diversité dans les nombreuses petites parcelles par rapport à une large parcelle (Fahrig 2020) et peut confirmer la place de la Réserve Spéciale d'Ambohitantely en tant que laboratoire naturel pour l'étude de la fragmentation (Langrand et Wilmé 1997). Des programmes de restauration des zones dégradées par les feux et surtout entre le bloc A et bloc B dans la réserve permettant d'assurer leur continuité écologique doivent être réalisés par le reboisement avec des arbres autochtones, particulièrement ceux ayant des fruits dispersés par les vertébrés frugivores (Hansson 2002, Ratsirarson et al. 2004, Pareliussen et al. 2006).

A ce propos, cette recherche s'avère la première à combiner les images aériennes et les images satellitaires pour étudier les caractéristiques de la fragmentation de la forêt d'Ambohitantely. Cependant, des compléments de travail sont nécessaires, des enquêtes sur terrain sur la localisation des menaces et pressions ou l'utilisation des données sur les points de feu devraient être effectuées pour interpréter efficacement les causes de chaque fragmentation. Le maintien de la connectivité est crucial pour atténuer les pertes de biodiversité et la fragmentation de l'habitat sur la diversité biologique (Liu et al. 2018, Damschen et al. 2019). De perspective de modélisation comme le calcul des corridors de moindres coûts est envisageable, et d'un intérêt inestimable pour une planification efficace de restauration écologique.

CONCLUSION

Deux approches complémentaires ont été utilisées dans cette étude dans le but de comprendre l'évolution de la fragmentation dans la Réserve Spéciale d'Ambohitantely et toutes les zones dans les 10 km aux alentours de ses limites pour les années 1949, 1989, 1995, 2002, 2010 et 2017. La première approche a consisté à détecter les changements de la couverture végétale par télédétection et études diachroniques. La deuxième approche a permis de caractériser la fragmentation des forêts à l'aide des mesures quantitatives de la configuration du paysage.

Avec la première approche, les différentes formations végétales ont été cartographiées pour les années 1949, 1989, 1995, 2002, 2010 et 2017. Les types de formation les plus dominants ont été les prairies, les savanes arbustives, et d'autres formes de forêts dégradées. L'ensemble a été regroupé sous la dénomination de non-forêt. L'étude diachronique de la couverture végétale dans la Réserve Spéciale d'Ambohitantely et ses alentours entre deux intervalles de temps consécutifs a révélé une diminution notable de la superficie de la forêt dense humide, avec un taux de déforestation annuelle de 1,31%. Cependant, pour éviter de probable confusion, l'interprétation du taux de déforestation soulevé dans cette étude exige de la prudence, car il englobe les zones à l'intérieur de la réserve et celles situées à la périphérie. A travers les six métriques de la fragmentation calculées pour les années 1949, 1989, 1995, 2002, 2010 et 2017, l'évolution spatio-temporelle de la forme, du nombre et de l'isolement entre les fragments a été examinée. Une perte intensive des fragments a été enregistrée depuis 1989, surtout dans les zones en dehors de l'aire protégée. Si la fragmentation se poursuit, les deux principaux blocs à l'intérieur de la réserve seront encore morcelés, favorisant ainsi l'apparition de nouveaux fragments.

Dans le domaine de la conservation, les informations fournies à l'issue de cette étude sont précieuses et à jour pour planifier des stratégies de conservation et de gestion de la Réserve Spéciale d'Ambohitantely. Dans le cadre de la recherche scientifique, il serait envisageable de croiser les données obtenues avec des données biologiques (distribution des espèces), ou des répartitions des menaces et pressions et de les valoriser pour la modélisation des corridors de moindres coûts.

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MATÉRIEL SUPPLÉMENTAIRE

Tableau SM1. Données enregistrées sur la dynamique du couvert végétal dans la Réserve Spéciale d'Ambohitantely.

Figure SM1. Cartographie de l'occupation du sol (d'après la photographie aérienne, 1949)

Figure SM2. Cartographie de l'occupation du sol (d'après l'image Landsat, 1989)

Figure SM3. Cartographie de l'occupation du sol (d'après l'image Landsat, 1995)

Figure SM4. Cartographie de l'occupation du sol (d'après l'image Landsat, 2002)

Figure SM5. Cartographie de l'occupation du sol (d'après l'image Landsat, 2010)

Figure SM6. Photographie aérienne d'Ankazobe. FTM Mission-0-23-1949. Cliché n°341. 1/40 000

SHORT NOTE http://dx.doi.org/10.4314/mcd.v17i1.4

Preliminary survey of the threatened carnivores in the Daraina Loky-Manambato Protected Area, Madagascar

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ABSTRACT

Madagascar's protected areas safeguard numerous threatened endemic plant and animal species, including Euplerid carnivores, considered to be the most threatened yet understudied group of carnivores globally. The Loky-Manambato Protected Area (PA) in northern Madagascar encompasses a unique transitional forest ecosystem that is under pressure from forest loss and fragmentation. We provide the first photographic survey of Madagascar's carnivore community occupying this region with the aim of documenting carnivore species richness, relative activity (Trap Success), and spatial distribution (Naïve occupancy) across the landscape. To do this, we used 60 motion-activated cameras to survey along established trails in three forest patches across the Loky-Manambato PA: Antsahabe, Bekaraoka, and Antsaharaingy. We surveyed each forest for two weeks in September and October 2018. We collected 498 independent captures of fauna across the landscape, including five of the six endemic carnivores known to occupy eastern Madagascar: *Galidia elegans*, *Galidictis fasciata*, *Eupleres goudotii*, *Fossa fossana*, and *Cryptoprocta ferox*. We found *F. fossana* and *G. elegans* to be the most active and widely distributed carnivores, while *C. ferox*, *G. fasciata* and *E. goudotii* were the least. Additionally, we documented the presence of two invasive carnivores: *Canis familiaris* and *Felis catus*. These findings extended the northern-most known range of *Galidictis fasciata* (Antsahabe) and *Fossa fossana* (Bekaraoka) into the Loky-Manambato PA. Forest size was not a good predictor of activity or occurrence as the largest forest patch in Bekaraoka had the fewest captures of all carnivores. Our findings highlight some of the biodiversity within the Loky-Manambato PA and the need for effective management across this unique transitional forest ecosystem.

RÉSUMÉ

Les aires protégées de Madagascar protègent de nombreuses espèces végétales et animales endémiques menacées, y compris les carnivores eupléridés. Les carnivores eupléridés sont considérés comme l'un des groupes de carnivores les plus menacés mais les moins étudiés au monde. L'aire protégée (PA) de Loky-Manambato dans le nord de Madagascar englobe un écosystème forestier de transition unique qui subit la pression de la perte et de la fragmentation des forêts. Nous fournissons la première étude photographique de la communauté de carnivores de Madagascar occupant cette région dans le but de documenter la richesse en espèces de carnivores, l'activité relative (Trap Success) et la distribution spatiale (Naïve occupancy) à travers le paysage. Pour ce faire, nous avons utilisé 60 caméras activées par le mouvement pour surveiller le long des sentiers établis dans trois parcelles forestières à travers l'AP Loky-Manambato : Antsahabe, Bekaraoka et Antsaharaingy. Nous avons étudié chaque forêt pendant deux semaines en septembre et octobre 2018. Nous avons procédé à 498 captures indépendantes de la faune à travers le paysage, incluant cinq des six carnivores endémiques connus pour habiter l'Est de Madagascar : *Galidia elegans*, *Galidictis fasciata*, *Eupleres goudotii*, *Fossa fossana* et *Cryptoprocta ferox*. Nous avons constaté que *F. fossana* et *G. elegans* étaient les carnivores les plus actifs et les plus largement distribués, tandis que *C. ferox*, *G. fasciata* et *E. goudotii* étaient les moins nombreux. De plus, nous avons documenté la présence de deux carnivores envahissants : *Canis familiaris et Felis catus*. Ces découvertes ont étendu l'aire de répartition la plus septentrionale connue de *Galidictis fasciata* (Antsahabe) et de *Fossa fossana* (Bekaraoka) dans l'AP Loky-Manambato. La taille de la forêt n'était pas un bon prédicteur de l'activité ou de l'occurrence car la plus grande parcelle forestière de Bekaraoka avait la moindre présence de tous les carnivores. Nos résultats mettent en évidence une partie de la biodiversité au sein de Loky-Manambato PA et la nécessité d'une gestion efficace dans cet écosystème forestier de transition unique.

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INTRODUCTION

Madagascar is recognized for its rich biodiversity and endemism; 84% of all vascular plants and 100% of native mammal species on the island nation are endemic (Goodman and Benstead 2005, Callmander et al. 2011). Most of these organisms are found across the eastern humid, western deciduous, and southern spiny forest regions (Lourenço and Goodman 2013). Unfortunately, Madagascar's forests have experienced widespread deforestation (Harper et al. 2007, Vieilledent et al. 2018), and are projected to lose their remaining forest cover within the coming decades if current climate and forest loss trends continue (Morelli et al. 2020). Importantly, forest conversion has contributed to increased forest fragmentation and ecosystem degradation, threatening endemic species with extirpation or extinction (Vielledent et al. 2018). As Madagascar's forests dwindle, research on its threatened biodiversity has intensified, often with a focus on lemurs and seldom the island's carnivores (Gardner 2009). This is troublesome, as the endemic carnivores of Madagascar are already among the world's most threatened carnivores (Brooke et al. 2014, IUCN 2022). Habitat selection and preference for each native carnivoran varies across the eastern rainforest region. For a summary of habitat use see Wampole et al. (2021). Over the past decade, most of Madagascar's national parks have been surveyed and the carnivore populations within them estimated (Gerber et al. 2010, Murphy et al. 2018). Lower tier protected areas, however, still lack initial surveys such as Loky-Manambato PA in north-eastern Madagascar. Here, missing information on carnivore populations is paired with increasing anthropogenic destruction of the ecosystems they inhabit (Ingram and Dawson, 2005). Though results have been contrasted, genetic studies and aerial imagery suggest that while forest cover remained relatively stable from 1950-2000, forest fragmentation began around the arrival of humans to the area ca. 4,000 years ago (Quéméré et al. 2012; Salmona et al. 2017). Between 1996 and 2016, 9.2% of humid forests and 1.1% of dry deciduous forests in the Loky-Manambato PA were destroyed (Goodman and Wilme 2006, Goodman et al. 2018). Deforestation and forest degradation leads to decreased carnivore populations in Madagascar (Wampole et al. 2021).

