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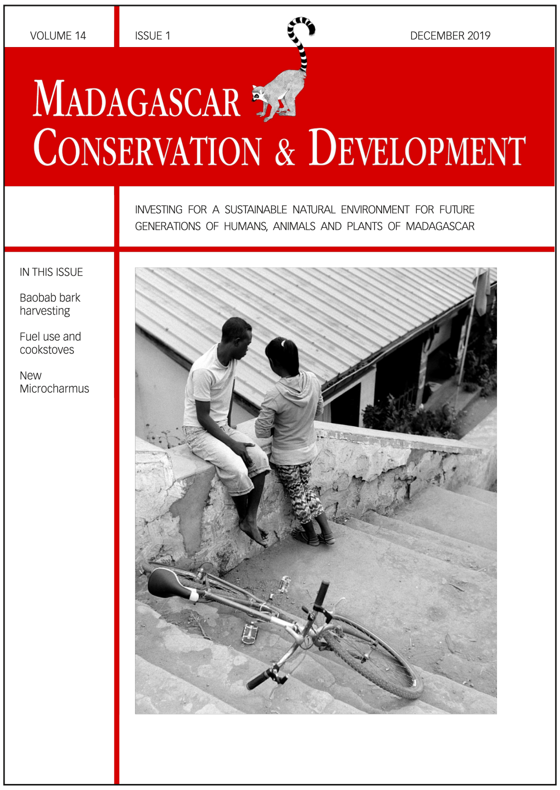

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EDITORIAL

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We have got to up our game substantially for forests, carbon, biodiversity, and ultimately people

A recently published contribution in Nature by Lenton et al. (2019) shows that Earth is risking an irreversible planetary tipping point. This means that the Earth's climate system is in a state of emergency, rushing its way towards a point of no return. The authors have identified nine tipping points—inter alia—melting Arctic and Antarctic ice sheets, retreating permafrost, changing boreal forest fire and pest regimes, and increased frequency of droughts in the Amazon forest. These signals are raising global concerns. While science expected these tipping points to be reached at 3°C increase (e.g., Lemoine and Traeger 2016), recent trends are corroborating the hypothesis that these points of irreversible and abrupt system change already show high probability of being reached within the bounds of 1.5–2°C. During the COP21 of the United Nation Framework Convention on Climate Change (UNFCCC), 195 countries adopted the Paris Agreement to limit global temperature rise to well below 2°C.

Planetary boundaries are shifting and we are facing a global environmental crisis. What does this mean for forests and biodiversity? A report released in May this year by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)—the Intergovernmental Panel on Climate Change (IPCC)-pendant for biodiversity—shows that 1 million animal and plant species are at high risk of extinction due to deforestation, overfishing, and other human activities (Tollefson 2019). Forests—tropical, temperate, and boreal—are home to the majority of all terrestrial species. Deforestation continues unabated and thus the risk of losing biodiversity increases. Deforestation is taking place mainly in the tropics, also because the largest forest areas are pantropical. Fifteen percent of tropical forests are designated for the conservation of biodiversity versus 13% at the global level (Pancel and Köhl 2016). The Global Deal for Nature (GDN)—a science-driven plan to save the diversity and abundance of life on our planet—suggests to increase conservation efforts: by 2030 we need 30% of the terrestrial area under protection for biodiversity conservation, with an additional 20% for climate buffering in order to stay below the 1.5°C threshold (Dinerstein et al. 2019). Reasons for deforestation are the usual suspects but vary from region to region. In Latin America and South East Asia, commodity driven deforestation accounts for 64 and 61%, respectively. In Africa, 93% is due to subsistence agriculture. At higher latitudes, deforestation is mainly an affair between wildfires (59% Russia/ China/ South Asia) and forestry production (95% in Europe, 48% in North America); 68% of Australia's deforestation is caused by wildfires (Curtis et al. 2018).

Burning forests have been in global media for a large portion of the past months, especially tropical forests with high biodiversity. Interestingly, when temperate forests in rich countries burn, media report on property loss, desperate people and economic aspects but seldom on loss in biodiversity or climate change. The Amazon made headlines due to ever-increasing fires, despite this year not having been exceptionally dry (Barlow et al. 2019). Should deforestation continue, a tipping point will be reached far sooner than expected (Lovejoy and Nobre 2018). Other global fire hotspots—with less media attention—burning every year (here we are not referring to wildfires but human induced fires) are Congo Basin, Indonesia, and Malaysia (Gaveau et al. 2018, Turubanova et al. 2018, Tyukavina et al. 2018). These regions are renowned for high biodiversity but also for highly contested land used for production, be it small-scale subsistence farming or commodity production at larger scales.

Humans are driving a lot of (land-use based) change, while the climate is acting as the Uber-driver and amplifier, potentially reducing system resilience and pushing trends beyond breaking points. Is Earth lost, or is there a shred of hope left? Well, we would be more than happy to report here that things are actually on a good track. There certainly is a global awareness across regions, countries, and societies that we humans need to take care of our planet. At the UN level, a number of initiatives embarked to restore and reforest our planet to turn the tide within this decade with a growing number of countries, corporations, civil societies, indigenous people and NGOs endorsing reforestation. Many pledges have been making global headlines. However, a recently published five years assessment by the New York Declaration on Forests shows a rather sombre picture. Since the declaration's inauguration in 2014, more than 200 parties have endorsed the stated targets and goals. Yet, compared to the 2002–2013 baseline, tropical primary forest loss has accelerated by 44% (4.3 million hectares per year versus 3M hectares per year baseline). The stated targets for 2020 will be impossible to meet (NYDF Assessment Partners 2019). Have we failed? Almost.

A study assessing the numbers of trees on Earth published by Crowther et al. (2015) made the restoration initiatives change gears and relabel their campaign from the billion trees to the trillion trees campaign. Since, reforestation has dramatically gained in momentum. However, trying to get numbers on how many forest restoration landscape (FLR) projects have been undertaken in the past five years has proven to be difficult since there are many different initiatives at various scales involving various groups of actors, making the task of keeping track challenging. Lewis et al. (2019) calculated that based on the 43 Bonn Challenge countries, and based on their pledges/goal to reforest 350M hectares by 2030, outcomes of carbon sequestration depend on the forest strategy applied. Forty-two pentagrams of carbon (PgC) could be stored by the year 2100 if the entirety of pledges would actually reach the 350M hectares and be fully based on natural regeneration. If the strategy would be for agroforestry, 7 PgC would be sequestered, and under monoculture only 1PgC. By 2019, a total of

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292M hectares had been pledged for restoration. Out of these, only 34% of area for restoration are to fall under the natural regeneration strategy (with the lowest implementation cost), 21% account for agroforestry, while 45% of all commitments involve the planting of monocultures. According to the IPCC, 199 PgC need to be removed from the atmosphere by 2100 to keep global warming below the 1.5°C. Of course, reforestation is just one pathway to achieve this. However, the right restoration strategy needs to be envisaged, while also keeping an eye on deforestation. "Restoring forests can't offset forest loss. They have to be complementary, and they have to be done at the same time" (Stephanie Roe, one of the NYDF assessment lead author in an interview for Mongabay 2019).

Madagascar's forests host some 80% of its terrestrial biodiversity (Waeber et al. 2019) and is threatened by ongoing deforestation. Madagascar—a signatory to the Bonn Challenge and now also member of the African Forest Landscape Restoration Initiative AFR100—has pledged to restore 4M hectares by 2030. In this context, the president of Madagascar announced in 2019 a plan to annually plant trees on 40,000 hectares over five years. These are ambitious plans. Madagascar's FLR strategy, released in early 2017, identifies main governance challenges and the need for trans-sectoral collaboration. A study conducted by CIFOR (Ranjatson et al. 2019) identified main barriers to implementation in the lack of weak forest law enforcement and particularly tenure security for smallholder farmers, an issue still unresolved despite years of REDD+ experience in Madagascar (Hockley et al. 2018). Unresolved land tenures are a recipe for trouble. In a frenzy to achieve the set targets, mainly fast growing exotic species such as pine, acacia and eucalyptus risk to be favoured to serve harvesting for firewood, charcoal or construction. The 22 regions in Madagascar are each responsible to reforest some 2000 hectares. The regional governments, on their turn, rely on schools, NGOs, or the private sector to fulfil the goal. However, there are no guidelines provided by the government on how and where to target land with what kind of native species. The government also plans to use drones to spread seeds in remote areas. However, even after 30 years of natural restoration, a recovering forest is much poorer in terms of species richness, abundance and composition (Klanderud et al. 2010).

According to Lenton et al. 2019, in order to reduce the chances of these irreversible changes actually happening, countries need to ensure that greenhouse gas emissions do not lead to an increase above 1.5°C. It would take, however, at least 30 years to achieve this target—time we do not have anymore. Governments seem not to have the power nor maybe the necessary long-term vision to step up to the plate, while other segments of society have shown more courage. It seems quite embarrassing that young people like Greta Thurnberg have to skip school in order to protest for our Earth—we have the highest admiration for such civil courage and perseverance. Many scientists and conservationists should mustard up some of hers, speak out, and take action on their own warnings to humanity (Gardner and Wordley 2019). There will be more and more such protests in the future, where societies are tired of the political inertia and corporate greediness, irresponsibility and non-accountability (many of these are directly or indirectly driving deforestation for the production of commodities). We need transformational partnerships where politics, representatives from the corporate and financial worlds, NGOs and civil societies sit at one table and start talking about tangible and feasible actions. Scientists and practitioners need to provide and share expert guidance when it comes to restoration and reforestation. We need locally tailored solutions; there is not one-fits-all solution. Verbatim intentions alone will not suffice to slow down negative trends or even reverse them. Wrong planning and planting risks only to exacerbate and undermine good intentions. The right trees need to be put in the right place and need to benefit the people in the vicinity. A robust and systematic monitoring needs to accompany the process of restoration while reporting needs to adhere to ethical principles of transparency, accountability and timeliness. Time for voluntary, non-binding commitments is over.

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REFERENCES

Barlow, J., Berenguer, E., Carmenta, R. and França, F. 2019. Clarifying Amazonia's burning crisis. Global change biology. <https://doi.org/10.1111/gcb.14872>

Crowther, T. W., Glick, H. B., Covey, K. R., Bettigole, C., Maynard, D. S., et al. 2015. Mapping tree density at a global scale. Nature 525: 201–205. <https://doi.org/10.1038/nature14967>

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. 2018. Classifying drivers of global forest loss. Science 361, 6407: 1108–1111. <https://doi.org/10.1126/science.aau3445>

Dinerstein, E., Vynne, C., Sala, E., Joshi, A. R., Fernando, S., et al. 2019. A global deal for nature: guiding principles, milestones, and targets. Science Advances 5, 4: eaaw2869. <https://doi.org/10.1126/sciadv.aaw2869>

Gardner, C. J. and Wordley, C. F. 2019. Scientists must act on our own warnings to humanity. Nature Ecology & Evolution 3, 9: 1271–1272. <https://doi.org/10.1038/s41559-019-0979-y>

Gaveau, D. L., Locatelli, B., Salim, M. A., Yaen, H., Pacheco, P. and Sheil, D. 2018. Rise and fall of forest loss and industrial plantations in Borneo (2000–2017). Conservation Letters 12, 3: e12622. <https://doi.org/10.1111/conl.12622>

Hockley, N., Mandimbiniaina, R. and Rakotonarivo, O. S. 2018. Fair and equitable conservation: do we really want it, and if so, do we know how to achieve it? Madagascar Conservation & Development 13, 1: 3–5. <https://doi.org/10.4314/mcd.v13i1.11>

Lemoine, D. and Traeger, C. P. 2016. Economics of tipping the climate dominoes. Nature Climate Change 6, 5: 514–519. <https://doi.org/10.1038/nclimate2902>

Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., et al. 2019. Climate tipping points—too risky to bet against. Nature 575: 592–595. <https://doi.org/10.1038/d41586-019-03595-0>

Lovejoy, T. E. and Nobre, C. 2018. Amazon tipping point. Science Advances 4, 2: eaat2340. <https://doi.org/10.1126/sciadv.aat2340>

Mongabay. 2019. Worldwide deforestation rising despite bold commitments, report finds. Available online <https://news.mongabay.com/2019/09/worldwide-deforestation-rising-despite-bold-commitments-report-finds/>

NYDF Assessment Partners. 2019. Protecting and Restoring Forests: A Story of Large Commitments yet Limited Progress. New York Declaration on Forests Five-Year Assessment Report. Climate Focus (coordinator and editor). Available online <https://forestdeclaration.org>

Pancel, L. and Köhl, M. 2016. Tropical Forestry Handbook. Springer Berlin Heidelberg 4 vol.: i–lx,1–3633. <https://doi.org/10.1007/978-3-642-41554-8>

Ranjatson, P., McLain, R., Mananga, J., Randrianasolo, R., Razafimbelo, Ny T., Lawry, S. 2019. Tenure Security and Forest Landscape Restoration: Results from Exploratory Results from Explanatory Research in Boeny, Madagascar. Paper prepared for presentation at the"2019 World Bank Conference On Land And Poverty". The World Bank, Washington DC. Available online <http://www.cifor.org/publications/pdf_files/Papers/PMcLain1901.pdf>

Styger, E., Rakotondramasy, H. M., Pfeffer, M. J., Fernandes, E. C. andBates, D. M. 2007. Influence of slash-and-burn farming practices on fallow succession and land degradation in the rainforest region of Madagascar. Agriculture, Ecosystems & Environment 119(3–4): 257–269. <https://doi.org/10.1016/j.agee.2006.07.012>

Tollefson, J. 2019. Humans are driving one million species to extinction. Nature 569: 171. <https://doi.org/10.1038/d41586-019-01448-4>

Turubanova, S., Potapov, P. V., Tyukavina, A. and Hansen, M. C. 2018. Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia. Environmental Research Letters 13, 7: 074028. <https://doi.org/10.1088/1748-9326/aacd1c>

Tyukavina, A., Hansen, M. C., Potapov, P., Parker, D., Okpa, C., Stehman, S. V., et al. 2018. Congo Basin forest loss dominated by increasing smallholder clearing. Science Advances 4, 11: eaat2993. <https://doi.org/10.1126/sciadv.aat2993>

Waeber, P. O., Rafanoharana, S., Rasamuel, H. A. and Wilmé, L. 2019. Parks and reserves in Madagascar: managing biodiversity for a sustainable future. [Online First], IntechOpen. <https://doi.org/10.5772/intechopen.85348>

ARTICLE

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Bark harvesting: a potential threat for the Grandidier's baobab *Adansonia grandidieri* in western Madagascar

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ABSTRACT
The Grandidier's baobab conveys the image of Madagascar worldwide. Locally, these trees have multiple uses with all parts of the plant being exploited by the population. We investigated the patterns of bark harvesting on the Grandidier's baobab in three districts in the Menabe Region: Mahabo, Manja and Morondava. Following 103 transects of 1 km each, we found that 54.0% of the baobab trees had been subject to bark extraction. The mean total area exploited per tree was 3,1 ± 0.2m2. Between April 2013 and January 2014, we also monitored four markets that regularly sell baobab products: Bemanonga, Mahabo, Morondava and Analaiva. Bemanonga revealed to be the largest market for the baobab bark with 21,594 straps and 34,517m of ropes recorded during the observation period. We estimate that some 9800 Grandidier's baobab trees have been affected by debarking to supply the demands recorded over the ten months monitoring period. If this demand remains constant, all baobab trees in Menabe would be debarked within the next 39 years. Since most baobab trees have been located in hard-to-reach areas and in protected areas, bark extraction may intensify in accessible sites and populations without protected status may disappear locally. This would result in local extinction of the species within a short period. To ensure sustainable management of the Grandidier's baobab, we recommend enriching the population by planting young baobabs, regulating access to the resources through local management structures and promoting alternatives to baobab ropes.

