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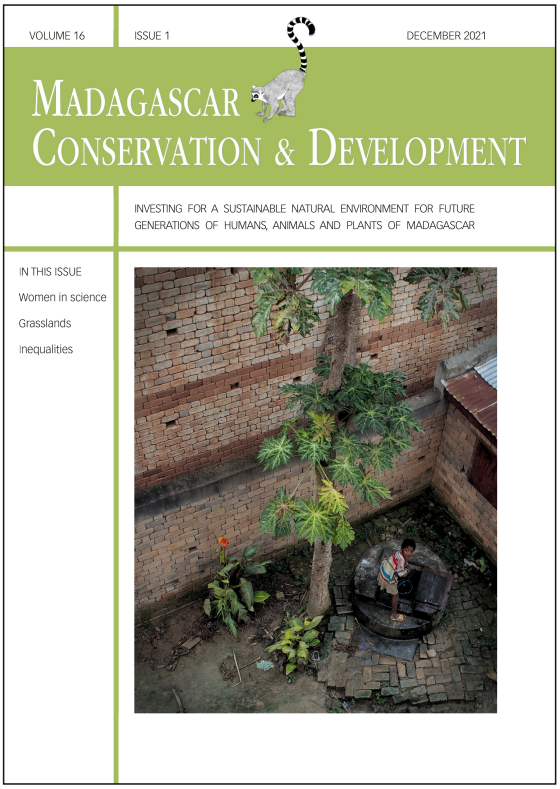
MADAGASCAR CONSERVATION & DEVELOPMENT

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

IN THIS ISSUE



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Increasing inequalities: climate change, biodiversity, forests

In a world that is increasingly hot and suffering from global warming, or rather, global weirding, as it is not just the temperatures that are climbing but weather events that are turning "weird", as we have seen just this year with increased and prolonged rainfalls causing floods, earlier storm seasons with increased frequency of stronger and more severe storms, longer fire seasons with increased extreme fire weather and forest fires, or extended droughts. One such drought has been and still is affecting the southern portion of Madagascar. The region is experiencing the worst drought in four decades (FAO 2021a). A million people are on the brink of starvation. Is this drought due to climate change? Interesting to note in this context, is the fact that while Joe Biden gets cited in the news all over the World linking the Kentucky tornado with increasing temperatures, associating the current drought in Southern Madagascar has been formally excluded from an effect of climate change (Harrington et al. 2021). Worth noting here but not surprisingly, the Madagascar drought got very little global coverage. Both events cannot yet scientifically establish a causal link with climate change. While the tornado is referred to as a tragedy, the Madagascar drought is exacerbating the suffering of an already structurally impoverished region. Water levels are sinking. Lands are drying. Food is getting scares. Drinking water is getting scares. Reliable climate data are often lacking—as in most countries in the global south—weather stations are isolated and few and far between. There is a pressing need to strengthen the research capacities in Madagascar to face climate change, with support from wealthier countries (Schiermeier 2021). Worse, due to the ongoing Covid-19 pandemic, the government has restricted flights to Madagascar, which is also affecting critical humanitarian cargo to relieve the suffering. To top this off, FAO analyses predict an increased vulnerability to locust plague in the same region during the locust's migration period, from November 2021 to March 2022 (FAO 2021b).

CLIMATE CHANGE AND RELATED WEATHER EVENTS HAVE BEEN ON EVERYBODY'S SCREEN THIS YEAR

Climate COP26 in Glasgow saw some 20k people participating despite Covid cases being yet again on the rise. A gargantuan task by the organizers. An even bigger task to fulfil the expectations: "keep 1.5°C alive"—a stated goal of the Paris Agreement, COP21 in 2015. It is hard to tell how many still believe in this goal being reachable; as Lewis and Maslin put it, "limiting global warming to 1.5°C is on life support—it has a pulse, but it's nearly dead" (Lewis and Maslin 2021). Good news first: this was the first time that a COP put the IPCC report center-stage—it looks like politics are considering science, which is, unfortunately, not a given in these times. Remember, the world renown expert panel for climate change put out a "Code Red for Humanity" in August 2021 in their sixth assessment report (IPCC 2021). The IPCC report issued that to limit global average temperature increases to 1.5°C requires a reduction of CO_2 emissions of 45% in the year 2030 or a 25% reduction by 2030 to limit warming to 2°C. Another piece of good news: The term "carbon" has also found first time mention in a final agreement of a climate COP, despite strong opposition by fossil fuel lobbyists—a taboo has finally been broken. It took the world only 26 such meetings (which probably shows how strong the economic grip on politics is versus the weak position science is holding). The final Glasgow Document (COP26 2021) mentions "accelerating efforts towards the phasedown of unabated coal power and phase-out of inefficient fossil fuel subsidies"—yes, that's right, "phasedown" instead of "phase out"… semantics, one may say, but this subtle change in the final text may actually matter a lot given the little time left to align with the 1.5°C trajectory. Less good news: Only weak commitments were issued and submitted by 151 countries to deepen their commitments to cut their carbon emissions by 2030 (UNFCCC 2021) (viz. the NDCs or nationally determined contributions). Some of the NDCs (by Australia, China, Saudi Arabia, Brazil, Russia) are so weak that it seems very likely impossible to reach net zero emissions by mid-century… A good thing is that they all could agree to revisit their pledges and targets on a yearly base. We will see more clearly next year whether 1.5°C is still feasible. Another shocking but not surprising revelation is the fact that the rich countries keep ignoring their historic responsibility. COP26 failed to secure the establishment of a new loss and damage financial facility. Such a facility would provide funds for climate change impacts that are hard or impossible to prevent or adapt to, which is especially crucial for vulnerable countries that risk losing much of their land, e.g., Marshall Islands or Fiji, or countries with a high proportion of smallholder farmers unable to cope with effects of climate change. Remarkably, while the G20 failed to fulfill the loss and damage fund agreed upon during COP21 in Paris—only 80% of the first 100 billion has been organized up to date, the same countries managed to subsidies fossil fuel industries with 3.3 trillion US$ since 2015 (BloombergNEF 2021), and 5.9trn US$ in 2020 alone (Parry et al. 2021).

Climate change received very welcome global attention this year, finally, one may say; but there is also a parallel urgency to slow down the rapid biodiversity loss. This received much less attention, or it almost got lost amidst all the carbon talking; admittedly, carbon has a business appeal that biodiversity simply lacks. But did you notice that there was also a United Nations meeting for biodiversity? It was in the media, but got dwarfed by the Climate COP. Split into two, a virtual meeting this October, and a second in-person meeting next spring in Kunming, China, the CBD COP15 discussed important aspects for the post-2020 GBF (global biodiversity framework); how to stop and reverse the fast decline in biodiversity, and what should be the targets and goals for 2030, and how to achieve the biodiversity vision "Living in Harmony with Nature" for 2050. Reading through the CBD Kunming Declaration (CBD 2021), it is astonishing how frequently the terms "recognizing", "stressing", "noting", "step up our efforts" were used. All kind of a lingo that stresses the urgency of the moment, and speaking of

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time, there literally is not much time left for actions; but all is veiled in a diplomatic language so as to not offend and to have as many appeased as possible. Question begs, whether such a declaration is enough to finally convince governments to move beyond pledges? We shall see a continuation sometime in the next spring.

In the meantime, on 2 November 2021 at COP26 in Glasgow, Scotland, 127 countries, Madagascar included, signed the Glasgow Leaders' Declaration on Forests and Land Use (yet another declaration). This declaration, a follow-up of the failed New York Declaration on Forests, aims to end net forest loss by 2030. How is this different from the New York Declaration on Forests? Both have the same targets, but the Glasgow declaration has been signed by almost three times more governments covering some 850 million hectares of tropical primary forest in 2010, vs the 558 million hectares represented by all the signatories of the NY Declaration (Butler 2021). So, how can we make sure that these new pledges are not falling short as the previous one? Signs certainly are not encouraging: in 2020 alone, tropical deforestation increased by 12% compared to 2019—some 12 million hectares, of which some 4 million hectares of primary ("undisturbed") forests. According to Seymour (2021), the pandemic lockdowns may restrict not just regular people but also law enforcement, thus leaving forests more prone to illegal activities such as burning, logging, and mining.

Forests are the Earth's lungs! This has become an alarming message since the Amazon rainforests became a CO_2 emitter due to deforestation and climate change (Gatti et al. 2021). The Central African forests are therefore the best candidate to become the new green lung for the planet.

AND WHAT ABOUT MADAGASCAR FORESTS?

Media reports are often negative when depicting forest status in Madagascar. Sometimes with reason. The extreme—probably unparalleled—deforestation happens in the reserves of Menabe-Antimena and Ranobe-PK32, two protected areas of IUCN category V. According to estimates with a Tree Cover Density of 29% for the dry forests in the region, the Menabe-Antimena (in the West) has lost more than 4 km² of forest cover over the last 20 years, and Ranobe-PK32 (in the Southwest) has lost almost half of its forest cover over the same period (Rafanoharana et al. 2021). The national park Ankarafantsika (Northwest), infamous for its annual fires and consequent deforestation has been in the news in Sept. 2021 for extreme fires and deforestation. The park has lost some 1.5 km² of forest over the last 20 years. The Menabe is especially renowned for its large and impressive baobabs; these baobabs are not endemic to the region, nor does the Menabe harbor the largest and most spectacular populations of endemic baobabs—e.g., Mikea and Tsimanampesotse have nothing to be ashamed of—but the Menabe-Antimena is the last refuge for the giant jumping-rat *Hypogeomis antimena*. This vegetarian monogamous (!) large rodent only found in the forests of the Menabe-Antimena is currently threatened by extinction.

But not everything is negative when we talk forests in Madagascar. There is a bunch of "better" news. For instance, the park of Mikea in southwestern Madagascar is famous for its dry spiny forest but also for the ravaging fires and deforestation which occurred in 2013, several months after cyclone Haruna disturbed the area in February of the same year. A total of 784 fire alerts (MODIS) have been reported in 2013 when the mean number for the years before was around 60. In 2020, the number decreased to 16 and only four

Figure. Giant jumping rat (*Hypogeomis antimena*) found only in the Menabe forests. Photo courtesy of Harald Schütz.

fire alerts have been reported so far in 2021. This is the result of a close collaboration between the park managers and the local communities in the survey and conservation of the park with the implementation of local laws (Ollier Andrianambinina, pers. comm.). In national park Tsimanampesotse, the number of fire alerts always exceeded 100 annually before 2010, but a maximum of 10 annually have been reported afterwards, and only 4, 4 and 2 over the last three years despite the extreme drought.

Forests are important for both biodiversity and carbon sequestration. We must consider both challenges simultaneously. Climate change and biodiversity loss, including the still growing problem of deforestation. These are big challenges, not because we cannot solve them but because we are running out of time. Never have forest transitions, which take on average some 200 years to happen, been achieved within some 10 years. Yes, this is the time frame we must deal with when tackling the simultaneous urgencies of carbon, trees, and diversity.

In the meantime, another urgency needs to be dealt with. The pandemic. The world is getting vaccinated. Since the end of 2020, an unprecedent rollout of vaccine distribution and application has taken place. Signs for hope to finally put an end to a pandemic that has been wrenching havoc. While some 8.5 billion doses of vaccines have been administered globally, there are still some 40+ percent of the global human population that need to be vaccinated as of the writing of this editorial, mid December 2021 (Our World in Data 2021 https://ourworldindata.org/covid-vaccinations). Now, after a closer look, it becomes apparent that there are gaps of vaccination for two main reasons. In some regions, like the Germanic speaking countries, there is a rather high refusal of getting vaccinated based on libertarian values of individual choice and rights. In other regions, like sub-Saharan Africa, and Madagascar in particular, there is another reason for lack of vaccination: Lack of vaccines. Here people have no choice. They simply have no vaccine! To add to this misery comes another devastating fact: The global race to beat this pandemic has funneled unprecedented money to research and develop Covid-19 vaccines and medication, which resulted in less funds available to fight malaria, which resulted in an increase of Malaria cases—14 million more in 2020 compared to 2019 pre-pandemic (WHO 2021a). A double whammy. At least there is a bit of hope: this year, finally (!), the long-awaited effective malaria vaccine for children has been developed (WHO 2021b). Though again, the question of fair and equitable distribution is up next…

This year—with the environmental urgencies and vaccination inequalities—is our window into a future, where we see two things at play: First, we are dealing with parallel urgencies, where human actions are leading to overreach planetary boundaries—currently science reports that we have already broken through the planetary ceiling (i.e., four boundaries have been breached: climate change, biodiversity loss, land-system change, bio-geochemical flows; Steffen et al. 2021). Second, we will also trespass social tipping points. The world's richest people now own 11% of global wealth as a recent World Inequality Lab report shows (WIL 2022), exacerbated by the pandemic. UNICEF just published its report on children, documenting that children are worse off than in the past 75 years due to the pandemic (UNICEF 2021). In all this, inequality is laid bare, brutally and unforgivingly. The already poorest billion on Earth will pay for what the more privileged did and enjoyed. The environmental challenges of climate change, biodiversity loss, deforestation will only be more unforgiveable on the already disqualified. "Inequality is a political choice" (WIL 2022: 11). As seen at the COP26, the challenge is not one of "we can't", but one of "we don't want to", or maybe it is simply that we do not yet know the right strategy (Waeber et al. 2021). What is for sure is that poverty is not a question of choice. We must ensure that in all our efforts to bend the curves of environmental unsustainability, the price is not exacerbating already existing inequalities.

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Assessing the challenges and initiatives to increase women's integration into science in Madagascar

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ABSTRACT

We present here a commentary essay on the challenges and perspectives on the recruitment and retention of Malagasy women in STEM (Science, Technology, Engineering, and Mathematics). We base the essay on our personal experience as Malagasy women scientists and support the arguments with the responses of 60 Malagasy women scientists to an online survey that was shared among Malagasy scientists. We identified that the main causes for a limited number of Malagasy women in STEM relied upon traditional expectations and heavily ingrained cultural values. The situation becomes more complicated when accounting for familial constraints, financial constraints, and communication gaps between students and professors. This is obviously an unfortunate situation; however, there have been bridging-gap initiatives—financial, awareness to family pressure, and knowledge difference between senior and junior scientists—that should be continued to provide support to promising students and enhance STEM education as a tool for development in Madagascar.

RÉSUMÉ

Cet essai discute les défis et les perspectives dans le recrutement et le maintien des femmes citoyennes de Madagascar dans les sciences, la technologie, l'ingénierie et les mathématiques (STIM). Les arguments présentés sont basés sur nos expériences personnelles en tant que femmes scientifiques nées et ayant grandies à Madagascar. Ces arguments sont soutenus par des informations issues d'un sondage effectué en ligne auprès de 60 femmes scientifiques, s'identifiant elles-mêmes originaires de Madagascar. Les raisons pour lesquelles ces femmes sont peu nombreuses à participer activement dans les domaines des STIM à Madagascar sont liées à des contraintes traditionnelles et à des valeurs culturelles fortement ancrées depuis leur enfance. La situation se complique lorsqu'on tient compte des contraintes financières et des écarts de communication entre étudiants et professeurs. Si cette situation est évidemment regrettable, il existe cependant des initiatives visant à combler le fossé qui sont financières, ou qui s'inscrivent dans la sensibilisation à la pression familiale et à la différence de connaissances entre les scientifiques seniors et juniors. Ces encouragements devraient être poursuivis afin d'apporter un soutien aux étudiantes prometteuses et d'améliorer l'enseignement des femmes en STIM qui sont importantes pour le développement de Madagascar.

INTRODUCTION

The role of women in science (a relative term that we use here to collectively refer to Science, Technology, Engineering, and Mathematics—STEM) is as important and crucial as their role in society (Harding 1998, Fox 2001). The involvement of women in the scientific workforce has, for instance, provided opportunities toward increasing social justice, gender equity, and reduction in poverty (Harding 1998). However, the worldwide percentage of women versus men in the scientific workforce is still relatively low with a global average of 29.3% (UNESCO 2019), leaving a significant gap in gender-equal contributions towards science and the society (Blickenstaff 2005, Larivière et al. 2013, Clark et al. 2017). This gap could worsen if one considers the level of education, race, ethnicity, or other society-driven factors. Recent studies have additionally highlighted that, globally, women tend to publish less peer-reviewed scientific articles and lead fewer scientific disciplines than men (Larivière et al. 2013, West et al. 2013). Such bias has become more pronounced since the COVID-19 pandemic (UN Women 2020, Viglione 2020, Vincent-Lamare et al. 2020).

In Madagascar, gender bias is still heavily felt at various scales (Rabenoro 2012). Despite the high level of girls' enrollment in schooling at an early stage (Gastineau and Ravaozanany 2011, Rabenoro 2012), the percentage of women's enrollment in the

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STEM-fields decreases with the level of education. Only 35% of Malagasy scientists are women, and the number of women enrolled in universities beyond B.Sc. and M.Sc. degrees dramatically decreases (UNESCO 2016). Although it decreased to 32.9% in 2018, this number is slightly higher than that of Sub-Saharan Africa (UNESCO 2019). If we look closer at student enrollment at the University of Antananarivo, which represents about 44% of enrolled students in all six provinces of Madagascar (MESUPRES 2014a), there is substantially lower integration of women in Ph.D. programs in some scientific fields (Figure 1). This reduction in higher-level enrollment is associated with a combination of factors, similar to what has been observed globally. These usually include local history, early age stereotyping, cultural background, religious belief, family pressures, lack of senior female role models, lack of governmental funding, and the existence of an unwelcoming environment for women in science classes and other academic settings—an environment considered a "chilly climate" (Duteil 2009, Gastineau and Ravaozanany 2011, Sugimoto 2013, UNESCO 2016, Clark et al. 2017).

In this essay, we aim to highlight some major challenges faced by Malagasy women in STEM and discuss the variety of initiatives that have been implemented with success to leverage gender diversity in STEM in Madagascar. We also seek to provide insights and perspectives on how to improve these initiatives to reach a sustainable development goal, aiming at minimizing gender bias towards equality and empowering all women, not only those at higher levels (university) but also those at lower-level education who aspire to pursue a career in STEM.

While some of the aspects discussed in this essay are based on our personal knowledge and experience as being Malagasy women scientists, i.e., born and raised in Madagascar, we support our viewpoints with published information from peer-reviewed journal articles and from public domains. To back up the accountability of our own experience, we conducted a structured online survey using Google Forms (see questionnaires in Supplementary Material), disseminated on Facebook between February and March 2018. This survey was accessible to everyone. Facebook was chosen as the main platform for disseminating the survey because it is the most used and the most easily accessible means of social media in Madagascar. We received 80 responses, 75% of which were from women in STEM (60 individuals, 78% of which were in Sciences, 2% in Technology, 11% in Engineering, and the rest classified as 'Others'). These participants owned at least a B.Sc. degree, started university studies between 1980 and 2014 and finished their highest degree between 1991 and 2018. Among the remaining 25% respondents, 11 (14%) were not affiliated with any STEM field and therefore did not continue with the rest of the survey; nine (11%) were men. The analyses presented here were from these 60 women in STEM and our personal experience. We understand that our survey data is not comprehensive and may be biased, especially given that the respondents are female scientists that overcame the challenges. However, we believe that they are invaluable to help us understand better the challenges and opportunities for the recruitment and retention of Malagasy women in STEM.

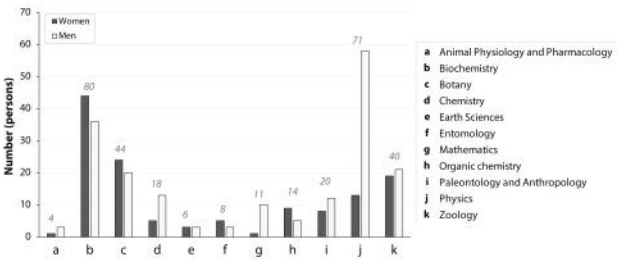

Figure 1. Number of doctorates and higher level-degree recipients at the Faculty of Sciences of the University of Antananarivo, grouped by gender, from 2000 to 2013 (V. Jeannoda, unpublished data). The italic numbers above the bars represent the total of male (black bars) and female (grey bars) degree recipients.

CHALLENGES FACED BY MALAGASY WOMEN IN STEM

Challenges experienced by Malagasy women enrolled in STEM studies include financial constraints (68.3%), communication gaps between professors and students (35%), family pressure (28.3%), political instability (26.7%), lack of female role model (21.7%), and other minor but influencing factors such as the lack of education among parents (5%), peer-pressure (8.33%), and culture (8.33%) (Figure 2). The remaining 10% of these challenges were not specified in the survey results. Many of these factors appear to be exacerbated by Malagasy colonial history and conservative culture, like what was highlighted by observations of Malagasy women pursuing higher education in another study in the region of Toliara (Skjortnes and Zachariassen 2010).

FINANCIAL CONSTRAINTS AND POLITICAL INSTABILITY. Many families in Madagascar are poor (with at least 75% of the population living under $1.90 a day, World Bank 2019); most parents cannot afford to support their children to continue education beyond elementary or high school (Moreira et al. 2017). This financial constraint is often aggravated by the prevalent political instability. For instance, we have experienced negative impacts from the 2002 and 2009 political crises, through a delayed starting date of the academic year and change in the schedule of national exams, both at the university and at lower-level education. These situations extended the duration of the academic year, forcing many students in need of more funds than expected to support their education. Besides, scientific research requires adequate funding to be successful, but Madagascar does not have its own national funding agency to support its researchers; only a handful of funding opportunities targeted to support young Malagasy scientists are available in Madagascar (Randriamahenintsoa 2013). For example, national public spending on education was below 4% despite the GDP increase in 2003–2007 and only 13–18% of the national budget was allocated to education (Randiamahenintsoa 2013). In the national budget for 2021, only 0.01% of the total proposed budget is allo-

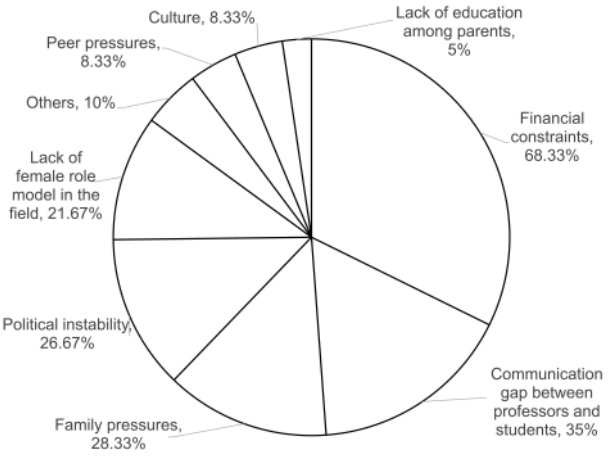

Figure 2. The different challenges faced by Malagasy women in STEM that may hinder their ability to pursue a career in those fields (data collated from an online survey conducted in February 2018; N = 60 women in STEM).

cated to higher education and scientific research, and only 4% of this is for actual scientific research (MEFB 2021). Most of the financial support comes from foreign collaboration (Waeber et al. 2016), and even in such circumstances, the number and the amount are unequal among different disciplines. One obvious example is the distribution and allocation of funds during COVID-19 times. Even though such situations affect both genders, women tend to be more vulnerable to the burden they may represent in their families (Skjortnes and Zachariassen 2010, Gastineau and Ravaozanany 2011). Additionally, women at a very young age often bear the costs of education dropout during economic shocks in middle-class Malagasy families (Gubert and Robilliard 2008). Thus, choosing a less expensive and less time-consuming major seems to be an adequate and wise decision to promote others' success, here, represented by the men of the family.