Madagascar's carnivores, like other small carnivores, are difficult to study due to their elusive behavior, large home ranges, and low population densities (Hawkins and Racey 2005, Brooke et al. 2014). To survey and estimate Madagascar's carnivores, studies have employed motion activated camera traps to photographically capture fauna that cross the camera's line of sight (Wampole et al. 2021). These authors reviewed carnivore research in Madagascar and found the primary threats to carnivores include forest loss and fragmentation, invasive predators, disease transmission, and poaching. These threats from invasive species, namely free-ranging dogs (*Canis familiaris*) and cats (*Felis catus*), as well as the small Indian civet (*Viverricula indica*) have increased competition, influenced the spatial distribution (Farris et al. 2015, Beaudrot et al. 2018), temporal activity (Gerber et al. 2012, Farris et al. 2015, Merson et al. 2019), disease transmission (Rasambainarivo et al. 2017, 2018, Apanaskevich and Goodman 2020), and even long-term occurrence (Farris et al. 2017) of native carnivores across multiple protected areas. In addition, these invasive carnivores have negatively influenced native birds, small mammals, and lemur species across Madagascar's forests that many of Madagascar's native carnivores predate (Brockman et al. 2008, Farris 2014, Murphy et al. 2018). The widespread, invasive nature of *C. familiaris* and *F. catus* present a serious threat to Madagascar's threatened wildlife and to similar wildlife globally (Doherty et al. 2016). These negative effects on native carnivores and co-occurring wildlife are exacerbated as forest habitat shrinks and becomes increasingly fragmented.

Carnivores previously known to exist within the Loky-Manambato PA from opportunistic observations include: *Eupleres goudotii*, observed in the Binara forest, *Galidia elegans*, observed at the Antsahasolika fragment and forests adjacent to Lac Isahaka, and *Cryptoprocta ferox*, observed in the Binara forest and in forests adjacent to Lac Isahaka (Safford 2000). The invasive carnivore *Viverricula indica* has been confirmed to inhabit the Binara forest, Antsahasolika forest, and forests near Lac Isahaka. The goal of our project was to provide the first standardized survey of the carnivore community across the Antsahabe, Bekaraoka, and Antsaharaingy forest patches of the Loky-Manambato PA with the aim of: 1) documenting the presence of native and invasive carnivores, 2) estimating trap success and naïve occupancy, 3) describe temporal activity patterns for all carnivores, and 4) examine if native carnivore trap success or naïve occupancy vary between distinctive forest patch sites. Naive occupancy is a measure of the spatial distribution of a given species and is referred to as "naïve" due to the lack of accounting for imperfect detection (MacKenzie et al. 2006), which results in a lower estimate of spatial occurrence compared to models that use detection to estimate true occupancy (MacKenzie and Bailey 2004).

MATERIALS AND METHODS

STUDY AREA. Among the numerous protected areas of Madagascar, the Loky-Manambato PA (Figure 1) is unique for its organismal composition and variety of habitat types (Goodman et al. 2018). The Loky-Manambato PA legally became an IUCN category V protected area in April 2015, and is the only protected area to overlap the range of many threatened endemic species, such as the critically endangered golden-crowned sifaka *Propithecus tattersalli* (Vargas et al. 2002, Ranirison et al. 2007). The Loky-Manambato PA is located approximately 74 km to the southeast of Antsiranana of northeastern Madagascar. It consists of ten forest patches and a marine sanctuary. The Loky-Manambato PA encompasses 250,000 ha total, but its forests are patchy and only cover 44,000 ha of the area (2018). All of the Loky-Manambato PA forests are separated from one another by barren hills and grazing maintained grasslands. Forest types range from moderate-elevation (ca. 1,000 m asl) humid forest to low-elevation (10 m asl) deciduous forest. Despite being legally protected, the region is threatened by slash-and-burn subsistence farming, as well as logging and charcoal creation (Goodman et al. 2018). We surveyed three forests across the Loky-Manambato PA: Antsahabe, Bekaraoka, and Antsaharaingy. These forests were chosen to represent the wide range of forest types found within the Loky-Manambato PA. We intentionally selected remote sites to minimize the risk of camera theft.

FOREST DESCRIPTION. Antsahabe is a deciduous mid-elevation humid forest that during 2021 covered 4370 ha (Semel 2021). It has the highest average elevational range, 790m asl, and is the wettest of the three sites we examined in the Loky-Manambato PA. Antsahabe is characterized by steep, ridged mountains

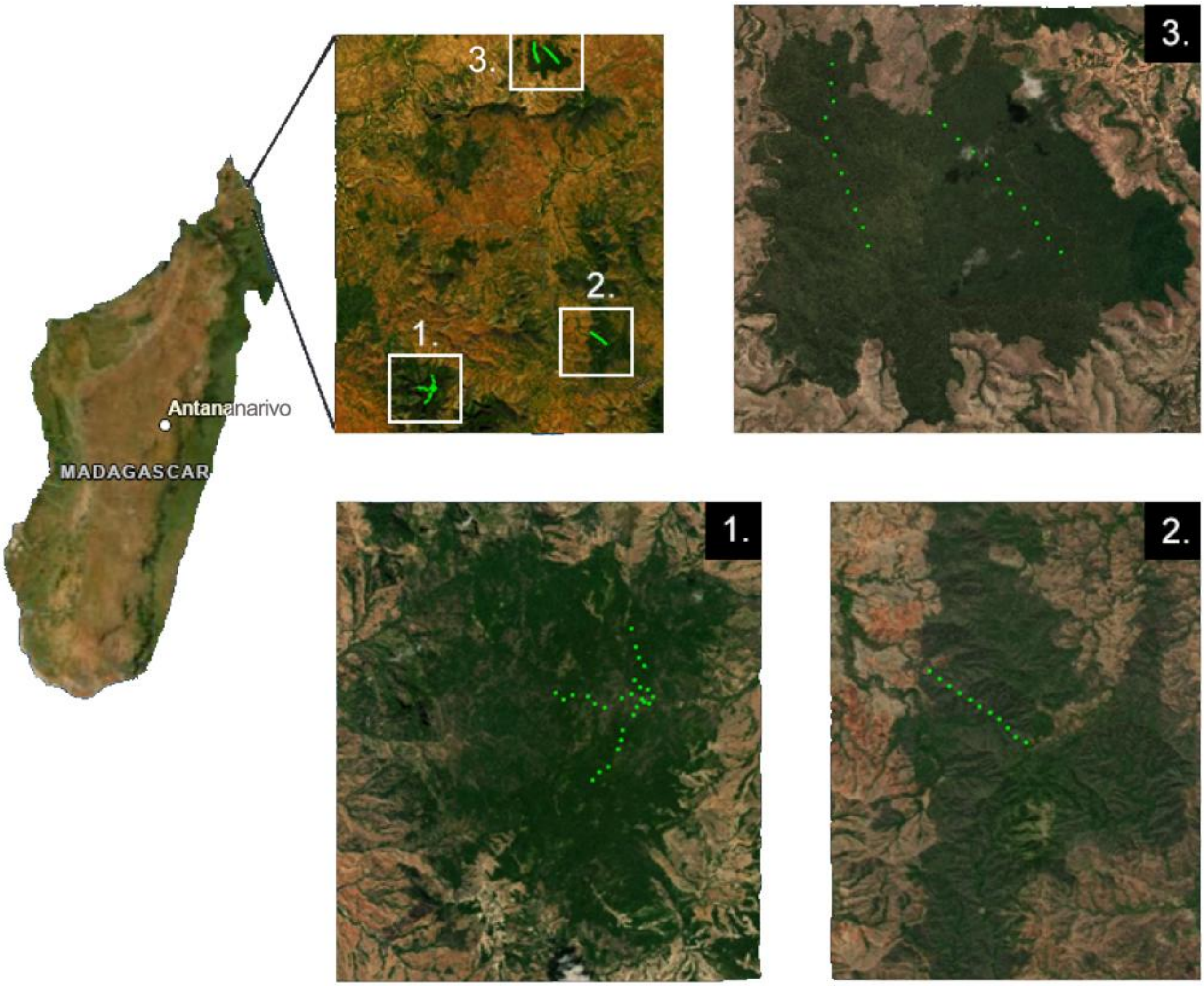

Figure 1. Map of Madagascar (left) with the location of the three Loky-Manambato PA forests surveyed. (1 = Antsahabe (bottom left), 2 = Bekaraoka (bottom right), 3 = Antsaharaingy (top right); we surveyed the three forests from September to October 2018; green dots represent camera trap locations)

with a tall, closed overhead canopy (8–12m in height in steep, exposed areas; 20–25m in height on more gentle slopes (Goodman et al. 2018).

Bekaraoka is the largest forest patch in Loky-Manambato PA, covering 69.1 km2 and stretching from north to south along a massif (Semel 2021). Its average elevation is 198m asl, and its forests are dry and deciduous. Thick shrub layers are dominated by an 8–12m high canopy. A large gold mining site exists around the town of Andranotsimaty, which is characterized by a heavily disturbed understory and dry riverbeds during the dry season (May–November), and deep pits (Goodman et al. 2018).