RÉSUMÉ
Le baobab de Grandidier est une espèce emblématique de Madagascar. Il évoque la Grande Île dans le monde entier. Dans sa zone d'occurrence, c'est une espèce à usage multiple pour les riverains qui utilisent toutes les parties de ce baobab. La présente étude porte sur l'exploitation de l'écorce du baobab de Grandidier dans la région Menabe, plus particulièrement dans les districts de Mahabo, Manja et de Morondava. Pour estimer l'étendue de l'exploitation des écorces sur les pieds de baobabs, des observations ont été réalisées sur 103 transects de 1 km de long entre avril 2013 et janvier 2014. Pour évaluer l'importance des écorces de baobab pour les riverains, des observations ont été conduites au niveau de quatre marchés de la région dans les villes de Bemanonga, Mahabo, Morondava et Analaiva au cours de la même période. Au total, 21 594 lanières d'écorce et 34 517 m de corde de baobab ont été recensés dans les quatre marchés. La plus importante quantité d'écorce de baobabs commercialisée a été enregistrée à Bemanonga. À partir des données récoltées, il est estimé que près de 9800 pieds de baobabs à écorcer sont nécessaires pour couvrir les besoins des riverains pendant la seule période d'études de 10 mois. Si la demande devait se maintenir à ce niveau, tous les pieds de baobab de la région Menabe, dont la population avait été estimée à environ un million d'individus, seraient écorcés au cours des 39 prochaines années. Comme la plupart des pieds de baobab ont été localisés dans des zones difficiles d'accès et dans les aires protégées, l'extraction des écorces pourrait s'intensifier dans les sites accessibles et les populations qui ne bénéficient d'aucun statut de protection pourraient disparaître localement. Pour assurer la gestion durable du baobab de Grandidier, il est ainsi recommandé de renforcer la population existante par la plantation de jeunes plants, la régulation de l'accès aux ressources par des structures locales de gestion et la promotion d'alternatives aux cordes réalisées avec les écorces de baobab.

INTRODUCTION
Madagascar has a unique biodiversity that places the country among the world's conservation priorities (Myers et al. 2000, Brooks et al. 2002). Considering the vascular plants only, 11,220 species were recorded in Madagascar, of which 82% are endemic (Callmander et al. 2011). The eastern Malagasy rainforest is among the centres of species richness with more than 3000 species per 10,000 km^2 (Mutke et al. 2011). The western tropical dry forest has a lower species richness but is famous for the iconic baobabs, which have important functions for people and the ecosystem

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and are facing multiple threats (Miles et al. 2006, Graf et al. 2009, Ehrensperger et al., 2013, Grinand et al. 2013, Zinner et al. 2013).

Eight species of baobabs are known worldwide, six of which are endemic to western Madagascar (Cron et al. 2016, Karimi et al. 2019). According to Cuni Sanchez (2010), the baobab tree has a multitude of use in Africa and Australia. Besides utilizing the fruit, bark and leaves, the size and shape of the tree lends itself to spaces for water storage, prisons, toilets, burial grounds, sleeping places, shelters, ritual sites and venues for prayers (Mukamuri and Kozanayi 1999, Wickens and Lowe 2008). Malagasy baobabs have multiple functions and uses. The Grandidier's baobab *Adansonia grandidieri* stands out because of its iconic image representing Madagascar on most documentaries and advertisements. The Allée des Baobabs in Morondava attracts many tourists and is a major source of income for the Region (Scales 2014).

Non-timber forest products (NTFPs) are important resources for people in western Madagascar. Bushmeat, medicinal plants, materials for construction, weaving and other handicrafts are collected from the wild (Garcia and Goodman 2003, Norscia and Borgognini-Tarli 2006, Randrianandrianina et al. 2010, Scales 2012). These resources are collected for household consumption, but also sold on markets as a source of income. NTFPs often provide economic buffers to the Malagasy rural populations when crops fail and can help provide additional seasonal income when the benefits of other economic activities are reduced (Neudert et al. 2017).

NTFPs significantly contribute to livelihood security in the Menabe Region and have traditionally been used by rural communities for subsistence and trade (Ramohavelo and Sorg 2008). Tubers from *Dioscorea maciba* and *Tacca pinnatifida*, *Tenrec ecaudatus* bushmeat (a mammal species), and honey are important NTFPs for local livelihoods (Ramohavelo and Sorg 2008). Grandidier's baobab *Adansonia grandidieri* trees also provide locally important NTFP products, mainly for consumption (fruits, seeds, leaves and bark as infusion) and construction (Baum 1996, Marie et al. 2009). The Grandidier's baobab is listed as Endangered on the IUCN Red List of Threatened Species; the major threat is poor regeneration (IUCN 2016). This species is the most heavily exploited of Madagascar's baobabs (Perrier de la Bâthie 1924, Bond 2002, Rakotondrazanany 2016, pers. comm.). The fruits and seeds are collected for food and extraction of cooking oil, the bark is used to make ropes, and the spongy wood is dried and sold for thatch. However, the greatest threat to Grandidier's baobab comes from the conversion of its habitat into agricultural land. Mature trees are left standing, presumably because of their cultural importance and the value of the fruit, bark and wood. The impacts of local exploitation of NFTPs from this species remains poorly understood, limiting our ability to define appropriate conservation measures, especially in areas of conservation importance from where sustainable extraction is permitted.

In this article, we focus on the activity of bark collection from the Grandidier's baobab. We aim to understand the importance of this activity to rural communities in the Menabe Region and the potential impacts of bark harvesting on the species population. This information helps designing targeted conservation strategies for the Grandidier's baobab.

METHODS

STUDY AREA. This study was carried out in the Menabe Region, in the western region of Madagascar, an area identified as priority for conservation (Kremen et al. 2008, Wilmé et al. 2012). We focused on five communes in the three districts, where the Grandidier's baobab is frequently observed in the wild and derivates found for sale at local markets (Figure 1).

BAOBAB SURVEYS. We used T-square sampling to estimate baobab density within seven different areas (Ankoba, Ampataka, Bepeha, Andoviana, Benato, Tanambao Sara and Bekonazy) between August 2009 and November 2011 (Krebs 1999, Greenwood and Robinson 2006). Following a random 1 km transect, the survey team stopped every 100 m—this is the observation point O, measured the distance xi from the observation point to the nearest Grandidier's baobab (B1) and the distance y_i from B1 to its nearest neighbour with the condition that the angle OB1B2 is more than 90°. Baobab density was calculated using the formula:

$$D = \frac{n^2}{2.828 \sum x_i \sum y_i}$$

where D is the density and n is the total number of random points (Krebs 1999).

For each baobab tree, we estimated the trunk height, measured the circumference at breast height and if there are signs of bark removal, measured the area removed. Trunk height was measured based on the trigonometric method by West (2009), in which a team member held a horizontal T-shaped stick of 1 m at eye-level. The observer walked back until they can observe the base of the tree and the tip of the trunk. The distance between the observer and the base of the trunk, which is equivalent to the height of the tree, was then measured. Circumference at breast height (1,30 m) was measured with a tape measure. Considering that baobab barks are put in a rectangular shape after harvesting, we used the trunk height (h) and circumference (c) to calculate the surface of bark available (s) (s = h * c). Similarly, if the barks have been removed from the tree, we measured the height (h1) and width (w) of the area without bark to calculate the surface of bark removed (s1 = h1 * w). The proportion of surface exploited is the ratio between the total surface removed and the total surface available (p = s1 / s). During the surveys, we collected information on baobab harvesting methods from our guides and the use of bark.

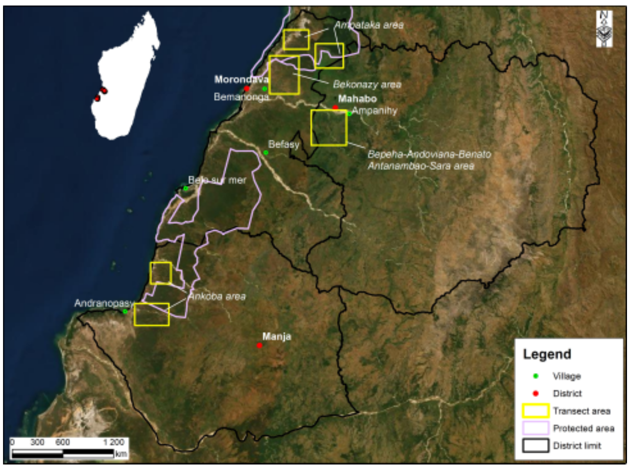

Figure 1. Study area.

MARKET MONITORING. Between April 2013 and January 2014, we employed four local observers to record baobab products available for sale at four markets: Morondava, Mahabo, Bemanonga, Analaiva (Figure 1). This method allowed us to estimate the supply of various baobab products (fruits, straps, ropes, barks, bark parts or pieces for infusion and powder), prices, provenance and quantity. The observers recorded data weekly with a logbook to ensure data are recorded in a similar way. We used Kruskall-Wallis test to compare monitoring efforts between markets and the frequency of observation of the different products.

For the barks and derived products, observers recorded the number of straps (strips of baobab bark) observed per vendor and estimated the length of the ropes made from baobab bark. They also recorded the price per strap and per meter of rope. Strap dimensions varied between 25–30 cm in width and 2–2.5 m in length. In the analysis, we assumed that all straps were 25 cm wide and 2 m long, and that the same dimensions of baobab bark are extracted. Open discussions with rope makers revealed that 1 m of rope can be produced with one strap. Using these data, we calculated the total surface of baobab barks needed to produce the products available on the market (surface = width * length). Using the unit cost of each product, we calculated the price of baobab bark per square meter.

RESULTS

PATTERNS OF BARK HARVESTING. We recorded a total of 1247 *Adansonia grandidieri* trees, of which 54.0% have been subject to bark extraction. Baobab density varied between our study sites and was highest in Analaiva and Andranopasy and lowest in Ampanihy and Bemanonga. In contrast, levels of bark extraction were highest in Bemanonga and Befasy and were lowest in Andranopasy and Ampanihy (Table 1). Large trees with a total bark surface of 14.8 ± 0.3 m^2 were preferred for bark extraction (Mann-Whitney, U = 141 981, Z = -2.981, p = 0.0003). Smaller trees with a total bark surface below 13.2 ± 0.4 m^2 were left intact. In general, only parts of the barks are removed, with an average height of 0.7 m and 0.9 m width on each tree. This was described as the traditional way to harvest the barks by the local guides. We also observed 41 baobab trees that had been deliberately felled for bark extraction, of which 16 were in Andranopasy, 14 in Ampanihy, 7 in Analaiva and 4 in Befasy. This practise was described as unusual and due to the increasing demands for baobab ropes. In 2010, we also found eight baobabs that were felled naturally by cyclones in Befasy. Barks of fallen and cut trees were extracted from the entire trunk.

PATTERNS OF BAOBAB BARK TRADE. We made 1240 observations of baobab products from the four local markets. Although monitoring effort varied between sites (n = 103, 71, 70 and 52 days, respectively: 6.7 ± 0.7 days per month), up to 80% of baobab products were observed in Bemanonga despite this site only accounting for 35% of our monitoring effort. Observations of baobab products in the other three markets never represented more than 8% of the records from Analaiva, Mahabo and Morondava.

Three baobab species were reported in the markets: *Adansonia grandidieri* (91%), *A. za* (9%) and *A. rubrostipa* (only one record). Baobab products found in the markets included ropes made of fibres (36.0%), fruits (31.5%), thin straps made from fibres and used as twine (21.5%), bark pieces for infusion (4.6%), fungi collected from dead trees (5.1%), thick straps used for roofing and walls (1.0%), and seeds as well as leaves (0.1% each).

Observation of *Adansonia grandidieri* straps and ropes was significantly more frequent in Bemanonga with 58.6 ± 8.0 records per month compared to 2.1 ± 0.4 records for the other markets (Kruskall Wallis test: H3= 25.271, p < 0.001). In total, 21,594 straps and 34 517 m of rope were recorded from Bemanonga compared to less than 1500 straps and 1500 m of ropes in Analaiva, Mahabo and Morondava (Table 2). Only straps were available in Morondava, where it is more expensive compared to the other markets (Table 2). This is probably because 45.6 % of the straps in this market are from Andranopasy (Table 3), a commune 126 km away from Morondava. In Mahabo, ropes were twice as expensive as the straps (Table 2), although individual bark workers reported that a strap (generally of 0.25 cm wide and 2 m long) can make 1m of rope.

Straps are sold at $US0.10 ± 0.002 per unit while ropes are sold at $US0.17±0.003 per meter. All straps sold in Mahabo market were from Ampanihy, a commune within the district and only 5.5% of the ropes are from outside the district (Table 3). Analaiva is the only market where ropes are cheaper than the straps (Table 2). This suggests that the demand for ropes in this market is low. Ropes not sold locally are sold in Bemanonga (Table 3) where the price is higher. Straps and ropes from Befasy and Belo-sur-Mer are also found in Bemanonga market (Table 3).

BARK TRADE AND HARVESTING. We estimated the number of baobab trees partially debarked between April 2013 and January 2014 to make the total quantity of ropes recorded (34,517m) to vary between 5230 and 5991. Estimations of strap and exploited bark surface area per one meter of rope are based on: (i) A typical strap being approximately 25 cm wide and 2 m long (0.5 m^2); (ii) the mean surface exploited per baobab tree being 3.1 ± 0.2 m^2.

According to our calculations, 62.3% of the trees could be from Bemanonga, 26.4% from Analaiva, 5.6% from Befasy, 3.3% from Ampanihy and 2.5% from Andranopasy and Belo-sur-Mer. Analaiva and Bemanonga have the lowest estimated baobab den-

Table 2. Baobab fibers in the markets. Quantities of straps and ropes recorded during the monitoring between March 2013 and January 2014 and the mean (± SE) per product at each market.

Market	N observation days	N straps	Price strap (MGA/unit)	Total length of ropes (m)	Price rope (MGA/m)
Analaiva	71	760	287.5 ± 54.9	640	203.3 ± 15.0
Bemanonga	103	21.594	190.2 ± 3.3	34.517	336.5 ± 5.3
Mahabo	70	632	241.7 ± 22.9	1.45	534.6 ± 11.0
Morondava	52	1.315	500.0 ± 21.8	-	-

Table 1. Estimated densities of *Adansonia grandidieri* at the five communes surveyed in Menabe Region between 2008 and 2010 and patterns of bark harvesting.

Commune	Area (km^2)	N transects	N trees	Density/km^2	% trees harvested	Surface harvested (± SE m^2)	% total bark surface (± SE)
Ampanihy	1.602	34	399	209.4	48.4	2.5 ± 0.3	2.1 ± 0.2
Analaiva	546	12	66	173.4	56.1	5.7 ± 1.2	4.7 ± 0.9
Andranopasy	1.718	20	439	485.5	44.9	3.9 ± 0.5	4.0 ± 0.4
Befasy	640	20	246	429.1	63.4	4.2 ± 0.4	3.5 ± 0.3
Bemanonga	1.113	17	97	107.4	96.9	3.0 ± 0.7	1.2 ± 0.3

sity (Table 1) but have the highest bark harvesting rate (2.7 and 5.1% of the populations, respectively).

DISCUSSION

This study showed that more than half of the Grandidier's baobab trees in the wild have been subject to bark extraction. Since only part of the bark has been removed, the trees are still standing many years after the extraction. However, we started to observe intensive harvesting which consists in cutting down the trees to remove all the bark. If this practise continues, it will cause the decline of the species in the short term.

Ropes made with baobab barks are used as harnesses for the cattle and for attaching canoes (Wickens and Lowe 2008, Marie et al. 2009). They are preferred to the nylon ropes because of their low cost but also, they last longer and do not harm the cattle. In villages where the palm *Bismarckia nobilis* is growing, it is also used in place of the baobabs for making ropes (Mamilaza 2009). However, people would still prefer using baobab ropes and straps if those were available. Selling 10m of ropes per day would be necessary for a person living only on baobab rope trade to reach the poverty line of $US2 per day (World Bank 2014). Although baobab bark harvesting and making ropes does not represent a major activity in the Menabe, it can be an important source of income for some. This aspect should be considered when developing rules related to bark harvesting. Planting the palm *Bismarckia nobilis* is an alternative measure to be promoted as it is a fire-resistant fast-growing species with similar use by local populations as the baobabs.

This study could not solve the 'dispute' between local communities and scientists regarding the impact of bark harvesting on the baobab trees. On one hand, community members argue that bark removal do not harm the baobab trees while they agree that bark does not regenerate. However, in the wild, the baobabs are still standing. On the other hand, scientists advocate that bark harvesting might represent a threat to the trees as they are more exposed to ecological and climatic threats (Wickens and Lowe 2008). In the Allée des Baobabs, lower barks have been removed on almost all the trees but they are still standing (Wickens and Lowe 2008). In order to determine if the Grandidier's baobab barks can be sustainably managed and how, in-depth studies on the impact of bark harvesting is required (Ticktin 2004). In fact, trees may recover from bark harvesting depending on the species, the technique used and the environmental conditions (Delvaux et al. 2009). Bark harvesting also has different impacts on tree growth or fruit production and hence on population sizes (Gaoue and Ticktin 2008, Schumann et al. 2010, Schmidt et al. 2011).