COMMUNICATION GAP BETWEEN PROFESSORS AND STUDENTS. Malagasy university students often have a passive attitude when interacting with some educators, especially if the latter have stronger opinions, an attitude that makes them unapproachable. This, of course, is not always the case in Madagascar as a few professors are more approachable and more encouraging, supporting the success and professional development of their female students. The problematic communication type is exacerbated by the fact that most professors in Madagascar are men (Hayward and Rasoanampoizina 2015), and strongly rooted cultural attitudes venerating older men and reluctance to speak in mixed-gender settings often prevent female students from communicating freely with professors. Interactions with students are limited to monologues of professors lecturing during classes, as has been common in colonial period (Duteil 2009), rather than helping and preparing the students to become future educators or leaders. In this scenario, it has often been considered disrespectful if students boldly criticize seniors and express their opinions, even with valid arguments (Rakotonanahary 2019), hence leaving a cold and unwelcoming learning environment. This student-professor interaction is additionally compromised because of the traditional stereotyping of women in the society and their fear of appearing stupid. The lack of warm communication between professors and students can hinder the latter's personal development and their acquisition of scientific knowledge and skills, as they may feel insecure and lack self-esteem to undertake a career in science, which is qualified as a tough field in Madagascar. This communication gap could affect not only women but also men; it represents one third of each gender in our survey. As recorded from the survey respondents' answers, among the nine male participants, three of them identified this gap as a challenge, and among the 60 women participants, 21 identified this gap.

This gap is not only felt at the intellectual level but also at the age level. Following a hiring freeze in the civil service in the 1980s and 1990s (IMF 1997), there was no recruitment and/or promotion of university professors from 1986 to 2006 at most of the universities in Madagascar (Gerety 2017), leading to a decrease in the number of new university professors between 2006 and 2014 (MESUPRES 2014b). This has resulted in an increasing age gap between students and professors over the years, and potentially could have enhanced gender discrimination and eventually the colonial behavior of the 'old' professors towards their potential 'successors'.

FAMILY PRESSURES. alagasy societies hold very strong and highly conservative views in all aspects, including the role attributed to and expected from women, generally a housewife or the doer of soft jobs, which often conflicts with the women's career path in science (Skjortnes and Zachariassen 2010, AEFE 2012). Even if Madagascar has advanced on gender justice by reducing gender inequity while supporting schooling young girls up into higher education (Gubert and Robilliard 2008, Gastineau and Ravaozanany 2011)—with almost half of university students being women (Mama 2003), the culture belittled the strength of women. There is a tacit expectation that women—even if well educated—are the caregivers for the immediate and extended family (Gubert and Robilliard 2008, Gastineau and Ravaozanany 2011, AEFE 2012). Despite a saying in Madagascar "Education is the best legacy" ("*Ny fianarana no lova tsara indrindra*"), obtaining a degree and pursuing a successful career path in a STEM field, unfortunately, remains a synonym of sacrifice. Furthermore, while Malagasy women are expected to have children at an age deemed optimal by the family and the society, usually in their 20s, the lack of an adequate societal system in morally and financially supporting families with young children represents a barrier. Furthermore, having many children is still perceived as a blessing in Madagascar. With such an engraved mindset, junior female scientists are afraid to compromise their family life. Young Malagasy women are often not attracted to a scientific career, often viewed as a highly demanding position. In fact, most women are often told that the time involved and the responsibilities taken towards work as a scientist (supplementary hours, repetitive fieldwork and travel abroad) may drive negligence in their children's education and emotions (Sonnert and Holton 1995, Skjortnes and Zachariassen 2010). Consequently, the chances for Malagasy women scientists to achieve their scientific career goals are likely to decrease under these circumstances.

LACK OF FEMALE ROLE MODELS IN THE FIELD. Young Malagasy women lack senior female role models in STEM. Although they exist, illustrating the possibility of overcoming gender barriers to achieve success in these fields is daunting. Students and junior women scientists often do not have good perspectives on the scientific activities that potential role models could show them, such as producing new articles, getting grants, and obtaining leadership positions. Because very few Malagasy women appear to have a successful career in STEM (UNESCO 2016), many young women tend to think that such fields are not for them (Blickenstaff 2005). Moreover, the fear of not having a good work-life balance is often discouraging to young women.

LACK OF EDUCATION AMONG PARENTS. The lack of parental education sometimes represents a critical challenge for many Malagasy, irrespective of gender, to choose a scientific career path. While the overall literacy rate is relatively high in Madagascar (~71%), the older generations are more likely to be illiterate than younger ones (UNESCO 2018), and more than 50% of the workforce in Madagascar has no formal education (Stifel et al. 2007). The low level of parental education has been associated with limited financial resources, limited access to health care, and poor quality of education of children, which is observed in many societies worldwide (Flores et al. 1999). While this lack of parental education can affect the opportunities and achievements for both genders, its impact can be stronger on women when it is combined with the tradition-

ally male-centric societal values and some anti-feminist attitude in Madagascar (Rabenoro 2012).

Parents with minimal education levels are more likely to underestimate the value of science as a tool for their children's development, which is in fact the foundation of several countries' success and development (van Driel et al. 2001, Bernardes and Albuquerque 2003). These parents do not understand the benefits of having well-educated children in promoting scientific and societal values. Indeed, parents' low education-level might be more likely to advise their children to pursue a non-scientific/academic career in which the returns are directly visible in a timely manner (Nguyen 2008). In contrast, investment in education and academic career means putting money upfront for years, with no insurance of increased return. In fact, potential returns are only felt within many years after the investments, something that people living in low-income countries cannot afford. This may be felt more in girls and young women because of a stronger fear of taking risks. From this standpoint, STEM may not be an attractive discipline for Malagasy women when enrolling at the university level. The financial benefits of scientific research may, depending on the field, only be applicable, felt, and visible after quite a long time, as explained earlier. For these reasons, young Malagasy women are missing the necessary guidance and support to become a confident STEM-researcher and scientific leader.

OTHER CHALLENGES FACED BY MALAGASY WOMEN IN STEM. Other challenges include the lack of inclusive opportunities, the lack of perspectives, the lack of resources and the lack of connection with foreign institutions. Even though each of these listed factors is important, it is quite difficult to assess which ones weigh more than the others in influencing Malagasy women's successful scientific career. In our view, these factors can be grouped into two categories: internal (i.e., more personal) vs. external categories (i.e., with more external influence). Internal categories group both the lack of ambition and the evidence of peer pressure. They seem to be complementary factors halting the ambitious goal of pursuing a career in STEM. External categories combine the absence of inclusive opportunities and international connections, which could enhance women's scientific and academic growth. Both internal and external factors, however, are like 'chicken-and-eggs', in a way that more opportunities could increase the motivation and the ambition of women to pursue a STEM-oriented career. On the other hand, external funders should support more scientific activities with an inclusive approach to attract more women to a STEM career.

INITIATIVES IMPLEMENTED TO LEVERAGE GENDER DIVERSITY IN STEM IN MADAGASCAR

Governments and non-governmental organizations (NGOs), private sectors, universities, and individuals have implemented several initiatives, as detailed below, to increase and retain the enrollment of women in STEM fields in Madagascar. In addition, many groups of Malagasy women have advanced into making changes either individually or by forming networks. For example, the Association Ikala STEM (https://www.ikalastem.org/), founded in 2016 and run by Malagasy women has a mission to "empower the next generation of women in STEM in Madagascar" and acts upon reaching that objective. With such initiatives, Ikala STEM has been shortlisted among the top five global initiatives for the Nature Research Awards for inspiring women in STEM. We further discuss the interventions, programs, and other incentives that have encouraged Malagasy female scientists to overcome these above-mentioned challenges. In the discussion, we provide arguments based on our own experience and our personal involvement in these initiatives. We additionally include the supporting responses from the 60 surveyed women in STEM, as presented in Figure 3.

NETWORKING. Collaboration with peers and sharing of knowledge constitute important pillars for advancing science. Evidence-based methods are used worldwide to promote ethics and learning in science, as well as to involve future scientists in it. Networking can also expand one's access to the crucial role models that are lacking in their own community. Increasing the numbers of female models known in different areas of research is favorable to inspire and raise the participation of young female scientists (Ibarra 1993, Breda et al. 2020). Among the benefits from belonging to a network is the confidence to share knowledge and the sense of STEM identity, both can affect achievements and increase interests (Wiest 2014, Seyranian et al. 2018). Malagasy women are keen to step forward with the raising of a new generation of scientists that are ready to improve the participation of women in science.

INTERVENTIONS OF NGOS AND PRIVATE ORGANIZATIONS. Several NGOs and different associations (all termed 'organization' in this paper), either at national or international levels, have been contributing to empowering Malagasy women in science, by enhancing their ability to develop themselves in the field of science and offering them the possibility to get assistance from other scientists to improve on their scientific skills. At the national levels, these come in the form of funding Malagasy female student researchers to address the challenge of financial constraints (e.g., Small Grants provided by Malagasy women-run Ikala STEM: https://www.ikalastem.org/news-room/categories/small-grants), providing professional development and capacity building opportunities (e.g., Django Girls' coding initiative: https://djangogirls.org/antananarivo/) and offering mentorship to female students (e.g. Ikala STEM's mentoring program: https://www.ikalastem.org/news-room/categories/mentoring). Several organizations have implemented different scientific projects involving Malagasy women (e.g., Association Vahatra, Madagasikara Voakajy, and GERP), in which Malagasy female scientists are not only involved in research but also supervise and guide other young women in their scientific studies. At the international level, several organizations have taken initiatives to support female scientists from developing countries to pursue academic

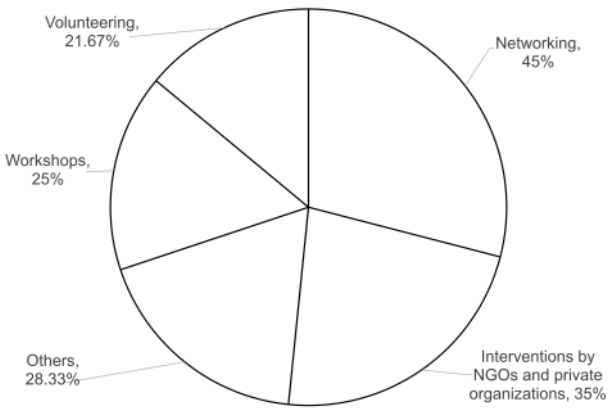

Figure 3. The different initiatives undertaken by Malagasy women in STEM during their STEM-academic milestones (data collated from an online survey conducted in February 2018; N = 60 women in STEM).

studies at reputed host institutions, e.g., the Schlumberger Foundation Faculty for the Future has supported at least five Malagasy women so far in their academic field of studies, many of whom are leaders in their field. Other institutions are specialized in solely supporting young scientists from the developing world, such as The World Academy of Sciences (TWAS; twas.org) and the AuthorAid program, which offers several training curricula to enhance the academic capabilities of young scientists from developing countries.

Besides these, what is more attractive and inspiring is when Malagasy women are actively participating in any relevant scientific organization. They become role models for young girls, thus reducing the 'lack of Malagasy role models' that we have identified as a challenge. From such active participation, young female scientists can gain experiences, enhance their learning skills, and expand their knowledge. The exchange of practical advice among members of the scientific committees within the organization as well is also beneficial. With all these positive benefits from being active in STEM-related activities, encouraging and motivating Malagasy women to get themselves active in different science-oriented organizations can also be relevant to improve their scientific skills. Promoting the success of these role models can also inspire young women to pursue a career in STEM.

More inclusive opportunities should also be put forward. Specific opportunities for women to help them build a career and limit their excellence in their careers. Such opportunities are perceived among Malagasy society as a 'personal kick-off', without which women cannot succeed (Astuti and Bloch 2015), especially when they are given a quota. Even the granted women would feel troubled when confronted with such a situation, belittle themselves as incompetent, and become unconfident, which would discourage them to excel and step up their careers. Organizations should thus offer an equal number and consideration to men and women instead of just placing women in a position over a demanded quota. For example, applying for a position or funding open to both genders could increase women's competitiveness, and add to their acquired competencies to overcome other general issues and challenges on top of gender inequality.

PARTICIPATION IN TRAINING OPPORTUNITIES. Intellectual exchange platforms such as workshops, conferences, and seminars provide many opportunities for learning, gaining new experiences, and growing a professional network. For women in science, participating in such platforms is a great opportunity to learn to communicate their own work to other participants, and share their interests. More importantly, since workshops are considered as educational opportunities, participating in them increases levels of networking. Meeting people with the same field of interest may provide different advice to improve their own skills. For Malagasy women, scientific workshops are relevant to improve their communication skills (especially oral communication) not only via networking but also via the presentation of their own work in an open and comfortable environment. In this way, they learn to raise their voice and share their own work with other experts with confidence. Due to cultural norms, Malagasy women are often expected to refrain from being vocal (Ramamonjisoa 1993, Razafindratsima and Dunham 2015). Thus, having a platform where they are encouraged to speak up is particularly important. Attending workshops allows them to strengthen their scientific skills but also gives them intensive knowledge on a specific theme via presentations and discussions.

Apart from these above-mentioned benefits, being the organizer of scientific workshops is also important for Malagasy women in science. They learn not only to plan different scientific programs but, most importantly, they can professionally develop and confidently shape their scientific expertise. Attending or organizing educational platforms, therefore, plays an important role for Malagasy women in the field of science as they have a lot to offer but also learn many new things.

VOLUNTEERING. Based on the survey data and our own experience, volunteering is an important tool for Malagasy scientists' personal growth. The existence of movements promoting young women such as supporting their integration in Information Technology (Women in Tech Madagascar: http://pointgg.com/women-in-tech-madagascar/), providing mentoring (Ikala STEM mentoring program) and bringing them to participate in activities that allow them to interact and learn about STEM is a promising start. This early education awareness brings about change in the perception of science.

LOOKING FORWARD

One cannot deny the many challenges that prevent women in Madagascar from pursuing a career in STEM, but there is also room for opportunities to improve the recruitment and retention of women in the STEM workforce. Even though Malagasy girls dream of becoming 'a scientist' at a young age, that dream vanishes when life becomes difficult and requires more responsibilities, hence the 'leaky pipeline' that needs to be fixed. Initiatives have been taken and have been successful to encourage Malagasy women participation in science, but given that the current percentage of female scientists is still lower than the percentage of male scientists, we need to (1) enhance the initiatives that are already successful to keep them in the STEM workforce, (2) develop some initiatives that can help break gaps between students and professors (e.g., via mentoring and training dedicated to addressing specific issues) for mutual benefit, (3) establish some funding bodies/agencies to provide partial or full support to promising students in need, and (4) enhance science education as a tool for development in Madagascar. Additionally, there is a need to better inform parents and the community about the benefits of involving girls in STEM. More importantly, we need to promote the success of Malagasy women scientists to inspire girls because science is not only the art of conveying what is important in gathering data and defining a new trend of evolution but also it is the art of conveying oneself to be a role model and a leader in one's field so a change can be initiated.

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Grasses of the Isalo National Park, Madagascar – checklist, origins, and significance

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ABSTRACT

Grasses are one of the best documented plant families worldwide in terms of taxonomy, but they are still poorly known in Madagascar. Our understanding of their diversity remains incomplete since grasses and grasslands are assumed by many to be weeds and degraded wastelands. This project aimed to list the grasses in Isalo National Park (NP) in order to understand their diversity and endemicity, as well as the history of Isalo's grasslands. Examination of herbarium specimens and new field inventories allowed us to confirm 589 records of grass occurrences in our study area. They were assigned to 112 species, of which 38 species are new records for Isalo NP. The Isalo grass flora includes seven of the eleven Poaceae subfamilies present in Madagascar and is particularly rich in Panicoideae, which make up 65% of the species. Nearly 22% of the grass species of Isalo are endemic to Madagascar, of which three species and one variety are restricted to Isalo massif, including two unusual ground cover species *Tristachya humbertii* A.Camus and *Tristachya* [*Isalus isalensis*]. Open grasslands harbour the highest diversity of grass species, followed closely by riparian forests. The history of the management of Isalo NP by the Bara people, as well as the endemism and the native origin of its grasses and other species are consistent with an ancient origin of Isalo's ecosystems. We urge that the conservation of Isalo's grassy ecosystems, as well as that of the plants and animals that inhabit them be prioritized.

RÉSUMÉ

Les graminées sont parmi les familles de plantes les mieux documentées au niveau mondial en termes de taxonomie, mais sont encore mal connues à Madagascar. Notre compréhension de leur diversité reste incomplète, vu que les graminées et les savanes sont considérées par beaucoup comme des mauvaises herbes et des friches dégradées. Ce projet visait à établir une liste des graminées connues du Parc National (PN) de l'Isalo, afin de comprendre leur diversité et leur endémicité, ainsi que l'histoire des écosystèmes herbeux de l'Isalo. L'examen des spécimens d'herbiers et les nouveaux inventaires sur terrains nous ont permis de générer 589 occurrences de graminées de notre site d'étude. Elles ont été attribuées à 112 espèces de Poaceae, dont 38 sont de nouvelles collectes pour le massif de l'Isalo. La flore herbacée du massif de l'Isalo comprend sept des onze sous-familles de Poaceae présentes à Madagascar et est particulièrement riche en Panicoideae qui représentent 65% des espèces. Près de 22% des espèces de graminées de l'Isalo sont endémiques de Madagascar, dont trois espèces et une variété sont restreintes à Isalo, y compris les deux espèces de plantes couvre-sols inhabituelles *Tristachya humbertii* A.Camus et *Tristachya* [*Isalus isalensis*]. Les prairies ouvertes abritent la plus grande diversité d'espèces de graminées, suivies de près par les forêts ripicoles. L'histoire de la gestion du PN de l'Isalo par les habitants de la région du groupe Bara, ainsi que l'endémisme et l'origine autochtone de ses graminées et autres espèces sont cohérents avec une origine ancienne des écosystèmes de l'Isalo. Nous préconisons instamment que la conservation de ces prairies et savanes de l'Isalo, ainsi que les plantes et les animaux qui les habitent soit priorisée.

INTRODUCTION

Grasses (plant family Poaceae) are one of the most diverse and widespread plant families and are comparatively well known in the world (Kellogg 2015). They diversified throughout the Cenozoic in India, northern Africa and South America (Bouchenak-Khelladi et al. 2010, Strömberg 2011). They now represent the 5th largest angiosperm family with ca. 12000 species and are distributed on all continents (Convey 2001, Bouchenak-Khelladi et al. 2010, Soreng et al. 2017, Vorontsova et al. 2021). Linnean Poaceae classification systems were first developed in the 18th century, once based on morphological treatments, and then continuously updated using molecular data (Grass Phylogeny Working Group or GPWP 2001, Kellogg 2015, Soreng et al. 2015). For many parts of the world, comprehensive grass floras have been published over the last 30

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years (e.g., Davidse et al. 1994, Barkworth et al. 2003, Barkworth et al. 2007).

Unlike the rest of the world, Malagasy science still overlooks grasses as they are often considered to be weeds and cattle feed not requiring study. Consequently, the data we have about them remains incomplete and outdated. A single book has long been the only reference source for the grasses in Madagascar: *Graminées des pâturages et des cultures à Madagascar* by Jean Bosser (1969), even though it covers only around a half of the grass species in Madagascar. Taxonomic studies of Malagasy grasses, which were largely made by Aimée Camus, as well as most collection of specimens, pre-date 1970 (Vorontsova et al. 2018). Moreover, a significant number of the species held in the main herbaria of Tsimbazaza, Antananarivo (TAN) and of *Muséum National d'Histoire Naturelle* Paris (P), are represented by just a single specimen, or remain unidentified. Yet, many of them potentially represent new taxa to science and remain undescribed (Rabarivola et al. 2019a-c; for a full analysis see Vorontsova et al. 2021). However, grasses and grasslands are omnipresent in Madagascar and in Malagasy people's lives, as the source of daily rice and cattle forage, and forming extensive grassy vegetation types.

In Madagascar, grasslands occupy ca. 65% of the island's surface, while 70 to 80% of the primary forests would have been lost due to human activities (Du Puy & Moat 1996, Moat and Smith 2007, Vieilledent et al. 2018). The assumption that Madagascar was once entirely covered by forests has led to the belief that grassy ecosystems are degraded wastelands. Scientific debates on the real origin of these ecosystems in Madagascar continue to date. Previous research showed that some endemic grass lineages already evolved on the island millions of years before human settlement and that some pollen and charcoal deposits are pre-human, which indicates open habitats with natural fires (Burney 1987, 1997, Gasse and Van Campo 1998, Hackel et al. 2018). Recently, highland grassy assemblages confirm the existence of fire and herbivory disturbance regimes before human settlement (Solofondranohatra et al. 2020). Moreover, ancient diversity and endemicity of many plants and animals in grasslands have been recognized (Bond et al. 2008, Vorontsova et al. 2016). These discoveries tend to gradually highlight the presence of grassy ecosystem before the arrival of people on the island. Currently, the distinction between secondary and ancient grasslands remains more at the heart of the debate, which shall involves multidisciplinary and even more complex studies.

Grasses represent the 4th largest plant family in Madagascar with 541 recognized species and an estimated 40% endemicity (Vorontsova et al. 2016). Following the recent progress in documenting grass diversity in Madagascar, the grass family is expected to be more diverse than what we currently know. New species are still being described and new records are being made following new botanical surveys and re-examination of specimens held in herbaria (Vorontsova and Rakotoarisoa 2014, Vorontsova et al. 2015).

This study documents the grass diversity within the Isalo National Park (NP). We establish a list of species, build grass diversity knowledge among the protected area employees, evaluate the diversity and endemicity of grasses and discuss the origin of Isalo's grasslands using data on the historical use, and the flora and fauna of the Isalo's grassland. In this paper we use the term "grassland" to denote grass-dominated open canopy ecosystems with few or no trees to standardize our terminology to Gautier et al. (2018), and we use the term "tapia" for tapia grassland (find Solofondranohatra et al. 2018); these terms are merely used for consistency and do not imply any assumptions regarding their origins.

STUDY SITE

Isalo NP is one of the largest National Parks and one of the earliest protected areas in Madagascar. It was created in 1962 and covers an area of about 86 579 ha, currently managed by the Madagascar National Parks (MNP) (MNP 2017). It is found in the southwestern corner of Fianarantsoa and belongs in general to the commune of Ranohira, District of Ihosy, Region of Ihorombe, Province of Fianarantsoa. However, a part of the park is included in the commune of Ilemby and Berenty, District of Ankazoabo, Region of Atsimo-Andrefana, Province of Toliara. Isalo NP is unique for its landscape made of plateau grassland interspersed by deep canyons (reaching 200m deep), and natural geological sandstone outcrops that sometimes takes spectacular shapes (e.g., formations locally named-known as boot, queen, window).