Antsaharaingy exists upon sandy substrates at the northern end of the Loky-Manambato PA and was the smallest forest surveyed, at 11.6 km2 (Semel 2021). Its average elevation is 71m asl. This dry, hilly lowland is covered by dense, sclerophyllous forest 6–7m in height (Semel 2021, Goodman et al. 2018).

PHOTOGRAPHIC SAMPLING. We used motion-activated camera traps to sample terrestrial wildlife. For Antsahabe, we placed 27 cameras that were operational from 7 September 2018 to 19 September 2018. For Bekaraoka, we placed 11 cameras that were operational from 21 September 2018 to 30 September 2018. For Antsaharaingy, we placed 22 cameras that were operational from 5 October 2018 to 15 October 2018. Each of the surveyed areas consisted of existing transects, 2-2.5 km in length, totaling 11 km across the three surveyed forests. Camera models included Moultrie M888, M880, D55, A35 (Moultrie Feeders, Birmingham, AL 35201), WGI Terra Extreme (WildGame Innovations Grand Prairie, TX), Bushnell Trophy Cam HD (Bushnell Overland Park, KS), HCO-SG565 (HCO ScoutGuard Duluth, GA) and Stealth Cam ZX3 (Stealth Cam Grand Prairie, TX). Detection differences were negligible in our study. Cameras were placed an average of 181m ± 34m (SD) apart. This distance is smaller than the estimated home range for five of Madagascar's endemic rainforest carnivores (Goodman 2012) but was used due to the small size of each forest patch. This spacing did not ensure spatial independence throughout the photographic captures, meaning the same individual carnivore could have triggered a camera at more than one location/station. Across all three forests, camera sites included degraded, edge forest nearest to villages (< 500m from edge; n = 12) and non-degraded forest (> 500m from edge; n = 48). All cameras were set to high sensitivity and programmed to record three consecutive photographs per independent trigger. We mounted cameras 25–45 cm above the ground and used no baits or lures. We recorded the location of each camera (UTM) and elevation using handheld Garmin Etrex GPS units. We verified the functionality of all cameras within three days of deployment. To ensure proper functioning of cameras (e.g., battery percent, angle of camera, and normal functioning), we checked on all cameras every two days and retrieved all cameras 10 days after their initial deployment.

DATA ANALYSIS

To conduct species identifications and to produce a capture history for statistical analyses, we manually sorted and identified the photos using the tagging software DigiKam (www.digikam.org) and the package "CamtrapR" (Niedballa et al. 2016) in program R (RStudio 2020 edition, R Core Team 2017). We defined a capture event as a photograph of an animal at a camera station within a 30-minute period (Di Bitetti et al. 2006). This half-hour time period allows the captured species temporal independence among other captures.

We defined a trap night as a 24-hour period during which the cameras ran with no malfunctions. We calculated trap success to represent a measure of relative activity for all fauna to compare their activity and presence across the three surveyed forests and previously surveyed protected areas of Madagascar. Trap success is calculated by dividing the total number of captures by the total trap nights, and then multiplied by 100. We did this for each carnivore species, within each forest. We calculated naïve occupancy to understand the spatial distribution of each species across each forest and to compare with other protected areas. Naïve occupancy is calculated by dividing the total number of camera stations where a species was captured by the total number of camera stations. We analyzed temporal activity patterns by constructing temporal activity charts from "time of capture" metadata embedded within each photo. We used Google Earth Pro (Google, 7.3. 2020) and ArcMaps (ESRI, 10.8.1 2019) to generate maps of each forest and the camera trap locations within them.

RESULTS

We sampled from September 2018 to October 2018, across a total of 60 camera stations for 494 trap nights total. Across the three surveyed forests we collected 27 unique capture events including 6 captures of invasive terrestrial carnivores (Table 1). We observed five endemic carnivore species: *Galidia elegans*, *Galidictis fasciata*, *Eupleres goudotii*, *Fossa fossana*, and *Cryptoprocta ferox* and two invasive carnivores *Canis familiaris* and *Felis catus*. *Galidictis fasciata* and *Fossa fossana* were range extensions. We did not observe the endemic *Salanoia concolor* or the invasive *Viverricula indica*.

CARNIVORE TRAP SUCCESS AND NAÏVE OCCUPANCY ACROSS THE LMPA. Across the LMPA landscape, the native carnivores with the highest trap success estimates were *G. elegans* and *F. fossana* (Table 1). The remaining native carnivores had considerably lower relative activity and spatial distributions (Table 1). Conversely, for invasive carnivores we found free-ranging *F. catus* to be almost as active and widely distributed as *F. fossana* and *G. elegans* while *C. familiaris* was similar to the sparser native carnivores (Table 1).

Table 1. Comparison of trap success estimates from the Loky-Manambato Protected Area to the larger, intact protected areas of Anjanaharibe Sud Special Reserve (ASSR) and Makira Natural Park (Makira) found south of the Loky-Manambato PA. (Species in bold represent invasive carnivores; 1 Ross et al. 2020, 2 Farris et al. 2015a)

Species	Loky-Manambato	Anjanaharibe-Sud	Makira
Cryptoprocta ferox	0.25	0.53	2.18
Fossa fossana	2.13	4.7	3.17
Eupleres goudotii	0.25	0.05	1.04
Galidia elegans	1.03	0.47	1.09
Galidictis fasciata	0.1	0.86	0.8
Canis familiaris	**0.13**	**2.2**	**9.64**
Felis catus	**0.63**	**NA**	**0.79**

TEMPORAL ACTIVITY PATTERNS. Using the limited number of captures for each native and invasive carnivore, the only two species to demonstrate diurnal activity were the native *G. elegans* and invasive *C. familiaris*. The native *C. ferox* and *G. fasciata* showed strictly nocturnal activity, though this resulted from only a single capture each. The remaining carnivores, including native *F. fossana* and *E. goudotii*, as well as the invasive *F. catus*, demonstrated nocturnal activity, with captures bordering crepuscular periods (Figure 2).

FOREST SPECIFIC TRAP SUCCESS AND NAÏVE OCCUPANCY. Since the forests of the Loky-Manambato PA are all separated from one another and vary in altitude as well as floral and faunal composition, we report the findings of each independently. In Antsahabe , we sampled 204 trap nights and captured three native carnivore species, *G. elegans*, *F. fossana*, and *G. fasciata*. *Galidia elegans* were the most captured native carnivore TS= 1.03 Naïve occupancy was 0.11 for *G. elegans* compared to *F. fossana*, and *G. fasciata*, (Table 1, 2). In Bekaraoka, we sampled 99 trap nights and captured only a single native carnivore, *F. fossana*. Naïve occupancy was 0.36 (Figure 3, 4). In Antsaharaingy , we sampled 191 trap nights and captured two native carnivores (*C. ferox*, *E. goudotti*) and two invasive carnivores (*C. familiaris*, *F. catus*). Naïve occupancy for *C. ferox* was 0.08, *E. goudotii* was 0.04, *C. familiaris* was 0.04, and *F. catus* was 0.20 (Figure 3, 4).

DISCUSSION

We provide a preliminary survey of the native and invasive carnivores of the Loky-Manambato PA, evaluating relative activity and spatial occurrence across multiple forest patches. Due to the low number of forests surveyed (n=3) and overall capture events (n=27) the results should be considered cautiously, as trends may be the result of low sampling effort rather than interpretable patterns. Our results suggest that there are fewer captures and lower relative activity for native carnivores in the Loky-Manambato PA when compared to larger protected areas across the north-eastern region of Madagascar, including Anjanaharibe Sud Special Reserve (Ross et al. 2020), Makira Natural Park (Farris et al. 2015a) and Betampona Strict Nature Reserve (Rasambainarivo et al. 2018). Across the three Loky-Manambato PA forests, we found high species diversity with five out of Madagascar's six eastern rainforest carnivores captured, with the exception of *Salanoia concolor*. These findings point to the need for more in-depth surveys that measure multiple landscape and micro-habitat variables to effectively explore and understand carnivore habitat use and selection across species. Additional variables for evaluation should include local bushmeat hunting as studies across northern Madagascar have revealed that bushmeat hunting is common and widespread (Golden 2009, Borgerson et al. 2019, Borgerson et al 2021,).

For spatial occurrence, we used estimates of naïve occupancy. Compared to true occupancy, it provides potentially biased estimates as it fails to account for imperfect detection (MacKenzie

Table 2. Summary of study site forest patches across the Loky-Manambato Protected Area, including type of forest, elevation, area, and total area surveyed by camera traps. (This survey was conducted from September to October 2018)

Species	Antsahabe	Bekaraoka	Antsaharaingy	Total	IUCN Status
Galidia elegans	0.11	N/A	N/A	10	LC
Galidictis fasciata	0.037	N/A	N/A	1	VU
Cryptoprocta ferox	N/A	N/A	0.08	2	VU
Eupleres goudotii	N/A	N/A	0.04	2	VU
Fossa fossana	0.11	0.363	N/A	12	VU
Canis familiaris	N/A	N/A	0.04	1	N/A
Felis catus	N/A	N/A	0.2	5	N/A