The most recent population estimation of the Grandidier's baobab is at one million trees (Vieilledent et al. 2013). During a period of 10 months, we recorded 34 517m of baobab ropes at the four markets monitored. Assuming that these ropes came exclusively from the partially debarked baobabs, they would come from 5230–5991 trees. By extrapolation, there should be enough baobab bark stock for 1912 months (159 years) of baobab barks in the wild. However, we also found that 54% of the baobabs we found during the field surveys have already been debarked. As a result, if the demand remains constant, there is stock only for about 73 years (159 years * 46%).

Other studies in Africa reported that bark harvesting affects negatively the survival of baobab trees (e.g., Hall and Bawa 1993, Peters 1994, Cunningham 2001). Survival is threatened because the extraction of barks could make the individual more susceptible to pathogen attacks or could expose stem cortex tissue, impairing the flow of water and nutrients, hence reducing survival rates (Cunningham 2001). Botha et al. (2004) also found that on other tree species, bark removal affected fruit production. In the wild, we have seen that some Grandidier's baobab had fruits while others did not. Bark harvesting might be a factor contributing to this variation.

Effective management of the protected areas will play a central role to ensure conservation of the Grandidier's baobab. The Menabe region, where the Grandidier's baobab is most abundant, has four protected areas: Kirindy-Mitea National Park (72 200 ha), Andranomena (6420 ha) and Ambohijanahary Special Reserves (27 650 ha) and the Menabe-Antimena Reserve (125 000 ha) (Gardner 2011, Waeber et al. 2019). These protected areas represent 36% of the Menabe terrestrial ecosystems. If these protected areas also had 36% of the baobab population—bark harvesting is prohibited in protected areas—people will have access to only 640 000 baobab trees, providing barks for some 40–47 years using the traditional method (i.e., removing the bark without sophisticated, modern tools at heights not exceeding that of the exploiter). After this period, risks of felling trees to meet the demands of the market will increase in accessible areas (Marie et al. 2009). We thus recommend the establishment of local management structures that can monitor and regulate exploitation of baobab barks outside of protected areas by following the rights transfer system by which communities can regulate access to natural resources in their territory, including the baobabs (Antona et al. 2004). In this case, it is necessary that the governement who gives the rights builds the capacity of the communities to do so and support them until they can independently manage the resources and get benefits.

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Table 3. Origin of the baobab bark products available at the markets monitored. (Numbers indicate the percentage of products in the market coming from the Commune)

Market	Ampanihy	Analaiva	Andranopasy	Befasy	Belo-sur-Mer	Bemanonga
Straps						
Analaiva	-	36.8	-	-	-	63.2
Bemanonga	-	0.6	-	9.1	2.9	87.4
Mahabo	100	-	-	-	-	-
Morondava	-	-	45.6	5.7	-	48.7
Ropes						
Analaiva	-	100	-	-	-	-
Bemanonga	-	43.3	-	3.9	0.9	52.0
Mahabo	94.5	5.5	-	-	-	-

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REFERENCES

Antona, M., Biénabe, E. M., Salles, J.-M., Péchard, G., Aubert, S. and Ratsimbarison, R. 2004. Rights transfers in Madagascar biodiversity policies: achievements and significance. Environment and Development Economics 9, 6: 825–847. <https://doi.org/10.1017/S1355770X04001640>

Baum, D. A. 1996. The ecology and conservation of the baobabs of Madagascar. Primate Report 46: 311–327.

Bond, J. 2002. Baobabs. In: Guide to Madagascar, 7th edn. Bradt H. (ed.), pp 40–46. Bradt Publications, Chalfont St. Peter.

Botha, J., Witkowski, E. T. F. and Shackleton, C. M. 2004. The impact of commercial harvesting on Warbugia salutaris (pepper-bark tree) in Mpumalanga, South Africa. Biodiversity & Conservation 13, 9: 1675–1698. <https://doi.org/10.1023/B:BIOC.0000029333.72945.b0>

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., Rylands, A. B. et al. 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16, 4: 909–923. <https://doi.org/10.1046/j.1523-1739.2002.00530.x>

Callmander, M. W., Phillipson, P. B., Schatz, G. E., Andriambololonera, S., Rabarimanarivo, M. et al. 2011. The endemic and non-endemic vascular flora of Madagascar updated. Plant Ecology and Evolution 144, 2: 121–125. <https://doi.org/10.5091/plecevo.2011.513>

Cron, G. V., Karimi, N., Glennon, K. L., Udeh, C., Witkowski, E. T. F., et al. 2016. One African baobab species or two? A re-evaluation of Adansonia kilima. South African Journal of Botany 103: 312. <https://doi.org/10.1016/j.sajb.2016.02.036>

Cuni Sanchez, A., Osborne, P. E. and Haq, N. 2010. Identifying the global potential for baobab tree cultivation using ecological niche modelling. Agroforestry Systems 80, 2: 191–201. <https://doi.org/10.1007/s10457-010-9282-2>

Cunningham, A. 2001. Applied ethnobotany: people, wild plant uses and conservation. Earthscan Publications Ltd., London, UK.

Delvaux, C., Sinsin, B., Darchambeau, F. and Van Damme, P. 2009. Recovery from bark harvesting of 12 medicinal tree species in Benin, West Africa. Journal of Applied Ecology 46, 3: 703–712. <https://doi.org/10.1111/j.1365-2664.2009.01639.x>

Ehrensperger, T., Urech, Z. L., Rehnus, M. and Sorg, J. P. 2013. Fire impact on the woody plant components of dry deciduous forest in Central Menabe, Madagascar. Applied Vegetation Science 16, 4: 619–628. <https://doi.org/10.1111/avsc.12034>

Gaoue, O. G. and Ticktin, T. 2008. Impacts of bark and foliage harvest on Khaya senegalensis (Meliaceae) reproductive performance in Benin. Journal of Applied Ecology 45, 1: 34–40. <https://doi.org/10.1111/j.1365-2664.2007.01381.x>

Garcia, G. and Goodman, S. M. 2003. Hunting of protected animals in the Parc National d'Ankarafantsika, north-western Madagascar. Oryx 37, 1: 115–118. <https://doi.org/10.1017/S0030605303000206>

Gardner, C. J. 2011. IUCN management categories fail to represent new, multiple-use protected areas in Madagascar. Oryx 45, 3: 336–346. <https://doi.org/10.1017/S0030605310001808>

Graf, E., Andriambelo, L. H. and Sorg, J.-P. 2009. Ecological and social issues, availability and uses of four timber tree species in Menabe, Madagascar. Bois et Forêts des Tropiques 302, 4: 33–41.

Greenwood, J. J. D. and Robinson, R. A. 2006. General census methods. In: Ecological Census Techniques. Sutherland, W. J. (ed.), pp 87–183. Cambridge University Press, Cambridge.

Grinand, C., Rakotomalala, F., Gond, V., Vaudry, R., Bernoux, M. and Vieilledent, G. 2013. Estimating deforestation in tropical humid and dry forests in Madagascar from 2000 to 2010 using multi-date Landsat satellite images and the random forests classifier. Remote Sensing of Environment 139: 68–80. <https://doi.org/10.1016/j.rse.2013.07.008>

Hall, P. and Bawa, K., 1993. Methods to assess the impact of the extraction of non-timber tropical forest products on plant populations. Economic Botany 47, 3: 234-247. <https://doi.org/10.1007/BF02862289>

IUCN 2016. The IUCN Red List of Threatened Species 2016. Version 3.1. Available online <www.iucnredlist.org>

Karimi, N., Grover, C. E., Gallagher, J. P., Wendel, J. F., Ané, C. and Baum, D. A. 2019. Reticulate evolution helps explain apparent homoplasy in floral biology and pollination in baobabs (Adansonia; Bombacoideae; Malvaceae). Systematic Biology. <https://doi.org/10.1093/sysbio/syz073/5613901>

Krebs, C. J. (ed.) 1999. Ecological Methodology. Benjamin Cummings, Menlo Park, California.

Kremen, C., Cameron, A., Moilanen, A., Phillips, S. J., Thomas, C. D. et al. 2008. Aligning conservation priorities across taxa in Madagascar with high-resolution planning tools. Science 320, 5873: 222–226. <https://doi.org/10.1126/science.1155193>

Mamilaza, L. E. 2009. Diagnostic de la filière baobab : quelles limites et perspectives ? Cas de Adansonia grandidieri dans la commune de Bemanonga, région du Menabe. Mémoire d'études pour l'obtention du Diplôme d'Etudes Supérieures Spécialisées. Option Développement Local et Gestion de Projet. 63 pp. Faculté de Droit, Economie et de la Sociologie. Département Economie. Université d'Antananarivo.

Marie, C. N., Sibelet, N., Dulcire, M., Rafalimaro, M., Danthu, P. and Carrière, S. M. 2009. Taking into account local practices and indigenous knowledge in an emergency conservation context in Madagascar. Biodiversity and Conservation 18, 10: 2759–2777. <https://doi.org/10.1007/s10531-009-9672-9>

Miles, L., Newton, A. C., DeFries, R. S., Ravilious, C., May, I., et al. 2006. A global overview of the conservation status of tropical dry forests. Journal of Biogeography 33, 3: 491–505. <https://doi.org/10.1111/j.1365-2699.2005.01424.x>

Mukamuri, B. B. and Kozanayi, W. 1999. Institutions surrounding the use of marketed bark products. The case of Berchemia discolor, Adansonia digitata, and Warburgia salutaris. IES Working Paper Number 17. Available at <https://opendocs.ids.ac.uk/opendocs/>

Mutke, J., Sommer, J. H., Kreft, H., Kier, G. and Barthlott, W. 2011. Vascular plant diversity in a changing world: global centres and biome-specific patterns. In: Biodiversity Hotspots—Evolution and Conservation. J. C. Habel and F. Zachos (eds.), pp 83–96. Springer, Berlin, Heidelberg, Germany.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853–858.

Neudert, R., Ganzhorn, J. U. and Waetzold, F. 2017. Global benefits and local costs—the dilemma of tropical forest conservation: A review of the situation in Madagascar. Environmental Conservation 44, 1: 82–96. <https://doi.org/10.1017/S0376892916000552>

Norscia, I. and Borgognini-Tarli, S. M. 2006. Ethnobotanical reputation of plant species from two forests of Madagascar: A preliminary investigation. South African Journal of Botany 72, 4: 656–660. <https://doi.org/10.1016/j.sajb.2006.04.004>

Perrier de la Bâthie, H. 1924. Sur quelques plantes non cultivées de Madagascar à fruits comestibles ou utiles et sur la possibilité de leur culture. Journal d'Agriculture Traditionnelle et de Botanique Appliquée 38: 652–662. <https://doi.org/10.3406/jatba.1924.4224>

Peters, C. M. 1994. Sustainable harvest of non-timber plant resources in tropical moist forest: an ecological primer. WWF, Washington.

Ramohavelo, D. and Sorg, J.-P. 2008. Using NTFPs to drive rural development without threatening biodiversity? A concrete example concerning four NTFPs in Central Menabe, Madagascar. Tropentag 2008 University of Hohenheim, October 7–9, 2008 Conference on International Research on Food Security, Natural Resource Management and Rural Development.

Randrianandrianina, F. H., Racey, P. A. and Jenkins, R. K. B. 2010. Hunting and consumption of mammals and birds by people in urban areas of western Madagascar. Oryx 44, 3: 411–415. <https://doi.org/10.1017/S003060531000044X>

Scales, I. R. 2012. Lost in translation: conflicting views of deforestation, land use and identity in western Madagascar. The Geographical Journal 178, 1: 67–79. <https://doi.org/10.1111/j.1475-4959.2011.00432.x>

Scales, I. R. 2014. Tourism, conservation and development in Madagascar: moving beyond panaceas? In: Rainforest Tourism, Conservation and Management: Challenges for Sustainable Development. B. Prideaux (ed.), pp 255–256. Earthscan, London.

Schmidt, I. B., Mandle, L., Ticktin, T. and Gaoue, O. G. 2011. What do matrix population models reveal about the sustainability of non-timber forest product harvest? Journal of Applied Ecology 48, 4: 815–826. <https://doi.org/10.1111/j.1365-2664.2011.01999.x>

Schumann, K., Wittig, R., Thiombiano, A., Becker, U. and Hahn, K. 2010. Impact of land-use type and bark and leaf-harvesting on population structure and fruit production of the baobab tree (Adansonia digitata L.) in a semi-arid savanna, West Africa. Forest Ecology and Management 260, 11: 2035–2044. <https://doi.org/10.1016/j.foreco.2010.09.009>

Ticktin, T. 2004. The ecological implications of harvesting non-timber forest products. Journal of Applied Ecology 41, 1: 11–21. <https://doi.org/10.1111/j.1365-2664.2004.00859.x>

Vieilledent, G., Cornu, C., Cuni Sanchez, A., Leong Pock-Tsy, J.-M. and Danthu, P. 2013. Vulnerability of baobab species to climate change and effectiveness of the protected area network in Madagascar: Towards new conservation priorities. Biological Conservation 166: 11–22. <https://doi.org/10.1016/j.biocon.2013.06.007>

Waeber, P. O., Rafanoharana, S., Rasamuel, H. A. and Wilmé, L. 2019. Parks and reserves in Madagascar: managing biodiversity for a sustainable future. [Online First], IntechOpen. <https://doi.org/10.5772/intechopen.85348>

West, P. W. 2009. Tree and Forest Measurement. Springer-Verlag Berlin Heidelberg.

Wickens, G. E. and Lowe, P. 2008. The Baobabs: Pachycauls of Africa, Madagascar and Australia. Springer, The Netherlands.

Wilmé, L., Ravokatra, M., Dolch, R., Schuurman, D., Mathieu, E., et al. 2012. Toponyms for centers of endemism in Madagascar. Madagascar Conservation & Development 7: 30–40. <https://doi.org/10.4314/mcd.v7i1.6>

World Bank. 2014. Poverty Overview. Available at <http://tiny.cc/4wbghz>

Zinner, D., Wygoda, C., Razafimanantsoa, L., Rasoloarison, R., Andrianandrasana, H. T., et al. 2013. Analysis of deforestation patterns in the central Menabe, Madagascar, between 1973 and 2010. Regional Environmental Change 14, 1: 157–166. <https://doi.org/10.1007/s10113-013-0475-x>

SUPPLEMENTARY MATERIAL

Table S1. Starting points of transects in the Menabe Region.

ARTICLE

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Fuel use and cookstove preferences in the SAVA region

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ABSTRACT

Madagascar's population relies almost exclusively on solid biomass, i.e., firewood and charcoal, for subsistence. The ongoing extraction of such natural resources is unsustainable, threatening endemic biodiversity with extinction, and jeopardizing the long-term livelihoods of local populations. Improved, or fuel-efficient, cookstove programs have been implemented in Madagascar for more than a decade to mitigate deforestation. The Duke Lemur Center-SAVA Conservation (DLC-SAVA) and other NGOs have subsidized "rocket" fuel-efficient ADES-brand stoves in the SAVA region as part of ongoing conservation activities. To re-assess our DLC-SAVA subsidy program, we conducted surveys in 15 communes in the SAVA region to document fuel use, cookstove preferences, and the potential impact of ADES-brand stoves. We show that: (i) firewood was used more frequently than charcoal in more remote villages; (ii) metal tripods were the most frequently used cooking structure despite their low fuel efficiency; (iii) ADES-brand stoves were rarely owned and oftentimes underused; and (iv) "cooking time" and "fuel efficiency" were the most commonly preferred stove features given by respondents using firewood-fueled and charcoal-fueled cookstoves respectively. The low incidence of ADES stoves in our sample calls for a larger-scale program to increase their availability and accessibility to the region, a more comprehensive training/advertising strategy, and more effective logistical planning to distribute and sell the stoves across larger regions far from urbanized centers. Moreover, NGOs could assist in providing training on fuel-efficient stove design to experienced individuals who are already producing and distributing stoves locally, as a way to support sustainability while promoting and leveraging local knowledge. We conclude that because a large portion of the population is using metal tripods on a regular basis, introducing any type of "fuel-efficient" stove at a large scale, is expected to make a difference in biomass consumption, in addition to reducing the burden imposed on biomass collectors and carriers.