Isalo NP is phytogeographically included in the central ecoregion and is part of the central Tapia (*Uapaca bojeri* Baill.) sclerophyllous woodlands, recently shown to be functionally a grassy ecosystem (Humbert 1955, Moat and Smith 2007, Solofondranohatra et al. 2018). About 40% of the park is covered by open grassland interspersed by fire-resistant trees. Tapia occurs in the northeast and the western third of the protected area, whereas riparian forest in the deeply carved canyons from the centre towards the east. A dwarf and xerophytic vegetation occurs in open rocky areas, whereas marsh and *Pandanus* thickets are found in humid ones (Gautier 2018). The climate is seasonal, mainly hot, and sub-humid (Koechlin et al. 1974). Temperatures range from monthly means of 17°C to 25°C (Swierkosz 2007) but may drop to 7.3°C during the cold season between June and August or may increase over 32°C during the hot season between December and February (Goodman et al. 2018, 1561–1575). Around 850 to 1200 mm of rain falls every year, with 90 to 93% falling between November and April (Swierkosz 2007), and permanent rivers, streams and seasonal watercourses cross the area.

Isalo NP is located in one of the least populated regions of the country, where the Bara group is dominant (INSTAT Madagascar 2020). These semi-nomadic zebu-herding people, once in search of grazing land, settled in Ranohira before the 19th century. They mainly used the current Isalo's spectacular sandstone cliffs for burials and open grasslands for grazing cattle (zebu), where fire is regularly set at least once a year to generate forage (Rajaofera 2007, Zafisoalizy 2011). Today grasslands continue to burn, and the Park is under additional pressures such as tourism, informal resources exploitation, wood clearing and species introduction in the park (Swierkosz 2007).

Isalo massif is dominated by grasslands, therefore providing a suitable site to understand grass diversity conserved in a protected system undisturbed by modern agriculture (MNP 2017, Goodman et al. 2018, 1561–1575).

METHODS

To compile the checklist, a database of previous and current grass collections from Isalo NP was compiled. Previous records of Isalo NP grass were downloaded from the Global Biology Information Facility (GBIF), which contains full data from herbarium specimens collected from the 18th century onwards and held in TAN and P (Rabarivola et al. 2019 a,b). Previous knowledge of the grasses of

Isalo massif was also synthesized from Bosser (1969), Morat (1973), Swierkosz (2007), Vorontsova et al. (2016), MNP (2017) and Solofondranohatra et al. (2018).

Field inventories were made in March and April 2018 and new grass records were generated (Figure 1). As many different grasses as possible were collected and their presence was recorded in all accessible habitats of Isalo NP. For each species, herbarium, and DNA samples (leaf fragments) were collected to be conserved in herbaria of TAN, P and K in London. Herbarium specimens were

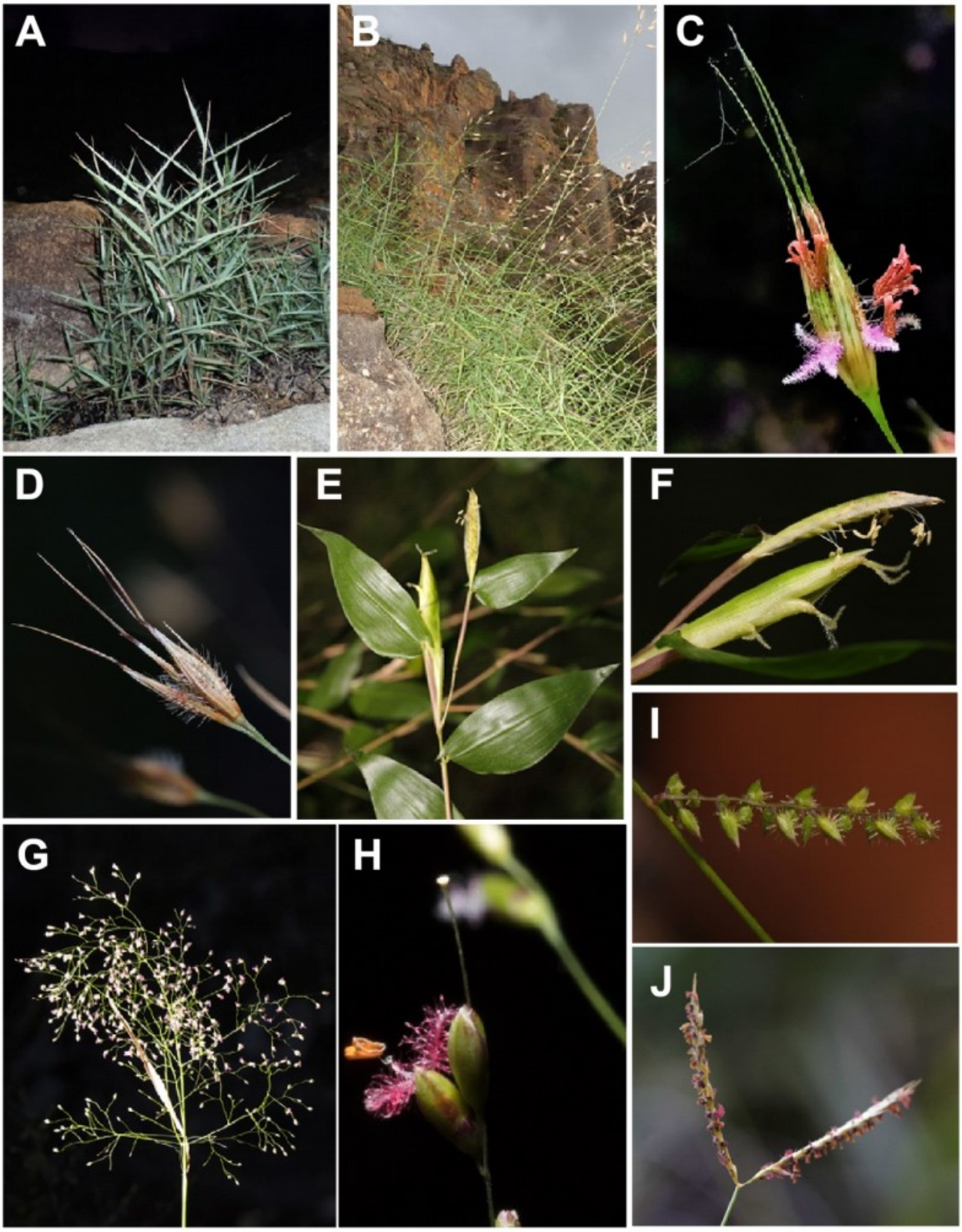

Figure 1. Madagascar endemic grasses found in Isalo massif. (A: *Tristachya humbertii* in vegetative state (Isalo NP, in April 2019); B: *Tristachya* (*Isalus isalensis*) in flower (Isalo NP, in April 2019); C: Flowering spikelets and D: mature spikelets of *Tristachya* (*Isalus isalensis*) (Isalo NP, March 2018); E: habit and F: inflorescence of *Humbertochloa bambusiuscula* (Isalo Sakamalio, March 2018); G: Inflorescence and H: spikelet of *Panicum ibitense* A.Camus (Isalo NP, March 2019); I: one raceme of *Pseudechinolaena perrieri* (Isalo Sakamalio, March 2018); J: digitate racemes of *Andropogon eucomus* Nees subsp. *huillensis* (Rendle) Sales (native to Madagascar) (Isalo NP, March 2018). Credit photo: David Rabehevitra (E, F, G, H & I); Andotiana M. Andriamanohera (C); Nantenaina H. Rakotomalala (A, B, D & J)

identified using spikelet dissections (e.g., Figure 2), using existing herbarium specimens for comparison with our collections, and the identification keys available in Bosser (1969), Nanjarisoa et al. (2017) and Vorontsova et al. (2018).

The occurrence records were compiled in a single database using BRAHMS software (Botanical Research and Herbarium Management System) version 7. Species names and authorities were verified against the *Plants of the World Online* (http://www.plantsoftheworldonline.org), whereas the global distribution of each species was obtained from the *Madagascar Grass Atlas* (Rabarivola et al. 2019d). Information on the photosynthetic system of each species was obtained from Soreng et al. (2017). Data were exported from BRAHMS as a CSV file and analysed in MS Excel.

RESULTS

We assembled a total of 589 records of grasses from Isalo NP, representing 112 species. The list of species and the information on the collections and collectors of each species, the endemicity status, the type of ecosystems occupied, and the photosynthetic system are presented in Table 1 (see at the end of the document). Selected endemics and common native grasses are illustrated in Figures 1 and 2.

EXPLORATION HISTORY AND NEW LIST OF GRASSES OF ISALO NP. The collection of grasses in Isalo NP began in the 20th century, but the real effort of documentation was expanded significantly by the mid-twentieth century. The first collection was made by Henri Perrier de La Bâthie in 1919, who recorded *Aristida barbicollis* Trin. & Rupr. From this period, the number of collections grew steadily and slowly, reaching 12% of the currently known grasses in Isalo NP by the end of 1950 (Figure 3). It was at this time that dedicated botanical investigation began in Isalo massif (Goodman et al. 2018, 1561–1575). Knowledge of grass species increased rapidly to reach 52% of the currently known species within the next two decades (1950-1970). Three collectors who recorded the most specimens and the most species in Isalo NP were part of this mid-twentieth century documentation boom, namely: Jean Bosser (112 specimens, 39 species), Henri Humbert (46 specimens, 26 species) and Philippe Morat (28 specimens, 10 species). Grass collection almost ceased for a long period between 1970 and 2013. From 2013 onwards, one of the authors Maria Vorontsova and the Kew Madagascar Conservation Centre (KMCC) resumed the exploration of the diversity of grasses in Madagascar and in Isalo NP. Their collection efforts, combined with our own, significantly increase the number of grass species and specimens known from Isalo massif. Overall, 19 principal collectors with more than 30 co-collectors contributed to the current list of grass species in Isalo NP.

Figure 2. Line drawing of one triad of spikelets, 8-12 mm, on a branch of the panicle of *Tristachya* (*Isalus isalensis*). (Each spikelet is lanceolate and laterally compressed with bulbous-based trichomes on the nerves and twisted awns on the upper lemma. Drawing by Nantenaina Herizo Rakotomalala, from NHR 179, collected in Isalo NP on 27 April 2018)

According to the available records, species have not been collected uniformly and only a few species are well enough sampled to give us an understanding of their distribution within the park. The most frequently recorded species was *Loudetia simplex* (Nees) C.E.Hubb. with 50 records. The next most frequently recorded species are *Tristachya* (*Isalus isalensis* (A.Camus) Phipps), *Schizachyrium sanguineum* (Retz.) Alston, and *Craspedorhachis africana* Benth., all collected over 30 times each. Many species were collected from Isalo NP only once (31 species) or twice (26 species).

There is a strong geographical bias in the grass collections carried out across the park (Figure 4). The southeastern part of Isalo NP is disproportionally well known because of its easy access and famous tourist landmarks, while the west and the north remain rarely or never explored. A minimum of one day drive followed by three days of walking are required to reach the northernmost part of Isalo NP. Our farthest expedition looking for grasses reached Sakamalio after one day's drive inside the park, followed by a day's walk to the campsite (blue stars in Figure 4). Access to Sakamalio was physically challenging and involved crossing a dense open grassland dominated by *Heteropogon*, *Hyparrhenia*, and *Hyperthelia* over 2 m tall and in fruit.

NEW GRASS RECORDS FOR ISALO NP. In this study, we worked to explore maximum spatial and habitat diversity across Isalo NP, and to conduct a more thorough inventory in places where researchers had previously collected grasses. From our field expeditions in 2018, we collected a total of 178 specimens representing

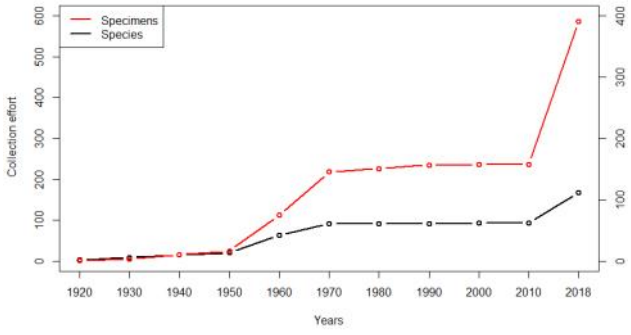

Figure 3. Cumulative number of Poaceae specimens and species collected in Isalo massif between 1919 and 2019.

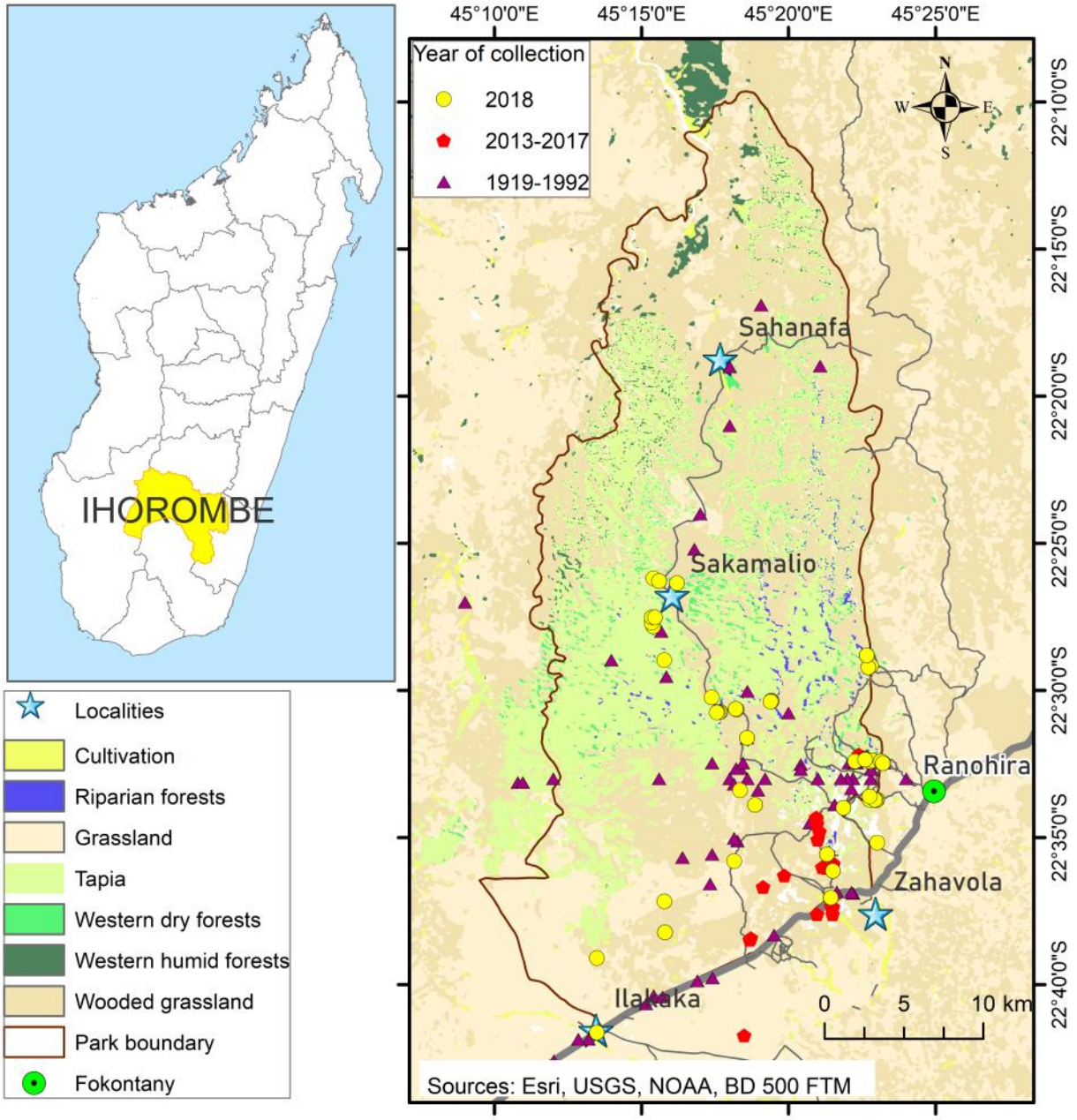

Figure 4. Location of Poaceae collection sites in the Isalo NP, all collections made in 1919-2018. (Collections made 1919–1999 in violet triangles, collection made 2013-2017 by M. S. Vorontsova in red polygons, and 2018 collections by N. Rakotomalala in yellow circles)

93 species, of which 38 were collected in Isalo NP for the first time (Table 1). Four of these new records document species endemic to Madagascar: *Acroceras boivinii* (Mez) A.Camus, *Cyrtococcum deltoideum* A.Camus, *Humbertochloa bambusiuscula* A.Camus & Stapf. and *Neostapfiella perrieri* A.Camus (member of a Madagascar endemic genus). These 38 new occurrences were recorded both from rarely explored areas of Isalo NP and from the frequently visited ones. The new records we made in previously explored areas are generally represented either by tiny species that are difficult to notice (e.g., *Aristida cumingiana* Trin. & Rupr.; *Schizachyrium brevifolium* (Sw.) Nees ex Büse), or by large species that are troublesome to collect (*Neyraudia arundinacea* (L.) Henrard; *Rottboellia cochinchinensis* (Lour.) Clayton), or by common weed species which collectors are likely to ignore (e.g., *Chloris pycnothrix* Trin., *Eleusine indica* Gaertn.). Most of these newly recorded species were previously known only in remote areas of Isalo massif, and often ecologically different. Information on their previous distribution ranges is available in Rabarivola et al. (2019d). One of these new records, *Neostapfiella perrieri*, was found in a disturbed and trampled habitat in a single location along a frequented road: previously, this species was only known for the northwest and in the southernmost regions of Madagascar (Vorontsova and Rakotoarisoa 2014). In addition to the newly recorded grass species from Isalo NP, we made the third ever collection of a species endemic to Madagascar: *Pseudechinolaena perrieri* A. Camus in Sakamalio.

TAXONOMIC DIVERSITY OF ISALO'S POACEAE. The 112 known species in Isalo NP include three varieties and represent 59 genera and 16 tribes, according to the classification of Kellogg (2015). Of the 11 subfamilies present in Madagascar, seven are found in Isalo massif (Vorontsova et al. 2018). The tropical clade PACMAD (Panicoideae, Arundinoideae, Chloridoideae, Mi-

crairoideae, Aristidoideae, and Danthonioideae) comprises most of the grasses in Isalo NP (109 species, 97%). Panicoideae is the most dominant with 73 species (65%), largely represented by the tribes Paniceae (45 species, 40%) and Andropogoneae (19 species, 17%), followed by Chloridoideae with 25 species (22%). As for the temperate C3 clade BEP (Bambusoideae, Ehrhartoideae, Pooideae), it was represented by only one unidentified species of Bambusoideae and two species of the rice relatives Ehrhartoideae. The subfamily Pooideae, which is the most species-rich grass subfamily in the world and which is predominantly temperate (Kellogg 2015, Soreng et al. 2017), was not found in Isalo NP. At the generic level, *Panicum* sensu lato (morphologically similar but polyphyletic species historically called "Panicum" which have not yet been assigned to monophyletic groups, Vorontsova 2018) is the most diverse with 8 species, followed by *Eragrostis* sensu lato (including *Pogonarthria*, Soreng 2017) and *Digitaria* with 7 species, and by *Sporobolus* with 6 species. Of the 59 genera, 35 (60%) are represented by a single species only. Species with the C4 photosynthetic system dominate with 91 species (81%), suggesting a flora adapted to tropical open and seasonally dry habitats (Bond et al. 2008). The highest diversity in terms of species number has been recorded in the eastern part of the park, where not only most of the collections were made, but also where habitats are the most diverse: this is where the largest riparian forest and the only accessible canyon vegetation are found.

BIOGEOGRAPHIC AFFINITIES. The probable native origins of the grass species recorded from Isalo massif are shown in Figure 5. Three species and one variety (4%) are endemic to Madagascar and restricted to the Isalo area: *Styppeiochloa* sp. nov. ined., *Tristachya humbertii* A.Camus, *Tristachya* (*Isalus isalensis*) and *Pseudolasiacis neoperrieri* (A.Camus) A.Camus var. *leroyana* Bosser & Florens. Seven other endemic species (6%) are restricted to the central highlands, and a further 12 endemic species (12%) are widespread across the island (Table 1). Overall, 24 of the grass species of Isalo massif are endemic to Madagascar, with 22% endemicity, which is below the 40% grass endemicity for the country recorded by Vorontsova et al. (2016). Most of the grasses recorded in Isalo NP (81 species, 72%) would be native to Madagascar and are also present in other parts of the world, predominantly in tropical Africa. Out of the 112 species, only seven (6%) are thought to be introduced according to the literature survey by Kull et al. (2012), although the native versus introduced origin of many grasses remains unconfirmed. These possible aliens are: *Cenchrus echinatus* L., *Cenchrus polystachios* (L.) Morrone, *Cenchrus purpureus* (Schumach.) Morrone, *Chloris virgata* P.Durand, *Digitaria violascens* Link, *Echinochloa colona* (L.) Link, *Enteropogon prieurii* (Kunth) Clayton.

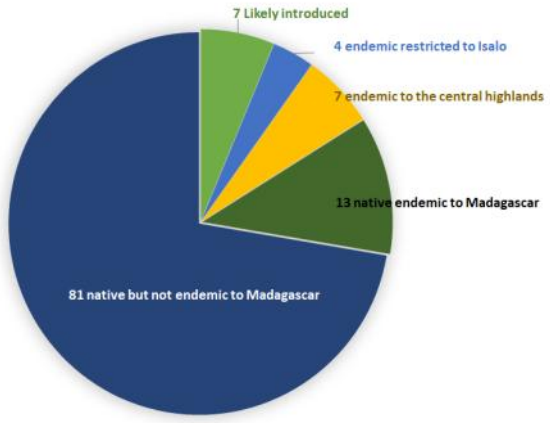

Figure 5. Distribution ranges and likely native/introduced status of the 112 grasses recorded in Isalo NP.

ENDEMIC GRASSES RESTRICTED TO ISALO MASSIF. Among the 112 grass species found in Isalo NP, three species and one variety are restricted to the area. One represents a new species: *Styppeiochloa* sp. nov., collected in 1940 and in 2013, and pending a revision of *Styppeiochloa* in Madagascar. Within the park, it was recorded in three locations associated with open and rocky environments. The other two species belong to the pantropical genus *Tristachya*. These are *Tristachya humbertii* and *Tristachya* (*Isalus isalensis*), previously assigned to the genus *Isalus* which has been subsumed within the genus *Tristachya*. They differ in habit and leaf morphology but have similar easily recognizable inflorescences: each inflorescence branch terminates in a cluster of 3 spikelets (Figures 1, 2). They often grow together, usually in open habitats on rocky substrates or under the Tapia canopy. As for the endemic variety *Pseudolasiacis neoperrieri* var. *leroyana*, revised by Bosser and Florens (1992), it was collected 6 times in riparian forest understory. It is a bamboo like liana plant that scrambles up into the wet forest canopy and is not immediately recognizable as a member of the Poaceae.