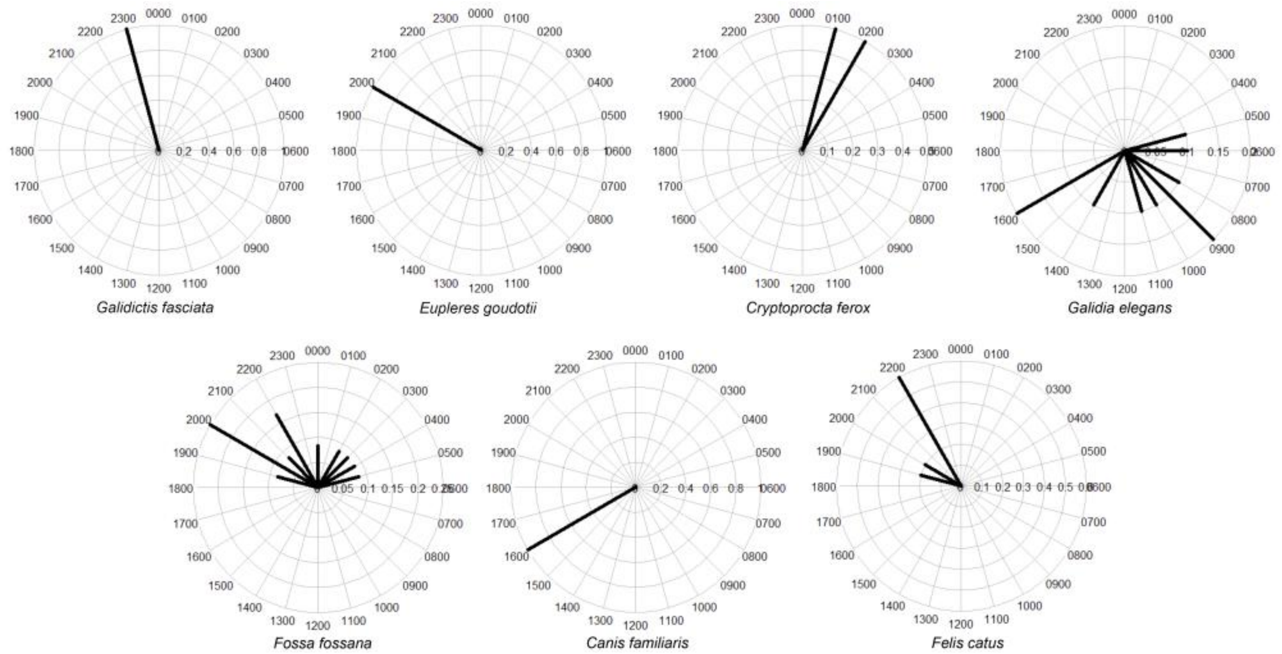

Figure 2. Temporal activity estimates/patterns for all carnivores captured within our survey. (Each temporal graph includes all captures across the three surveyed forests for both native (*Galidictis fasciata*, *Eupleres goudotii*, *Cryptoprocta ferox*, *Galidia elegans*, and *Fossa fossana*) and invasive (*Canis familiaris* and *Felis catus*) carnivores; length of the bar is equal to the percentage of captures at the indicated time)

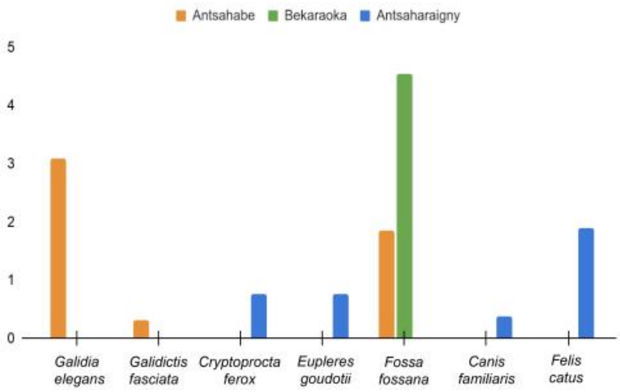

Figure 3. Trap success calculated for all native and invasive carnivores across the three surveyed forests, Antsahabe (orange), Bekaraoka (green), and Antsaharaingy (blue) from the Loky-Manambato Protected Area. (Trap success is the number of captures divided by the number of total trap nights and multiplied by 100. Surveys were conducted from September to October 2018)

and Bailey 2004). Therefore, we did not compare our estimates to other published studies from nearby regions. Our findings on temporal activity are in line with previously published findings of native and invasive carnivore diel activity (Farris et al. 2015b, Gerber et al. 2012, Merson et al. 2019): However, for this study most activity patterns were determined by very few capture events.

Canis familiaris and *F. catus* were only found within the Antsaharaingy forest, *C. familiaris* and *F. catus* are known to represent a serious threat to Madagascar's native fauna. The Antsaharaingy forest was the only site where Madagascar's top predator, *C. ferox*, was observed. *C. ferox* is one of the most widespread, flexible and resilient euplerid species (Wampole et al. 2021). The overlap with two invasive carnivore species with *C. ferox* warrants additional surveys to determine if this leads to local extinction for smaller endemic carnivores across the Loky-Manambato PA forests. We suspect that our lack of *S. concolor* and *V. indica* detection are explained by habitat preference for *S. concolor*, which has been shown to prefer low-mid altitude rainforest (Wampole et al. 2021) and our survey's low sampling effort for *V. indica*. Long-term and large-scale surveys are needed particularly across un-surveyed forest patches in the Loky-Manambato PA. These studies are needed to explore carnivore temporal activity and spatial distributions, including which factors or variables influence these parameters and contribute to reductions in richness and abundance.

The Loky-Manambato PA safeguards a unique transitional forest landscape that many carnivore species rely upon. The loss of habitat and resulting fragmentation presents a large threat to the native carnivores we surveyed and the threatened wildlife with which they co-occur and depend upon. Surveys in other highly degraded, fragmented patches across the north of Madagascar have revealed a considerable decrease in carnivore richness (Mann et al. 2015) and the on-going trends across the Loky-Manambato PA could result in similar patterns if these pressures are not addressed. Efforts that include and incorporate local desires, needs and livelihoods are needed to slow or stop these losses and protect the native carnivores occupying this protected area landscape.

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SUPPLEMENTARY MATERIAL

Camera traps photos of the 27 unique capture events of native Madagascar carnivores in the Loky-Manambato Protected Area

SHORT NOTE http://dx.doi.org/10.4314/mcd.v17i1.7

Clarification on protected area management efforts in Madagascar during periods of heightened uncertainty and instability

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ABSTRACT

In early May 2022, Eklund and colleagues published an article in Nature Sustainability in which they attempted to demonstrate that the early 2020 lockdown imposed in Madagascar by the emerging COVID-19 pandemic had a direct impact on Protected Areas (PAs), with an increase in the number of fires, which then stabilized once the lockdown was over. The authors, undoubtedly in good faith but based on an incomplete understanding of the situation on the ground, were attempting to draw the attention of the international community and donors to the need to maintain and strengthen PA management efforts. Their contribution, while highlighting a real and urgent need, does not, however, do justice to Madagascar's PA managers, who, in collaboration with the populations living in the vicinity of parks and reserves, maintained and in some instances increased efforts to ensure the integrity of parks and reserves during the COVID-19 period. Following the publication of this paper, we contacted the authors as well as the editors of Nature Sustainability in a collegial effort to draw their attention to the errors identified in the analysis and to point out how this led to a misinterpretation of what actually transpired during the lockdown. We submitted a carefully worded and argued rebuttal for possible publication in Nature Sustainability, which we regarded as justified given the nature and significance of the considerations we had carefully presented. Unfortunately, after several exchanges with the editor and indirectly with the authors, during which we made an honest and concerted effort to explain the problems identified and their reputational implications for PA managers in Madagascar, the journal ultimately declined to publish our response, to our considerable surprise. In order to ensure that these issues are shared with the diverse stakeholder groups involved in conservation and PA management, in Madagascar and elsewhere, we feel that it is our duty to draw attention to their potential consequences, rather than adopting the questionable strategy of sitting back and hoping they will somehow self-correct themselves (see Vazire 2019).

RÉSUMÉ

Début mai 2022, Eklund et ses collègues publiaient un article dans Nature Sustainability dans lequel ils ont tenté de démontrer que le confinement de début 2020 imposé à Madagascar par la pandémie naissante du COVID-19 a eu un impact direct sur les aires protégées (AP) avec une augmentation du nombre de feux qui s'est stabilisée dès la fin du confinement. Les auteurs, certainement de bonne foi mais sur la base d'une compréhension incomplète de la situation sur le terrain, tentaient d'attirer l'attention de la communauté internationale et des bailleurs sur la nécessité de maintenir et renforcer les efforts de gestion dans les AP. Leur contribution, même si elle souligne un besoin réel et urgent ne fait en revanche pas justice aux gestionnaires des AP qui, en collaboration avec les populations riveraines des AP, ont maintenu, parfois accru leurs efforts pour maintenir l'intégrité des AP pendant la période COVID-19. Suite à la publication de l'article,

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nous avons contacté les auteurs ainsi que les éditeurs de Nature Sustainability dans un effort collégial pour attirer leur attention sur les erreurs identifiées dans leur analyse et pour souligner la msure dans laquelle elles ont mené à une interprétation totalement erronée de la situation qui prévalait pendant le confinement. Nous avons soumis une réfutation soigneusement formulée et argumentée à Nature Sustainability que nous estimions largement justifiée compte tenu de la nature et de l'importance des considérations présentées, mais après plusieurs échanges avec le rédacteur en chef et indirectement avec les auteurs au cours desquels nous présentions de manière honnête et concertée les problèmes que nous avions identifiés avec leurs les implications sur la réputation des gestionnaires des AP à Madagascar, le journal a finalement refusé de publier notre réponse, à notre grand étonnement. Pour nous assurer que ces questions soient partagées avec tous les acteurs et parties prenantes impliqués dans la conservation et la gestion des AP, à Madagascar et ailleurs, nous estimons qu'il est de notre devoir d'attirer l'attention sur les problèmes que nous avons identifiés ainsi que sur leurs conséquences éventuelles plutôt que d'attendre que les problèmes se règlent d'eux-mêmes (voir Vazire 2019).