RÉSUMÉ

La population de Madagascar dépend presque exclusivement d'une biomasse solide, c'est-à-dire du bois de chauffage ou du charbon de bois, pour sa subsistance. Le niveau actuel de l'exploitation des ressources naturelles n'est pas pérenne et menaçe d'extinction la biodiversité endémique en mettant en péril les moyens de subsistance à long terme des habitants. Des programmes destinés à la promotion de foyers améliorés ou économes en énergie ont été mis en œuvre à Madagascar pendant plus de dix ans pour atténuer la déforestation. Le Duke Lemur Center-SAVA Conservation (DLC-SAVA) et d'autres ONG ont subventionné des foyers améliorés d'une grande efficacité énergétique de la marque ADES dans la région SAVA dans le cadre des activités de conservation en cours. Pour ré-évaluer le programme de subvention DLC-SAVA, des enquêtes ont été menées dans 15 communes de la région SAVA afin de documenter l'utilisation de combustible, les préférences en matière de foyers et l'impact potentiel des foyers de la marque ADES. Les résultats obtenus ont permis de montrer que (i) le bois de chauffage est plus fréquemment utilisé que le charbon de bois dans les villages les plus reculés ; (ii) les trépieds métalliques sont la structure de cuisson la plus utilisée malgré son faible rendement énergétique ; (iii) les foyers améliorés de la marque ADES ont été trouvés en petit nombre et souvent sous-utilisés ; et (iv) le temps de cuisson et l'efficacité énergétique étaient les deux choix les plus souvent mentionnés par les répondants utilisant respectivement des fourneaux à bois et à charbon de bois. La faible incidence des foyers ADES dans notre échantillon montre qu'un programme à plus grande échelle doit être déployé et devra être élaboré sur une stratégie de formation et de sensibilisation plus complète avec une meilleure planification logistique pour la distribution et la vente de foyers améliorés dans l'ensemble de la région, y compris dans les zones éloignées des centres urbains. Les ONG pourraient participer à une formation spécifique des personnes qui ont déjà une expérience dans la production et la distribution de foyers au niveau local pour qu'elles acquièrent les compétences en matière de conception de foyers améliorés à haute efficacité énergétique, afin de favoriser la durabilité tout en

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profitant des connaissances locales. Comme une grande partie de la population utilise régulièrement des trépieds en métal, l'introduction de tout type de réchaud « économe en combustible » à grande échelle devrait faire une différence dans la consommation de la biomasse, en plus de réduire les coûts liés à la récolte et au transport.

INTRODUCTION

Deforestation rates in Madagascar are among the greatest in the world, posing a threat to the survival of unique biodiversity but also, ultimately, threatening the livelihoods of local human populations. Land is predominantly cleared for subsistence agriculture, timber and firewood (Dasgupta et al. 2015). At current rates, extractive practices are unsustainable, a matter that is further complicated because most people in Madagascar (and indeed worldwide) are expected to rely on solid biomass energy, i.e., firewood and charcoal, for decades to come (World Bank 2011). For example, a 2010 report from the Living Standards Measurement Survey (LSMS), showed that ~99% of households depended on solid biomass for cooking in Madagascar, with more than 77% of households relying on gathered firewood and only 17% relying on charcoal (INSTAT 2011). When urban areas are compared to countryside regions, however, there is a significant divide in the predominant type of biomass used for cooking. Whereas people in the countryside seemingly rely more on firewood, those in urban areas prioritize charcoal (Dasgupta et al. 2013).

To tackle the global biomass challenge, international efforts, including governmental and non-governmental organizations (NGOs) are implementing "clean" or "improved" stove programs (Duflo et al. 2012). The relevance of cookstoves is undeniable: food is at the center of a household, and cookstoves and cooking practices have immediate implications for the economy of the household, the health of the users, and, more broadly, the environment. "Improvement" is a relative term, and "improved stoves" encompass a diversity of stove structures that are better, in some regards, to more simple or traditional stoves, such as three-stone open fires. Any improvements, for example, to increase energy efficiency or reduce smoke/air pollution will upgrade the cookstove's status (World Bank 2011). Improved stoves should also be affordable and relatively portable, so that they can be sold and distributed at a large scale. Traditionally, improved stoves have been promoted by international organizations to better economic and health conditions of communities across the globe, as growing scientific data link smoke production to the increase of infectious respiratory conditions (Dasgupta et al. 2015). More recently, however, proponents of clean stoves have emphasized their important role in addressing critical environmental concerns. The threat of global warming, resulting from the loss and ineffective burning of solid biomass, has led to programs aimed at minimizing the contributions of CO_2 production to the atmosphere. Despite the disparity of results across international programs, with some setbacks and failures, the implementation of fuel-efficient cookstoves can have a large environmental impact when conducted at a relatively wide scale (Adler 2010).

In Madagascar, one such effort has been spearheaded by ADES (Association pour le Développement de l'Énergie Solaire), which has been manufacturing fuel-efficient stoves since 2001 (Vetter 2006). ADES' "rocket" stoves comprise a fired-clay combustion chamber and a sheet-metal shell, rendering them durable and energy efficient. ADES claims that their wood and charcoal rocket stoves save 46–68% more fuel compared to traditional structures like a metal tripod or open fire (MyClimate.org 2006). The stoves come with a 3-year warranty and production costs are subsidized to keep them affordable. ADES currently operates nine regional centers for production, sales and maintenance of stoves in Madagascar (Antananarivo, Antsirabe, Ejeda, Fianarantsoa, Mahajanga, Morondava, two centers in Toliara and one mobile center in central-northern Madagascar). Because ADES does not have a regional center in the northeastern SAVA (initials from the main towns of Sambava, Andapa, Vohemar and Antalaha) region, the Duke Lemur Center-SAVA Conservation program (DLC-SAVA), established in 2011, has been supporting ADES stoves, by subsidizing transportation costs from the capital Antananarivo to SAVA. The introduction of ADES cookstoves was among the first community-based conservation activities supported by the DLC-SAVA program. Thus far, over 500 cookstoves, including both wood and charcoal models, have been imported and distributed in SAVA, particularly in the main town of Sambava and villages near Marojejy National Park.

The SAVA region in northeastern Madagascar is socially and environmentally complex. On the one hand, it is densely populated with four large towns at the region's corners: Sambava, Antalaha, Vohemar, Andapa; on the other hand, it includes one of the largest protected forest blocks in Madagascar (Anjahanaribe Sud, COMATSA, Makirovana/Tsihomanaomby, Marojejy, Masoala) (Rabearivony et al. 2015). This contrasting landscape results in a strong pressure on natural resources by local communities, even though most of the remaining forest is use-restricted and illegal to target by local populations. Moreover, the SAVA region, known as the vanilla capital of Madagascar, produces a significant portion of the country's exportable vanilla. This means that a large portion of the regional economy is shaped by vanilla market price fluctuations, with an unprecedented injection of cash in the local markets during the harvest periods. Despite differences in people's standards of living, occupation, and access to markets or bartering practices, it is unknown whether SAVA community members differ in cookstove use in any measurable manner across a social or economic spectrum and, if so, how those differences may affect their communities and surrounding environments.

OBJECTIVES

Although DLC-SAVA, along with other local NGOs, has imported hundreds of stoves to the SAVA region to date, we have not documented the use and distribution of the stoves to assess whether improved stoves are frequently used in the region. Thus, as part of our evaluation program, we conducted general surveys on the use and preferences of cookstoves in the SAVA region, with a focus on fuel source, stove type use, household economy, and preferred features in cookstoves. These data will inform our future intervention strategies and maximize our efforts by targeting communities based on their needs, consumer preferences and behaviors.

We predict variation in the source of fuel, and stove type, as households are distributed from large towns to remote villages. Community members in more isolated villages may have access to forest fragments, or woody agricultural plots, i.e., fruit or commercial trees, for firewood, but be more limited in their access to charcoal (unless it can be produced locally). Similarly, and consistent with previous studies in different regions of Madagascar (Dasgupta et al. 2013), we predict that charcoal will be used more frequently in large towns (Antalaha, Andapa, Sambava) due to its availability in the markets, concomitant with a lack of firewood access.

As DLC-SAVA has concentrated its efforts for ADES distribution in Sambava and in several villages surrounding Marojejy National Park, we predict that these areas will have a greater prevalence and usage of ADES stoves, with Sambava specifically relying on charcoal models. With regard to Marojejy's surrounding villages (e.g., Ambohimanarina, Manantenina, Mandena and Maroambihy), perhaps ADES charcoal stoves will be used to offset the greater monetary cost and more limited availability of this fuel source. In contrast, perhaps ADES wood stoves will be more frequently used in villages around Marojejy National Park, where firewood can be gathered from nearby areas, without monetary expense.

Finally, we predict that, compared to charcoal users, firewood users will spend less money on fuel, but spend more time gathering it.

METHODS

SURVEY STRUCTURE. To gather information about household stove uses and preferences, we designed surveys (Table S1 in Supplementary Material) that recorded the household's basic location, including the name of the district, commune, *fokontany* (local village name); proxies of household economic status, including wall and roof materials; and information regarding stove use, including the number and types of stoves, fuel source, cooking space, and the money and time respectively spent buying or collecting fuel. We also included a list of cookstove features that respondents had to select based on their preferences: type of fuel, fuel efficiency, doesn't dirty pots, cooking time, amount of smoke, cost, durability, portability, size of cooking surface, other. The questionnaire was designed and implemented using the DataWinners software. The field surveyor (LJD) used a portable tablet to enter surveys responses, which were then stored in a password-protected DataWinners cloud.

We followed standard guidelines and practices for ethical conduct (Wilmé et al. 2016). At each village, the field surveyor (LJD) paired with a local community member, who became familiarized with the nature of the research and questionnaire. Surveys were conducted in Malagasy. Household visits started with a description of the survey and the surveyor indicated that participation was voluntary and could be interrupted at any time. Consent for the interview was verbally requested and, if the household member accepted, the surveyor explained the general objectives and emphasized that surveys were anonymous and that gathered information was untraceable to the respondents: e.g., no names or other identifiers were entered in the database. As reward for the time and effort (about 25 min per survey) all respondents were given phone credit worth ~US$0.35 (1,000MGA). All surveys were conducted between May and December 2017.

SAMPLING AND CATEGORIZATION OF VILLAGES. The surveys were conducted in villages and towns belonging to three districts in the SAVA region: Sambava, Andapa and Antalaha (Figure 1). Villages were selected randomly by picking names out of a bag. Villages close and relatively far from main, paved roads were specifically included in the sampling pool. At each village, the surveyor and a local assistant recruited ~ 20 participants per village, opportunistically walking along the central road. Selected villages were categorized by district affiliation as well as by their relative location with respect to a paved road, and thus their access to consumer goods. First, surveys were divided in three districts, which included their capital towns: Sambava, Andapa and Antalaha. Towns across districts may differ in terms of ethnic composition, economic status and in terms of how close they are to natural environments or protected areas. For example, villages in the Andapa and Sambava districts are closer to Marojejy National Park, Anjanaharibe Sud and COMATSA protected areas. Antalaha and Sambava districts concentrate vanilla businesses due to their proximity to airports and/or ports. Second, we binned surveys into three categories based on a village's distance from a main, paved road: (a) Villages on paved roads: This category includes surveys conducted in villages along the national road system that connects Sambava to Andapa (#3b) and Sambava to Antalaha (#5a to the south) or Vohemar (#5a to the north); (b) Villages on good, dirt (unpaved) roads: This category includes surveys conducted in villages found along well-travelled dirt roads, where cars and small taxis run frequently. This category only includes villages in the Andapa district; (c) Villages off roads: This category includes villages that are located at an aerial distance greater than 10 km from a paved road. Access to these villages varies seasonally and, in many cases, is limited only to foot.

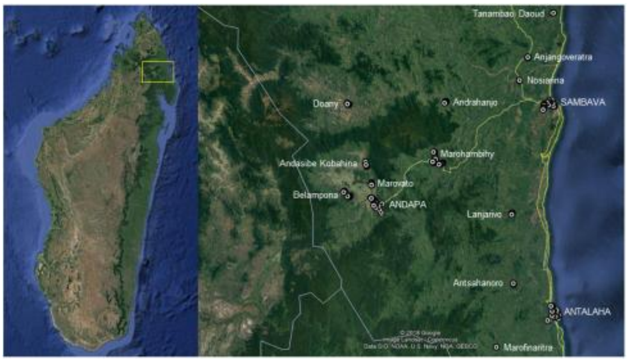

Figure 1. Maps of (left) Madagascar highlighting the study area and (right) pinpointing district capital towns (in caps) and the communes surveyed in this study.

COOKSTOVE CATEGORIES. We classified cooking structures by fuel source: firewood vs. charcoal. Firewood-fueled structures were grouped in one of the following categories: (a) stone structure, (b) metal tripod, (c) brick structure, (d) ADES-wood, and (e) other (Figure 2). This last category encompassed variations of idiosyncratic stoves such as wood-chip burning stoves, which are found in low abundance in the region. Charcoal-fueled structures were grouped as: (a) simple metal, (b) brick-clay stove (with or

Figure 2. Examples of cooking stoves or structures, top, left to right, firewood-fueled: stone structure, metal tripod, brick structure, ADES-wood; bottom, left to right, charcoal fueled: simple metal, brick-clay stove with metal protection, brick-clay stove without metal protection, ADES-charcoal.

without a metal protective rim), (c) tile-cement structure, (d) ADES-charcoal (Figure 2).

STATISTICAL ANALYSIS. Simple summary statistics were used to calculate the proportion of survey responses within particular categories. We used contingency analysis and ran Pearson's Chi-square tests in JMP Pro 13, to specifically test for differences in fuel source and cookstove-structure prevalence when households are classified by distance to paved road or by district. To further test whether proximity to main roads, house quality, or cooking-space features had associations with fuel type, we computed a generalized linear mixed model using the glmmADMB package (Fournier et al. 2012) implemented in Rstudio. The response variable was fuel-type (two categories: firewood or charcoal) and entered as binary data: We therefore used the binomial distribution function. We used the following suite of explanatory variables: distance to paved road as a proxy for access to consumer goods (three categories: paved road, dirt road, off road); house wall materials as a proxy for economic status (five categories: bamboo, cement, *ravinala*, i.e., traveler's palm, tin, and wood); and kitchen structure as a proxy for smoke exposure (four categories on a gradient from most to least ventilated). *Fokontany* (i.e., small village unit) was ranked as a random variable. We reran the above model exchanging the response variable from exclusive firewood or charcoal use to also include households where both fuel sources were used.

RESULTS

ON FUEL USE. Out of 517 households surveyed, comprising 25 villages in 15 communes (Table S2 in Supplementary Material), 49% used exclusively firewood as a source of fuel, compared to 36% of charcoal-exclusive fuel users. An additional 16% use both firewood and charcoal as fuel sources. Other sources of fuel, such as gas, had a negligible presence in our sample (n=6) and were removed from the analysis.

When fuel use was analyzed against distance from paved road, there was a significant difference, with the use of firewood increasing when households were farther away from paved roads (Pearson's chi-squared test = 93.520, $p < 0.0001$). More specifically, only 34% of households on paved roads use firewood-exclusive stoves, whereas 75% of off-road households did so. These percentages increase to 48% and 88% respectively, when households using both fuel types are included. The proportion of households using firewood and/or charcoal did not vary by district (Figure 3).

When we compared district capital communes, Andapa, Antalaha and Sambava, to other smaller communes per district, large towns have the greatest proportion of charcoal use, supporting the prediction that there is an "urban" signature in charcoal use (Table 1).

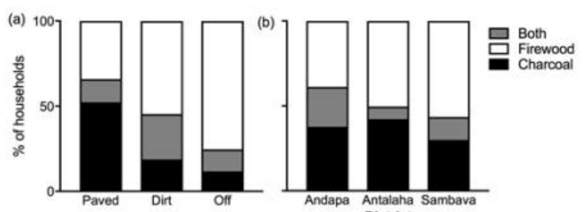

Figure 3. Fuel use reported, including all surveyed households, categorized by (a) distance to paved road or (b) district.

When fuel type was analyzed with respect to distance from paved road, house features and kitchen structures, firewood (including households where charcoal may be also used) was used significantly more often in off-road households, constructed with locally available materials, in contrast to more expensive materials such as cement/wood. Firewood use was also significantly correlated with "enclosed" kitchen structures, which appears counterintuitive from the ventilation perspective, assuming that smoke levels increase when firewood is compared to charcoal (Table 2).