MYSTERIOUS BAMBOO. The population of arching long-necked pachymorph bamboo (bamboo terminology specifying the three-dimensional structure of its rhizomes which are narrow and short but belong to the clumping bamboo group, see Vorontsova et al. 2018) growing around the Namaza stream is clearly a member of Madagascar's endemic bamboo radiation, subfamily Bambusoideae, tribe Bambuseae, subtribe Hickeliinae (Vorontsova et al. 2018). It was first collected by Vorontsova in 2013. The identity of this species is not yet well defined. It was initially erroneously identified as *Valiha diffusa* S.Dransf., the common arching bamboo of eastern and northern Madagascar. But phylogenetic analysis of its chloroplast markers shows that it is more closely affiliated with the poorly known western coast genus *Perrierbambus* (Hackel et al. 2018). However, the characters of its culm sheaths do not match this genus (Soejatmi Dransfiled, pers. comm.). It could be an undescribed genus. This species has not been known to flower, and the flowering time is unpredictable, as most bamboos.

SPECIES HABITATS. Grasses occur everywhere in Isalo NP, from open and arid (grassland, Tapia, roadsides, rock), to shady and/or damp areas (riparian forests, humid zones in canyons or marshes). Only the darkest understory of closed-canopy wet forest does not support Poaceae. The highest number of species was recorded in the grasslands (46 species) and in riparian forests (42 species) and the lowest on rocks (11 species) (Figure 6). Endemic species are present across all habitats with the highest number also recorded in grasslands and in riparian forests (Figure 6).

With the exception of *Tristachya* (*Isalus isaloensis*) and *Urochloa maxima* (Jacq.) R.D.Webster, which were found in almost all categorized habitats (see Table 1), Isalo massif grasses are usually restricted to specific habitats and environmental conditions. Grasses in arid and open habitats, i.e., grassland, Tapia, rock, and roadside, are represented mostly by Andropogoneae, Panicoideae and Chloridoideae. They are all C4, except the C3 *Sartidia isaloensis* Voronts., Razanatsoa & Besnard, which grows on the exposed sandstone cliffs to benefit from the light and to avoid fire. These C4

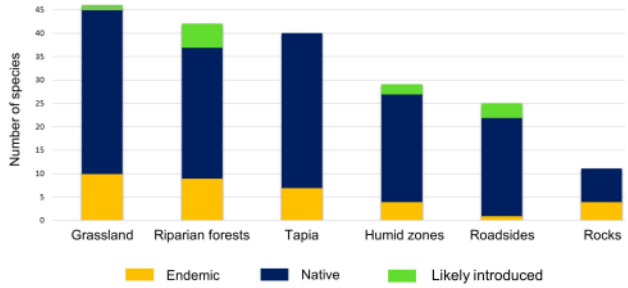

Figure 6. Distribution of species in the 6 available habitats in Isalo NP with proportion of native, likely introduced and endemic species in each habitat. (Species numbers for each habitat were obtained from species distribution information in the project database and from field observation)

species are in general hemicryptophyte perennials, with tall, erect, and tufted habit, and coriaceous leaves which drive ground fires while not being damaged by them. These characters were shown by Solofondranohatra et al. (2018, 2020) to be an adaptation to fire, aridity, and light availability. This set of species is similar to the open arid and fire grasses of Itremo, which require prolonged exposure to sunlight and benefit from fires (Nanjarisoa et al. 2017). In damp and shady areas of Isalo NP (riparian forests and canyons), grasses are represented both by C3 and C4 species belonging mostly to Paniceae and to BEP clade. They generally have creeping habit with broad herbaceous leaves to adapt to limited light availability (Solofondranohatra et al. 2018). In the partially shaded understory of riparian forests of Isalo NP, the margins and gaps are dominated by shade-tolerant species: especially *Oplismenus burmannii* (Retz.) P.Beauv. and *Panicum brevifolium* D.Jahn ex Schrank. (Nanjarisoa et al. 2017). These species require permanent soil moisture and avoid sunlight. As for humid and riparian habitats, found in permanent or temporary marshes of Isalo NP, grasses are represented by species associated with prolonged inundation including especially *Sacciolepis* spp., *Setaria sphacelata* Stapf & C.E.Hubb. ex M.B.Moss, and *Echinochloa colona* (L.) Link. These species form an ecological group associated with organic soils with high moisture that require high light exposure and at least a temporary immersion during their life cycle (Morat 1973).

ISALO AND ITREMO. The only other recent and comprehensive regional checklist of Madagascar grass is that of Itremo which is ca. 520 km north of Isalo NP, where 99 grass species have been recorded (Nanjarisoa et al. 2017). With an area of 24 788 ha, Itremo is 3.5 smaller than Isalo NP and is also at a higher altitude (Table 2). Both areas are part of the central ecoregion with similar climatic conditions: Isalo NP is somewhat drier and warmer than Itremo, with a longer dry season. The grass flora of Isalo NP and Itremo are similar at subfamily, tribe, and genus levels. By calculating the similarities through Jaccard index, their subfamilies are 88% similar, tribes 65% similar, and genera 61% similar (see Appendix I, II). Fifty-six of the grass species of Isalo NP have also been recorded in Itremo. Except for the Pooideae, which are present in Itremo but not in Isalo NP, subfamilies are represented in similar proportions and both are dominated by the C4 major clades: Paniceae, Andropogoneae and Chloridoideae. The highest species diversity has also been recorded in the grasslands of both areas (Nanjarisoa et al. 2017). The total number of endemic grasses and the endemicity are higher in Itremo, despite the lower level of protection and greater human exploitation. Currently, compared to 22% of Isalo NP's grasses, 32% of Itremo's are endemic to Madagascar which likely reflects Itremo's higher elevation quartzite outcrops and its richer

Table 2. Comparison of the grass floras of Isalo and Itremo protected areas and their geographical and biological contexts. (Information about Itremo was obtained from Nanjarisoa et al. (2017) and from the Management Plan of the New Protected Area of Itremo (Ministère de l'Environnement et des Forêts 2012))

	Isalo National Park	Itremo New Protected Area
Surface area (Ha)	81 540	24 788
Altitude (m)	541 - 1268	1400 - 1700
Mean annual temperature (°C)	21	19.5
Annual average rainfall (mm)	800-1200	1000-1600
Wet season (months)	4 to 5	7 to 8
Main vegetation	Grassland, Tapia, Riparian forests	Grassland, Tapia, Riparian forests
Total of species	112	100
Number of shared species	56	56
Total endemic	24 (22%)	32 (32%)
Number of local endemics	4	2

adventitious and agriculture-associated flora (KMCC 2012). Isalo NP is however home to two more locally restricted endemic species than Itremo.

DISCUSSION

CHECKLIST. This study presents a list of grass species found in the Isalo NP: a total of 112 species, representing a tripling of the number of grasses reported by the Madagascar National Parks in Isalo NP in 2017 (MNP 2017).

Our results are broadly congruent with our expectations. Like the Itremo grass checklist, which increased the number of known grasses in the area threefold, this checklist brings the number of grass species of Isalo NP from 38 as cited by the MNP Ranohira in 2017 to 112 (MNP 2017). Our final species count is comparable to that of Itremo (Nanjarisoa et al. 2017), but significantly higher than that of the Andringitra National Park (18 species) (Lewis et al. 1996), and that of the forest reserve of Manongarivo (60 species) (Gautier 2002), possibly due to the lack of an attentive search for grasses in Andringitra and Manongarivo.

The checklist presented in this study was based on both historic and new herbarium specimens, which were identified via spikelet dissections and comparison with verified herbarium specimens. All collections were successfully identified except the 21 specimens where images were not available from the P herbarium. A species checklist can never be fully complete without comprehensive and repeated field observations carried out over multiple field seasons and throughout the year, which were not practically possible within a time limited project like this one, especially as identification without flowering material remains largely impossible. We anticipate that further grass species are likely to be found flowering outside the wet season months of March – April when fieldwork for this study took place.

DIVERSITY AND ENDEMICITY. The highest diversity of Poaceae species was recorded in the vehicle-accessible eastern part of the Isalo park, where the diverse habitats created by forests and streams in deep canyons create a variety of niches separated by sandstone outcrops, allowing both the fire-dependent and fire-vulnerable C4 and C3 grasses to grow. But since this is the only area of the park that was well investigated, we still expect to uncover further diversity in the north and west of the park, where habitat diversity, canyons, and different forest types are also prominent. Other species-rich families also seem to be under-recorded in Isalo NP. For Fabaceae, only 42 of 592 of the total species in Madagascar were recorded from Isalo NP, and for the Asteraceae, only 21 of 516 species (Du Puy 2002, MNP 2017, Goodman et al. 2018, 1561–1575). Poaceae are the first large plant family present in Isalo NP that was fully inventoried via a specialist survey. The reasonable similarity of grass taxa found in Isalo NP and Itremo supports the assertion of Vorontsova et al. (2016) claiming that sites of the same ecoregion

and of the same vegetation types are similar in terms of grass species composition.

Poaceae endemism is known to be geographically the lowest in the central highlands where grasslands are dominant, excluding high mountains (Bond et al. 2008). Preliminary lists of grasses in other ecoregions have already revealed higher levels of endemism compared to that Isalo NP, such as 97% (17 out of 18 species) in montane grasslands of Andringitra and 58% (19 out of 33 species) in the montane region (Humbert 1955, Lewis et al. 1996, Vorontsova et al. 2016), although grass endemism there is likely inflated due to under-recording of common weedy species. However, grass checklists of Tanzanian protected areas record much lower endemism ranging from only 2 to 12% (Vollesen et al. 1999, Williams et al. 2016). These areas are an order of magnitude larger than Isalo NP but demonstrate even lower endemism. The level of endemism in the Madagascar's grass flora is well above the global average for large islands (Vorontsova et al. 2016), and that of Isalo NP is consistent with this expectation.

In spite of their discreet appearance, more than a hundred different grasses are found in Isalo NP, dominating and driving the function of its extended grasslands, and carpeting much of its forest understory. Isalo grasslands are mainly dominated by *Loudetia simplex*, *Loudetia filifolia*, *Trachypogon spicatus*, *Chrysopogon serrulatus*, and *Schyzachyrium sanguineum*. Isalo massif is part of the central highland grasslands, long assumed to be secondary biomes (e.g., Morat 1973, Koechlin et al. 1974), as they are considered species-poor with lower endemism compared to other ecoregions and other woody biomes (Morat 1973, Bond et al. 2008, Vorontsova et al. 2016). In Isalo NP, they are described by Gautier (2018) as "vast stretches of secondary grasslands and pastures" which "cover 40% of the site". Morat (1973) judged the southwestern grasslands to be largely anthropogenic as they are species-poor, consisting of only a few endemic species and grassland species but apparentely with many ruderal and introduced species.

HISTORY OF ISALO'S GRASSLANDS AND PEOPLE. Environmental changes and disturbances are indeed prevalent in many parts of the island, as Malagasy people have depended on forests and their destruction since their settlement probably around 1350–1100 y B.P. (Anderson et al. 2018). However, no history of change in vegetation cover has been recorded for the open canopy ecosystems of Isalo NP (e.g., Goodman 2018, 1561-1575). Their only documented human use is cattle grazing by the Bara people, which may not have significantly altered a naturally fire-driven tropical grassy ecosystem (Zafisoalizy 2011). Instead, the Bara's historical activities seem likely to have maintained Isalo's ancient grasslands until the establishment of the Isalo NP in 1962. These cattle herders settled in Ranohira for its extended grasslands that could make good pasture (Rajaofera 2007, Zafisoalizy 2011). Their livelihoods were always more dependent on grassland and fire than on agriculture. They frequently burned grasslands but did not cut many trees (Rajaofera 2007, Zafisoalizy 2011). For construction, they built their houses out of clay and grass. Recent studies suggest that the Bara are indeed protectors of nature and forest, and they conserved trees because they believe that trees and forests create rain and because they use forests to hide their zebu from thieves (Zafisoalizy 2011, Saandi 2012). Comparatively few people occupy the immense territory of Ranohira. In 1945, the population density of this area was 0.3 inhabitants/km^2 (Gourou 1945).

TAPIA. Grasses make up the herbaceous layer of the Tapia ecosystems of the central highlands. These ecosystems are dominated by *Uapaca bojeri* trees, which are endemic to Madagascar (Kull 2003, Kull et al. 2005). Swierkosz (2007) called them sclerophyllous woodland and defined them as a lax formation with many gaps, where shrubs and herbaceous vegetation cooccur. This ecosystem was also previously classified as a "forest" (e.g., Rajeriarison & Faramalala 1999), but a recent study has demonstrated it to be functionally a form of savana grassland (Solofondranohatra et al. 2018). Tree-less grasslands and Tapia are both fire-resistant and light-dependent, with an understory composed of similar grass species (Solofondranohatra et al. 2018). Their grass species are taxonomically and phylogenetically highly diverse, indicating that they have a long evolutionary history and should have been present in the region before human settlement (Solofondranohatra et al. 2018). During our survey, we also found a similar species composition in open-canopy grasslands and under Tapia (Table 1). This suggests that grasses and their functional traits have always been an integral part of these ecosystems.

Addressing the question of origin of grasslands (and distinguishing between grasslands of different ages) remains a challenge and must involve multi-disciplinary studies. However, our results are consistent with the presence of ancient grasslands in Isalo massif.

OTHER ORGANISMS IN ISALO GRASSLANDS. Grasslands are home to a diversity of plants and animals, including those in Isalo massif. A diversity of ants, amphibians, reptiles and birds are found there (although not all are well documented), as well as restricted endemic species (e.g., *Monotes madagascariensis* trees, *Mantella expectata* frogs) (Mercurio et al. 2008, MNP 2017). Bond et al. (2008) hypothesized that the presence of endemic plants and animals in Madagascar's grasslands is consistent with a pre-human history. A natural open canopy grassland ecosystem would be expected to have associated dicotyledonous herbs, animals, and an invertebrate fauna (e.g., Bond and Parr 2010) and the lack of a specialised fauna has been cited as a sign of anthropogenic origin (Morat 1973). The absence of endemic amphibians and reptiles in the high plateau grasslands was used by Raxworthy and Nussbaum (1996) as evidence that the current grasslands are recent and artificial, and that the original vegetation and endemic herpetofauna must have been lost. Nevertheless, highland grassland ant assemblages are more diverse in Madagascar than forest ones (Fisher and Robertson 2002), and species diversity and distributions of local termites and other invertebrates remain incompletely documented. Fungi and microorganisms need study.

ISALO COMPARED TO OTHER PARTS OF MADAGASCAR AND THE REST OF THE WORLD. Isalo massif is part of the central and western grasslands, which represent 70% of the Madagascar's grassy ecosystems (Faramalala 1988). In Madagascar, grasslands have probably formed during the Miocene as part of their global expansion (Strömberg 2011), which is congruent with the similarity between the diversity of C4 grass lineages in Madagascar and Africa (Bond et al. 2008) and with the dating of Malagasy endemic C4 grass clades to around 1–6 Ma (Hackel et al. 2018). Rather than starting to expand from one region, grasses and grasslands likely already existed in many parts of Madagascar, generating high spatial and ecological turnover in the flora across the island (Vorontsova et al. 2016). Eighty one percent of Isalo's grasses

are C4, 15 of these endemic and the rest belonging to common African genera. Moreover, the grass flora of Isalo NP demonstrates some affinity with that of Itremo, as they belong to the same ecoregion, but has also its own specificity, especially when compared with other sites in different ecoregions. The C4 grasses of Isalo massif and their ancestors are therefore likely to have been part of the global diversification of Miocene grass and grass-dominated ecosystems, as grassland already existed in this area before human arrival. Fire and grazing regimes prior to human arrival in the area are likely to have maintained these grasslands even where climatic conditions can support forest (Solofondranohatra et al. 2020). However, we cannot ignore the fact that human activities are also leading to a significant expansion of grasslands in Madagascar, and the inherently dynamic nature of grassy ecosystems makes it difficult to infer the exact history of any single specific location with any level of confidence. Understanding the history of Madagascar's grasslands is a complex task and requires more detailed ecological, genetic, and soil science studies.

CONSERVATION. The recent tree-planting programs in Madagascar highlight the need for clearer conservation policy for the island's grassy ecosystems that may have a pre-human origin and could suffer irreversible damage from the introductions of pine and eucalypt trees. It has been shown that some of the world's ancient grasslands hold more carbon under the ground than plantation forests in the same area (Gibson 2009), as the roots of water-hungry trees dry out the deep grassland soils, causing aerobic decomposition of carbon-rich soils. There is hence an urgent need for further research on grassy ecosystems such as those of the Isalo NP, preferably by delineating pre-human versus post-human grassy ecosystems, in order to avoid this damage from exotic tree planting in grasslands.

CONCLUDING REMARK

We hope this work contributes to the growing body of knowledge of Madagascar's grasses as a beautiful and diverse, as well as ecologically significant component of Madagascar's botanical wealth. We invite all biologists working in Madagascar to notice the Poaceae and make collections of these amazing plants to build this knowledge together, and we are happy to assist colleagues with learning to identify grasses. We also hope to promote the study of open canopy ecosystems in order to redress the historical focus on wet forest to the exclusion of other ecosystems.

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SUPPLEMENTARY MATERIAL

Appendix I: Comparison of grasses recorded by dedicated grass checklist projects in Isalo NP (this study) and in Itremo (Nanjarisoa et al. 2017). (Taxa marked in pink are unique to Isalo massif, and those in green to Itremo)

Appendix II: The numbers of grass subfamilies, tribes, genera, and species found in Itremo and in Isalo protected areas and listed in Appendix I, followed by the number present in both areas. Jaccard (Sj) similarity indexes were calculated as follows: Shared taxa between Isalo and Itremo/(Total for Isalo + Total in Itremo – Shared species).

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"Thank you, Marojejy:" affective learning outcomes of student participants in place-based field trips to Marojejy National Park

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ABSTRACT

Evaluations of conservation education programmes are most often concerned within the cognitive domain, where logical learning takes place. In place-based education, emphasis is instead placed on learning in multiple domains, including the cognitive and affective domains. Here, we quantitatively and qualitatively evaluate student learning in the affective domain following a series of short educational trips to Marojejy National Park, Northeast Madagascar. Student responses to the prompt "write about your trip to Marojejy" were evaluated for content, including emotional responses using cultural consensus, saliency scoring, and qualitative evaluation. The most salient term used in responses were "a good trip". when tested 1.5 to 2 weeks after their trip. Students wrote about the emotional impact of the trip in four out of five levels of the affective domain. Our findings highlight the value of place-based education for learning in the affective domain. We demonstrated that even over a brief period of three days, place-based conservation education can have a marked impact on the values and emotions of participants.

RÉSUMÉ

Les évaluations de programmes d'éducation en matière de préservation sont le plus souvent axées sur le domaine cognitif, là où s'effectue l'apprentissage logique. Dans l'éducation effectuée sur place, l'accent est au contraire mis sur un apprentissage multidisciplinaire, qui inclut à la fois les domaines cognitifs et affectifs. Ici, nous évaluons de façon quantitative et qualitative l'apprentissage des étudiants dans le domaine affectif en suivant une série de brèves excursions à but éducatif au Parc national de Marojejy, dans le Nord-Est de Madagascar. Les réponses des étudiants à l'instruction « Parlez-nous de votre excursion à Marojejy » ont fait l'objet d'une évaluation tenant également compte des aspects émotionnels, sur la base du consensus culturel, du score de saillance et du point de vue qualitatif. L'expression la plus saillante utilisée dans les réponses a été « bonne excursion » dans les tests effectués 1,5 à 2 semaines après leur retour. Les étudiants ont relaté l'impact émotionnel de l'excursion dans quatre des cinq niveaux du domaine affectif. Nos résultats mettent en évidence la valeur d'une éducation sur place pour un apprentissage au niveau affectif. Nous avons démontré que même après une brève période de trois jours, l'éducation en matière de préservation peut avoir, lorsqu'elle est effectuée sur place, un impact significatif sur les valeurs et les émotions des participants.

INTRODUCTION

Educational trips to national parks are built on a pedagogy of place-based education. Place-based education focuses on the interactions of learners with a particular place, including their cognitive, emotional or affective, and physical or psychomotor interactions (Sobel 2004, Semken and Freeman 2008). It considers a learner's past experiences and present way of being in a place as indivisible from the learning process, making it particularly applicable to places like Madagascar, where spiritual values and cultural knowledge such as taboos, or fady as they are known in Madagascar, are a significant force for understanding one's place in the world (Schachenmann 2006, Jones et al. 2008). Place-based education aims to form a bond between learner and place and in the case of place-based conservation education, aims to encourage environmental protection through the formation of this bond (Smith 2002, Semken and Freeman 2008).

The affective domain is concerned with learners' feelings, emotions, and values, and is termed the 'gateway to the learning process' (Eiss and Harbeck 1969 pp 9–17, Iozzi 1989, Savickiene 2010). Learning in the affective domain is structured into a taxonomy of five levels. The pyramidal structure of this taxonomy suggests that learning at one level must be achieved before the learner can progress to the next. The levels—receiving, responding, valuing, organisation, and internalisation—move from recognising new values, to incorporating those values into one's existing moral structure, and finally to shaping one's behaviour in response to those values (Eiss & Harbeck 1969 pp 9–17, Savickiene 2010).

While place-based educational pedagogy asserts that learning in the affective domain is critical to achieve educational outcomes,

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many conservation education programs assume that knowledge rather than emotion is the entryway into pro-conservation behaviour change (Sobel 2004). As a result, many programs do not assess learners' affective response independent of their cognitive response (Wright et al. 2017). Given that achievement in the affective domain is theorised to promote behavioural changes in line with internalised values, it follows that a goal of conservation education, which aims to induce change towards pro-conservation behaviour, should be impactful learning in the affective domain. Many conservation education programs state affective engagement as a goal (Kals et al. 1999, Reis and Roth 2009, Jacobs and Harms 2014, Powell and Bullock 2014); however, evaluation of these programs primarily assesses learning in the cognitive domain (Kuhar et al. 2010, 2012, Nekaris 2018).

In many wild places throughout the Madagascar, organisations offer learners the opportunity to engage with the biodiversity of the island nation through trips to the forest; however, evaluations of the learning outcomes of these trips are limited. Ormsby (2008), details a participatory action research methodology for developing an education program in Masoala National Park. Patel et al. (2005) describe a preliminary framework for an education programme that would eventually become the initiative detailed here. Reibelt et al. (2014) present a detailed analysis of the state of environmental education in the Lac Aloatra region. While these frameworks and analyses are essential for developing sustainable and scalable conservation programmes throughout the country, evaluations of their efficacy, as represented in this paper, are also necessary for determining which aspects of an education programme work in practice and the results they produce.

As a result of the conservation pressures in Madagascar, including significant threats to largely endemic, highly diverse species and environments (Myers et al. 2000, Ganzhorn et al. 2001), education is increasingly identified as an important component of a nation-wide conservation strategy (Schwitzer et al. 2013). Ninety percent of Malagasy people do not live near a forest. According to Ratsimbazafy (2003), most Malagasy students knew more about lions, giraffes, and polar bears than they do their own endemic species. Conservation education aimed at introducing Malagasy people to the nature that surrounds them may be an effective means of promoting conservation (Dolins et al. 2010).