INTRODUCTION

It has been purported that Madagascar's protected areas (PAs) experienced a dramatic spike in fire events during the period of government-imposed COVID-19 lockdown from March to July 2020 (Eklund et al. 2021). In this study, the authors suggested that the reason for increased fires in 16 PAs in the western part of the country was a lack of management during that period, which was rendered impossible due to the consequences of Madagascar's government-imposed COVID-19 lockdown. However, while PAs were indeed officially closed to all visitors during that time, management activities not only continued, but were in fact intensified. Although the modeling utilized by Eklund et al. (2022) is robust, other key elements of the methodology they used are problematic, involving data compilation and validation, as well as park manager consultations, which led to ill-informed and erroneous conclusions.

Madagascar's terrestrial protected area network covers some 11% of its surface. Of the 114 PAs, 43 in IUCN categories I, II and IV are officially managed by a parastatal organization, Madagascar National Parks (MNP), while management of the others involves a mixed regime linking NGOs and local communities, mostly corresponding to IUCN categories V and VI (Dudley et al. 2010). Thirteen PAs are referred to as 'orphan sites' because, although they are the responsibility of the Ministry of Environment and Sustainable Development, they benefit from little or no actual management (Gardner et al. 2018, Rafanoharana et al. 2021). Here we provide clarification with regard to the 43 PAs currently managed by MNP and the five orphan sites that previously were under MNP management. MNP has a centralized management approach utilizing a standardized protocol across its network, which provides transparent management and curation of data across all the PAs under its umbrella. It is important to note that all five orphan PAs in western and northern Madagascar experienced an increase in the number of fires from March to July 2020, even though their management has remained unchanged for several years; they did not benefit from any management efforts either before or during the 2020 lockdown period. Management—or lack thereof—therefore cannot be invoked as a causal mechanism for changes in fire incidences in these five orphan PAs.

MAJOR ERRORS IDENTIFIED AND OUR RESPONSES

DATA COLLECTION. When attempting to analyze the cause of a perceived change, it is important that the veracity of the data used be carefully checked. The World Database of Protected Areas (UNEP-WCMC and IUCN 2020) used by Eklund et al. (2022) serves information on PA boundaries as officially reported by governments. In Madagascar, however, park managers utilize updated and corrected shapefiles showing official PA borders, as formally established by decree (Table 1). By applying this corrected and updated resource, it can be seen that many fires detected by the sensor Visible Infrared Imaging Radiometer Suite (VIIRS) used to monitor fires amongst other features (Elvidge et al. 2017) in western Madagascar were in fact situated outside official PA limits. The areas indicated in the WDPA are inflated because they include outer buffer zones, the so-called "zone de protection". In seven PAs, the number of fires in the outside buffers accounted for 1257 fires, therefore increasing the total number of fires wrongly reported for these PAs by more than 50% (Table 1).

In 2020, deforestation decreased substantially at the national level, and this was especially the case in PAs when compared with 2019 (i.e., prior to the COVID-19 pandemic) (Figure S1). Most of Madagascar's remaining undisturbed forests occur in PAs, which are primarily surrounded by anthropogenic grassland and degraded forests, formations that are highly susceptible to fire. The forest cover in the "zone de protection" is always lower than the forest cover within the network of PAs in Madagascar (Rafanoharana et al. 2021). In many cases, the outer buffers of PAs, including in the seven PAs reported in Table 1, the "zone de protection" is mostly dominated by grasslands.

VALIDATION OF COLLECTED DATA. In order to assure accurate data for their analyses, Eklund et al. (2022) should have consulted practitioners involved in the day-to-day management of PAs, including those utilizing GIS-based tools and who are aware of the details and consequences of the COVID-19 lockdown and PA closures. MNP has 30 management units comprising local offices and full-time staff, which remained fully operational during the lockdown to ensure continuous management and patrolling. MNP agents were granted an exemption from travel restrictions, and while the PAs were closed to visitors in 2020, patrols were proactively intensified at most sites to strengthen protection (MNP 2019, 2020). In Kirindy Mite and Ankarafantsika NPs, prescribed fires have increased the number of fires remotely detected. Prescribed burning was used as a management practice in most large NPs in the dry biome from February to April/May and cannot be distinguished or qualified as such with satellite information. Prescribed burning was enhanced during 2020 in anticipation of increased drought and modeled fire risk (Prasetya et al. 2019, Harrington et al. 2021, Figure 1). These intentional burns were conducted in grasslands within the PAs to reduce fuel loads and to preclude fires from entering the forests, a priority element in MNP's management strategy to safeguard forest biodiversity.

Table 1. Protected areas managed by MNP as reported by the World Database on Protected Areas (https://www.protectedplanet.net/) pointing to errors which over report the number of foresee by Eklund et al. in 2022 (*surplus fires out of total fires reported by Eklund et al. 2022)

Protected areas	Management	IUCN category	Decree	Area per decree in km²	Errors in WDPA	Fires reported by Eklund et al. in March–July 2020 *	
						outside PAs	prescribed burns
Ambohijanahary	orphan	IV	N. 58-08 on 28 Oct. 1958	247.5	fine as is with reported area of 243.02 km² (1)	./.	./.
Andranomena	MNP	IV	N. 58-13 on 28 Oct. 1958	64.2	includes the external buffer with reported area of 207.29 km²; the external buffers overlap the Menabe Antimena PA (2)	27 / 102 (26.5%)	./.
Ankarafantsika	MNP	II	N. 2015-730 on 21 Apr. 2015	1365.13	includes the external buffer with reported area of 1695.33 km² (3)	52 / 234 (22.2%)	2
Bemaraha	MNP	II	N. 2011-498 on 6 Sep. 2011	1577.1	Two PAs - Tsingy de Bemaraha Strict Nature Reserve with reported area of 1520.0 km² (4) - Bemaraha with its outer buffer as "Zone de protection" with reported area of 2316.31 km² (5)	694 / 1884 (36.8%)	./.
Bemarivo	orphan	IV	GI RS on 10 Sep. 1956	115.75	fine as is with reported area of 120.46 km² (6)	./.	./.
Corridor forestier Bongolava	NGO	V	N. 2015-790 on 18 Apr. 2015	605.89	fine as is with reported area of 605.9 km² (7)	./.	./.
Kasijy	orphan	IV	GI RS 10 Sep. 1956	198	fine as is with reported area of 229.56 km² (8)	./.	./.
Kirindy Mite	MNP	II	N. 2015-735 on 21 Apr. 2015	1563.50 (including 282.5 marine)	given as a marine PA, including for its terrestrial biggest portion, and also includes the external buffer with reported area of 2374.03 km² (9)	326 / 1211 (26.9%)	367 / 1211 (30.3%)
Mahavavy Kinkony	NGO	V	N. 2015-718 on 21 Apr. 2015	3020.0 for its terrestrial part	given as a marine PA, including for its terrestrial biggest portion with reported area of 3509.28 km² (10)	./.	./.
Mangoky Ihotry	NGO	V	N. 2015-719 on 21 Apr. 2015	4261.46	fine as is with reported area of 4265.76 km² (11)	./.	./.
Marotandrano	MNP	IV	N. 56-208 on 20 Feb. 1956	422	includes the external buffer with reported area of 671.19 km² (12)	16 / 21 (76.2%)	./.
Menabe Antimena	NGO	V	N. 2015-762 on 28 Apr. 2015	2103.12 (including 293.1 marine)	with reported area of 2094.61 km² (13)	./.	./.
Montagne d'Ambre	MNP	II	N. 2015-776 on 28 Apr. 2015	305.38	includes the external buffer with reported area of 586.7 km² (14)	51 / 65 (78.5%)	./.
Ranobe PK32	orphan	Not defined	N. 2015-808 on 5 May 2015	1685	Reported as a marine protected area with reported area of 1685.0 km²	./.	./.
Tampoketsa Analamaitso	orphan	IV	N. 58-14 on 28 Oct. 1958	171.5	fine as is with reported area of 225.62 km²	./.	./.
Zombitse Vohibasia	MNP	II	N. 97-1454 on 18 Dec. 1997	368.03	includes the external buffer with reported area of 806.72 km²	91 / 163 (55.8%)	./.

(1) https://www.protectedplanet.net/5030; (2) https://www.protectedplanet.net/5040; (3) https://www.protectedplanet.net/1299;
(4) https://www.protectedplanet.net/26653; (5) https://www.protectedplanet.net/303702; (6) https://www.protectedplanet.net/5031;
(7) https://www.protectedplanet.net/352244; (8) https://www.protectedplanet.net/5033; (9) https://www.protectedplanet.net/303700;
(10) https://www.protectedplanet.net/352248; (11) https://www.protectedplanet.net/555697877; (12) https://www.protectedplanet.net/5035;
(13) https://www.protectedplanet.net/352251; (14) https://www.protectedplanet.net/2314; (15) https://www.protectedplanet.net/555549460;
(16) https://www.protectedplanet.net/5036; (17) https://www.protectedplanet.net/20273

MNP uses VIIRS alerts to map fire locations for swift deployment of tactical management in response to potential fire threats. To verify incoming fire alerts, MNP employs both VIIRS and Moderate Resolution Imaging Spectroradiometer (MODIS), and patrols then conduct verification and surveillance, equipped with SMART tools (https://smartconservationtools.org/) to apply GPS coordinates to track the evolution of each fire. These units can either operate as a mixed brigade with police officers in charge, as park rangers with MNP agents in charge, or as a 'Comité Local du Parc—CLP' with committee members from local communities in charge (Bodonirina et al. 2018, MNP 2019). Collectively, variously composed patrols walked 170,046 km in 2019 and 215,478 km in 2020 within the 43 PAs managed by MNP (MNP 2019, 2020 in litt., https://smartconservationtools.org/). In addition to using MODIS for operational fire management, MNP also employs it for global fire monitoring related to a key conservation indicator: reducing the area burnt within PAs. MODIS provides information on the area impacted by each fire and assists in identifying severity as well as the type of ecosystem that has been affected (i.e., forest or grassland). In Ankarafantsika national park, for example, similar numbers of fire hotspots were observed in grasslands and forests, but almost twice as much area was burned in grasslands (Figure 1). The conclusions by Eklund et al. (2022) are flawed because the authors overestimated the size of the PAs, were unaware of the

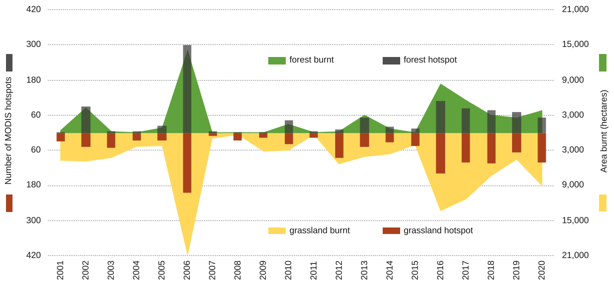

Figure 1. Burnt areas by fires in Ankarafantsika national park and number of MODIS (https://modis.gsfc.nasa.gov/data/dataprod/mod14.php) fire hotspots reported from 2001 to 2020.

existence of prescribed fires, and misinterpreted the lockdown as a halt in PA management. Most of these errors could have been avoided by involving PA managers in the discussion.