ON THE MONEY AND TIME SPENT ON FUEL. As predicted, charcoal users spent more money (on average, weekly) than did firewood users. More than 80% of respondents, who were firewood users exclusively, reported that they spent no money on fuel; however, they spent more than 4 hours per week, on average, to gather firewood, and up to 20 hours per week in extreme cases (Table 3).

ON STOVE PREVALENCE. When firewood-fueled stoves were considered, the metal tripod was the most commonly used structure, and was well represented in all towns and villages, in proximity to or from paved roads. For example, 77% of households on paved roads, 65% of households on good dirt roads, and 78% of households off roads used at least one metal tripod stove. Such differences across types were significant when compared to distance from paved road (Pearson's chi-squared test = 42.762, $p < .0001$). After the metal tripod, brick structures tended to be used more often in the Andapa district (29%) compared to stone structures which were more common in the Antalaha district (16%). Such differences across types were also significant when

Table 1. Comparison between household in large towns (Andapa, Antalaha, Sambava) to other communes within their respective districts.

Commune	# households	Some charcoal use (%)	Only charcoal use (%)
Andapa town (urban villages)	60	88.3	75
Andapa communes (rural villages)	118	47.5	18.6
Antalaha town (urban villages)	60	86.7	78.3
Antalaha communes (rural villages)	64	15.6	6.3
Sambava town (urban villages)	55	85.5	72.7
Sambava communes (rural villages)	162	29.6	14.8

Table 2. Results of generalized linear mixed model using fuel type (firewood, charcoal) as response variable. (Significant codes: * $p \leq 0.05$, ** ≤ 0.01, *** ≤ 0.001)

	Std	Error	z value	Pr(>|z|)
(Intercept)	-1.153	0.568	-2.03	0.0424 *
Paved road to off road	2.316	0.733	3.16	0.0016 **
Paved road to dirt good road	1.58	0.78	2.03	0.0427 *
Bamboo to cement walls	-2.573	0.81	-3.18	0.0015 **
Bamboo to *Ravinala* stem walls	0.129	0.56	0.23	0.8173
Bamboo to tin walls	0.68	0.639	-1.06	0.2873
Bamboo to wood walls	-1.433	0.486	-2.95	0.0032 **
"Good" to "poor" ventilation	3.002	0.345	8.7	<2e-16 ***

Table 3. Time and cost estimations by fuel type. Conversion rate 1US$=~3,000 MGA. (*this household makes banana chips for sale, **if households with fuel costs of 0 MGA are excluded, the weekly average per household increases to 6,890 MGA)

Fuel type	Charcoal only	Firewood only	Charcoal and firewood
# of households	182	251	80
% of households that do not buy fuel	2.7	83.3	25
Fuel cost (MGA/week)			
average	11,982	1 154**	9,084
max	120 000*	20,000	105,000
Fuel effort (hours/week)			
average	0	4.4	6
max	0	10	20

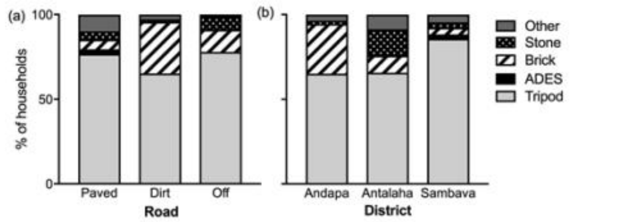

Figure 4. Firewood-fueled cooking structure prevalence, including all surveyed households, categorized by (a) distance to paved road or (b) district

compared by district (Pearson's chi-squared test = 60.508, $p < 0.0001$) (Figure 4).

When charcoal-fueled stoves were considered, two stove types are regularly used: the simple metal and the brick-clay stove. The latter was more frequently used in households on paved roads (53%), on good dirt roads (88%) and off roads (56%), whereas simple metal stoves took second place in households on paved roads (34%), on dirt roads (6%) and off roads (37%). Differences across types, however, were not significant (Pearson's chi-squared test = 10.881, $p = 0.0921$). When stoves were compared by district, brick-clay stoves were the most frequently used type in Andapa (78%), whereas simple metal stoves were the most common in Antalaha (45%). Both types were frequently used in Sambava district. These differences were significant (Pearson's chi-squared test = 26.625, $p = 0.0002$) (Figure 5). When "communes" were entered as the unit instead of households, there is more disparity, with some stove types preponderantly used in some communes, but not others: e.g., 6 households in Tanambao Daoud and 6 households in Doany used charcoal-fueled stoves: 100% of charcoal-fuel stoves were simple metal stoves in the former, whereas 100% were brick-clay in the latter. It should be noted, however, that overall the number of charcoal-fueled stoves was smaller when compared to the number of firewood-fueled

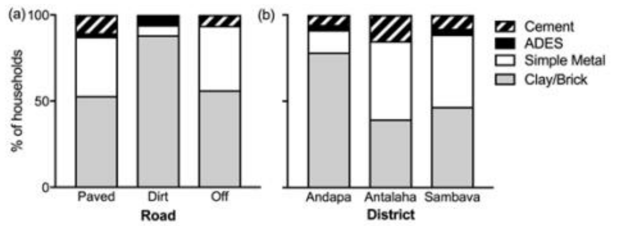

Figure 5. Charcoal-fueled cooking structure prevalence, including all surveyed households, categorized by (a) distance to paved road or (b) district

stoves, reducing the statistical power of the analysis.

We found a very low incidence of ADES stoves in our sample, such that predictions regarding their distribution could not be tested. ADES wood stoves were only found at very low abundance in the Sambava District, on paved roads, representing a negligible portion of the samples. ADES charcoal stoves were only found in 2 households each in Andapa and Sambava districts. In sum, 3% of all households surveyed had an ADES stove (18 out 517 households). Of the 18 households, 72% (n = 13) had an ADES wood and 33% (n = 6) had both types of stoves: ADES wood and ADES charcoal. Interestingly, 28% of ADES owners reported not using their stoves, often giving the reason that "it is too slow to cook". Finally, most ADES owners also have other cookstoves that they generally use for cooking (Table 4).

ON THE COOKSTOVE PREFERENCE. Regarding preferred cookstove features, "cooking time" and "fuel efficiency" were the most common choices given by respondents, including firewood and charcoal users (Tables 5, 6).

For respondents using at least one firewood-fueled stove (i.e., firewood users exclusively, or firewood and charcoal users) the most important feature was "cooking time", regardless of whether households were compared by distance from paved road or by district. Second choices included "fuel efficiency" and "amount of smoke" when stoves were compared by distance from paved road, or "fuel efficiency" and "doesn't dirty pots" when compared by district, though these differences were not significant in this case (Tables S3, S4 in Supplementary Material). For respondents using at least one charcoal-fueled stove (i.e., charcoal users exclusively or charcoal and firewood users), first choices comprised "fuel efficiency" and "doesn't dirty pots" when stoves were compared by distance from paved road, and "fuel efficiency" and "cooking time" were compared by district (Tables S5, S6 in Supplementary Material).

DISCUSSION

Subsistence practices in the SAVA region combine traditional rice agriculture and intensive vanilla cultivation. Differential land use is oftentimes reflected in economic disparities: a contrast between motorcycles and zebu carts, candles and generators, metal and thatch roofs. Despite these differences, our surveys indicate that relatively simple cookstoves are generally used, though this trend is accentuated in households that are more isolated from the

Table 4. Summary of households containing ADES stoves

Own ADES wood	Own ADES charcoal	USED?	Why Not?	Other stoves?
Yes	No	Yes		No
Yes	No	Yes		Brick structure
No	Yes	Yes		Metal tripod
Yes	No	No	too slow to cook	Metal tripod
Yes	No	Yes		Metal tripod
Yes	Yes	No	unclear-only used on special occasions	Metal tripod
Yes	Yes	Yes		No
Yes	Yes	No	unclear-only used on rainy days because wet firewood is difficult for metal tripod	Metal tripod
Yes	Yes	Yes		No
No	Yes	Yes		No
Yes	Yes	Yes		No
Yes	No	Yes		Metal tripod
Yes	No	No	too slow to cook	Brick-clay stove, Metal tripod
Yes	No	No	too slow to cook	Brick structure, Brick-clay stove
Yes	Yes	Yes		Brick structure
No	Yes	Yes		Metal tripod
No	Yes	Yes		No
No	Yes	Yes		No

Table 5. Preferred features in cookstoves including all households, compared by distance from paved road. Numbers in parentheses represent percentages of respondents selecting this choice; n represents the number of households. (Pearson $p < 0.0001$)

	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Paved road	Fuel efficiency (28) n=83	Cooking time (25) n=74	Doesn't dirty pots (11) n=33	Type of fuel (10) n=30
Dirt road	Cooking time (37) n=32	Fuel efficiency (30) n=26	Type of fuel (16) n=14	Other (7) n=6
Off road	Cooking time (27) n=38	Amount of smoke (19) n=27	Doesn't dirty pots (18) n=25	Fuel efficiency (12) n=17

Table 6. Preferred features in cookstoves including all households, compared by district. (Pearson $p < 0.0267$)

	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Andapa	Fuel efficiency (30) n=54	Cooking time (25) n=48	Type of fuel (16) n=28	Amount of smoke (8) n=14
Antalaha	Cooking time (32) n=40	Fuel efficiency (19) n=24	Other (14) n=17	Doesn't dirty pots (13) n=16
Sambava	Cooking time (27) n=59	Fuel efficiency (22) n=48	Amount of smoke (14) n=31	Doesn't dirty pots (13) n=29

large towns. Consistent with our first prediction, it appears that firewood is more frequently used when readily available, in households that are farther away from paved roads, and presumably closer to forest fragments or woody agricultural areas.

Although acquiring firewood may be "free", it adds a physical burden to the persons who procure and carry the fuel, not to mention the additional time investment of splitting, drying and transporting wood if the fuel source is relatively far from the household. Improved cookstoves are oftentimes promoted as "fuel efficient" when compared to more traditional structures like open fires. If basic information is gathered at target villages regarding average time investment by local members, a simple calculation can be made to illustrate how many hours per month, or year, can be saved by using an improved cookstove. Our results show that, on average, community members spend ~5 hours a week gathering firewood. These estimations are greater compared to the time spent by local villagers securing firewood at other eastern sites in Madagascar: e.g., ~30 minutes a day, or ~3.5 hours a week at Lac Alaotra (Borgerson et al. 2018), and between 15 and 30 minutes a day, or ~3 hours a week in villages around Betampona Strict Nature Reserve (Golden et al. 2014). We believe that these data should be discussed in the context of program implementation, in addition to advertising other potential long-term benefits of proposed cookstoves. NGOs or governmental organizations highly value the reduction of emissions to prevent long-term health complications, but cooks may prioritize other more pragmatic reasons: e.g., burning less fuel means less time for women, and possibly children, to spend gathering solid biomass (Adler 2010).

We were somewhat surprised by the very low incidence of ADES cookstoves in our sample. It was also interesting to note that, when present, ADES stoves were not always used. The low visibility of ADES in the region may be due to a variety of factors, including the fact that NGOs may not have introduced enough stoves to make a difference at regional scale. Moreover, efforts should be placed to target remote villages instead of focusing on a few selling locations as it has been done thus far. Moreover, DLC-SAVA has been selling stoves promoted by word of mouth, and we have had a few buyers purchasing several stoves at once, and likely concentrating their distribution in large towns, or "wealthy" households in small villages. This would mean that some households will use and or store multiple ADES, and that the number of stoves sold does not equate to the number of households owning one.

Including preference data could also help us understand the potential desirability of improved stoves like ADES. We showed that respondents using firewood-fueled stoves prioritize "cooking time" over other features like "fuel efficiency" (though the latter comes as a close second). Metal tripods, which are extensively used as cooking structures, allow for rapid transference of heat to pots, although at a greater fuel cost. Charcoal users, however, ranked fuel efficiency as a main feature they prefer in a cookstove, presumably in response to the greater monetary costs of charcoal. Other considerations, such as "doesn't dirty pots" and "amount of smoke" were also selected as top three choices indicating a clear desire for cleaner burning stoves and an awareness of the respiratory health costs of current practices.

One question we did not fully address is whether people would be inclined to purchase a more fuel-efficient stove like ADES at a higher price. DLC-SAVA subsidies make ADES stoves highly competitive in the local market: at ~15,000 MGA a piece (~US$5; conversion rate 1US$=~3,000 MGA), they are cheaper or comparably priced to other options available in the region. For instance, an imported artesian clay stove is sold at ~25,000 MGA, and a local "dung" cookstove at ~25,000 MGA (Klug 2017 in Supplementary Material). Although "cost" did not make it to the top of the preference rankings across households, 83 respondents selected this option as one of the preferred features in a cookstove, and 19 respondents chose "cost" as the most important feature. Thus, increased prices for ADES cookstoves may lower their appeal or reduce local demands.

Selling stoves is more than showing the product – for instance, information about how to economize fuel, how to properly load a stove for maximum efficiency, how to avoid dirtying kitchen equipment, should be carefully explained (Adler 2010). Although we are aware that ADES designed pamphlets and training routines, we are not sure how many NGOs subsidizing stoves embraced the program to the maximum potential. For instance, as it is shown in this study many interviewees considered "cooking time" as an important feature in a cookstove. This may pose a challenge to make ADES and other fuel-efficient stoves appealing, because fire-clay combustion chambers may take additional time to heat up. Incidentally, once the chamber is fully heated, less fuel may be needed to maintain the same temperature for long periods. A more comprehensive discussion about trade-offs may help counterbalance traits that may be initially perceived as negative. It is clear from this study that receptiveness and willingness to learn is present.

Based on this preliminary study, we suggest a more strategic plan to introduce and distribute improved cookstoves such as ADES in the SAVA region: (i) we suggest matching stove models (wood and/or charcoal) with the most commonly used fuel source at any particular village, based on prior surveys like this. We would particularly favor the ADES wood stoves to be distributed in the more remote villages, where people greatly rely on gathered firewood. It is perhaps noteworthy that ADES wood stoves performed better than ADES charcoal stoves in terms of fuel consumption, when each one was tested against baseline stoves by a DLC-SAVA volunteer student (Klug 2017 in Supplementary Material): ADES wood used 3 times less fuel than a metal tripod, but ADES charcoal used only slightly less fuel than a basic metal stove; (ii) we suggest adding a short training/and or demonstration to highlight features that are perceived as important by community members. For example, ADES wood stoves may take longer to cook food, but they may not dirty pots as much as do metal tripods. Additionally, we should provide useful information to ensure the stoves are being used to their maximum potential. For instance, learning to load the stoves properly may, in fact, reduce the cooking time. In addition to training sessions by experienced users, a pictographic instructional pamphlet handed out with stoves might be useful; (iii) we suggest finding reliable local "partners" to sell stoves once they arrive to SAVA. This is no minor detail, as we have faced the problem of assistants re-selling stoves for profit.

It was commonly observed in the sampled communities that cooking habits and stove use were largely based on tradition, cost and availability, as opposed to practical long-term health benefits and/or environmental impacts. Future research in this area should seek to account for this when designing more fuel-efficient stove models and strive to educate and build capacity within their clientele and their resources. Although DLC-SAVA supports the continuation of the ADES program to disseminate these improved stoves to the SAVA region, and although we welcome more NGOs to do the same in this and other regions in Madagascar, we understand that there is no single ideal stove to solve the environmental crisis, and that a variety of options should be made available depending on peoples' socioeconomic levels, cultural traditions and geographic locations (Adler 2010). Technological advances are constantly introducing better products, that can provide multiple benefits at affordable prices. However, given the fact that large portions of the communities in the SAVA region are using metal tripods on a regular basis, introducing some type of "fuel-efficient" stoves at a larger scale than current distribution, is expected to make a difference in biomass consumption, in addition to reducing burden on collectors and carriers. Providing focused training on fuel-efficient stove design to experienced individuals who are already producing and distributing stoves locally could be an excellent way to support the sustainability of such efforts while utilizing and leveraging local knowledge.

Finally, for NGOs interested in community-based conservation, discussing the importance and potential impact of improved cookstoves in environmental education activities, can help communicate a message of sustainability and natural resource management, with implications for the daily lives of primary and secondary school student participants.