Here, we provide analyses of students' affective responses independent of their cognitive responses to a place-based education program in Northeast Madagascar designed to foster pro-conservation knowledge and attitudes and instill students with wonder about the natural world. We hypothesised that students who had learning experiences stimulating the affective domain, they would likely write about these in response to the open-ended prompt; "write about your trip to Marojejy National Park" and that analysis of these responses would reveal learning at various levels of the five domains of affective learning.

METHODS

STUDY SITE. The "Marojejy protected area complex", is one of the largest and least disturbed rainforest landscapes in Madagascar. Marojejy (E049°42', S14°27') is 60,050 hectares and is located in the SAVA (Sambava - Antalaha - Vohémar - Andapa) region of Northeast Madagascar around the Marojejy Massif, one of the tallest mountain ranges in Madagascar. Marojejy was among the first protected areas in Madagascar, established in 1952 as a strict nature reserve or Réserve Naturelle Intégrale (RNI) N. 12, in 1998 as a National Park, and listed in 2007 as part of the UNESCO World Heritage Site "Rainforest of the Atsinanana" (Garreau and Manantsara 2003, Goodman et al. 2018 pp 701–715, Rainforests of the Atsinanana https://whc.unesco.org/en/list/1257). Tsimihety and Betsimisaraka are the predominant ethnicities of local residents around the park who first began to arrive in the late 19th Century (Loudon et al. 2017). Due to its unique elevational range (75–2132m), Marojejy harbors enormous botanical diversity including 1302 plant species of which 84 are only found in Marojejy. Fauna are equally remarkable with 84 reptile species, the highest of any protected area in Madagascar. Also present are 119 bird species, 74 amphibian species, 21 species of tenrecs, and 11 lemur species including the Critically Endangered silky sifaka (*Propithecus candidus*) (Goodman et al. 2018 pp 701–715). As the only National Park in the SAVA region, Marojejy is a major tourist destination and provides livelihoods for up to one hundred local guides, porters, and cooks. Documented conservation challenges in the last two decades include selective logging for rosewood, ebony and other native hardwoods, swidden or slash-and-burn agriculture, bushmeat hunting, and movement of the park demarcation signs or "bournes" (Patel 2007, Loudon et al. 2017).

PARTICIPANTS. Between 2016 and 2019, The nonprofit Lemur Conservation Foundation, henceforth LCF, took Malagasy students on three-day, two-night forest trips. to protected areas in Northeast Madagascar, including Marojejy National Park. LCF is a conservation NGO based in the USA and Madagascar. In Madagascar, LCF supports conservation research, family planning, sustainable agriculture, reforestation and LCF's forest education program. During this time, sixty students in primary and secondary schools in the city of Sambava participated in forest trips to Marojejy between May 2019 and July 2019. Sambava (E050° 10', S14° 16'), an urban centre in Madagascar, is located approximately 50 km east of Marojejy National Park in the SAVA region of Northeast Madagascar.

The collaborating schools—Lycée Mixte Sambava, Lycée Privé Orchidée, and Collège d'Enseignement Général—were chosen due to their pre-existing relationships with LCF. Students from Lycée Mixte Sambava and Lycée Privé Orchidée ranged in age from 15 to 22 and students from Collège d'Enseignement Général ranged from 13 to 17. Students were members of the environmental clubs at their respective schools. The focus of these clubs was to learn about and help take care of the environment. Many participated in environmental celebrations, such as World Environment Day, and activities such as beach clean-ups and plantings around their school and Sambava. Club members were chosen to go to Marojejy based on their marks and their never having been to the Park before, although due to the small size of some of the clubs and the prominence of Marojejy in the SAVA region, some students had already been to the Park. They were accompanied by two experienced guides employed by Marojejy National Park and LCF and engaged in various lessons in rainforest ecology, animal behaviour, and conservation, as well as creative endeavours and focused discussions over the course of the three-day trips. During trips, students, slept, ate, learned, and played outside. For many, it was their first-time camping!

EDUCATIONAL CURRICULUM. Participants learned about the forest through educational and exploratory trail hikes. Guides led students through the Park, stopping at interesting plants, ani-

mals, fungi, and landscapes to explain their ecology, behaviour, appearance, or significance. After their initial introduction, students were actively encouraged to explore the forest themselves by finding and asking questions about the things that interested them rather than being told what to learn about by the guides. This method gave students agency over their own learning process and allowed them to bring their own knowledge, experiences, and circumstances to their learning and exploration (Smith 2002, Sobel 2004). In an effort to foster active participation, we asked students to collect small samples of plants, fungi, or fruit that they found interesting during our hikes. Then, during a discussion at camp, students explained why they picked the plant while guides gave more information about it, effectively engaging the three domains of cognitive (The guides taught me…), affective (I like this because…), and motor (I gathered this…).

During free time, we gave students the option to engage in creative learning activities, such as making drawings based on species in the Park, making and decorating lemur masks, and making and decorating puppets. During the evenings, students sang songs, reflected on the events of the day, and participated in guide-led discussions on the history of the Park and the importance of its conservation. We offered a variety of different activities to appeal to different learning styles and intelligences that groups of students may possess. For example, singing songs appeals to musical intelligence, while group discussions employ interpersonal experiences, self-reflections appeal to intrapersonal intelligence, and drawing activities use bodily-kinaesthetic intelligence. By appealing to multiple learning styles and intelligences (Gardner 1983), we aimed to engage all students in the learning process. By presenting information in a variety of formats, we also aimed to facilitate multiple revisions of information, which adds in the learning process (Jacobson et al. 2006).

STUDENT EVALUATIONS. Students' knowledge and awareness of Marojejy were evaluated before and after their trip. Here, we only include post-trip evaluations as students could not reflect on the things they felt during the trip to Marojejy prior to visiting. For full list of questions asked, please see Supplementary Material. In order to assess students' affective engagement as a result of the trips, participants were asked to respond to the prompt "write about your trip to Marojejy" during an evaluation given 1.5–2 weeks following their trip. Students were given 1.5 hours to respond to this question as well as other questions given during their post-trip evaluation. Writing in their preference of French or Malagasy, they could answer with as much or as little information as they liked in their open-ended response. They were not permitted to share ideas with each other or to look at pictures or notes on their phones or in their notebooks. The authors conducting the evaluations stressed to students that they were interested in knowing what students thought about the trip and that they should not try to simply please the researchers with their answers; however, the possibility that students wrote positive answers for the researchers cannot be overlooked. Evaluations were conducted in classrooms in students' respective schools in Sambava. We translated all written responses from Malagasy or French to English.

QUANTITATIVE ANALYSES. To quantitatively assess the responses of students to their trips, we used cultural consensus analysis and saliency analysis. Cultural consensus is a method for measuring the collective awareness and feelings of a group (Weller 2007). The free lists in the form of essays that students created in response to the question, "write about your trip to Marojejy" were used to evaluate the collective knowledge of the group of students regarding their trip. While not expressly asking about their feelings about the trip, the prompt assumed that if emotions and attitudes were a salient feature of their trip, they would be mentioned in response to a general question about the trip. We loaded matrices of students' responses into UCINET version 6.682 and analyzed them using minimum residual factor analysis. We compared the eigenvalues of the first two factor groupings. A three-to-one ratio of the first to second eigenvalues indicated cultural consensus within the group, meaning the group reached agreement that the domain can be represented by students' responses within the first factor grouping (Weller 2007).

In addition to cultural consensus, we used Smith's S saliency to quantitatively measure the importance and familiarity of the ideas represented in students' responses (Smith 1993, Nekaris 2018). Ideas that are mentioned more frequently and earlier in their writing are said to be more salient among the study group. In addition to cultural consensus analysis, saliency analysis helps to determine the ideas, such as feelings and emotions, that students think are most important regarding their Marojejy trip.

QUALITATIVE. In order to further evaluate the affective learner students reported in their essays, we categorized their responses into the different domains of affective learning, as outlined by Eiss and Harbeck (1969 pp 9–17). To do this, raw phrases written by students were evaluated for meaning. For example, one student wrote, "The trip to Marojejy was amazing to me. Everything went well. No one got sick or broken. We lived on fresh and clean air. A calm place. In short, everything was great. So for me, this forest should always be protected in order to give fresh air and clean water."

Raw ideas from students' essays were categorised into the taxonomy of affective learning (Eiss and Harbeck 1969 pp 9–17). Categorisation was completed by Sorenson. To ensure intra-observer agreement, Sorenson repeated the classification of raw statements from essays into the affective domains at two different points in time, revealing 84% agreement between the two measures. In order to conduct saliency and cultural consensus analysis, raw statements were coded by their general ideas.

RESULTS

There was no consensus among students about their trip, as revealed by cultural consensus analysis. Some of the most prominent domains, as revealed in the eigenvalues of the cultural consensus were that students liked the guides and would like to go again, that Marojejy should be protected, and that it was a nice trip. The most salient idea represented in students' responses to trips

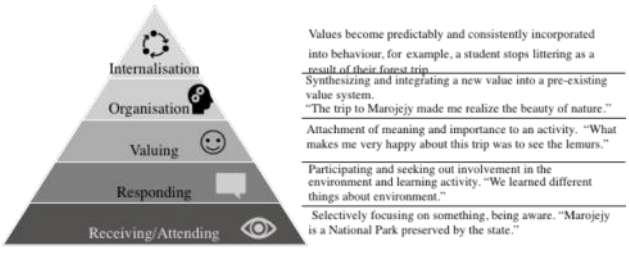

Figure 1. The five domains of affective learning. (Modified from Allen and Friedman (2010))

to Marojejy between May and July 2019 was "a good trip" (saliency=4.152, Table 1).

In their written responses, 13.3% of students' ideas (n=123) were in the receiving domain, 20.2% were in the responding tier, 42.2% were in the valuing tier, and 24.3% percent were in the organisation tier (Table 2). Students did not write about changes in their typical and consistent behaviour as a result of the Marojejy National Park trip; therefore, none of their responses were categorised in the highest domain of affective learning, internalisation (Table 2). Of the responses to which we ascribed a positive or negative value, the majority of responses included words such as *liked*, *fantastic*, *loved*, *marvellous*, and *great*. Students described that they enjoyed the trip, that the guides, cooks, and trip leaders were kind to them, and that the Park was clean and had fresh air. Only four students expressed negative feelings about their trip to the Park—these related to physical challenges experienced and the terrestrial leeches found in the Park.

In addition to expressing observations about their trip, such as "everyone followed the rules" students wrote about how the trip influenced their thinking and their future plans. For example, one student wrote "We loved it, and no one regrets going. We even want to come back. Thank you, Marojejy." Another wrote, "I will never forget what I saw there." A third wrote, "I hope we can continue [these trips] for future generations." Students' responses in the domains of receiving/attending, responding, valuing, and organisation, covered a wide range of aspects of the trip, from the food students ate to the teaching they received and the rules they followed.

LEVEL 1 RECEIVING/ATTENDING. Students (n=60) wrote 23 different ideas that could be classified as selectively attending to different elements of the trip. Responses were classified into seven different categories. The most frequent observations in this category were about Marojejy National Park ("I have seen Marojejy Mountain chains") and the people on the trip ("[the guides and cooks] took care of us" (Table 2). Statements in this level were, by nature of the first level of the affective domain, neutral in tone and emotion.

Table 1. The 20 most salient ideas reported by students (n=60) after their three-day educational trip to Marojejy National Park in Northeast Madagascar. Student participants, aged 13–22, came from three schools in the city of Sambava, Northeast Madagascar.

Student idea	Saliency
Good trip	4.152
See new things	0.831
We learned	0.814
Many animals	0.729
Many plants	0.712
Fresh air	0.593
Journey details	0.508
Nice people	0.492
Followed rules	0.356
Took care of us	0.322
Enough food	0.305
Safety	0.288
Got along	0.271
Protect forest	0.271
We played	0.237
Even though	0.220
Clean water	0.203
Made me happy	0.203
Good food	0.186
Good teaching	0.153
We swam	0.152
Good place	0.136
Good for health	0.119
Dinta	0.119
I want to go back	0.119
Glad to experience park	0.102

Table 2. Frequency of students' ideas categorised into the five levels of learning in the affective domain. Bold numbers represent the total frequency for each domain category.

Affective domain category	Frequency of responses
Receiving/attending	0.133
Responding	0.202
Valuing	0.422
Organisation	0.243
Internalisation	0

LEVEL 2 RESPONDING. 30 phrases written by students could be classified as participating and seeking out involvement in different aspects of the trip, including statements such as; "we increased our awareness and knowledge." Plants ("we also learned different trees and their uses and saw different trees that we have never seen before") were the most frequently discussed topic in this category (Table 2), while animals ("we learned about bamboo lemurs") and teaching ("we have learned many things because we get different lessons."). The remainder of the responses were largely neutral or slightly positive ("we saw fantastic animals.") Responses in this category are most frequently things that the group did: "we learned," "we saw," "we sang," "we swam." The majority of the statements in this category describe the activities of the group using 'we' rather than individual statements employing 'I.'

LEVEL 3 VALUING. Students (n=60) wrote 49 ideas that could be classified as valuing in the affective domain. This level contains the largest number of students' responses. Responses including evaluative reflections on the experience ("the trip was nice"), the people who accompanied them ("the cooks had prepared hot soup for us, they treated us very nicely") and animals ("what makes me very happy about this trip was to see the lemurs") (Table 2).

LEVEL 4 ORGANISATION. Students (n=60) represented a total of 23 ideas in their written responses that could be categorised as organisation in the affective domain. These responses, in which students demonstrate they are beginning to integrate values learned on the Marojejy National Park trip into their existing moral framework, reflected the trip ("it changed my whole life") and animals students observed ("I encountered many species that I had never seen") At this level of affective learning, students expressed the importance of protecting the forest and the organisms therein. Students reflected on the fact the Marojejy National Park is a special place.

LEVEL 5 INTERNALISATION. Students did not represent ideas in their responses that indicated they had reached the highest level of learning in the affective domain, internalisation.

DISCUSSION

As a result of educational trips to Marojejy National Park, our hypothesis that students would achieve learning in the affective domain was supported. Indeed, student participants demonstrated learning in four out of five levels of the affective domain: receiving, responding, valuing, and organisation. The intermediate level of affective learning, valuing, was most frequently indicated in students' responses.

While not written in their responses, informal conversations with students revealed that they shared ideas they brought back from the Park with their friends and family members. They told them about the things they saw on their trip and that nature is precious and must be protected. Research into conservation education has demonstrated that when children bring home conservation lessons and messages to share with their parents, their parents are more likely to engage in pro-conservation behav-

iours (Damerell et al. 2013, Rakotomamonjy et al. 2015). Moreover, we have anecdotal evidence that students continue to engage in thinking about the Marojejy National Park trips. Personal observations afterwards revealed that the participants shared pictures, poetry, and paintings influenced by the trip, suggesting internalising behaviours. In order to foster growth in the domains of affective learning, students should be exposed to longer-term education that builds on the emotions and knowledge they experienced over the course of their trip (Wallis and Lonsdorf 2010). In future trips, LCF should continue to prioritise student agency in learning, while also incorporating learning goals that reflect those of the National curriculum of Madagascar in collaboration with schools in the region. The efficacy of this method has been demonstrated in the Masoala Peninsula of Northeast Madagascar by Ormsby (2008) and provides added benefit for teachers, students, and conservation, as it aligns government prescribed learning with activities that promote the importance of the local environment.

There is evidence that positive childhood experiences are associated with later care for the environment (Tanner 1980, Chawla and Derr 2012). An evaluation of the effect of emotions on self-regulated learning found that positive emotions contributed to positive achievement and motivation (Mega et al. 2014). While research suggests that positive environmental experiences lead to pro-environmental sentiments in all ages of children, younger children are typically more responsive to these influences (Sobel 1996, Lieflander and Bogner 2014). In the future, LCF should expand its educational outreach to include younger primary school children in addition to the students represented in our study.

While the vast majority of affective experiences reported by students were positive, a few reported negative emotions. These negative feelings mainly concerned novel stimuli such as the terrestrial leeches found in the forest and the hiking and trails in the Park. The presence of these reported experiences does not undermine the utility of the educational experience. As Kellert (1983) and Sebba (1991) conclude, the utility of nature as a learning tool is due in part to the fact that nature is unpredictable and challenges learners by provoking not only positive feelings, but also fear and anxiety stemming from this unpredictability. Navigating these emotions and environments promotes critical thinking and creativity (Kellert 1983, Louv 2008). Anecdotally, we can confirm that these negative emotions promoted critical thinking in students—students that did not like being food for leeches used their critical thinking skills to develop ways to avoid them, including covering their legs with salt and inventing a leech-removal sponge with the help of one of the guides. Promoting these skills in youth will be critical if they are to navigate and develop creative solutions to the environmental challenges they are likely to face.

We utilised both qualitative and quantitative methodologies to analyse the ways in which our free-response evaluation could be used to assess affective learning. Results demonstrated students' personal association or value assignment to the Marojejy National Park trip via both methods. While saliency measures elucidated the ideas students most frequently written about, including personal values, and observations of the trip, qualitative analyses were required to categorize statements into taxonomic levels of the affective domain. Qualitative studies are frequently used in evaluating the outcomes of conservation education, as Alerby (2000), Bettinger et al. (2010), and Hughes (2013) demonstrated that nuanced thinking can be revealed and contextualized through holistic analyses in settings designed to understand students' perceptions of threatened species and local environments. Quantitative analyses, such as the cultural consensus and saliency measures used here, may be reductive (Kuhar et al. 2010, 2012). In future research, continued use of these mixed quantitative and qualitative analyses will retain the positives and minimise the limitations of both types of analyses.

The importance of learning in the affective domain is supported by a wide range of fields, from nursing education to general university education to environmental education (Bolin et al. 2005, Cazzell and Rodriguez 2011, Pearson et al. 2011). We demonstrated that even over a brief period of three days, place-based conservation education can have a marked impact on the values and emotions of participants. This is in accordance with Bogner (1998), who found that short-term outdoor environmental education can have long-term impacts on environmental attitudes. Place-based education is designed to engage cognitive, affective, and psychomotor learning domains (Semken and Freeman 2008). While many educational evaluations are concerned with cognitive domain, the affective is often ignored or minimised. While we acknowledge that the cognitive domain is where thinking and processing occurs (Osler 2013); we assessed affective domain as a means unto itself, demonstrating that learning experiences in nature largely resulted in positive emotions. It is likely that the relationship between these two domains ultimately facilitates students' achievement of learning goals (Osler 2013). Future research should investigate the learning outcomes that result from the interaction of these two domains. At Marojejy, LCF plans to continue these programmes. At time of publication, travel to the parks is restricted due to the COVID-19 pandemic, but education will resume when allowed. As previously mentioned, we recommend that LCF focus on bringing younger students to the forests as well, and that they focus on creating curriculum goals for the trip that align with the learning standards of local schools. To create these lessons and meet the needs of the local communities, LCF should collaborate with the communities with whom they engage in education using a participatory model. Involving Malagasy students and teachers in the planning and development process not only ensures that lessons and learning are culturally relevant, but also gives agency to the participants (Ormsby 2008, Reibelt et al. 2014) This helps them to recognise that they, not outside researchers and educators, have power and ownership of their environment and their education. Participants therefore develop skills in critical and creative thinking, and also create a model of environmental education that is sustainable even after outside educators and researchers move on from the project. The organization should aim to follow-up with students who attended these forest trips 6 months to one year after their programme to assess what they have retained from the trip. In addition to these formal education programmes, LCF engages in education that benefits the environment through their family planning outreach with the Marie Stopes Foundation and their sustainable wood stove distribution with ADES. Future research within the organisation should aim to assess the short-term and long-term environmental impacts of these programmes.

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Revue des textes fonciers et forestiers pour la mise en œuvre de la restauration des paysages forestiers à Madagascar

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RÉSUMÉ

La restauration des paysages forestiers (RPF) vise à restaurer la fonctionnalité du paysage au profit des populations locales, du climat et de la biodiversité. Elle requiert une gouvernance foncière efficace. Cette étude analyse les inconsistances et limites des stratégies nationales et textes juridiques par rapport à l'efficacité de la RPF et avance des recommandations politiques. Notre analyse montre que la loi malgache encourage le reboisement sur terre dégradée dont le domaine de l'État qui n'est pas délimité et souffre d'empiétement. Le succès du reboisement implique la délimitation de ces domaines, l'allègement des procédures pour les acquérir par les communautés locales ainsi que l'inclusion de ces dernières. Une révision des zones forestières sous régime forestier de l'État et des Collectivités Territoriales Décentralisées est aussi requise. Quant aux forêts naturelles, l'incertitude concernant leur statut et les droits des communautés rendent leur restauration très complexe. Nous recommandons que le projet de loi régissant ces terrains à statut spécifique considère plus explicitement la pluralité et la complexité de leur gestion et l'amélioration du droit des communautés locales et du *Fokonolona*. L'apport de bénéfices concrets aux communautés locales permettrait également de garantir la pérennisation des activités de RPF. Enfin, la restauration effective des zones agroforestières telles que les pâturages est parmi les motifs clés justifient la nécessité de reconnaître légalement et formellement les *Fokonolona* et les pratiques coutumières. La synergie des cadres juridiques et politiques des différents secteurs est essentielle pour assurer l'efficacité écologique et sociale de la RPF.

ABSTRACT

Forest landscape restoration (FLR) aims to restore landscape functionality for the benefit of people, climate and biodiversity. Increasingly, land tenure and rights are being considered as important enabling factors in FLR. This study analyses tenure considerations in Madagascar's legal texts and FLR policies, outlines their inconsistencies and potential limits in achieving FLR aims, and advances policy recommendations. We found that the current legal texts and framework present several inconsistencies that might impede the effectiveness of FLR in delivering positive environmental and social outcomes. Our analyses demonstrate that most of the target areas for reforestation prescribed by national guidelines are not physically demarcated on the ground and are frequently occupied by local people. This implies that reforestation on degraded lands and its upscaling urgently requires the identification and delimitation of these target lands, and greater involvement of local communities. There are incentives for private individuals or groups to plant trees in return for formalizing their land rights on these target areas, but procedures are very complex, and this has delivered little. To increase the positive impacts on local livelihoods and local uptake, we recommend reducing the complexity of devolving ownership rights of these reforested lands to the local community. A review of forest areas legally vested in the forest regime of the state and decentralized local authorities is also required to promote local participation and reduce potential land conflicts. Regarding natural forests, uncertainties around their legal status and the rights of communities make their restoration very complex. We recommend that the law that is currently being drafted to define the tenure status of these lands explicitly takes into account the plurality and complexity of their management and considers the rights of local communities more explicitly to secure their cooperation. In addition, the sustainability of FLR activities in the long term relies on delivering tangible economic benefits to local communities besides access rights, especially where ecological restoration of native species is prioritized. Currently, these benefits are mostly anticipated from payments for ecosystem services schemes which have not so far materialized. The FLR national strategy and draft law con-

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cerning the restoration of agroforestry areas such as pastures do not currently make any provision for the recognition of the *Fokonolona* (the village community) or customary practices. This may seriously undermine local communities' rights and risk encouraging land grabbing by more powerful entities. Inconsistencies in legal texts can undermine the effectiveness of the forest restoration in terms of hectares restored, it can also result in poor outcomes for local people. Finally, a greater synergy and coherence of public policies and legal texts across the land management, mining, agricultural and environmental sectors is required to increase the effectiveness of FLR in delivering positive social and environmental outcomes.