EXPANDED CONSULTATION WITH PROTECTED AREA MANAGERS. Based on a quick Google Scholar search in August 2022 using the key words "World Database of Protected Areas" and "shapefile*", there were over 40 environmental sciences-related articles published in international peer-reviewed journals in 2022 alone that relied on the boundaries provided by the WDPA. This highlights a potentially critical problem. While it is not possible to assess the impact of using potentially inaccurate PA boundaries, our example clearly shows (Supplementary Table 1) that significantly different results would be obtained and therefore substantially different interpretations formulated when using accurate data on PA limits. An effort is being made to ensure continuous improvement of the WDPA (Bingham et al. 2019), but this relies exclusively on information provided by governments. It is therefore imperative that users double check the veracity of PA boundaries and shapefiles, regardless of the source. Similarly, reviewers should flag this potential risk when the WDPA is used for studies that rely on accurate PA boundaries.

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SUPPLEMENTARY INFORMATION

Figure S1. Deforestation from 2017 to 2021 according to Global Forest Watch with a tree canopy density (TCD) > 30% and deforestation in protected areas (PAs) IUCN categories I, II and IV, and PAs IUCN categories V and VI. (left for total areas, right in percentage; according to Global Forest Watch https://www.globalforestwatch.org/dashboards/country/MDG/)

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Insights from practitioners in Madagascar to inform more effective international conservation funding

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ABSTRACT

Bending the curve on biodiversity loss will require increased conservation funding and a wiser resource allocation. Local conservation practitioner expertise will be vital in decision-making processes related to funding. Yet, the integration of their insights into funder priorities and strategies is often insufficient, particularly in countries where international funding comprises the bulk of support for conservation. More generally, the role of funding remains under-analyzed in conservation and opportunities for funder-practitioner dialogue at a broad strategic level are limited. We seek to address these critical gaps by presenting results from a participatory workshop of conservation practitioners in Madagascar, one of the world's biodiversity hotspots. Five major areas of need emerged, and these challenges need to be addressed if we are to see long-term solutions to the biodiversity crisis: (1) strengthen law and policy implementation; (2) ensure sustainability of funding; (3) improve coherence and coordination within and beyond the conservation sector; (4) support self-strengthening of local communities; and (5) invest in capacity development. This article elaborates on these thematic areas and their implications for international donors in Madagascar and beyond. Our approach demonstrates a way for amplifying in-country practitioner voices in a collaborative way and highlights the need for their inclusion at all stages of conservation program development so that funding priorities better reflect local needs and aspirations while enhancing prospects for enduring conservation outcomes.

RÉSUMÉ

Pour infléchir la courbe de la perte de biodiversité il est nécessaire d'augmenter le financement pour la conservation et d'assurer une allocation plus stratégique des ressources. L'expertise des praticiens de la conservation locaux sera vitale dans les processus décisionnels liés au financement. Toutefois, l'intégration de leurs connaissances dans les priorités et les stratégies des bailleurs de fonds est souvent insuffisante, en particulier dans les pays où le financement international représente la majeure partie du soutien à la conservation. Plus généralement, le rôle du financement reste sous-analysé dans le domaine de la conservation et les possibilités de dialogue entre

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bailleurs de fonds et praticiens à un niveau stratégique général sont limitées. Nous cherchons à combler ces lacunes essentielles en présentant les résultats d'un atelier participatif des praticiens de la conservation à Madagascar, l'un des points chauds de la biodiversité mondiale. Cinq grands domaines de besoins ont émergé et ces défis doivent être relevés si nous voulons voir des solutions à long terme à la crise de la biodiversité : (1) renforcer la mise en œuvre des lois et des politiques ; (2) assurer la durabilité du financement ; (3) améliorer la cohérence et la coordination ; (4) soutenir l'auto-renforcement des communautés locales ; et (5) investir dans le développement des capacités. Cet article développe ces domaines thématiques et leurs implications pour les bailleurs de fonds internationaux à Madagascar et au-delà. Les défis persistants identifiés sont par exemple le rôle de l'État et sa faible capacité à faire respecter la loi, la difficulté à trouver des financements pour les coûts opérationnels et la gestion de base, ainsi que les lourdes exigences en matière de rapports, et les capacités et ressources nécessaires à cet effet. La communauté des bailleurs devrait reconnaître que les solutions profitables pour les deux parties sont rares à court terme, et démontrer une plus grande volonté d'accepter et de discuter d'un échec comme un moyen d'avancer au lieu de le stigmatiser. Une plus grande coordination au sein et entre les différents groupes et secteurs est nécessaire pour éviter que les efforts ne soient dupliqués, que les lacunes restent non comblées ou que les échecs de mise en œuvre ne se répètent. En raison d'une mauvaise conduite, ou par crainte de celle-ci, de nombreux donateurs semblent avoir évité de travailler avec des acteurs étatiques, favorisant plutôt les ONG internationales de conservation. Cette approche n'est cependant qu'une solution à court terme, car elle ne contribue qu'à renforcer faiblement la capacité nationale à aborder et à surmonter la corruption dans le secteur de la conservation. Pour aller de l'avant, il est essentiel de donner une voix plus forte à ceux qui connaissent le mieux le contexte spécifique et la mémoire institutionnelle des projets précédents. Le processus de réflexion et d'interaction dans l'atelier a permis de dégager des perceptives concrètes pour Madagascar, mais pertinentes pour les autres pays tropicaux où le financement international prédomine dans le domaine de la conservation. Cette approche démontre une manière d'amplifier les voix des praticiens nationaux de manière collaborative et souligne la nécessité de les inclure dans toutes les étapes du développement des programmes de conservation afin que les priorités de financement reflètent mieux les besoins et les aspirations locaux tout en améliorant les perspectives de résultats durables de la conservation.

THE NEED TO REFORM FUNDING STRUCTURES

Enduring biodiversity conservation success requires adequate funding. In the highly biodiverse but often economically poor countries of the tropics, the lion's share of conservation funding derives from official development assistance, private philanthropy, and other international sources (Waldron et al. 2013). Such funding remains well below estimates of financial need (Deutz et al. 2020), with many high-biodiversity countries in the Global South especially underfunded (Waldron et al. 2013). However, successful funding outcomes are not only a matter of amounts, but also how and on what the money is spent. Effective spending is therefore paramount as the global community seeks to find solutions to bridge conservation financing gaps under a post-2020 biodiversity framework (Convention on Biological Diversity 2020). In-country practitioner insights and experience are critical to the wise allocation of resources (Ostrom 1990, Smith et al. 2009). Yet, local practitioners' voices are not always heard in shaping funding priorities and strategies at the possible cost of effective, just, and long-lasting biodiversity outcomes (Smith et al. 2009, Rai et al. 2021).

We address the need for in-country practitioner perspectives to inform conservation funding decision-making with a focus on Madagascar. Recognition of the importance of Madagascar's rich endemic biological heritage in combination with it being among the poorest countries in the world, has led to major international donor investments over the past three decades (Miller et al. 2013, Waldron et al. 2013, Waeber et al. 2016). Despite this, Madagascar has lost 44 % of its forest area since the 1950s (Vieilledent et al. 2018) and has the highest number of threatened species of any country (IUCN 2019). Saving Madagascar's biodiversity is thus of global concern. However, despite decades of financial support to save the island´s unique biodiversity, the impacts of conservation funding have been meagre (Freudenberger 2010, Corson 2016, Waeber et al. 2016).

What has made it so challenging to translate invested funds to conservation success in Madagascar? We address this question and provide a forum through which practitioners in Madagascar can share their insights on how funders might more effectively support conservation in this globally important biodiversity hotspot. The funders we address are bi- and multilateral aid agencies and private foundations, recognizing that these donor types have different mandates and objectives and may operate differently in how they engage with in-country practitioners. Different donor types may therefore have different roles to play in relation to the recommendations we present.

We believe the insights and approach to amplifying in-country practitioner voices developed in this article will be applicable in many other countries, especially where international funding predominates in conservation. Given that Madagascar has faced political instability, corruption, and weak institutions (Kull 2014, Jones et al. 2019), recommendations may be especially relevant to countries that have struggled with such governance issues.

ELICITING PRACTITIONER INSIGHTS

The findings presented in this article derive from a two-day workshop held in Antananarivo, Madagascar in January 2020. Representatives from well-established organizations with documented experience receiving international conservation funding from a range of aid and foundation donors were invited. Invitees included those from Malagasy conservation and development organizations and networks, the national parks agency, international conservation nongovernmental organizations (NGOs), and university units involved in conservation. Eighteen participants (7 women, 11 men), representing eleven conservation organizations attended (8 were from Malagasy associations or networks, 8 from in-country offices of international NGOs, 1 from local universities, and 1 from the national parks agency). Three international researchers and three Malagasy collaborators helped facilitate the workshop.