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REFERENCES

Adler, T. 2010. Better burning, better breathing: improving health with cleaner cook stoves. Environmental Health Perspectives 118, 3: A124–A129. <https://doi.org/10.1289/ehp.118-a124>

Borgerson, C., Vonona, M. A., Vonona, T., Anjaranirina E. J. G., Lewis, R., et al. 2018. An evaluation of the interactions among household economies, human health, and wildlife hunting in Lac Alaotra wetland complex of Madagascar. Madagascar Conservation & Development 13: 25–33. <https://doi.org/10.4314/mcd.v13i1.5>

Dasgupta, S., Martin, P. and Samad, H. A. 2013. Addressing household air pollution: a case study in rural Madagascar. The World Bank Africa Region Sustainable Development Department. Available at <https://bit.ly/2XuQ1oS>

Dasgupta, S., Martin, M. and Samad, H. A. 2015. Lessons from rural Madagascar on improving air quality in the kitchen. Journal of Environment & Development 24, 3: 345–369. <https://doi.org/10.1177/1070496515588590>

Duflo, E., Greenstone, M. and Hanna, R. 2012. Up in smoke: the influence of household behavior on the long-run impact of improved cooking stoves. Harvard Environmental Economics Program. Harvard Kennedy School. National Bureau of Economic Research Working Paper: #18033. Available at <http://projects.iq.harvard.edu/files/heep/files/dp41_hanna-etal.pdf>

Fournier, D. A., Skaug, H. J., Ancheta, J., Ianelli, J., Magnusson, A., et al. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27, 2: 233–249. <https://doi.org/10.1080/10556788.2011.597854>

Golden, C. D., Rabehatonina, J. G. C., Rakotosoa, A. and Moore, M. 2014. Socio-ecological analysis of natural resource use in Betampona Strict Natural Reserve. Madagascar Conservation & Development 9, 2: 83–89. <https://doi.org/10.4314/mcd.v9i2.4>

INSTAT. 2011. Enquête Périodique auprès des Ménages 2010. Institut National de la Statistique, Direction des Statistiques des Ménages, Madagascar. Available at <http://catalog.ihsn.org/index.php/catalog/5127/related-materials>

MyClimate.org. 2006. ADES Solar and efficient stoves in Madagascar. Project design document submitted to The Gold Standard. Available at <https://bit.ly/2XWRHLx>

Rabearivony, J., Rasamoelina, M., Raveloson, J., Rakotomanana, H., Raselimanana, A.P., et al. 2015. Roles of a forest corridor between Marojejy, Anjanaharibe-Sud and Tsaratanana protected areas, northern Madagascar, in maintaining endemic and threatened Malagasy taxa. Madagascar Conservation & Development 10, 2: 85–92. <https://doi.org/10.4314/mcd.v10i2.7>

Vetter, H. 2006. Solar cooker project of ADES. Madagascar Conservation & Development 1, 1: 22–24. <https://doi.org/10.4314/mcd.v1i1.44034>

Wilmé, L., Waeber, P.O., Moutou, F., Gardner, C.J., Razafindratsima, O., et al. 2016. A proposal for ethical research conduct in Madagascar. Madagascar Conservation & Development 11: 36–39. <https://doi.org/10.4314/mcd.v11i1.8>

World Bank. 2011. Household cookstoves, environment, health, and climate change: a new look at an old problem. Environment Department (Climate Change). Available at <https://bit.ly/2K1Ozr8>

SUPPLEMENTARY MATERIAL

Table S1. Survey questions.

Table S2. List of villages (*fokontany*) surveyed in this study, ordered by commune, district and distance from paved road.

Table S3. Preferred features in cookstoves including households using firewood, compared by distance from paved road.

Table S4. Preferred features in cookstoves including households using firewood, compared by district.

Table S5. Preferred features in cookstoves including households using charcoal, compared by distance from paved road.

Table S6. Preferred features in cookstoves including households using charcoal, compared by district.

Klug, T. 2017. Improved cookstove catalog. Duke Lemur Center-Sava Conservation Report.

ARTICLE http://dx.doi.org/10.4314/mcd.v14i1.1

Développement d'un logiciel (3C-BIOVIS) pour la détermination de la disponibilité des ressources fourragères par une approche de modélisation et télédétection

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ABSTRACT

Cattle husbandry is a common activity practiced for several generations in Madagascar. Unfortunately, cattle farmers have not fully taken full advantage of the potentialities of this sector, mainly because of poor management of the available range lands and fodder resources. An improved cattle production could be achieved through the use of prediction tools integrating remote sensing data with modelling. Here, we present a novel tool developed to aid in husbandry management. We collected measurement field data related to fodder biomass and converted data obtained from remote sensing into fodder quantity. These data were used to program a multispectral SPOT 5 satellite to calculate correlations between the normalized difference vegetation index (NDVI) and the existing plant biomass. Using these correlations, we developed and tested several mathematic models to predict the quantity of biomass and the dry matter content. We developed a software, called 3C-BIOVIS, using computer programming and modelling of the obtained data. The tool predicts the quantity of available dry matter content within a defined rangeland and the number of animals that could be fed within a given time and space. It was designed to support rural development stakeholders in decision-making and to advise cattle farmers in forage resource management for an optimum output.

RÉSUMÉ

L'élevage de bovin est une activité pratiquée depuis de nombreuses générations à Madagascar. Malheureusement, les éleveurs n'ont pas su jusqu'à aujourd'hui, tirer pleinement profit des potentialités de ce secteur. La mauvaise gestion des parcours et des ressources fourragères représente une des principales causes de cette faible performance. Ainsi, l'amélioration de la production bovine pourrait être obtenue à travers l'utilisation d'un outil de prédiction de la disponibilité des ressources fourragères en utilisant une approche combinée de modélisation et télédétection. Des mesures de données agronomiques de terrain sur la biomasse fourragère ont été effectuées pour convertir les données issues de la télédétection en quantités de biomasse fourragère. Cette approche a nécessité une programmation de passage du satellite multispectral SPOT 5 en parallèle avec l'acquisition de données de terrain pour calculer des corrélations entre l'indice de végétation (NDVI) et la biomasse végétale existante. À partir des régressions, plusieurs modèles ont été élaborés et testés pour pouvoir prédire la quantité de biomasse ainsi que la teneur en matière sèche. La programmation et la modélisation informatique ont permis de développer un logiciel "3C-BIOVIS". L'outil prédit les informations sur la quantité de matière sèche disponible au niveau des parcelles et le nombre d'animaux pouvant être alimentés par chaque parcelle à une période donnée et dans un espace déterminé, via les données obtenues des images satellites. Cet outil a été conçu pour aider les acteurs du développement rural à prendre des décisions de manière à conseiller les éleveurs sur la façon optimale de gérer les ressources fourragères.

INTRODUCTION

Madagascar est un pays caractérisé par de vastes zones de pâturages et de grandes variabilités spatio-temporelles quant aux précipitations. Ces variabilités font qu'il est délicat pour les éleveurs malgaches de tirer pleinement profit des ressources exploitables pour l'alimentation des ruminants. Cela affecte le

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développement du pays, car une grande fraction de la population subsiste grâce à l'élevage. Le cheptel bovin, symbole national de la population, est devenu la référence de l'élevage malgache. En effet, il représente une valeur en capital estimée à 36 000 milliards d'Ariary (MGA), soit environ US$ 1,8 milliards en 2014 (Ministère de l'Élevage à Madagascar 2014). Par ailleurs, le zébu est utilisé dans les rituels des us et coutumes de la population et assure plusieurs fonctions socio-économiques. Dans certaines régions de l'île, l'importance du troupeau est une marque de prestige, une forme d'épargne et d'investissement (Ribot 1987, Kaufman 2008, Waeber et al. 2015). Les principaux atouts de la production de viande bovine sont sa qualité pour la boucherie et son faible coût de production, notamment grâce à une alimentation sur parcours basée sur des ressources naturelles renouvelables. Allant de pair avec la filière viande, la filière lait commence à se développer dans les activités d'élevage à Madagascar. En effet, elle apparait comme l'une des filières animales présentant le potentiel de développement le plus élevé, avec une production annuelle estimée à plus de 100 millions de litres, toutes races confondues. La filière lait représente une valeur de 100 milliards de MGA (environ US$ 50 millions en 2014) (Ministère de l'Élevage à Madagascar 2014). La production bovine actuelle est cependant encore loin du potentiel de production de l'élevage malgache. Cette faible production est généralement liée au déficit alimentaire du cheptel, surtout durant la saison sèche, pendant laquelle les éleveurs sont confrontés à un déséquilibre entre la demande et la disponibilité en fourrage aussi bien en quantité qu'en qualité. Pourtant, Madagascar dispose encore de grandes surfaces de terrain exploitable pour l'alimentation des ruminants. Une estimation de la distribution des ressources fourragères des grandes étendues éloignées reste toutefois difficile et complexe (Coughenour et Makkar 2014). La production des ruminants pourrait ainsi être améliorée par la mise en place d'un outil fonctionnel pour la gestion à grande échelle de ces ressources en utilisant des imageries satellitaires.

Cet article est destiné à présenter l'outil dénommé 3C-BIOVIS qui a été développé pour aider à la gestion des ressources fourragères par une approche de modélisation et de télédétection. Cet outil fournit des données quantifiables sur la disponibilité des ressources, pour une prise de décision optimale sur l'utilisation des parcelles et parcours fourragers. Il permet aussi de définir la quantité de fourrage vert pour alimenter le cheptel durant les saisons pluvieuses ainsi que le surplus de fourrage qui sera conservé pour les saisons sèches sous forme de foin ou d'ensilage. Ainsi, à chaque acquisition d'une image satellite, il serait possible de gérer et d'ajuster le troupeau, ainsi que son alimentation, en fonction de la disponibilité des fourrages au niveau de l'exploitation ou au niveau territorial.

MATÉRIELS ET MÉTHODES

PRÉSENTATION DE L'OUTIL. Le sigle 3C-BIOVIS correspond à « Calculateur de la Capacité de Charge, et de la BIOmasse Végétale par Imagerie Satellite ». Il s'agit d'un outil de calcul qui permet de déterminer la quantité des ressources fourragères à partir des données obtenues par traitements d'images satellites. Le noyau de cet outil est configuré à partir de l'Indice de Végétation Normalisé (NDVI) (Rouse et al. 1974) qui est fortement corrélé avec la densité du couvert végétal. Ainsi, les utilisateurs de ce logiciel doivent avoir des notions de base en traitement d'image satellitaire, comme l'extraction de NDVI à l'aide de logiciels tels les Systèmes d'Information Géographique comme QGIS, pour pouvoir utiliser cet outil. Le logiciel 3C-BIOVIS est un modèle indicatif qui contient trois sous-modèles intégrés, à savoir le calcul de la quantité de biomasses, la teneur en matière sèche (MS) et la capacité de charge liée à la classe animale et l'espèce fourragère. Cet outil fournit des informations en temps réel sur la quantité de ressources fourragères ainsi que le nombre d'animaux pouvant être alimentés durant une année sur une parcelle géo-localisée dans une image satellite (Hervé et al. 1989). Un système d'alerte par feu tricolore permet une aide à la décision des utilisateurs du logiciel sur une éventuelle réorganisation de la gestion de l'exploitation ou du pâturage suivant la disponibilité des ressources. La couleur rouge indique un surpâturage de la parcelle. Cela signifie que la production prédite est inférieure à 1,5tonnes de MS/ha et qu'il est indispensable pour les éleveurs d'arrêter l'exploitation de la parcelle. À l'inverse de cette surexploitation, l'outil indique une coloration verte qui désigne une production de biomasse supérieure à 3,5tonnes de MS/ha, qui pourrait conduire à un gaspillage des ressources (Barbet-Massin et al.2004). Entre ces deux couleurs se trouve l'orange qui indique qu'il y a assez de biomasse pour alimenter le cheptel. Par conséquent, cet outil permet d'apporter conseil aux exploitants sur la gestion et/ou la mobilité de leurs troupeaux par rapport à la disponibilité des ressources (itinéraire des parcours, charge animale). Un système de saisi des données (NDVI, date de l'acquisition de l'image satellite, coordonnées GSP, taille de la parcelle, estimation du pourcentage d'utilisation de la parcelle par l'animal, type d'animal) avec une interface facile à utiliser (Figure 1) a été élaboré donnant accès direct aux informations exploitables, sur les fourrages disponibles dans les bases de données du logiciel. Toutefois, des options supplémentaires ont été introduites, comme la possibilité d'utiliser le logiciel sans avoir accès aux données satellitaires, mais par des mesures directes sur le terrain à l'aide d'une placette de $1m^2$. Cette option « mesure directe » a été utilisée pour tester la fiabilité de l'outil, tout en considérant les intervalles de confiance, vu les hétérogénéités intra-pixel de la biomasse. Une autre option disponible est la possibilité d'utiliser l'outil pour d'autres espèces de ruminants (ovins et caprins) par des coefficients d'équivalence en fonction de leur consommation en aliments grossiers. Le logiciel 3C-BIOVIS est principalement conçu pour les acteurs du développement rural comme les techniciens de l'élevage, mais d'autres acteurs peuvent l'utiliser comme les coopératives d'éleveurs, les ONG, les ministères, les établissements d'enseignement ou de recherche.

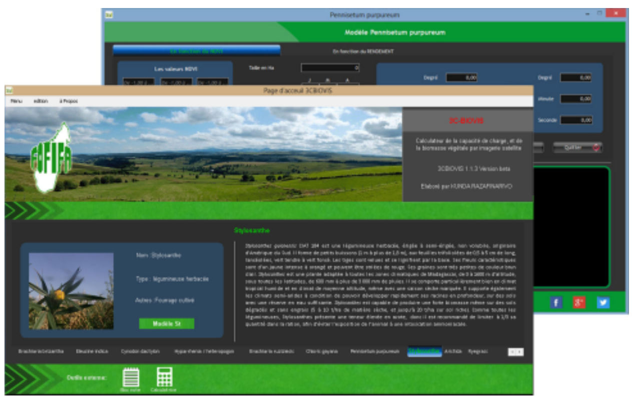

Figure 1. Interface du logiciel 3C-BIOVIS.
<https://www.dp-spad.org/projets/acheves/biova>
<http://www.cirad.mg/c3biovis/>

ZONES D'ÉTUDE. L'outil a été calibré sur deux zones clés de l'élevage de bovin à Madagascar, à savoir les régions du Vakinakaratra et du Bongolava (Figure 2) ; ces régions représentent les deux tiers du triangle laitier malgache (Rakotozandrindrainy et al.2004). La région du Vakinakaratra, située sur les Hautes Terres de Madagascar (18°59' S et 47°19' E), produit plus de 70% de la production laitière nationale (Ministère de l'Agriculture, de l'Élevage et de la Pêche 2004). De ce fait, la plupart des éleveurs cultivent des fourrages durant toute l'année pour alimenter leur cheptel. Le climat tempéré d'altitude dans cette région entraîne une forte saisonnalité dans la production des espèces fourragères tropicales et une dominance des espèces tempérées (Marcel 1986). L'optimum de température pour la photosynthèse des espèces fourragères tempérées est compris entre 10 et 25°C (Murata et al. 1965), qui sont des températures caractéristiques de cette région. Dans cette partie de l'île, les espèces tempérées comme le ray-grass, l'avoine ou l'orge, sont généralement plantées en contre-saison dans les bas-fonds en rotation avec la riziculture (Mouret 2012). Les données agronomiques portant sur les fourrages usuellement utilisés en saison sèche ont donc été mesurées dans cette zone.

La région du Bongolava, située dans le Moyen Ouest de Madagascar vers E046° 02', S18° 44' (Figure 2) a la réputation d'être plutôt orientée vers l'élevage extensif de zébus. La région assure les deux tiers de l'approvisionnement en viande bovine de la capitale par le marché de Tsiroanomandidy (Ministère de l'Élevage à Madagascar 2014). Dans cette zone, les cultures de fourrage en contre-saison sont moins pratiquées (Razafindrakoto 2010). Cependant, il existe de grandes surfaces de pâturage naturel pour alimenter les bovins, y compris les animaux en transhumance. La région est caractérisée par un climat tropical à deux saisons distinctes (sèche et pluvieuse). La température moyenne est de 30°C (Razafindrakoto 2010) qui représente l'optimum pour la photosynthèse des espèces tropicales comme *Cynodon dactylon*, *Pennisetum purpureum* et *Brachiaria brizantha* (Jolliffe et al. 1968, Archimède 2009).