INTRODUCTION

La restauration des paysages forestiers (RPF) suscite de nombreux intérêts du fait des multiples avantages qu'elle offre (Besseau et al. 2018). Elle contribue à la capture du carbone ainsi qu'à la conservation de la biodiversité (Stanturf et al. 2015, Beatty et al. 2018). La restauration des forêts à grande échelle constitue un outil efficace d'atténuation du changement climatique (McCauley et al. 2019). Outre la capacité de la RPF de restauration des fonctionnalités écologiques d'un paysage, cette approche permet aussi d'améliorer le bien-être humain (Stanturf et al. 2017).

La réussite de cette approche repose sur l'implication des communautés locales (Holloway et Short 2014, Erbaugh et al. 2020) et les efforts de restauration peuvent nettement améliorer les conditions de vie locale (Weston et al. 2015, Wilson et Cagalanan 2016). Toutefois, elle risque d'aggraver la pauvreté si sa mise en œuvre restreint l'accès à la terre, aux ressources essentielles et aux moyens de subsistance des populations ou si elle s'accompagne de restrictions liées à la conservation (Adams et Hutton 2007, Rakotonarivo et al. 2017, Poudyal et al. 2018). Le manque de prise en compte des communautés et de leurs droits pourrait entraîner un manque de soutien local et entraver le succès des efforts de restauration (Höhl et al. 2020, Di Sacco et al. 2021).

À Bonn en 2011, Madagascar s'est engagé à relever le défi de restaurer 4 millions d'hectares de paysages et de forêts d'ici 2030 dans le cadre de l'initiative africaine sur la RPF ou AFR100. Cinq types de paysages prioritaires pour la restauration ont ainsi été identifiés : les terres dégradées, les forêts naturelles, les mangroves et les pinèdes dégradées et, enfin, les paysages agroforestiers (République de Madagascar 2017). Toutefois, l'ambiguïté du droit foncier constitue un défi important dans l'usage de la terre et aussi dans l'efficacité de la RPF (République de Madagascar 2017). Une bonne compréhension des règles de gouvernance encadrant l'usage et la gestion des ressources foncières aux niveaux national et local est alors primordiale (Robinson et al. 2018, Mclain et al. 2018).

Cette étude est établie pour analyser les incohérences et limites des textes légaux encadrant l'usage des terres et des forêts ainsi que la gestion des paysages forestiers à Madagascar. Pour ce faire, nous établissons tout d'abord un état des lieux des textes existants se référant à la RPF. Ensuite, nous les analysons et identifions leurs limites. Nous terminons avec des recommandations pour une mise en œuvre plus effective de la RPF.

MÉTHODOLOGIE

La présente étude s'intéresse aux textes légaux en vigueur liés à la mise en œuvre de la RPF à Madagascar. Ces textes englobent à la fois des textes juridiques tels que les lois, décrets, arrêtés et ordonnances ; mais aussi divers instruments tels que les politiques publiques, la vision nationale et les stratégies en vigueur. Les textes sélectionnés soulèvent des questions relatives à la réalisation des activités de RPF. Notre analyse exclut les problèmes liés à l'exploitation forestière qui n'influencent pas directement la mise en œuvre des activités de restauration (Tableau 1) .

La majorité des documents a été obtenue en ligne sur le site de la Direction du centre national d'information sur les documentations législatives et juridiques (<http://www.cnlegis.gov.mg/>) des documents a été obtenue auprès des services techniques compé-

Tableau 1. Récapitulatif des textes légaux analysés dans l'étude

Type	Date	Secteur	Intitulé / Descriptif
Stratégie	2017	Environnement	Stratégie nationale sur la restauration des paysages forestiers
Vision	2019-2023	Tous	Initiative émergence à Madagascar
Politique publique	2015-2019	Tous	Plan national de Développement
	2006	Environnement	Programme d'action national d'adaptation au changement climatique
	2017	Environnement	Nouvelle politique forestière
	2015-2030	Energie	Nouvelle politique énergétique
	2015	Agriculture	Lettre politique agricole
	2015-2030	Foncier	Nouvelle lettre politique foncière
Loi	2005-019 du 17/10/2005	Foncier	Fixe les principes régissant les statuts des terres dont le statut foncier spécifique des aires protégées et des terrains à reboiser
	2006-031 du 24/11/2006	Foncier	Fixant le régime juridique de la propriété privée non titrée
	2008-013 du 23/07/2008	Foncier	Régissant le domaine public de l'Etat
	2008-014 du 23/07/2008	Foncier	Régissant le domaine privé de l'Etat.
	2015-051 du 03/02/2016	Aménagement	Portant sur l'aménagement du territoire ainsi que des dispositions intéressant sur l'aménagement forestier, surtout sur les réserves foncières forestières
	2015-003 du 19/02/2015	Environnement	Charte de l'Environnement malagasy actualisée qui définit des principes généraux de l'environnement en lien avec le foncier des aires protégées et la politique de reforestation
	2015-005 du 26/02/2015	Environnement	Refonte du code de gestion des aires protégées
	97-017 du 08/08/1997	Environnement	Portant révision de la législation forestière
	97-072 du 06/06/1997	Environnement	Appliquant la sécurisation foncière relative
	96-025 du 30/09/1996	Environnement	Relative à la gestion locale des ressources naturelles renouvelables (GELOSE)
Décret	2017-376 du 16/05/2017	Foncier	Politique forestière définissant le régime foncier applicable aux aires protégées et aussi le régime de l'utilisation des terres par les communautés
	2017-415 du 30/05/2017	Environnement	Fixant les modalités et les conditions de la loi n°2015-005 sur les codes des AP
	2000-383 du 07/06/2000	Environnement	Application de l'article 43 de la loi forestière n° 97-017
	2005-849 du 13/12/2005	Environnement	Portant application de la législation forestière
	2001-122 du 04/02/2001	Environnement	Conditions de mise en œuvre de la gestion contractualisée des forêts de l'Etat
	98-610 du 13/08/1998	Environnement	Réglementant les modalités de la mise en œuvre de la sécurisation foncière relative
	87-143 du 20/04/ 1987	Environnement	Portant des révisions de l'ordonnance 60-127 fixant le régime des défrichements et des feux de végétation
Arrêté	4355/1997 du 13/05/1997	Environnement	Portant sur la définition des zones sensibles
	9398/2000 du 05/09/2000	Environnement	Fixant les modalités d'application du décret N°2000-383 du 07/06/2000 relatif au reboisement
	29211/2017 du 28/11/2017	Pêche	Fixant les modalités de transfert de gestion des ressources halieutiques et écosystèmes aquatiques.
Ordonnance	60-127 du 03/10/1960	Environnement	Fixant le régime des défrichements et des feux de végétation
	75-028 du 22/10/1975	Environnement	Modifiant certaines dispositions de l'ordonnance 60-127 fixant le régime des défrichements et des feux de végétation.

tents des ministères concernés. Afin d'analyser les limites des différents textes, des entretiens semi-directifs avec six autorités gouvernementales au sein de ces ministères ont été menés (dont deux du secteur environnement, deux du secteur aménagement du territoire, et deux du secteur foncier). Ces entretiens se sont focalisés sur la praticabilité des textes en vigueur et sur leurs impacts dans la mise en œuvre de la RPF. Par exemple, certaines discussions ont porté sur les textes liés à la sécurisation foncière des domaines forestiers nationaux, la réalisation des restaurations (les zones cibles, les incitations…), la considération des communautés locales et du *Fokonolona*, les synergies des différentes politiques ministérielles. Ensuite, deux des auteurs (Stefana Raharijaona et Eric Raparison), juristes experts du foncier, nous ont permis de confronter et de mettre à jour les incohérences entre les assertions théoriques et l'application pratique des textes, surtout pour ceux prêtant à confusion et qui pourrait impacter la mise en œuvre de la RPF.

RÉSULTATS ET DISCUSSIONS

ANALYSE DES CADRES POLITIQUES ET STRATÉGIQUES RELATIFS À LA RPF. Depuis sa participation au défi d'AFR100, Madagascar a élaboré une stratégie nationale de restauration des paysages forestiers (SNRPF). La SNRPF vise à restaurer les paysages forestiers et à les valoriser harmonieusement et durablement pour le bénéfice de la population.

La stratégie est liée aux objectifs de l'Initiative Émergence Madagascar de 2019-2023 qui reconnaît la RPF comme une utilisation pérenne des paysages pour le développement. Outre les actions de lutte contre les feux, les défrichements et la dégradation des aires protégées, cette initiative invoque la nécessité de procéder à une reforestation et à la restauration des forêts, des sols et des bassins versants (République de Madagascar 2018). Cette vision de l'initiative ainsi que la SNRPF s'inscrivent dans la continuité des objectifs du plan national de développement de 2015-2019. Le plan de développement encourage la valorisation durable du paysage par la promotion et le développement des espaces de croissance comme pour les zones spéciales : zones d'investissement agricole et les zones économiques spéciales. Ce plan incite aussi à l'aménagement des bassins versants par le reboisement et la restauration pour un objectif de 35,000 ha par an (République de Madagascar 2015).

Le programme d'action nationale d'adaptation au changement climatique identifie aussi la RPF parmi ses besoins urgents et prioritaires d'actions. Entre autres, elle vise l'adoption de techniques de protection et de restauration du sol, la remise en état des secteurs dégradés par divers reboisements et la promotion des transferts de gestion des forêts (Ministère de l'environnement, des eaux et forêts 2006).

La restauration est tout autant mise en exergue par la nouvelle politique énergétique de 2015-2030. Cette politique insiste aussi sur le besoin de préserver l'environnement tout en valorisant le capital naturel du pays afin de limiter la dépendance au bois et à l'énergie fossile. Elle suggère de protéger les ressources forestières et de réaliser un reboisement de 35 000 à 40 000 hectares par an afin de sécuriser l'approvisionnement en bois-énergie. Cette politique veut mettre en œuvre un financement national pour le reboisement avec les communautés locales et incite à la délimitation territoriale des zones d'exploitation de bois-énergie (Ministère de l'Energie et des Hydrocarbures 2015).

Les objectifs de la nouvelle politique forestière de 2017 sont aussi cohérents avec la SNRPF. En effet, cette politique a pour objectif de promouvoir le reboisement des terres dégradées et agroforestières. Pour ce faire, elle informe sur le besoin de délimitation consensuelle des terrains à vocation agropastorale et de promotion de la gestion à proximité des ressources naturelles (Ministère de l'Environnement de l'Écologie et des Forêts 2017).

Seule la lettre de politique agricole n'évoque pas la politique de restauration des paysages forestiers. Elle fixe surtout des objectifs dans l'extension des zones agricoles par la mise en place de 1,5 million hectares des zones d'investissement agricole. Ses plans s'attachent à la facilitation d'accès à la terre et à la propriété foncière pour augmenter la surface économique agricole par exploitation (Ministère de l'Agriculture 2015).

Les objectifs de la politique agricole de même que pour la restauration des paysages dépendent de la nouvelle lettre politique foncière de 2015-2030. Elle vise à la facilitation de reconnaissance des parcelles des usagers de terre par la mise en place du Plan d'Occupation Foncière (PLOF) sur tout le territoire dans le cadre de leur mise en sécurité par l'immatriculation. Cela concerne tant les propriétés privées que communautaires. La nouvelle lettre foncière assure la création d'outils de planification de gestion foncière, la précision des limites et usages des aires protégées (AP) et du domaine forestier ainsi que la délimitation des domaines de l'État et des statuts qui englobent toutes les zones spécifiques (Ministère d'État en charge des Projets Présidentiels de l'Aménagement du Territoire et de l'Équipement 2015).

À l'exception de la politique agricole, les cadres politiques en vigueur à Madagascar s'alignent avec l'objectif de la RPF. Ces divers secteurs mettent en exergue le besoin de participer à la restauration des paysages. Ces politiques ne peuvent cependant favoriser la RPF que si la restauration devient la priorité des différents secteurs, notamment sur l'usage des terres qui nécessite un juste équilibre de compromis (Slobodian et al. 2020).

LIMITES JURIDIQUES POUR LE REBOISEMENT SUR TERRES DÉGRADÉES. Difficulté d'identification et de délimitation des terrains de reboisement. En se référant à la loi 2000-383, les réserves foncières pour le reboisement ainsi que les terres sélectionnées par la Commission forestière constituent les zones propices au reboisement. Ces zones peuvent se créer sur des terrains domaniaux (terrains privés ou publics appartenant à l'État), des périmètres de reboisement (terrain destiné au reboisement des personnes privées ou publiques du domaine privé), le domaine forestier national nommé DFN (zones forestières de l'État) et/ou sur les anciennes zones d'action en faveur de l'arbre ou ZODAFARB (domaines privés de l'État délimités pour faciliter l'appropriation du terrain à travers le reboisement pour les reboiseurs en 1984) (art.2). La détermination physique de ces terrains pour le reboisement est assez problématique malgré l'existence de 151 périmètres de reboisement et de restauration anciennement créés sur une superficie totale de 1 129 372 hectares (FAO 2010). La limite physique de ces zones ne peut être exactement identifiée faute d'immatriculation voire d'absence de décret de création. De plus, avec la réforme foncière de 2005, les zones pouvant accueillir les réserves pour le reboisement sont difficiles à distinguer. La reconnaissance légale des droits coutumiers a presque amené à l'appropriation privative de nombreuses parties des domaines de l'État objet de reboisement. Les incitations foncières au reboisement évoquées à l'article 9 du décret 2000-383 sont ainsi devenues

inadaptées à cause du pluralisme juridique dans le pays (FAO 2014) qui induit des chevauchements de droits. Le reste des terrains inoccupés appartenant aux domaines de l'État, mais qui n'ont pas fait l'objet d'immatriculation par l'administration, notamment les domaines forestiers incluant les réserves foncières pour le reboisement, font face à un risque d'empiétement (Aubert et al. 2013). De plus, l'inexistence de schéma d'aménagement communal fixant le statut d'usage des terres pénalise la disponibilité de terrain pour la mise en œuvre de reboisement dans la majorité des territoires décentralisés.

Difficulté du processus d'appropriation des terrains reboisés. Les périmètres de reboisement ainsi que des terrains domaniaux affectés au reboisement sont soumis au régime forestier (art. 12 de la loi 97-017). Ils sont ainsi imprescriptibles et inaliénables, mais peuvent néanmoins être accédés à titre individuel par voie de bail emphytéotique (art. 10 du décret n°2000-383 et art. 7-12 de son arrêté n°9398/2000). Ce procédé de bail favorise plutôt le reboisement sur les terrains disponibles des grandes entreprises (Andrianirina Ratsialonana et al. 2010) du fait des clauses à respecter et des coûts d'investissement qui y sont attachés. Pour la motivation des individus ou de la communauté, le cas des terrains domaniaux non affectés ainsi que les anciennes zones d'action en faveur de l'arbre autorisent l'accession à la propriété par les incitations foncières au reboisement (décret n°2000-383 et de l'arrêté n°9398/2000). Le processus d'appropriation se base sur le respect des clauses résolutoires rédigées dans un cahier de charge permettant de lever les conditions d'imprescriptibilité pour l'acquisition individuelle de la zone (Ramarolanto-Ratiaray 1989). L'attestation de reboisement ne peut cependant s'obtenir qu'après 5 ans suite à une évaluation positive de la plantation. Cette attestation peut s'achever par une immatriculation sur une période totale de 10 ans à partir de la constatation de la reconnaissance du reboisement de terrain. À cause de la longueur et du coût de ce procédé, les législations forestières en vigueur ne promeuvent pas réellement un support à l'acquisition des terres par le reboisement (Desloges 2001). Les procédures n'ont que rarement abouti à une appropriation légale (Aubert et al. 2015).

Manque de coordination interministérielle. Outre les problèmes d'identification et d'empiétement sur le domaine de l'État, la désignation des autorités responsables en charge de l'identification et de la délimitation des terres destinées au reboisement démontre un conflit interministériel. La loi 2000-071 affirme qu'il revient à la commission forestière de déterminer les zones propices au reboisement. En revanche, l'article 72 de la loi 2015-051 insiste sur le fait qu'il relève des compétences des services techniques chargés de l'aménagement du territoire de déterminer ces zones. On note également un manque de coordination au niveau de l'utilisation de coordonnées géographiques différentes par les diverses entités lors de leur délimitation des terrains identifiés, une problématique régulièrement évoquée. De tels problèmes devraient pourtant être facilement résolus par une conversion et l'unification du type de projection utilisé lors du traitement des images. Néanmoins, le problème d'identification et de protection des zones propices au reboisement persiste faute d'engagement réel de l'État à le dénouer (Aubert et al. 2013) et malgré les nombreuses incitations établies (loi 97-017 art.43, la SNRPF orientation 3 - axe 3, lettre politique foncière orientation 3 - Axe 3.2).

Problème lié à la pérennisation des reboisements. Les reboisements effectués à Madagascar après 1985 se confrontent en majorité à des échecs (Desloges 2001). D'un côté, cet échec s'explique par le manque d'insistance des textes légaux sur la nécessité de maintenir les zones reboisées sous la prescription environnementale, soit à destination forestière ou zone pour plantation d'arbres uniquement. Les clauses régulatrices pour acquérir le terrain suite au reboisement requièrent le respect de la vocation du terrain et des plans de gestion nécessaires (Manjaribe et al. 2013). De même, la loi régissant la propriété privée titrée ou certifiée, requiert cette soumission aux règles d'aménagement prédéfinies pour éviter de renégocier à chaque fois l'application des servitudes forestières et environnementales (République de Madagascar 2017). Une telle pratique, accompagnée du manque d'inclusion des communautés locales dans la planification des reboisements, met en péril la viabilité des plantations d'arbres qui ne sont pas entretenues voire enlevées lorsqu'elles ne répondent pas à leurs besoins (Le et al. 2012). D'un autre côté, la mise en vigueur des textes sur l'usage de feux (décret 87-143 du 20 avril 1987) lors de la pratique de renouvellement de pâturage et de certains feux de végétation sont des pressions permanentes pour les zones restaurées à Madagascar. Les comités responsables du suivi (art. 1 du décret n° 2002-793) n'arrivent pas à surveiller l'usage local des feux. De plus, les peines lourdes affligées aux responsables pour réprimander les feux sauvages (ordonnance n° 75-028) et pour inciter les collectivités à lutter contre les feux de brousse (décret n° 2002-793) ne semblent pas limiter cette pratique. Les feux détruisent ainsi de nombreux hectares de zones reboisées et protégées chaque année (Alvarado et al. 2018) et ont brûlé plus d'un million d'hectares de terres boisées de 2010 à 2014 (FAO 2020).

En tout, malgré les nombreux projets de reboisement vulgarisés depuis longtemps à Madagascar, seule une superficie totale de 312 000 ha a réussi à perdurer dans le paysage (FAO 2020). Les limites juridiques précédemment analysées ont en effet contribué à limiter la mise en œuvre des reboisements sur terres dégradées. À petite échelle, l'expansion du reboisement participatif par les communautés locales nécessite l'accès et la sécurité liés à la valorisation des terres par les communautés (Desloges 2001, Mclain et al. 2018, Mclain et al. 2019). La mise en œuvre de reboisement à grande échelle convoitée pour atteindre rapidement les bénéfices issus de la RPF (Chazdon 2018) requiert une gouvernance cohérente et une synergie entre les services fonciers et forestiers. En effet, jusque lors, la détermination des terrains de grande superficie sans litige foncier dû au chevauchement de droit coutumier et positif est assez problématique. Les reboisements à grande échelle ont ainsi souvent entraîné la perte d'usage et d'accès des terres (Erbaugh et Oldekop 2018).

INCOHÉRENCES DES TEXTES POUR LA RESTAURATION DE FORÊT NATURELLE. La majorité des forêts naturelles malgaches, à savoir 98%, relèvent du domaine de l'État (Mansourian et al. 2014). Ces forêts sont soit dans le domaine forestier national (qui est 75% composé par les stations forestières, les forêts classées et celles dont la gestion a été transférée vers la communauté locale), soit des aires protégées.

Statut et régime juridique flous des aires protégées (AP). La restauration des forêts naturelles se heurte au statut et régime juridique flou de ces zones. Les forêts naturelles sont supposées faire partie du domaine de l'État qui se pose comme seul propriétaire légal (art. 12 de la loi 97-017). Cependant, dans la réalité, les aires protégées incluent une multitude de statuts, surtout au sein des zones périphériques. L'article 3 de la loi 2015-005 attribue le régime juridique des AP suivant leur vocation et les droits existants

dans ces zones. Suivant ces critères, les noyaux durs des AP relèvent exclusivement du domaine public de l'État ainsi que les réserves naturelles intégrales, au sein desquelles aucune présence ni activité humaine n'est autorisée. Les autres AP (AP publiques dont les parcs nationaux ou naturels, les réserves spéciales outre la réserve naturelle ; et les AP mixtes : monuments naturels les paysages harmonieux ainsi que les réserves de ressources naturelles, respectivement de catégorie III et V) peuvent quant à eux contenir plusieurs statuts juridiques car soumis à des régimes de propriété foncière divers. En effet, l'interaction entre homme et nature étant permise dans ces zones ; différentes activités humaines y ont ainsi depuis longtemps eu lieu. La mise en place des AP a par la suite essayé de régir les usages d'un commun accord avec les conventions de gestion communautaire (décret n° 2017- 415 de la loi 2015-005) mais ces conventions n'existent quasiment pas. La restauration de ces zones s'avère difficile (Elmqvist et al. 2007). Elles ne peuvent être sécurisées du fait de ces incertitudes liées au statut des terres (Mansourian et al. 2016). Elle risque même de porter atteinte aux droits de quelques-uns à cause de la superposition de titres existants dans plusieurs sites protégés (Aubert et al. 2015). La réussite des restaurations à grande échelle des zones forestières par la plantation d'espèces natives dépend cependant de cette prise en compte de l'historique de l'usage du terrain et du contexte de ce paysage (Nunes et al. 2020). Dans le prolongement des dispositions de la loi 2005-019, l'adoption de la nouvelle loi sur les terrains à statuts spécifiques est attendue pour clarifier la situation foncière au sein des aires protégées.