The overall goal of the workshop was to identify challenges and solutions in translating conservation funding into long-term impacts. To achieve this goal, we adapted scanning and visioning-methods commonly used in futures research (Bengston et al. 2012) and conservation research priority-setting (Sutherland et al.

2011). Workshop participants first recorded key challenges to adequate and effective conservation funding they had faced on individual notecards (Table 1). Workshop facilitators grouped the challenges thematically with iterative feedback from participants. Participants then anonymously voted on which topics they thought needed the most attention from the international funding community (Table 1). Potential solutions and enabling conditions required to implement them were discussed in breakout groups and subsequently among all workshop participants (Table 2). Finally, we refined conclusions drawn during the workshop through collective drafting of this article. All participants, including workshop facilitators, were offered the opportunity to be co-authors.

WHAT DONORS NEED TO KNOW

Workshop participants identified 64 challenges to effectively translate funding into long-term conservation outcomes (Table 1). The top five areas of need were: (1) strengthen implementation of law and policy; (2) ensure sustainability of funding; (3) improve coherence and coordination; (4) support self-strengthening of local communities; and (5) invest in capacity development. These areas of need are presented in the order of importance as ranked by workshop participants and each includes a description of the need and related recommendations for conservation funding. We highlight that actions to address these needs must involve a variety of actors across different scales.

STRENGTHEN IMPLEMENTATION OF LAW AND POLICY. Conservation actors in Madagascar face continuous challenges related to weak law enforcement, corruption, and insufficient involvement of relevant government agencies in conservation and environmental management. Madagascar is currently performing poorly on global governance metrics, ranking 158 out of 198 on the Corruption Perception Index (Transparency International 2020) and showing steady declines in good governance since 2008 (Kaufmann and Kraay 2020). Willingness to curb official misconduct is limited as those in positions of power sometimes benefit

Table 1. Identified challenges to adequate and effective conservation funding and their thematic categorization by workshop participants. Areas of need ordered based on votes (recorded in parentheses) for total number of identified challenges.

Areas of need	Thematic grouping	Identified challenges (individual notecards)
Law and Policy (21)	Law and Policy	Corruption Government and political system Lack of coherence between sectorial policies Lack of correct policies/laws Lack of enforcement of laws Lack of involvement of the administration (state) Lack of power/imbalance of power Misappropriation of law enforcement Seldom funding to deal with regional/national policies
Sustainability of funding (21)	Lack of funding	Access to funding Co-financing Funding insufficient to provide real/tangible impacts Funding not enough Funding too focused, not integrated, not addressing reality Lack of funding Reality on the ground not understood by funders
	Types of funding	Big donors/grants injecting too much money in area without proper foresight on effects Funding not flexible enough for other uses and to deal with unforeseen issues Limited means Lots of money for paper parks (not involving communities/others affected - not achieving conservation) Restricted funding
	Short-term funding	Funding too short-term (3 years or even less) No certainty (can we hire - will we have funding after 2, 3, 5 years?) Short-term Short-terms funding Short-terms funding of funders Sustainability of funding
	Heavy procedures (reporting etc.)	Governmental funding associated with heavy procedures Heavy administrative procedure Heavy procedures Inconsistent (changing during grant term) or too much administration and reporting requirements Procedures Requirements of donors State / local government procedure: e.g. delegation contract when legalization is required to obtain financing
Coherence and Coordination (15)	Coherence and Coordination	Competition between grantees to get funding (players) Inability to report negative results (negative effects on future funding) Intersectorality Lack of awareness or information at local level Lack of trust between stakeholders Limited coordination between funders and risk of duplication of funding Not coordinated among groups (NGOs, Government, etc.)
	Access to information	Capitalization of lessons learned Restricted access to information and research results
Local community and stakeholder involvement (13)	Local communities	Capacity Communities expect quick results Cultural barriers, e.g. inter-clan conflicts impeding collaboration Difficulty to get funding for local communities Do not consider the well-being aspect Involvement of local communities Lack of capacity at local level, those who should be managing the resources (and getting the funding) Lack of self-confidence for change Many barriers to engagement outside conservation, like social services (health, education, etc.) No recognition of local communities' contribution to biodiversity conservation Overlapping of protected areas and communities conserved areas Precarity of local communities Unsatisfying outcomes
	Other stakeholders	Involvement of stakeholders Lack of consultation of all stakeholders during policy making Mentality of stakeholders
Capacity development (11)	Capacities	Weak capacity of sub-grantees Writing proposals
	Personnel/ Human resources	Change of leadership and implementing team

from illegal activities (Randriamalala and Liu 2010). Previous research has repeatedly raised concerns about poor governance and its effect on conservation in Madagascar, but the issue is sensitive and exacerbated by political instability (Jones et al. 2019, Pyhälä et al. 2019).

Many of these governance challenges require structural fixes that might appear to lie beyond the scope of what the donor community can address or influence directly. This was something that workshop participants disagreed with. They provided several suggestions how funders could redress this issue. For example, donors could invest in awareness raising campaigns and specific training on how to deal with misconduct. Donors also can decide the actors they will support, and to require that principles of good governance are followed. Due to misconduct, or the fear of it, many donors appear to have avoided working with state actors, instead favoring international conservation NGOs (Kull 2014). This approach is only a short-term solution, however, as it does little to strengthen national capacity to address and overcome corruption in the conservation sector. When funders only work with international NGOs it gives these organizations unequal power and risks that they narrowly advance Western conservation agendas (Rodríguez et al. 2007), which in turn risks excluding various types of actors and national viewpoints, ranging from individuals, to communities, to the Malagasy state itself. To avoid this scenario, funders could provide greater support for intermediate solutions such as conservation trust funds that are managed from within the country but not directly under state control. Examples include the Madagascar Biodiversity Fund, which supports the country´s protected areas, and the Tany Meva Foundation, which supports conservation and sustainable development projects led by community organizations. Donors should also consider direct support to Malagasy research institutions that can investigate governance issues in relation to conservation and develop more specific policy recommendations for addressing them.

ENSURE SUSTAINABILITY OF FUNDING. Participants identified three main concerns related to the sustainability of funding: international priorities may not match in-country needs, access to funding for operational costs is limited, and short-term funding cycles inhibit long-term planning. Conservation projects often must align with trends in international conservation agendas to compete for international funding (Rodríguez et al. 2007, Redford et al. 2013). In Madagascar, such trends have shifted from protected area gazettement (often with a focus on forests); to integrated conservation and development projects; to decentralization and community-based natural resource management; to market-based approaches, such as ecotourism, payment for ecosystem services, and REDD+ (Reducing Emissions from Deforestation and forest Degradation) (Kull 2014, Pollini et al. 2014, Scales 2014). International donor agenda-setting creates a need to brand operations in accordance with current global trends, even though it may not reflect what is most needed or likely to work on the ground. Two especially striking examples of abrupt changes in the local Malagasy setting are 1) the shift away from community-based natural resource use approaches that occurred following the contested election of Ravalomanana in 2001 and implementation of the Durban vision to triple the protected area coverage (Corson 2014, Pollini et al. 2014), and 2) the shift in influence when the USA emerged as the main conservation donor around the onset of the first stage of the National Environmental Action Plan (1990 onwards) (Kull 2014) and their abrupt exit following the political coup in 2009 (Freudenberger 2010).

An additional barrier is the increasing difficulty in finding sustained funding for basic management and operational costs, which are crucial for maintaining trained staff and long-term planning. Finally, many conservation projects are funded on short-term cycles (< 3 years). This funding paradigm creates incentives for new projects that deliver short-term reportable outcomes, but that can do little to address the underlying long-term changes needed. Participants highlighted that building community support and trust can take decades, and such long-term relationships are the foundation of some success stories (Gilchrist et al. 2020). Even as donors in Madagascar have articulated a long-term vision (e.g., USAID across three National Environment Action Plans (1990–2009) (Freudenberger 2010), in-country practitioners experienced a different reality. Political crises in 2002 and 2009 both caused hesitations among donors (Kull 2014) and were reported by workshop participants to have affected the funding situation, which set conservation progress back by undermining trust that had been built with local communities and limiting education and enforcement of protected area regulations. Such funding gaps have also meant the temporary or permanent loss of experienced staff. Finally, the burden of constantly applying for and reporting on often small grants to ensure organizational continuity eats time and resources that otherwise could be used for operations.

The funding community could address these concerns by involving in-country experts earlier in the planning stages of new funding programmes and initiatives. They could conduct needs assessments so that calls for proposals can better reflect local priorities. Some funders have already started to explore different funding mechanisms and scales of intervention that focus on organizations instead of specific projects. More funders should provide grants to cover basic operational costs. Participants noted that some donors have started to explore such options (e.g., Swedish International Development Cooperation Agency, Sida). Lastly, funding cycles could be creatively lengthened to enable long-term planning and activities, including those that are more labor-intensive and require building trust with local communities, while still ensuring accountability. Options for doing so include extending project duration or making longer-term commitments explicit up front while structuring disbursements so they are contingent on performance. Further supporting conservation trust funds could also help address the issue of short-term funding and the insecurity it brings.

IMPROVE COHERENCE AND COORDINATION. Participants highlighted that there is very little formal coordination between grantees, government, and funding actors, even though they generally share the same conservation goals. More coordination within and among different groups and sectors is needed to ensure that efforts are not duplicated, gaps not left unfilled, or that implementation failures do not repeat themselves. Lack of coordination is especially troublesome given the high turnover rate of employees in conservation organizations. Participants also highlighted how important it was for them to share "lessons learned" and openly discuss "implementation failures", a need that has been recognized in conservation broadly (Catalano et al. 2019).