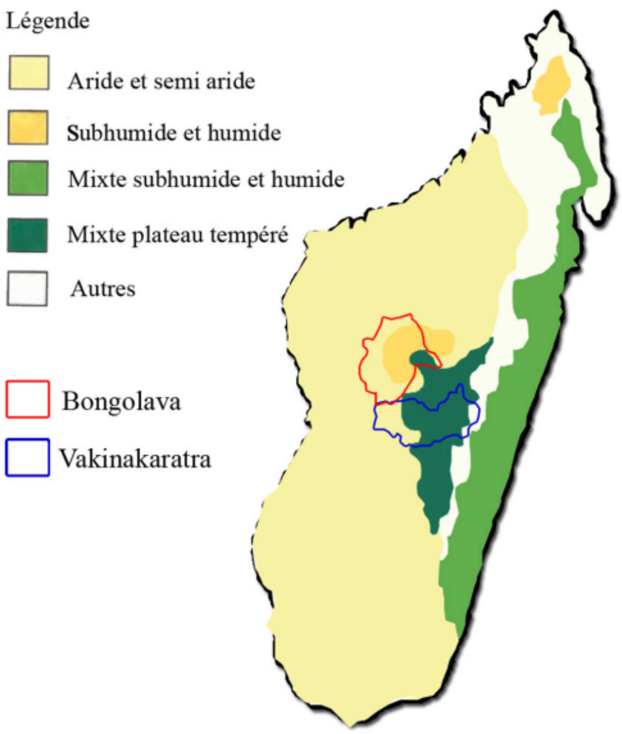

Figure 2. Répartition spatiale des zones pastorales à Madagascar (modifié d'après Vall et al. 2014)

CALIBRATION DU MODÈLE DE RENDEMENT DE LA BIOMASSE FOURRAGÈRE. La calibration consiste à élaborer des modèles prédictifs de la quantité de biomasses par des régressions statistiques entre les valeurs de NDVI obtenues d'une série temporelle d'images SPOT (Satellite Pour l'Observation de la Terre) et de rendements mesurés sur le terrain. 428 prélèvements de biomasses aériennes ont été effectués sur des placettes de 1m^2 (Guérif et al. 2008), dans les zones d'étude pour paramétrer et calibrer les modèles. Les observations portaient sur la hauteur des différentes espèces fourragères et leur rendement en matière verte. Les sites ont été sélectionnés avec (i) une taille suffisamment grande et (ii) une homogénéité des composants afin de réduire les effets d'erreurs entre les observations sur le terrain et par télédétection. Le seuil minimal de la dimension des parcelles a été fixé à 1600m^2, et le nombre de points de prélèvement a été défini selon la surface des parcelles. Sur chaque point, seule l'espèce majoritaire dans la placette a été considérée pour la calibration, et un prélèvement GPS a été effectué pour la géolocalisation des points. Ces procédés ont été répétés tous les 15 jours durant plusieurs mois (6 mois x 3) pour pouvoir suivre l'évolution des différents stades de développement de chaque espèce. Parallèlement, une programmation pour l'acquisition d'images satellites a été effectuée par la station de réception et de traitement d'images satellites SEAS-OI sise à la Réunion. Des Indices de Végétation Différentiels Normalisés (NDVI) ont été calculés à partir des images satellites multispectrales SPOT 5 de 10 m de résolution, acquises sur un pas de temps de 10 jours, en parallèle avec les prélèvements sur le terrain. L'indice de végétation correspond à la valeur de réflectance du vert qui est fortement corrélée avec la densité du couvert végétal et la capacité des plantes à absorber la lumière solaire pour la convertir en biomasse (Meneses-Tovar 2011). Dans le domaine spectral, la végétation chlorophyllienne a toujours des valeurs de réflectance plus fortes que les autres éléments (sols, eau, minéraux). Ainsi, différentes relations de régression ont pu être calculées entre les données agronomiques caractérisant chaque type de végétation et les données spatiales (NDVI), pour obtenir des modèles de prédiction (Figure 3).

CALIBRATION DU MODÈLE DE MATIÈRE SÈCHE. À chaque mesure du rendement fourrager sur le terrain, un échantillonnage de la biomasse des différents types de fourrages, en utilisant la méthode des placettes de 1m^2, a été effectué le long d'un transect pour réaliser les analyses de matière sèche au laboratoire. Le poids sec total des plantes a été déterminé selon les techniques standardisées de séchage à l'étuve à 60°C jusqu'à l'obtention d'un poids constant (Dulphy et al. 1975). Ces poids ont alors été multipliés par le facteur approprié en relation avec la taille du quadrat afin de les convertir en kg/ha. Les différentes teneurs en matière sèche dans le temps sont par la suite couplés puis corrélés avec la valeur du NDVI pour obtenir un ensemble de données sur la productivité en matière sèche à partir des données satellites et de la date de prise de l'image. Un modèle de prédiction de la variation temporelle de la teneur en matière sèche en fonction de la valeur de NDVI a été calibré. Ce deuxième modèle couplé au premier donnera, à partir d'une image satellite, la teneur moyenne en matière sèche d'une parcelle déterminée à une période déterminée. Par conséquent, connaissant la surface de la parcelle, il sera possible de définir la capacité de charge animale de chaque parcelle suivant la capacité d'ingestion de matière sèche par les ruminants.

CALCUL DE LA CAPACITÉ DE CHARGE. La capacité de charge animale est un indicateur important pour exploiter les parcelles de façon rationnelle. La capacité de charge correspond au nombre d’animaux, en unité bovin tropical (UBT) ou par unité gros bétail (UGB), par unité de surface en hectares (Hervé et al. 1989). Elle dépend de la production annuelle du fourrage (kg de MS/ha), de la capacité d'ingestion du ruminant et de la durée d’exploitation du fourrage au cours de l’année. La notion de capacité de charge animale présente l'avantage de donner un ordre de grandeur du nombre d'animaux susceptibles d'être alimentés sur les parcelles, dans les limites raisonnables d'une exploitation ménageant à peu près les productions à venir. La quantité de fourrage obtenue à partir des précédents modèles est paramétrée pour caractériser la densité du bétail en fonction du taux d'ingestion de matière sèche pour chaque bovin. La production totale annuelle de certains fourrages a été déterminée par une culture mise en défend dans des enclos ; lorsqu'il n’a pas été possible d'effectuer cette pratique, les données ont été récupérées à partir de la littérature.

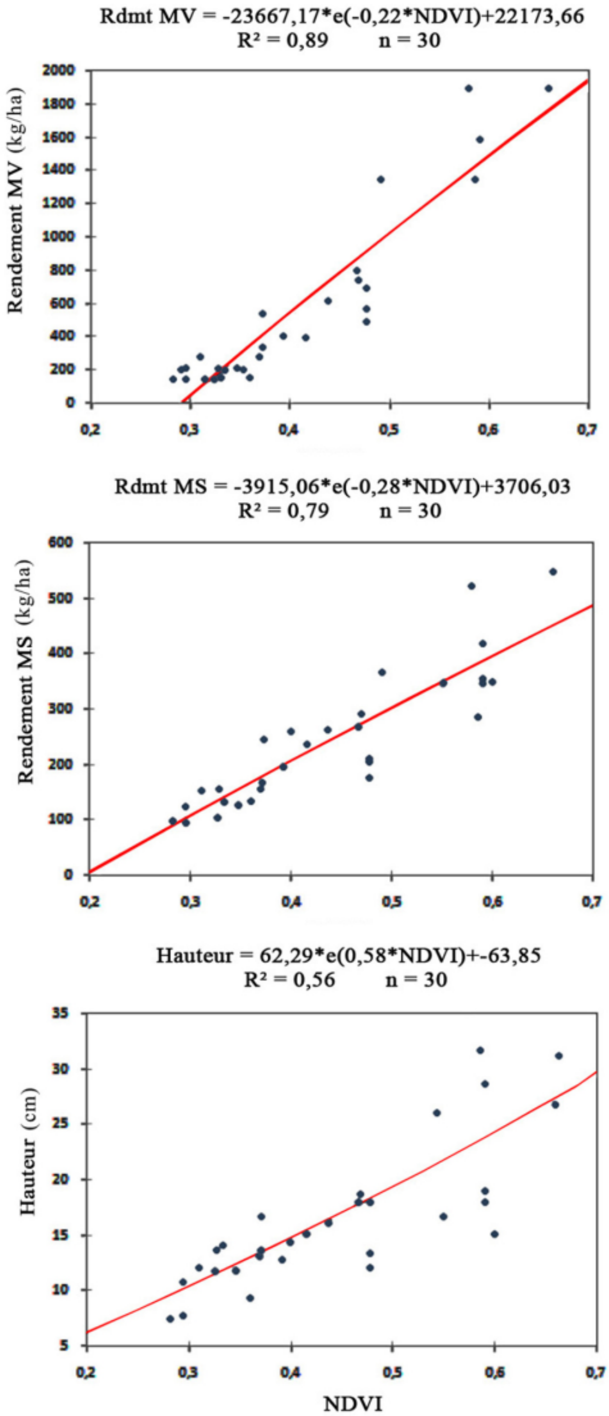

Figure 3. Représentations graphiques des régressions entre les données agronomiques et les valeurs de NDVI pour *Digitaria*.

MODÉLISATION ET PROGRAMMATION. Toutes les données ont été programmées et modélisées sous un langage métier dénommé WLangage (Vandevelde 2014) de manière à ce qu'à partir de variables d'entrées basiques, il soit possible d'obtenir des informations poussées sur la disponibilité des ressources. WLangage est un langage de programmation de quatrième génération exploitable dans des outils de développement informatique tel que WinDev. Cette version test du logiciel 3C-BIOVIS n'est exécutable que par un système d'exploitation Windows. WLangage contient des fonctions de haut niveau, qui permettent l'affectation du contenu des champs d'une fenêtre, c'est-à-dire les données d'entrées, vers les modèles stockés dans les bases de données pour ressortir ensuite les résultats des calculs. Une fois que les variables d'entrées (Tableau S1) sont saisies dans l'outil, tout le système subit un changement considérable pour faire calculer les différents indicateurs de la parcelle (Variables de sortie, Tableau S1). Ces variables d'entrées sont totalement indépendantes des autres variables. À l'opposé, les variables de sortie ont un rôle mineur dans le processus, mais elles sont les plus importantes, car elles fournissent les informations recherchées dont la productivité de la parcelle, la capacité de charge et l’indicateur traduisant la pression animale. Entre ces deux types de variables se trouvent les variables d'état, qui sont les générateurs du processus de calcul dans le logiciel.

VALIDATION DE L'OUTIL. La validation de l’outil a consisté à confronter les valeurs de biomasse mesurées sur le terrain dans les placettes aux valeurs prédites par l'outil. Cela désigne un processus qui permet de tester la précision prédictive d'un modèle dans un échantillon test par rapport à la précision prédictive de l'échantillon d'apprentissage à partir duquel le modèle a été développé. Dans ce cas, toutes les valeurs mesurées sur le terrain ont été employées pour cette validation par la technique de la validation croisée « leave-one-out », à savoir en supprimer un, ou « cross-validation », à savoir validation croisée (Holden et al. 1996). Pour ce faire, toutes les composantes de l'échantillon « n » (n = 428) original ont été divisées en « n » échantillons, puis, un des « n » échantillons a été sélectionné comme ensemble de validation et les « n-1 » autres échantillons constituaient l'ensemble d'apprentissage. L'erreur quadratique moyenne a été calculée pour donner le score de performance du modèle sur l'échantillon test. Cette opération a été répétée en sélectionnant un autre échantillon de validation parmi les « n-1 » échantillons qui n'avaient pas encore été utilisés pour la validation du modèle. L'opération a ainsi été répétée « n » fois pour qu'en fin de compte chaque sous-échantillon aura été utilisé exactement une fois comme ensemble de validation. La moyenne des « n » erreurs quadratiques moyennes a finalement été calculée pour estimer l'erreur de prédiction.

RÉSULTATS ET DISCUSSION

RELATION ENTRE L'INDICE NDVI ET LE RENDEMENT DES DIFFÉRENTES ESPÈCES FOURRAGÈRES. Lorsque la végétation est étudiée par télédétection, les variations de la réflectance mesurées au niveau d'un capteur satellitaire sont liées aux propriétés optiques de la biomasse végétale, mais également à la structure de la végétation et au taux de recouvrement du sol. Lorsque la végétation est peu couvrante, la réponse spectrale des plantes est affectée par la réflectance des sols (Nesrine 2015). Il y a donc une grande différence entre la calibration des parcelles fourragères naturelles et celles qui sont cultivées. Il est généralement plus difficile d'avoir une bonne corrélation pour les parcours et les pâturages naturels. Néanmoins, dans les deux cas, les valeurs de NDVI présentaient toujours une forte corrélation avec la densité du couvert végétal (Figure 3). Durant les différentes calibrations, les modèles exponentiels ont donné de meilleurs résultats par rapport aux modèles linéaires. Certains auteurs suggèrent une relation non linéaire entre NDVI et quantité de biomasse (Tucker et al. 1985, Santin-Janin et al. 2009). Les coefficients de détermination entre NDVI et le rendement de biomasse végétal sont meilleurs pour les parcelles cultivées. Cependant, les parcours naturels sont moins uniformes du fait de l'envahissement par d'autres espèces d'adventices. De plus, les indices de végétation sont également sensibles à la réflectance du sol sous-jacent (Moussa 2005). Ainsi, les coefficients de détermination sont moins bons pour ces pâturages naturels. En moyenne, 70% des variabilités des mesures directes sur le terrain sont expliqués par les modèles internes du logiciel à partir des données obtenues par imagerie satellitaire. Pour le reste, soit le logiciel sous-estime, soit il surestime, mais en général, les calculs se font dans l'ensemble en prenant en considération la totalité des pixels existant au niveau de la parcelle. La figure 4 représente graphiquement le nuage de points des valeurs réelles sur le terrain, du rendement en MV (tonnes/ha) des différentes espèces par rapport aux valeurs prédites MV (tonnes/ha) par le logiciel. Le nuage de points affiche la ligne qui illustre la prédiction parfaite, où la valeur prédite correspond exactement à la valeur réelle. La distance d'un point par rapport à cette ligne à un angle idéal de 45 degrés indique le niveau d'exactitude ou d'inexactitude de la prédiction. Ainsi, les résultats issus du logiciel confirment les capacités des données satellitaires à fournir des estimations de la productivité des fourrages (Le Mézo 2012). Les modèles de l'outil s'exécutent aussi bien sur l'échantillon test que sur l'échantillon d'apprentissage durant la validation croisée.

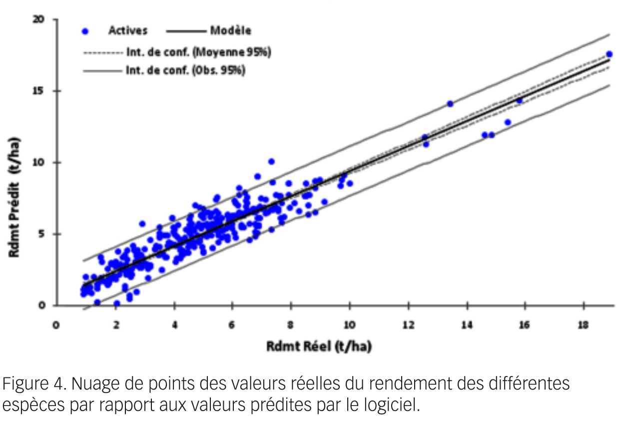

Figure 4. Nuage de points des valeurs réelles du rendement des différentes espèces par rapport aux valeurs prédites par le logiciel.