Incertitude des statuts et régimes fonciers des zones restaurées. La détermination des forêts soumises au régime forestier, imprescriptible et insaisissable, génère de la méfiance et nuit à la participation à la restauration de la forêt. Les terrains boisés et reboisés seront assimilés aux forêts sous régime forestier suivant la législation forestière (loi 1997-17). Le problème d'affiliation des zones boisées et reboisées à ce régime peut décourager les participations locales de peur de perdre catégoriquement leurs droits à la terre (Mansourian 2016). D'autre part, même si la terre a eu d'autres vocations que forestière, mais que les régénérations naturelles ou plantées d'arbres couvrent au fur et à mesure la zone, elle sera régie par ce même régime (art.4 de la même loi). La définition juridique des forêts régies sous ces réglementations selon la législation forestière (cf. Matériel supplémentaire) ne contribue pas suffisamment aux objectifs de la restauration forestière. De ce fait, en raison de l'inexistence d'une précision claire des zones sous le régime forestier, la mise en couvert arborée via la restauration d'une zone risque de déroger au droit de propriété en changeant le régime juridique du terrain pour l'État.

Mise à l'écart des droits de propriété de la communauté locale. Des droits communautaires dans le sens d'usage collectif sont reconnus juridiquement dans la législation, mais non le droit de propriété dans le sens du droit coutumier. La loi a en effet des difficultés à reconnaître l'existence de droits de propriété des communautés locales surtout au niveau des terrains à statut spécifique (art 2 de la loi 2006-031). Au sein des forêts naturelles protégées, la loi n'attribue qu'une possibilité de droit de jouissance (Binot et Joiris 2007) aux communautés locales (loi 2015-005 art. 49). Les droits sont restreints aux droits d'usage exercés dans le cadre d'une convention de gestion communautaire. Souvent même dans les pays en développement et y compris à Madagascar, les communautés locales ont été expropriées de leurs terres coutumières pour la conservation des forêts (Oviedo 2005). Les politiques publiques restent aussi muettes quant au droit à la terre des communautés dans les aires protégées, même quand elles participent à des activités de conservation et de restauration.

De même, cette reconnaissance de propriété communautaire est problématique au sein des forêts hors AP définie suivant la loi 97-017 et l'ordonnance 60-127 (les stations forestières, les réserves d'exploitation, les terrains affectés aux services des eaux et forêts et les réserves forestières). Malgré la formulation légale d'une possibilité d'immatriculation grâce à la sécurisation foncière relative de la zone communautaire (art. 15 du décret n° 98-610) gérée à travers la gestion locale sécurisée ou GELOSE (loi 96-025, art. 24 de la loi 97-017), seuls les droits de jouissance ont toujours été appliqués. Dans son esprit original, l'esprit de la GELOSE visait pourtant à s'ouvrir à la reconnaissance des propriétés coutumières et leur titrisation (Montagne et al. 2009). L'interprétation de l'administration de cette possibilité de sécurisation comme un mode privilégié d'acquisition de terres après la promulgation des lois foncières de 2005 et 2006, mais aussi l'absence d'un arrêté pour l'application de la sécurisation foncière relative ont alors mis à l'écart les droits de propriété des communautés par les gestionnaires et l'administration. Ce refus de reconnaître l'appropriation communautaire est pourtant la source de nombreuses déforestations mondiales (Zakout et White 2019) menaçant ainsi le maintien de la superficie forestière à Madagascar. Elle limite d'autant plus la participation des communautés aux activités de restauration (Mansourian et al. 2018, Mclain et al. 2019). Le droit réel des communautés locales est alors mis en péril (Aubert et al. 2013) et le problème persiste faute de cadres légaux qui l'explicitent (Aubert et al. 2015). Ce problème entraîne une concurrence dans l'accès, l'occupation et le contrôle de l'espace forestier entre cette communauté et les gestionnaires (Elmqvist et al. 2007). La mise en œuvre de la restauration est alors limitée par ces incohérences des droits des communautés locales (Stanturf et al. 2017). Le refus de l'appropriation de ces terrains par l'administration, sources de subsistance et de bien-être, risque également de dégrader les moyens d'existence des communautés riveraines (Notess et al. 2018).

Absence d'encouragement à la restauration des forêts naturelles. Les cadres politique et juridique à Madagascar intègrent l'importance de la régénération dans la pérennité des forêts pour les générations futures (République de Madagascar 2017). Toutefois, le lien entre communautés et régénération forestière n'est pas solidement établi par les textes. La participation des communautés locales à la régénération forestière n'est pas encouragée et ne donne pas lieu à des avantages concrets. Les seuls avantages accordés à la régénération naturelle des zones dégradées dépendent directement de la nature du projet qui soutient les communautés. Ces avantages pourraient provenir des paiements pour services environnementaux via la REDD+ suite à l'augmentation du stock de carbone forestier par régénération naturelle (objectif 3 de la Stratégie Nationale REDD+). Néanmoins, jusqu'à maintenant, les avantages conséquents attendus de la vente de carbone sont passés inaperçus, car ils se sont réduits à des appuis épisodiques pour les communautés locales (Demaze 2014, Poudyal et al 20018). D'autres avantages plus concrets et pérennes sont ainsi attendus. Par exemple, l'art. 54 de la loi GELOSE a prévu des avantages économiques en guise de compensation d'une bonne gestion de la part des communautés. L'article 54, resté non appliqué (Bertrand et al. 2014, Pollini et al. 2014), devrait pourtant permettre à la communauté de percevoir des bénéfices palpables à travers la parafiscalité qui y est soulevée. Sans la présence de tels avantages répon-

dant aux besoins locaux, les forêts risquent de disparaître plutôt que d'être gérées durablement (Scales 2014). Les transferts de gestion dont le but unique est la préservation des ressources sans possibilité de valorisation tels que la gestion contractuelle des forêts ou GCF, persistent pourtant encore (Bertrand et al. 2014, Pollini et al. 2014) malgré les expériences positives issues de la valorisation économique durable des ressources menées à Alaotra Mangoro, Boeny et Anosy. Cette stratégie a amélioré la gestion communautaire des forêts grâce à l'autofinancement (contrôle de l'exploitation et de la restauration) ainsi qu'un développement régional (Bertrand et al. 2014). La mauvaise gestion de l'environnement contribuant à un progrès limité de la restauration des forêts persiste alors faute d'une insuffisante application de la loi (Jones et al. 2019).

Manque de synergie dans les gouvernances foncières en relation avec la forêt. Le cadre légal du foncier forestier ne permet pas d'assurer une bonne efficacité de la gestion des forêts. Même si la loi indique que la gestion des forêts relève du ministère chargé de l'environnement, la gestion du terrain n'y est pas incluse. Selon la Lettre Politique Foncière de 2015 (MEATP 2015), la terre est sous la gestion de l'administration foncière. De telles confusions rendent difficile la conservation de la forêt, notamment en cas d'occupation illicite. En effet, malgré leur création, plusieurs AP ne sont pas inscrites dans les PLOF au sein des services de transactions foncières de l'État. De nombreux cas de superposition de titres d'appropriation sont ainsi observés dans plusieurs AP (Aubert et al. 2015). De plus, le plan d'aménagement et de gestion qui détermine les objectifs de gestion des AP et fait partie des outils clés du code des AP (article 25) est absent des dispositions sur les plans de gestion dans la loi 2015-051 en tant qu'outils d'aménagement du territoire. De tels problèmes diminuent le poids et la force de ces plans dans la pratique malgré l'importance de leur contribution dans le cadre de l'aménagement forestier.

INEFFICACITÉ DE LA RESTAURATION DES MANGROVES DÉGRADÉES. Les mangroves font partie du domaine public naturel de l'État (loi 2008-013) et sont classées parmi les zones sensibles (arrêté interministériel nº4355/97). Ces forêts publiques offrent une possibilité d'usage individuel ou collectif par l'obtention de permis de coupe (art 40 et 41 de la loi 97-017). En tenant compte de la nature sensible de cet écosystème, les exploitations doivent se soumettre à des exigences strictes (art. 4 du décret 2004-167) telles que le respect des prescriptions d'aménagement établies (art. 10 du décret n°98-782). Cet accord d'exploitation est effectué afin d'encourager la participation locale dans la gestion de cette ressource. Cependant, à cause du sous-effectif de l'administration, les contrôles sont quasiment inexistants, laissant à tous un libre accès d'usage (Bertrand et al. 2014, Andriatsiaronandroy 2018). Pourtant, leur conservation voire leur restauration par les communautés locales pourrait avoir des bénéfices concrets, notamment grâce à des financements issus des paiements des services écosystémiques via le REDD+. Le montant obtenu risque de ne pas suffire à la communauté, car l'État reste le bénéficiaire principal en tant que propriétaire (Jones et al. 2016). La forêt de mangrove, au lieu de s'étendre, fait l'objet de déforestation suite aux activités humaines et l'exploitation (Rakotomavo et Fromard 2010). Elle disparaît ainsi d'année en année pour être transformée en charbon, mais aussi pour laisser place à l'extension de l'agriculture ou de l'aquaculture (Giri et Muhlhausen 2008, Jones et al. 2016).

Outre cette problématique, la restauration des mangroves se confronte aux conflits générés par la mise en application de deux différentes procédures de transfert de gestion (GELOSE-GCF face au transfert de gestion des ressources halieutiques (TGRH) de l'arrêté n°29211/2017). Des superpositions de transferts de ressources sont en effet observées (c'est le cas de Nosy Be par exemple) entraînant des conflits entre les communautés (la communauté locale de base VOI par rapport aux communautés de pêcheurs par exemple) et sur la gestion des zones transférées (les zones délimitées pour la restauration étant différentes pour le plan d'aménagement et de gestion de la GELOSE/GCF et le plan simple de gestion du TGRH). Cet état indique une inefficacité et incohérence des politiques établies qui affectent de manière importante la conservation et la restauration de ces zones (Mojica Vélez et al. 2018).

LIMITES POUR LA RESTAURATION DES PAYSAGES AGROFORESTIERS. Manque de vision commune entre les politiques des secteurs concernés. À Madagascar, comme ailleurs, l'approche de restauration de ces zones (terrains privés et à statut spécifique comme les pâturages de grande superficie suivant la loi 2008-014) consiste à combiner les plantes agricoles annuelles et les plantes ligneuses pérennes avec des possibilités d'existence de pâturage entre les parcelles (Lacroix et al. 2016). Cependant, les politiques publiques existantes relatives à la forêt, à l'agriculture, au foncier et à l'aménagement ne possèdent pas une telle vision commune. Pour les politiques agricoles et forestières, l'arbre n'est pas considéré dans sa nature multifonctionnelle pouvant contribuer à l'atteinte des objectifs intersectoriels (Saïd et Sibelet 2004). En effet, la politique agricole de 2015 n'inclut pas d'orientation sur l'articulation de l'activité agricole avec la conservation des arbres. La politique forestière quant à elle se concentre plus sur la gestion durable du capital forestier sans prendre en compte l'influence de l'agriculture. La législation forestière semble même au contraire limiter la combinaison des deux pratiques via l'application de son art. 4 qui risque de changer le régime foncier du terrain si l'agroforesterie est pratiquée.

Outre le manque de promotion de l'agroforesterie, aucun plan commun pour assurer la sécurisation des zones de pâturages n'est élaboré par les divers secteurs concernés (fonciers, forestiers, agricoles et d'élevage). Pourtant, inscrire uniquement ces zones dans les plans d'aménagements communaux ne serait pas suffisant du fait du faible pouvoir juridique de ces outils dans la pérennisation de l'usage des terres.

Refus de reconnaissance du *Fokonolona*. Les paysages agroforestiers constituent 65% des terres de Madagascar (Dewar et Richard 2012) et assurent la subsistance des communautés ainsi que l'habitat de plusieurs espèces maintenues par les activités pastorales (Solofondranohatra et al. 2020). Dans la pratique, du fait des dispositions coutumières, l'accès et la gestion de ces zones reviennent au *Fokonolona*, entité de base de la communauté (art. 152 Constitution) et reconnue parmi les acteurs d'aménagement (art. 13 de la loi 2015-051). L'effectivité de la restauration de ces zones est réellement dépendante de leur régime foncier et de leur gouvernance (Robinson et al. 2021). Pourtant, comme de nombreux pays dans le monde (Ykhanbai et al. 2014), l'État malgache ne reconnaît pas le droit d'appropriation de ces zones par cette entité communautaire (Montagne et al. 2009). Il a plutôt préféré attribuer la gestion à des groupements de quelques personnes volontaires (dits « communauté locale de base » qui n'est pas tenue d'être représentative de la communauté) qui ne suivent pas le modèle de gouvernance locale basé sur le *Fokonolona*. Les leçons tirées des

expériences d'autres régions du monde montrent cependant que les systèmes fonciers rendus incertains ont un impact sur la gestion et la restauration de ces zones gérées par les communautés (Robinson et al. 2021). La reconnaissance du droit foncier communautaire aiderait la communauté à se projeter dans une gestion durable de ces zones et à diminuer le risque d'accaparement des terres (Ykhanbai et al. 2014). À cause du refus de reconnaissance de cette entité et de leur possibilité d'appropriation foncière, la réalisation des délimitations et de sécurisation de ces zones suivant le souhait des politiques publiques (la nouvelle politique forestière et de la lettre politique foncière de 2015) peut affecter négativement le bien-être de la communauté. Les sécurisations peuvent ainsi conduire à un risque de privatisation individuelle de ces zones jusqu'à affecter toute une communauté (Mclain et al. 2019).

RECOMMANDATIONS

À l'issue de cette revue se dessinent dix recommandations pour permettre une réalisation effective de la RPF à Madagascar.

DANS LE CADRE DU REBOISEMENT DE TERRES DÉGRADÉES.

1. Inventaire parcellaire du domaine privé de l'État : les besoins d'inventorier le domaine de l'État ont déjà été mis en exergue afin de faciliter leur gestion et leur usage. Des expériences des inventaires parcellaires élaborés par certains projets ont montré leur efficacité et pourraient servir de modèle. Par exemple, l'utilisation de la délimitation participative a permis de recenser les divers occupants en impliquant la communauté locale, les autorités traditionnelles, le *Fokontany* et la Commune (Mclain et al. 2019). Les aînés au sein des communautés locales pourraient s'assurer d'identifier chaque propriétaire coutumier de terrain et les terres sans maître, à justifier par la suite par le Fokontany et la commune. Les services fonciers vérifient à la fin les informations obtenues avec leur base de données avant de classer les zones disponibles dans le domaine de l'État. De telles collaborations des collectivités territoriales décentralisées avec les services topographiques sont également sollicitées lors de la mise en place des PLOF (art L'4 de la loi 2006-031). Lors de la demande d'immatriculation ou d'affectation de la zone, un procès-verbal d'inventaire parcellaire s'avère primordial car cet outil permet d'indiquer la considération de la communauté locale et le respect de leurs droits.

2. Allègement des processus d'acquisition du domaine de l'État : le procédé actuel d'acquisition de terrains via le reboisement limite la motivation individuelle et la réussite du reboisement. Pour pallier à ce problème, des politiques favorables au reboisement et l'apport de bénéfices socio-économiques concrets peuvent aider à accroître l'intérêt des ménages au reboisement (Worku et al. 2018). Entre autres, la révision des cadres légaux sur l'usage de terrains domaniaux par la cessation de terre à reboiser et la délivrance de permis d'utilisation des arbres plantés peuvent augmenter la participation locale au reboisement (Gençay 2020). La réplique des méthodes effectuées par Greenmad (financé par la GIZ) lors de la promotion des reboisements villageois individuels (RVI) est à refléter. Les terrains de l'État détectés sont transférés aux communes et puis affectés à titre individuel à des personnes volontaires au reboisement. Ces zones reboisées font l'objet d'acquisition individuelle après l'évaluation positive de la plantation par rapport au respect du cahier de charge tripartite. De même pour le reboisement effectué lors du Projet d'Appui au Reboisement Villageois, les reboiseurs ont pu obtenir des certificats verts à la fin du projet qui représentent un titre de propriété sous prescription environnementale. Les mesures d'obtention du certificat vert avant le titre se ralliaient d'abord au respect des suivis requis lors du reboisement (exécution des travaux d'entretien et de protection du terrain préconisés) (Gabathuler et al. 2014). Répliquer des expériences similaires sur les zones d'action en faveur de l'arbre (ZODAFARB) pour un reboisement communautaire, paraît aussi efficaces car la terre serait déjà transmise à la communauté. La mise en œuvre de reboisements à grande échelle repose sur une combinaison de gouvernance multipartite, incluant tous les secteurs œuvrant au sein du paysage (Erbaugh et Oldekope 2018).

3. Respect des prescriptions d'usage des terrains : les outils cartographiques de planification territoriale (les divers schémas d'aménagement, que ce soit national, régional ou communal, les plans d'urbanisme et les plans d'aménagement et de gestion) devront être réglementés dans leur mise en application afin qu'ils détiennent des forces coercitives sur le respect des prescriptions de terre. La loi doit alors requérir que les activités à mener respectent les outils cartographiques de planification territoriale et le règlement d'aménagement. Dans le cas de zone à vocation forestière destinée au reboisement ou à la restauration, les titres fonciers devraient spécifier de telle prescription pour éviter le changement d'affectation d'usage. La supervision effectuée par les polices d'aménagement de territoire (créées suivant le décret n°2017-646) s'avère impérative afin de vérifier le respect d'usage des terrains suivant le texte d'aménagement existant pour assurer l'efficacité de la RPF.

DANS LE CADRE DE LA RESTAURATION DE FORÊTS NATURELLES.

4. Clarification des statuts et régimes des aires protégées et sous droit forestier : pour le cas des AP, les statuts et régimes juridiques flous nécessitent d'être éclaircis pour répondre concrètement aux questions des propriétaires. La loi 2015-005 portant sur les codes des aires protégées devrait être révisée dans cet objectif. Concernant la mise en sécurité des AP ainsi que les autres zones sous droit forestier, les problèmes de procédé d'immatriculation dus aux coûts élevés et la complexité de sa réalisation devraient y être solutionnés. Une des solutions est d'inscrire les AP non publiques dans le domaine privé de l'État et/ou des Communautés territoriales décentralisées (Aubert et al. 2015) pour que l'État se charge de son immatriculation et de les affecter au ministère chargé de l'environnement afin de transférer leur gestion à d'autres entités. L'usage des images satellitaires peut aussi être mobilisé pour permettre la délimitation de ces zones. L'intégration de leurs données numériques dans le plan de repérage des services topographiques territorialement compétents peut à la fois éviter à recourir à l'opération de bornage coûteux et limiter l'octroi de titre privé dans ces espaces protégés.

5. Précision exacte des forêts sous régime forestier : la pérennisation des actions de restauration dépend de la détermination exacte des zones forestières sous régime forestier (imprescriptible et inaliénable). Une telle précision permet de clarifier l'appropriation de certaines zones après leur restauration et reboisement, et ainsi d'accentuer la participation locale. L'enjeu principal de cette définition est aussi de sécuriser les opérations liées aux forêts pour qu'elles ne soient pas perçues comme illégales et arbitraires vis-à-

vis du droit de propriété. Pour cela, la mise en application du droit forestier sur certaines zones par les commissions forestières doit provenir d'une définition consensuelle de la zone forestière à la fois adaptée aux enjeux diversifiés, aux exigences du moment et en cohérence avec les objectifs. Elle peut contribuer à renforcer le statut des zones dites forestières, de mieux délimiter le domaine privé forestier, de justifier l'application du régime forestier et de sécuriser indirectement les droits des personnes ayant participé aux reboisements.

6. Prise en compte de la complexité des terrains à statut spécifique dans l'élaboration de la loi les régissant : le projet d'élaboration de la loi régissant les zones à statut spécifique (AP, zone sous convention de gestion des ressources naturelles, zone sous droit forestier, zones sous convention internationale) devrait clarifier les questions relatives aux régimes juridiques spécifiques de ces terrains (la mise en articulation entre droits de propriété et le droit d'usage), dans la définition de leurs modalités de reconnaissance, de gestion, de sécurisation, d'acquisition et de perte de droits fonciers. Il est requis de prendre en compte les droits des communautés locales sur leurs terres coutumières dont elles ont été les premiers occupants et qui ont été transformés plus tard en aires protégées. Le principal enjeu de cette loi devrait être en outre le développement d'un cadre pour interpréter les dispositions des articles 34 et 152 de la constitution sur la propriété privée et le rôle du *Fokonolona* dans le développement afin d'aboutir à la reconnaissance juridique de formes de propriété collective.

DANS LE CADRE DE LA RESTAURATION DES PAYSAGES AGROFORESTIERS ET DES FORÊTS NATURELLES.

7. Reconnaissance du *Fokonolona* et de ses droits fonciers : les textes devraient être révisés de manière à permettre la reconnaissance des *Fokonolona* et de considérer leurs droits de propriété. La loi devrait consacrer la légitimité des droits fonciers des communautés locales même sous des terrains à statut spécifique en s'inspirant par exemple de la décision sur le peuple endorois du Kenya de la Commission africaine en 2010. Cette décision reconnaît en effet le droit des communautés locales à leur terre ancestrale incluant potentiellement leurs terres coutumières, mais vise aussi à leur protection contre les évictions forcées. Dans le cas d'usage à titre public de ces zones communautaires, des mesures de sauvegarde sociale devraient accompagner les actions menées en guise de compensation des droits locaux. Les mêmes droits devraient aussi s'appliquer dans le cadre des bénéfices obtenus lors des ventes de carbone ou autre. Par exemple, le code des aires protégées (loi 2015-005) reconnaît par ailleurs un droit de propriété aux communautés locales en son article 49 dont la teneur peut être développée par le projet de loi sur les terrains à statut spécifique.

DANS LE CADRE DE LA RESTAURATION DES MANGROVES ET DES FORÊTS NATURELLES.

8. Encouragement à la restauration : d'une part, il faut promouvoir des incitations économiques et/ou foncières pour que la population s'intéresse à la restauration forestière de même qu'au reboisement. De telles initiatives permettent une plus grande participation des communautés et un partage du coût de la restauration. D'autre part, le décret d'application de l'article 54 de la loi GELOSE qui promeut la valorisation durable des ressources naturelles par les communautés comme motivation de la gestion durable desdites ressources devrait être promulgué. De telles valorisations raisonnées des ressources forestières semblent être une solution pour une meilleure gestion des forêts et leur restauration (Bertrand et al. 2014).

POUR TOUTES LES ZONES PRIORITAIRES DE LA RPF À MADAGASCAR.

9. Cohérence et synergie interinstitutionnelle : afin d'assurer la cohérence des activités interinstitutionnelles, la restauration durable des paysages forestiers devrait être effectuée suivant une approche intersectorielle. Les objectifs ministériels devraient alors être voués à l'intérêt général. La RPF doit être imposée telle une vision commune et priorisée dans toutes les activités planifiées de l'État, d'où la nécessité de l'élaboration d'outils de planification pour assurer la bonne gouvernance. Dans ce sens, le Ministère chargé des forêts sur la base des documents nationaux doit élaborer une priorisation claire des attentes en termes d'objectif de restauration pour chaque secteur concerné et des indicateurs d'amélioration de bien-être de la communauté (République de Madagascar 2017).