Funders can both improve coordination across projects and normalize "failures" by formally acknowledging that setbacks are inevitably part of project implementation, dispelling the notion that reporting on them will foreclose future funding opportunities. Funders can encourage this by incorporating a discussion of setbacks in grant application and reporting processes. Specifically, funders could require grantees to reflect on the limitations of previous, related projects; discuss what issues may be a barrier to implementation and what steps they are taking to circumvent the roadblocks; and describe the potential costs of their project to socio-economic groups. Such changes can help reorient grantees from writing about wishful "win-wins" that gloss over potential problems to more frank treatment of potential limitations and trade-offs in implementation.

Funders should also be open to renegotiating terms when projects suggest alternative implementation strategies thereby supporting adaptive management. To foster more effective collaboration, funders can support communities of practice where grantees can network and learn from one another, build trust among conservation-relevant actors, and have a platform to raise emerging issues and provide more direct input into broader funding priorities. Such communities of practice have been shown to be effective in enabling social learning and boosting problem-solving capabilities (Watkins et al. 2018).

SUPPORT SELF-STRENGTHENING OF LOCAL COMMUNITIES. Participants identified several challenges for local communities to effectively engage in conservation. Communities do not typically have many opportunities to be meaningfully involved in the planning and implementation of conservation projects, even though they are affected by them. Formal hearings are often legally required at the onset of projects, but two-way communication is rare, inhibiting genuine participation (Corson 2014). Lack of information and capacity are key challenges: local people might not know their rights and how to engage in decision-making processes, especially as international and national interests drive local implementation (Corson 2014). Yet local communities typically carry the highest costs of conservation, and it is rare for conservation to bring greater short-term benefits than existing practices like swidden agriculture (Neudert et al. 2017). This imbalance has meant that many attempts to incentivize conservation using local management institutions have failed or resulted in conflicts (Kaufmann 2014, Pollini et al. 2014). However, there are examples where local knowledge, norms, and practices have supported conservation and where local resource use has been governed in a way that is compatible with conservation objectives (Pollini et al. 2014). We note that most of the workshop participants are involved with new protected areas established from 2015 onwards that emphasize strong community involvement. For such protected areas, management transfers have often been negotiated with local communities and build on Dina (traditional community regulation), supported by the protected area management agency to be formalized and recognized by the state.

Funders interested in promoting biodiversity conservation are increasingly having to acknowledge and accept that local communities might have views, perceptions, and priorities that do not serve the main interests of different conservation actors. This also means that attempts to change local customs to serve a conservation agenda may have far reaching consequences that in the long term might harm sustainable outcomes (Kaufmann 2014). More funding for social sciences, especially interdisciplinary research, and support to bring this knowledge into the conservation policy process, is needed. Funders could also improve participation and engagement by supporting civil society organizations to translate the technical language of legislation and ensure local communities know their rights and options to mediate potential conflicts with conservation and development projects. Issues related to equity and how best to compensate local communities for resource restrictions did not emerge as separate topics in the workshop, yet this is an area where the role of funders is crucial (Hockley et al. 2018). Previous research has shown that transaction costs can be high with on average only 59 % of project costs reaching local communities through microprojects related to REDD+ (Mackinnon et al. 2018). Investment in development-related projects, including direct cash transfers to alleviate poverty, may also boost community welfare while enhancing biodiversity impact as shown in other tropical countries (Ferraro and Simorangkir 2020).

INVEST IN CAPACITY DEVELOPMENT. The workshop participants recognized the need for more support for capacity development within local communities, within and across NGOs, and within the formal education sector. Many communities would benefit from communication, leadership, and problem-solving skills that can help empower them to self-organize and advocate for their rights and interests at larger spatio-administrative scales, not merely at village levels. Alternative livelihoods training promises to benefit communities living near protected areas specifically.

Participants identified several ways funders could support capacity development within and across civil society organizations, including support to develop individual skills in fundraising, communication, leadership, and certain technical areas, such as data analysis and statistics. To enhance capacity across organizations, funders can support the costs associated with face-to-face interactions among grantees so that they can learn about one another's efforts to minimize duplication of efforts, identify and plan to fill gaps, and discuss lessons learned. Successful networks like Forum Lafa for terrestrial protected area managers and the Mihari network (https://mihari-network.org/) for locally managed marine areas provide examples that could be further supported or expanded upon.

Finally, participants noted that Malagasy universities now train many conservation biologists, but existing programs do not adequately prepare students for the management roles that they are being recruited to fill. Funders could address this need by supporting efforts to revamp curricula to include core management competencies, such as developing management plans, fire monitoring with GIS software, and instruction on the use of the Management Effectiveness Tracking Tool to evaluate protected area management effectiveness. Relatedly, there is a particular need for greater support for conservation social science within universities in Madagascar to ensure graduates receive the necessary training and skillset to work with people and vulnerable groups.

CONCLUSION

The themes and recommendations identified here are interrelated and extend beyond traditional biodiversity conservation agendas. Together, they point the need for support to address key underlying conditions like good governance and coherence and coordination. Business as usual cannot continue if the necessary transformational change is to take place and be sustained over the long term (Díaz et al. 2019). Donors have often chosen to work with the international NGO sector to circumvent an inefficient state machinery, but there are limits to how much non-state actors can achieve on their own, especially as individual organizations. Strengthening both state and non-state institutions, ranging from local levels all the way to the level of ministries, is therefore crucial as doing so cannot only enhance the impact of specific conservation projects but also build a more broadly-based and resilient in-country conservation community (Nelson 2009). Most participants worked at the interface between international donors, government agencies, and local communities, and are therefore uniquely positioned to reflect on current challenges across actors and scales.

It is critical to allow a voice to those most familiar with the specific setting and 'institutional memory' of previous projects. The reflective and interactive process in the workshop led to grounded insights in Madagascar, but with relevance across tropical countries where international funding predominates in conservation. Structural changes need to take place in relation to how and when local experts are consulted, and their voices need to be heard. In-country funding recipients might be engaged in specific negotiations around project funding, but their voices are rarely heard in setting big picture priorities and strategic decision-making. We call upon the donor community to integrate in-country expertise much more strongly in conservation program and project development. In this way, true progress can be made toward 'letting the locals lead' (Smith et al. 2009) and advancing conservation over the long term.

Even as the operational environment in Madagascar has been very challenging for international donors at times (Freudenberger 2010, Corson 2016, Jones et al. 2019), in-country practitioners have kept pushing forward, gaining valuable insights along the way. We have distilled these here, highlighting major challenges (Table 1), together with specific recommendations (Table 2) for addressing them based on hard-won experience by in-country practitioners. We recognize that donors are different and will need to coordinate among themselves which role they can play in implementing the recommendations, but given the importance of protecting biodiversity and the limited previous successes in doing so, makes it imperative to develop funding approaches that address systematic barriers. Given the on-going development of the post-2020 international biodiversity framework, the time is ripe for creative thinking and concerted action to support a transformation away from business as usual in conservation funding. Insights from in-country practitioners, as presented here, help point the way forward, especially in areas where no easy solutions exist.

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Table 2. Recommended actions for international conservation donors to address identified areas of need.

Areas of need	Recommendations
Strengthen law and policy implementation	Invest in awareness raising campaigns about corruption and offer training at all levels on how to deal with misconduct.
	Support intermediate solutions in countries with weak governance in the state sector, such as conservation trust funds managed from within the country but not directly under state control; make good governance a condition for continued funding.
	Support in-country research institutions to investigate governance issues in relation to conservation and develop more specific policy recommendations for addressing them.
Ensure sustainability of funding	Involve in-country experts already at the start of the planning stages of new funding programs, initiatives, and strategies.
	Conduct needs assessments so that calls for proposals can be designed to better reflect local and national priorities.
	Provide grants to cover basic operational costs and for building organizational capacity.
	Extend project duration or make longer-term commitments explicit up front while structuring disbursements so they are contingent on performance.
Improve coherence and coordination	Normalize "failures" by formally acknowledging that setbacks are inevitably part of project implementation, dispelling the notion that reporting on them will foreclose future funding opportunities. Encourage this by incorporating a discussion of setbacks in the application and reporting processes.
	Require grantees to reflect on the limitations of previous, related projects; discuss what issues may be a barrier to implementation and what steps they are taking to reduce them; and describe the potential costs of their project across socio-economic groups.
	Adopt adaptive management strategies that are open to renegotiating terms when projects suggest alternative implementation strategies.
	Foster communities of practice where grantees can network and learn from one another, increase trust among different actors, and have a platform to raise emerging issues and provide more direct input into broader funding priorities.
Support self-strengthening of local communities	Fund initiatives where local communities collect data to highlight conservation-relevant cultural norms and practices, which can help increase interest in, motivation for, and ownership of positive conservation outcomes.
	Fund civil society organizations to translate the technical language of legislation and bureaucracy to suitable formats so that local communities are well informed and articulate about their rights and options when negotiating possible conservation and development projects.
	Where deemed appropriate by local communities, invest in community-managed development projects for alleviating poverty and boosting community welfare and wellbeing.
Invest in capacity development	Fund initiatives to develop individual skills in fundraising, communication, leadership, and some specific technical skills, such as data analysis and statistics.
	Provide for costs associated with face-to-face interactions across grantees so that they can learn about one another's efforts to try and minimize duplication of efforts, discuss lessons learned, and identify gaps and reorient their projects to fill these gaps.
	Encourage efforts to revamp domestic university curricula to include core management competencies so that future conservation actors have both the scientific knowledge and practical skills for competence
	Invest in formal education initiatives for training future conservation social scientists in universities across the Global South

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Addenda à l'article Revue des textes fonciers et forestiers pour la mise en œuvre de la restauration des paysages forestiers à Madagascar. Madagascar Conservation & Development 16, 1: 32–42.

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