10. Planification spatiale harmonisée de l'usage des terres : l'efficacité de la RPF s'articule avec une planification spatiale harmonisée par la détermination des zones de reboisement, de restauration des forêts et des paysages agroforestiers. La mise en place d'une telle planification intégrée requiert la coordination de nombreux secteurs concernés (ex. agriculture, pêche et élevage, forêt, foncier, mine) dirigée par celui de l'aménagement du territoire. Les décisions devraient se baser sur une vision nationale qui est de prioriser la restauration des paysages. De ce fait, dans le cadre de la coordination de la déconcentration et de la décentralisation, à partir des schémas d'aménagement national et régional élaborés, les communes devraient être équipées de moyens suffisants pour élaborer un schéma d'aménagement communal pour respecter les diverses prescriptions d'usage de leur zone. Ces schémas devraient ainsi s'assurer de l'articulation entre la planification ayant une vocation écologique avec celle ayant une vocation administrative et socio-économique. La mise en œuvre des schémas d'aménagement communaux ne doit se faire qu'après participation des parties prenantes et du *Fokonolona* à leur élaboration accompagnée d'un consensus sur leur contenu. Les schémas adoptés doivent revêtir le caractère obligatoire comme prévu par les dispositions de l'article 33 de la loi n° 2015-05. Ce caractère d'opposabilité aux tiers vise la préservation de l'intérêt général.

CONCLUSION

La participation de Madagascar au défi de Bonn et de l'AFR 100 souligne la nécessité de restaurer quatre millions d'hectares de paysages forestiers. Le pays possède de nombreux textes relatifs à la mise en œuvre d'un tel objectif qui présentent de nombreuses limites et incohérences. Les analyses des instruments élaborés ont montré que les diverses politiques ministérielles, outre l'agriculture, démontrent l'importance de la restauration. Toutefois, des incohérences entre les textes indiquent un manque de vision commune. La mise en œuvre de la RPF à Madagascar devrait cependant partir de cette base pour acquérir de la cohérence, synergie et harmonie dans l'atteinte globale de ses objectifs. La mise en place de plans d'aménagement décentralisé participatif devrait permettre une planification spatiale harmonisée sur l'ensemble du territoire, ce qui est cruciale pour la RPF.

Outre les problèmes de synergie et de cohérence entre les ministères, les problèmes fonciers sont une des limites importantes soulevées dans cette analyse. Entre autres, nous avons identifié des difficultés d'identification et de délimitation des domaines de l'État destiné au reboisement, des processus d'appropriation longs et un manque d'insistance des textes sur la pérennisation des terrains reboisés , des statuts et régimes juridiques flous des aires protégées, des incertitudes de statuts des terres des zones restaurées, le refus de reconnaissance des droits fonciers communautaires et de l'entité *Fokonolona* pour gérer les espaces communs.

Nous recommandons le dénouement de ces problèmes par le biais de la révision et même par l'adoption de nouvelles lois tenant compte de ces problématiques. Par exemple, l'allègement des processus d'acquisition de terre, la clarification des statuts et régimes des aires protégées et la définition des zones sous régime forestier devraient aider à résoudre les problèmes de participation locale. D'autres textes devraient être promulgués, notamment les textes régissant les terrains à statut spécifique ainsi que les textes encourageants à la restauration. Malgré cela, sans considération et participation totale des communautés locales, la mise en œuvre de la RPF présente des risques considérables. Il faudrait ainsi réfléchir à la reconnaissance du principe de gouvernance locale par le biais du *Fokonolona*, et à la reconnaissance des droits communautaires et coutumiers. La collaboration étroite avec les communautés locales a en effet déjà démontré son succès dans la facilitation d'inventaires des domaines de l'État et dans les initiatives de restauration, de suivi et de contrôle des terres restaurées afin d'en assurer la pérennité. Outre les recommandations émises, une meilleure compréhension des perceptions des diverses parties prenantes lors de la conception et de la mise en œuvre des projets RPF s'avère aussi nécessaire.

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MATÉRIEL SUPPLÉMENTAIRE

La définition des forêts et leur régime juridique à Madagascar

SHORT NOTE http://dx.doi.org/10.4314/mcd.v16i1.3

Pressions anthropiques sur la forêt de Besalampy : richesse faunique, caractère socio-économique et accords pour la création d'une nouvelle aire protégée

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RÉSUMÉ

Des inventaires biologiques et des enquêtes socio-économiques ont été effectués dans un site potentiel pour la protection de la biodiversité, subissant une forte pression anthropique, à Besalampy, ouest de Madagascar, afin de créer un projet de conservation durable. Quatre espèces de lémuriens (*Eulemur rufifrons*, *Hapalemur occidentalis*, *Lepilemur ruficaudatus*, *Propithecus deckenii*), 31 espèces d'oiseaux avec des espèces appartenant aux familles (Vangidae : *Leptopterus viridis*) et sous-familles endémiques (Couinae : *Coua coquereli* et *C. cristata*) malgaches ; et la tortue endémique en danger critique d'extinction *Erymnochelys madagascariensis*, ont été échantillonnées. La création d'une nouvelle aire protégée pourrait profiter à la fois à la protection de la biodiversité et à l'amélioration du bien-être des villageois vivant à proximité de cette zone de Besalampy.

ABSTRACT

Based on the Réseau de la Biodiversité de Madagascar (ReBioma), the forest of Besalampy, western Madagascar, is a potential site to protect the biodiversity, although subject to high anthropogenic pressure. Hence, biological and socio-economic surveys have been made in order to create a sustainable conservation project. Direct observations, and song and call listening technics were used to list species of lemurs, reptiles, amphibians and birds along predefined transects. Some birds have been captured using nets. Thus, four species of lemur (*Eulemur rufifrons*, *Hapalemur occidentalis*, *Lepilemur ruficaudatus*, *Propithecus deckenii*), 31 species of bird including those belonging to Malagasy endemic family (Vangidae: *Leptopterus viridis*) and subfamily (Couinae: *Coua coquereli* and *C. cristata*), and the endemic critically endangered big-headed turtle *Erymnochelys madagascariensis* were sampled. The habitat loss resulting from anthropogenic activities and hunting threatened the biodiversity in Besalampy. The poor living condition forced the local community to use the forest resources in an irrational manner, and the creation of a new protected area should provide a conciliation between biodiversity and local people.

INTRODUCTION

À Madagascar, les activités humaines de ces dernières décennies ont conduit à la disparition de 44% de la couverture forestière entre 1953 et 2014 en se basant sur les images satellitaires (Vieilledent et al. 2018) ; les forêts caducifoliées ont été les plus touchées. Se trouvant dans la partie ouest de Madagascar, le district de Besalampy présente une forêt sèche caducifoliée abritant des espèces endémiques emblématiques malgaches, notamment les lémuriens (Ralison 2007), la chauve-souris à ventouses de Schliemann *Myzopoda schliemanni* de la famille endémique malgache des Myzopodidae, *Microgale brevicaudata* de la famille endémique des Tenrecidae (Rajemison et Goodman 2007, Soarimalala 2011) ou le pygargue de Madagascar en danger critique d'extinction CR *Haliaeetus vociferoides* de la famille des Accipitridae (Razafimanjato et al. 2013). Les zones humides de Besalampy abritent la râle d'Olivier en danger d'extinction CE *Zapornia olivieri* (Rallidae) (Rabenandrasana et al. 2009) et une tortue d'eau douce, la réré, en danger critique d'extinction CR *Erymnochelys madagascariensis* (Podocnemididae) (Rabenandrasana 2007). Ces zones humides s'étendent jusqu'au littoral, en passant par les estuaires, et sont connues par la présence des lémuriens dans les mangroves (Gardner 2016, Donati et al. 2019). Toutefois, les forêts de Besalampy ont subi un important défrichement durant ces dernières décennies (Vieilledent et al. 2018).

Le district de Besalampy est difficile d'accès par voie routière et sa biodiversité est encore mal connue même par les biologistes (Goodman et Raselimanana 2008). Les inventaires biologiques dans ce district étaient surtout concentrés dans sa partie nord, notamment Andranomahitsy à E044°29' et S16°31', avec des recensements de micromammifères et de lémuriens (Rajemison et

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Goodman 2007, Ralison 2007, Soarimalala 2011) ; et sa partie sud notamment les Réserves Spéciales de Bemarivo et Maningoza respectivement à E044°24'et S16°52', et E044°43' et S16°52' avec des études sur la flore, les insectes, les oiseaux et les primates (Fishpool et Evans 2001, Schatz et al. 2001, Rasamison et al. 2005, Randrianarisoa et al. 2000, Forthman et al. 2016). Par conséquent, la présente étude se focalise sur des inventaires biologiques et des enquêtes socio-économiques dans un site potentiel pour la protection de la biodiversité selon le Réseau de la Biodiversité de Madagascar (ReBioma), dans le district de Besalampy (en dehors des Réserves Spéciales de Bemarivo et de Maningoza), qui selon nos connaissances n'a pas encore été visité par les chercheurs en biologie et écologie. L'objectif est de présenter les espèces de vertébrés et le mode de vie des gens de la région ainsi que leurs activités en relation avec la nature. Ce travail consiste à mettre en évidence les pressions sur la faune et la flore sauvage de Besalampy afin d'envisager des projets de développement et de conservation durables.

MÉTHODOLOGIE

INVENTAIRES FAUNIQUES. Les inventaires ont été réalisés du 21 juillet au 9 août 2016 dans la forêt de Besalampy (entre les longitudes E044° 21' et E044° 28' et les latitudes S16° 43' et S16° 49'), plus précisément dans les stations d'Andranomanenty (E044° 28' et S16° 44'), Andranovorombahoaka (E044° 26' et S16° 47'), Antampolo (E044° 23' et S16° 45'), Marofototra (E044° 25' et S16° 43') et Marotondro (E044° 21' et S16° 47'). Le protocole d'échantillonnage des espèces d'oiseaux a été adapté à partir des méthodes standards utilisées sur des lignes d'observation directe et d'écoute (Bibby et al. 1992). Les caractères morphologiques et les chants des oiseaux ont été identifiés en se basant sur le guide de Hawkins et al. (2015). Dans la présente étude, deux lignes d'échantillonnage d'un kilomètre de longueur ont été choisies : (i) une ligne traversant la forêt intacte, et (ii) une ligne traversant les formations perturbées et anthropiques. Les espèces d'oiseaux ont été inventoriées d'une manière continue le long de ces lignes entre 0500 et 0700 durant trois jours dans chaque station en se déplaçant à une vitesse constante d'environ 2 km/h. Trois filets japonais de 12 m x 2 m ont été déployés près du campement dans chaque station pour capturer des oiseaux de sous-bois. Après que ces derniers ont été identifiés, ils sont ensuite relâchés entre 0500 et 0700 au voisinage des lignes d'échantillonnage .

Pour les carnivores endémiques malgaches (Eupleridae), des enquêtes auprès de la population locale appuyées par des observations directes et des prospections d'éventuelles traces de présence, notamment les traces de pattes et les fèces, ont été réalisées pour recenser les présences. Toutefois, les informations précises destinées à l'identification des traces de pattes et des fèces des Eupleridae sont limitées aux recherches faites par Albignac (1970) et Hawkins et Racey (2008) sur des *Cryptoprocta ferox* ; la reconnaissance des autres Eupleridae d'une manière indirecte s'avéraient ainsi difficile. Des observations directes suivant les mêmes lignes d'échantillonnage que les oiseaux ont été effectuées pour inventorier les espèces de lémurien.

La présence des espèces d'amphibiens et de reptiles dans le site d'étude a été déterminée par la technique d'observation directe et la fouille systématique des microhabitats suivant deux lignes d'échantillonnage de 250 m pour les amphibiens et 1 km pour les reptiles. Pour chacun des deux groupes, une ligne d'échantillonnage traversait la forêt intacte et une autre ligne passait par les formations perturbées et anthropiques. Les informations sur les espèces de poissons ont été recueillies auprès des pêcheurs en se basant sur les critères d'identification de King (1997) ainsi que Rham et Nourissat (2004).

ENQUÊTES SOCIO-ÉCONOMIQUES. La méthode d'enquête choisie a été adoptée à partir des techniques d'entretien individuel effectuées par Marcus (2001) qui a étudié la perception de la population locale vis-à-vis de la création des aires protégées à Masoala (partie nord-est de Madagascar) et Ranomafana (partie est de Madagascar). Dans le présent travail, après un entretien avec le président du « fonkontany » couvrant les stations d'Andranomanenty, d'Andranovorombahoaka, d'Antampolo et de Marofototra, les personnes adultes (> 18 ans) résidant dans ces stations ont été invitées à une réunion d'explication de l'objectif de l'investigation. Des volontaires ont été sélectionnés au hasard à partir de la fiche de présence à la réunion pour être enquétés ; les questionnaires d'enquête portaient sur les sources et le montant du revenu mensuel, le montant et la nature des dépenses familiales mensuels ainsi que la perception sur l'utilité de la forêt et de la biodiversité.

RÉSULTATS

FAUNE DE LA FORÊT DE BESALAMPY. Des groupes de *Propithecus deckenii* ont été observés dans toutes les stations de collecte de données (Tableau 1) ; les *Lepilemur ruficaudatus* ont été vus dans les stations d'Antampolo et de Marofototra, les *Hapalemur occidentalis* dans la station d'Antampolo et *Eulemur rufifrons* dans la station de Marotondro. Chez les Eupleridae, aucun individu n'a été rencontré ; toutefois, des traces de pas observées sur le littoral de Marofototra ont suggéré la présence de *Cryptoprocta ferox*.

Dans le souci de perdre les filets pour les captures des oiseaux, les filets n'ont pas été utilisés dans les stations d'Andranomanenty et d'Antampolo où les activités de banditisme et de vol sont fréquentes. Un nombre total de 31 espèces d'oiseaux réparties dans 21 familles ont été inventoriées (Tableau 1), dont des rapaces se trouvant au sommet de la chaine trophique (*Buteo brachypterus*, *Polyboroides radiatus* : Accipitridae), jusqu'aux Cuculiformes et Passeriformes, particulièrement ceux qui se trouvent dans les familles (*Leptopterus viridis* : Vangidae) et sous-familles endémiques (*Coua coquereli* et *C. cristata* : Couinae) malgaches.

Aucune espèce d'amphibien n'a été rencontrée. Chez les reptiles, sept genres appartenant à sept familles différentes ont été inventoriés (Tableau 1) et sont tous endémiques de Madagascar. Il n'a pas été possible de voir des individus vivants d'*Erymnochelys madagascariensis* ; toutefois, la population locale affirme que l'espèce est toujours présente et des restes d'individus qui venaient d'être chassés ont pu être observés.

Les poissons inventoriés constituaient les principaux moyens de subsistances de la population locale se trouvant dans les villages de pêcheurs. Les sept espèces recensées ont été observées dans les pièges des pêcheurs au sein des zones humides ; trois espèces sont authochnones dont une seule est endémiqe de l'île (Clupeidae : *Sauvagella madagascariensis*), trois autres espèces sont allochtones (Tableau 1).

ENQUÊTES SOCIO-ÉCONOMIQUES. Les enquêtes ont dévoilé qu'une famille gagne de 10 000 à 800 000 MGA par mois, soit une moyenne de 216 750 ± 182 800 MGA par mois (N = 20), soit près de US$ 65,7 ± 55,4 par mois en 2016. Leur principale source

Tableau 1. Listes des espèces de vertébrés rencontrés dans la forêt de Besalampy et leur statut de conservation selon l'UICN. (CR : en danger critique d'extinction (*critically endangered*), EN : en danger (*endangered*), VU : vulnérables (*vulnerable*), NT : quasi-menacée (*near threatened*), LC : préoccupation mineur (*least concern*)).

Groupe, Ordre	Famille	Espèce	Statut UICN
Lémuriens, Primates	Lemuridae	*Eulemur rufifrons*	NT
		Hapalemur occidentalis	VU
	Lepilemuridae	*Lepilemur ruficaudatus*	VU
	Indridae	*Propithecus deckenii*	EN
Oiseaux, Aves	Accipitridae	*Accipiter* spp.	-
		Buteo brachypterus	LC
		Polyboroides radiatus	LC
	Alcedinidae	*Corythornis vintsioides*	LC
	Anatidae	*Thalassornis leuconotus*	LC
	Ardeidae	*Egretta dimorpha*	LC
	Caprimulgidae	*Caprimulgus madagascariensis*	LC
	Charadriidae	*Charadrius hiaticula*	LC
	Columbidae	*Oena capensis*	LC
		Streptopelia picturata	LC
		Treron australis	LC
	Corvidae	*Corvus albus*	LC
	Cuculidae	*Centropus toulou*	LC
		Coua coquereli	LC
		Coua cristata	LC
	Dicruridae	*Dicrurus forficatus*	LC
	Meropidae	*Merops superciliosus*	LC
	Monarchidae	*Terpsiphone mutata*	LC
	Motacillidae	*Motacilla flaviventris*	LC
	Nectarinidae	*Nectarinia souimanga*	LC
	Numididae	*Numida meleagris*	LC
	Phalacrocoracidae	*Phalacrocorax africanus*	LC
	Ploceidae	*Foudia madagascariensis*	LC
	Podicipedidae	*Tachybaptus pelzelnii*	LC
	Psittacidae	*Agapornis cana*	LC
		Coracopsis vasa	LC
	Rallidae	*Dryolimnas cuvierii*	LC
	Sturnidae	*Acridotheres tristis*	-
	Turdidae	*Copsychus albospecularis*	LC
	Vangidae	*Leptopterus viridis*	LC
Reptiles, Squamata	Boidae	*Acrantophis madagascariensis*	VU
	Colubridae	*Leioheterodon madagascariensis*	LC
	Chameleonidae	*Calumma* sp.	-
	Gekkonidae	*Phelsuma* sp.	-
	Gerrhosauridae	*Zonosaurus* sp.	-
	Opluridae	*Oplurus cuvieri*	LC
Testudines	Podocnemididae	*Erymnochelys madagascariensis*	CR
Poissons, Siluriformes	Ariidae	*Arius madagascariensis*	LC
Gonorynchiformes	Chanidae	*Chanos chanos*	LC
Perciformes	Carangidae	*Caranx* sp.	-
	Cichlidae	*Oreochromis macrochir*	-
		Oreochromis mossambicus	-
		Oreochromis niloticus	-
Clupeiformes	Clupeidae	*Sauvagella madagascariensis*	LC

de revenus étant la culture et la pêche. Cinq familles gagnaient beaucoup plus que les autres familles enquêtées par la pratique illégale du charbonnage qui procurait un revenu irrégulier de 30 000 à 360 000 MGA par mois, soit entre US$ 9,0 et US$ 109,0 par mois en 2016.

La majorité des familles enquêtées (95 %) dépensaient une grande partie de leurs revenus pour l'alimentation. Les trois quarts des familles investissaient dans l'éclairage de leur maison en utilisant dans la majorité des cas des lampes à piles non rechargeables, des lampes à pétroles ou des bougies. Par ailleurs, 45 % des personnes enquêtées dépensaient une partie de leurs revenus mensuels dans l'habillement et 40 % constituaient une réserve pour les problèmes de santé. Seulement 35 % des individus enquêtés dépensaient de l'argent pour l'éducation des enfants. La plupart des personnes enquêtées (90 %) étaient conscientes de l'utilité de la forêt.

DISCUSSION

BIODIVERSITÉ ET PRESSIONS ANTHROPIQUES. La présence des lémuriens, en particulier l'espèce en danger critique d'extinction et endémique de la région ouest de l'île *Propithecus deckenii* (King et Rakotonirina 2020), la présence d'oiseaux appartenant à des familles et sous-familles endémiques malgaches et de la tortue en danger critique d'extinction et endémique de la région ouest de Madagascar *Erymnochelys madagascariensis* (Velosoa et al. 2013) dans le site d'étude, fournissent des informations supplémentaires sur la distribution spatiale de ces animaux emblématiques de l'île. D'autres espèces devraient encore être inventoriées puisqu'à cause de l'insécurité et faute de matériel, les lémuriens nocturnes ainsi que certaines espèces d'oiseaux, les Eupleridae et les *Erymnochelys madagascariensis* vivants n'ont pas pu être observés.

Les données publiées associées aux Réserves Spéciales de Bemarivo et Maningoza se focalisaient surtout sur la faune et la flore de Besalampy (Fishpool et Evans 2001, Schatz et al. 2001, Forthman et al. 2016). Ainsi, ce travail présente les premières informations sur les relations entre sa population locale et sa biodiversité. En effet, la plupart des familles à Besalampy vivent aux dépens de la forêt ; les zones humides associées aux aires forestières procurent à la fois l'eau pour l'agriculture et l'alimentation. Toutefois, le charbonnage à partir des plantes forestières et la culture sur brûlis, qui provoquent souvent l'érosion et la sédimentation des zones humides (Andrianandrasana et al. 2005, Styger et al. 2007), menacent la pérennité des services écosystémiques fournis par la biodiversité. Par ailleurs, la chasse des lémuriens et de la tortue *Erymnochelys madagascariensis* constitue une des menaces les plus importantes vis-à-vis de la biodiversité. De plus, *Eulemur rufifrons* subit aussi des pressions associées à la commercialisation et à la domestication.

Il serait ainsi nécessaire de mettre en place d'autres activités génératrices de revenus pour subvenir aux besoins de la population locale et diminuer les pressions envers la biodiversité. Des projets de conservation durable incluant des suivies périodiques de la taille des populations de la macrofaune endémique devraient être mis en place étant donné que ces animaux sont importants pour le maintien de l'équilibre d'un écosystème, à ne citer que la dissémination de graines pour la régénération forestière par les lémuriens (Wright et al. 2011, Razafindratsima et al. 2013) ou la régulation des populations des espèces nuisibles comme les rats, par les oiseaux de proies (Thorstrom et La Marca 2000, Rasoma et Goodman 2007).

ACCORDS POUR LA CRÉATION D'UNE NOUVELLE AIRE PROTÉGÉE. La population locale vivant à Besalampy est consciente de l'utilité de la biodiversité et des effets néfastes de l'exploitation abusive de la forêt. Ainsi, les membres de la communauté locale âgés de plus de 18 ans se trouvant dans les stations d'Andranovorombahoaka, d'Antampolo, de Marofototra et d'Andranomanenty, le maire de la commune urbaine et le chef district de Besalampy en 2016 se sont entretenus avec l'association Vakoka. Ils ont exprimé leur souhait de voir le développement d'un projet de conservation durable, notamment la création d'une nouvelle aire protégée (NAP) catégorie V (visant à maintenir d'une manière durable l'interaction entre la biodiversité avec ses zones côtières et la population locale) à Besalampy (Dudley 2008). La NAP devrait être gérée dans un premier temps par une association ou une organisation expérimentée dans la gestion des AP qui devra former les membres de la communauté locale afin de préparer un transfert de gestion des zones tampons vers cette dernière. Un cas similaire de plan de gestion a été établi dans la NAP catégorie V du Complexe Mahavavy-Kinkony (Blackham et Avent 2018).

Les restrictions des activités de la population qui ne s'effectueront plus que dans les zones tampons ont été expliquées durant les entretiens ; et les assemblées ont signé des procès-verbaux mentionnant un avis favorable pour la création d'une NAP. D'autres études plus approfondies sur la relation entre la biodiversité et les aspects socio-économiques et culturelles de la population de Besalampy devraient être effectuées afin de mieux cadrer

les restrictions à installer et pour bien définir les activités de compensation face aux restrictions.

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