VARIABLES DE SORTIE. Le logiciel calcule le rendement fourrager moyen ainsi que la teneur en matière sèche du fourrage déterminée à la date de la prise de l'image satellitaire. Ces données ont été traitées par l'outil pour calculer la quantité de fourrage total disponible pour le bétail à cette date, mais aussi la capacité de charge optimale de la parcelle. Des coefficients de conversion ont donné des informations sur le nombre maximum d'herbivores, selon leur type (espèce animale, taille), pouvant pâturer la surface de la parcelle sans détérioration de la végétation. Les utilisateurs de l'outil peuvent ainsi équilibrer la quantité ingérée par les animaux, la productivité en matières sèches de la végétation, la gestion à long terme du pâturage et les coûts de production (Klein et al. 2014). Toutes ces données sont géolocalisées en degré décimal pour faciliter l'introduction des données dans les logiciels courants en système d'information géographique. Ainsi, il sera désormais possible de réaliser des cartes de disponibilité des ressources fourragères. Les cartes de biomasse pourraient potentiellement être utilisées à plusieurs fins comme dans la gestion de troupeaux ainsi que leur affouragement en fonction de la disponibilité des ressources au niveau de l'exploitation et/ou au niveau du territoire. Mais d'autres fonctions peuvent être envisagées ; il a été démontré que ces cartes pouvaient être utilisées pour planifier les feux contrôlés dans la gestion de pâturage (Holechek et al. 1995). La quantité de biomasse utilisée comme combustible doit atteindre au moins 1500kg/ha pour que le feu se propage (Trollope et al. 1986). Des perspectives de développement de l'élevage à Madagascar peuvent être envisagées, comme en Afrique du Sud, sur la diffusion de cartes de disponibilité végétale rapportées tous les 10 jours au niveau des ministères et des districts agricoles (Coughenour et Makkar 2014). Par conséquent, il serait possible de profiter au maximum de la disponibilité des ressources, comme dans la gestion de pâturage, pour déterminer l'instant propice de la mise à l'herbe ou de la sortie d'herbe durant une saison déterminée. Durant cette étude, la calibration du logiciel a été effectuée à partir du satellite SPOT 5, mais rien n'empêche une adaptation à d'autres satellites (par exemple, Sentinel2) qui pourraient fournir les valeurs de NDVI. Cependant, quel que soit le satellite utilisé, certains paramètres devraient être considérés lors de l'utilisation de l'outil comme : (i) l'allure générale de la prairie qui ne doit pas être trop dégradée, c'est-à-dire que l'offre fourragère ne devrait pas être trop limitée par l'envahissement des adventices ou l'apparition de zones nues ; (ii) une variation saisonnière prononcée (par exemple, le prolongement de la saison sèche) pourrait affecter la teneur en matière sèche prédite par le logiciel. Par ailleurs, le logiciel est doté d'un système de partage en ligne des résultats, relié directement à l'adresse de l'auteur. Ce système prendra en compte les évaluations, ainsi que les contributions des utilisateurs du logiciel pour une éventuelle perspective d'évaluation ultérieure des ressources fourragères à l'échelle nationale.

CONCLUSION

L'élevage bovin est un secteur qui présente un grand potentiel dans le développement de Madagascar. Cependant, plusieurs manques à gagner subsistent encore dans ce domaine dû à une mauvaise gestion des ressources alimentaires. Le présent article présente les différentes étapes de développement d'un logiciel appelé « 3C-BIOVIS » qui permet la prédiction du rendement des ressources fourragères par l'utilisation combinée de modèles de prédiction et de la télédétection. Le logiciel a été calibré à partir des modèles résultants des régressions entre les données agronomiques mesurées au sol et les indices de végétation (NDVI) obtenus par imagerie satellitaire. Les régressions donnent une moyenne des coefficients de détermination (R^2) d'environ 0,7. Le logiciel fournit la quantité ponctuelle de biomasses sur chaque parcelle étudiée. Un système d'alerte, en feu tricolore offre une aide aux utilisateurs pour une éventuelle prise de décision sur la gestion des ressources fourragères. Il devient possible à partir de cet outil d'affirmer que les indices de végétation peuvent être utilisés pour la détermination de capacité de charge animale et de l'état de valorisation des parcelles de pâturage. Ce logiciel représente une grande innovation dans les systèmes d'élevage malgache pour la gestion des ressources fourragères à une échelle territoriale. Il sera possible de profiter au maximum de la disponibilité des ressources pour une plus grande contribution de l'élevage dans le développement du pays. Des perspectives sont déjà envisagées comme la conception mensuelle d'une carte de disponibilité des ressources dans les zones clés de l'élevage malgache. Il serait recommandable d'élargir le travail à d'autres espèces végétales et de les introduire dans les bases de données du logiciel. Ou encore, l'inventaire à l'échelle nationale des ressources disponibles dans l'outil pour une évaluation prospective de la situation fourragère.

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RÉFÉRENCES

Andriarimalala, H. J. 2014. Étude floristique de *Brachiaria* sp., *Chloris pennisetum purpureum* et élaboration d'un modèle d'estimation de leur productivité par télédétection. Unpubl. MS thesis, Université d'Antananarivo, École Supérieure des Sciences Agronomiques. Département Élevage. Disponible en ligne <<http://biblio.univ-antananarivo.mg/pdfs/andriarimalalaHerilalaoJ_AGRO_M2_14.pdf>

Archimède, H., Sauvant, D., Assoumaya, C., Fanchone, A. et Boval, M. 2009. Fourrages tropicaux : Valeur alimentaire comparée aux fourrages tempérés et évaluation au pâturage. .Rencontres Recherches Ruminants 16: 17–24. Disponible en ligne <http://journees3r.fr/IMG/pdf/2009_01_01_Archimede.pdf>

Barbet-Massin, V., Grimaud, P., Michon, A. et Thomas, P. 2004. Guide Technique pour la Création, la Gestion et la Valorisation des Prairies à la Réunion. Disponible en ligne <http://publications.cirad.fr/une_notice.php?dk=522332>

Bolton, J. K. & Brown, R. H. 1980. Photosynthesis of grass species differing in carbon dioxide fixation pathways: V. Response of *Panicum maximum*, *Panicum milioides*, and tall fescue (*Festuca arundinacea*) to nitrogen nutrition. Plant Physiology 66, 1: 9–100. <https://doi.org/10.1104/pp.66.1.97>

Boudet, G. 1975. Problèmes posés par l'estimation de la capacité de charge d'un pâturage naturel tropical. In: Inventaire et Cartographie des Pâturages Tropicaux Africains, Actes du Colloque de Bamako, Mali (3–8 mars 1975), pp 265–267. Institut d'Élevage et de Médecine Vétérinaire des Pays Tropicaux, Maison-Alfort, France. Disponible en ligne <http://bit.ly/2H5Q2XS>

Coughenour, M. B. et Makkar, H. P. S. 2014. La conduite d'évaluations nationales des aliments pour animaux. Manuel de Production et de santé animale FAO N. 15. Rome, Italie. Disponible en ligne <http://bit.ly/2I3xb0Y>

Dulphy, J. P., Demarquilly, C., Henry, M., Jailler M. et Jamot, J. 1975. Perte de composés volatils lors de la détermination à l'étuve de la teneur en matière sèche des ensilages. Annales de Zootechnie 24, 4: 743–756. Disponible en ligne <https://hal.archives-ouvertes.fr/hal-00887512/document>

Guérif, M. et Seguin, B. 1991. Estimation de la biomasse et du rendement des cultures à partir du satellite SPOT: Résultats d'une expérimentation sur blé dur en Camargue. Séminaire Méditerranéens 4: 115–127. Disponible en ligne <http://om.ciheam.org/article.php?IDPDF=CI911187>

Hervé, D. et Genin D. 1998. Capacité de charge animale ou indicateur de pression sur des ressources fourragères. Les Cahiers de la Recherche Développement, pp.38–49. Disponible en ligne <http://www.documentation.ird.fr/hor/fdi:010013720>

Holden, S. B. 1996. Cross-validation and the PAC Learning Model. Research Note RN/96/64, Department of CS, University College, London. Disponible en ligne <https://dl.acm.org/citation.cfm?id=238067>

Holechek, J. L., Pieper, R. D. & Herbel, C. H. 1995. Range Management: Principles and Practices, Second edition. Prentice-Hall, New Jersey, USA.

Jolliffe, P. A. & Tregunna, E. B. 1968. Effect of temperature, CO_2 concentration, and light intensity on oxygen inhibition of photosynthesis in wheat leaves. Plant physiology 43, 6: 902–906. <https://doi.org/10.1104/pp.43.6.902>

Kaufmann, J. C. 2008. The non-modern constitution of famines in Madagascar's spiny forests: "water-food" plants, cattle and Mahafale landscape praxis. Environmental Sciences 5, 2: 73–89. <https://doi.org/10.1080/15693430801912162>

Klein, H.-D., Rippstein, G., Huguenin J., Guerin, H., Toutain, B. et Louppe, D. 2014. Les Cultures Fourragères. Editions Quae, Versailles, France.

Le Mézo, L. 2012. Caractérisation de la ressource fourragère des prairies cultivées de la Réunion par image satellite. Ph.D. thesis. Agronomie Production Végétale Environnement, VetAgro Sup, CIRAD. Disponible en ligne <https://bit.ly/2pmI6uD>

Marcel, A. 1986. Capacité oxydative et résistance à la sécheresse de différentes plantes supérieures CAM-C3-C4 et de végétaux inférieurs. Bulletin de la Société Botanique de France. Lettres Botaniques 133, 3: 207–212. <http://dx.doi.org/10.1080/01811797.1986.10824702>

Ministère de l'Agriculture, de l'Élevage et de la Pêche 2004. Filières et Actions du Ministère de l'Agriculture, de l'Élevage et de la Pêche : Filière Lait. Fiche N. 202. Disponible en ligne <http://www.inter-reseaux.org/IMG/pdf_202_Filiere_Lait.pdf>

Ministère de l'Élevage à Madagascar. 2014. Statistiques des Cheptels à Madagascar. Rapport de la Direction des Ressources Animales. Disponible en ligne <http://www.mpae.gov.mg/donnees/statistique/>

Meneses-Tovar, C. L., 2011. L'indice différentiel normalisé de végétation comme indicateur de la dégradation. Unasylva 62, 2: 39–46. Disponible en ligne <http://www.fao.org/3/i2560f/i2560f07.pdf>

Mouret, P. 2012. Evaluation participative des stratégies d'évolution d'exploitations laitières dans la région Vakinankaratra - Madagascar. Mémoire d'ingénieur, Productions et innovations dans les systèmes techniques végétaux. AgroParisTech, Paris. Disponible en ligne <http://agritrop.cirad.fr/570246/>

Moussa, M. M. 2005. Application des Méthodes d'Évaluation de Rendements Agricoles à l'Aide des Images NDVI. Centre régional Agrhymet, Rapport de consultation, Niamey-Niger. Disponible en ligne <https://bit.ly/2mtmgUw>

Murata, Y., Iyama, J. & Honma, T. 1965. Studies on the photosynthesis of forage crops. IV. Influence of air-temperature upon the photosynthesis and respiration of alfalfa and several southern type forage crops. Japanese Journal of Crop Science 34, 2: 154–158. <https://doi.org/10.1626/jcs.34.154>

Nesrine, C. 2015. Méthodes de classification pour la cartographie de l'occupation du sol, Journée Etats de surface pour la spatialisation, Techniques d'observation et méthodes d'analyse pour la gestion de l'eau dans les bassins versants agricoles méditerranéens. Ecole d'Hiver, ENSEGID Bordeaux-INP. Disponible en ligne <https://bit.ly/2NUtd09>

Rahetlah, V. B., Salgado, P., Andrianarisoa, B., Tillard, E., Razafindrazaka, H., Le Mezo, L. & Ramalanjaona, V. L. 2014. Relationship between normalized difference vegetation index (NDVI) and forage biomass yield in the Vakinankaratra region, Madagascar. Livestock Research for Rural Development 26, 5: #95. <http://www.lrrd.org/lrrd26/5/rahe26095.html>

Rakotozandrindrainy, R., Razafindrajaona, J. M. et Foucras, G. 2007. Diagnostic rapide à la ferme des mammites subcliniques des vaches laitières du triangle laitier des hautes terres de Madagascar. Revue de Médecine Vétérinaire 158, 2: 100–105.

Razafindrakoto, H. A., 2010. Le dynamisme de l'élevage bovin dans la commune urbaine de Tsiroanomandidy, capitale du Bongolava. Unpbl. MS thesis. Université d'Antananarivo, Faculté des Lettres et Sciences Humaines. Disponile en ligne <https://bit.ly/2MMkQPY>

Ribot, J. J. 1982. Les comportements de l'éleveur et du zébu à Madagascar : l'adaptation du rôle et des actions du service de l'élevage à ces comportements. Terre Malgache. Tany Malagasy 21: 125–136. Disponible en ligne <https://bit.ly/2Dchru7>

Rouse Jr., J. W., Hass, R. H. ,Schell, J. A. & Deering, D. W. 1 974. Monitoring vegetation systems in the Great Plains with ERTS. NASA Goddard Space Flight Center 3d ERTS-1 Symp. 1 , A: 309–31 7. Disponible en ligne https://ntrs.nasa.gov/search.jsp?R=1 974002261 4>

Santin-Janin, H., Garel, M., Chapuis, J. L. & Pontier, D. 2009. Assessing the performance of NDVI as a proxy for plant biomass using non-linear models: a case study on the Kerguelen archipelago. Polar Biology 32, 6: 861–871. <https://doi.org/10.1007/s00300-009-0586-5>

Vall, E., Salgado, P., Corniaux, C., Blanchard, M., Dutilly, C. & Alary, V. 2014. Changements et innovations dans les systèmes d'élevage en Afrique INRA Productions Animales 27, 2: 161–174.

Waeber, P. O., Wilmé, L., Ramamonjisoa, B., Garcia, C., Rakotomalala, D., et al. 2015. Dry forests in Madagascar, neglected and under pressure. International Forestry Review 17, S2: 127–148. <http://dx.doi.org/10.1505/146554815815834822>

MATÉRIEL SUPPLÉMENTAIRE

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Tableau S1. Modèles et variables du Logiciel 3C-BIOVIS.

ARTICLE http://dx.doi.org/10.4314/mcd.v14i1.5

Additions to the geographical distribution of the Malagasy family Microcharmidae Lourenço 1996 (Scorpiones: Buthoidea) and description of three new species of *Microcharmus* Lourenço 1995

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ABSTRACT
A more up to date biogeographic analysis of the patterns of distribution presented by the scorpions of the family Microcharmidae Lourenço 1996 are presented. This family is revalidated here based on numerous morphological characters. This Malagasy group of scorpions is represented by two genera, *Microcharmus* Lourenço 1995 and *Neoprotobuthus* Lourenço 2000 both endemic to the Island. The family Microcharmidae seems to be restricted to dry and wet forests formations in the northern and northwestern portions of the island. Here we describe three species new to science: *Microcharmus andrei* sp. n., *Microcharmus antongil* sp. n. and *Microcharmus djangoa* sp. n. The distribution of these new species seems to be restricted to the northern range of Madagascar, in habitats ranging from dry to wet forests, confirming therefore the patterns previously observed.

RÉSUMÉ
Une analyse biogéographique à jour portant sur les schémas de distribution des scorpions de la famille des Microcharmidae Lourenço 1996 est présentée. La famille est ici revalidée sur la base de nombreux caractères morphologiques. Ce groupe de scorpions de Madagascar est représenté par deux genres, *Microcharmus* Lourenço 1995 et *Neoprotobuthus* Lourenço 2000 tous deux endémiques de l'île. La famille des Microcharmidae semble avoir une distribution limitée aux formations forestières sèches et humides des parties nord et nord-ouest de l'île. Ici, nous décrivons trois espèces nouvelles pour la science : *Microcharmus andrei* sp. n., *Microcharmus antongil* sp. n. et *Microcharmus djangoa* sp. n. La distribution de ces trois nouvelles espèces semble limitée à la partie septentrionale de Madagascar, dans des habitats allant des forêts sèches à humides, ce qui confirme ainsi les schémas préalablement observés.

INTRODUCTION
As already outlined in previous publications humiculous scorpions living in organic soil are rare in most regions of the world (Vachon 1974, Lamoral 1976, Lourenço 1998, 2003, 2004, 2005, Lourenço et al. 2006, Rossi and Lourenço 2015). In Madagascar, the most characteristic soil scorpions belong to the family Microcharmidae Lourenço which is represented by two genera *Microcharmus* Lourenço and *Neoprotobuthus* Lourenço. The genus *Microcharmus* was described by Lourenço (1995), based on one new species *Microcharmus cloudsleythompsoni* Lourenço having as holotype one female specimen collected by the Professor Jacques Millot in the region of Zangoa in the northwest of Madagascar in 1947 (Lourenço 1995). It is unclear however, how this specimen was collected or obtained, since no specific information was provided in the labels. No matter, in this same year of 1947 J. Millot collected a second specimen on the Island of Nosy Be which was described as *Microcharmus jussarae* Lourenço 1996 (Lourenço 1996a). This species was apparently collected under a piece of bark found in the soil. Coincidently two other species were described also in 1996, *Microcharmus hauseri* Lourenço and *Microcharmus sabineae* Lourenço, respectively from Nosy Be and the Marojejy Mountain. In both cases the specimens were obtained with the use of extractions methods of the Berlese type (Lourenço 1996a,b).

In the following years, two other genera were described in the family Microcharmidae, *Neoprotobuthus* Lourenço 2000 and *Ankaranocharmus* Lourenço 2004 (Lourenço 2000, 2004). Subse-

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quently, the validity of the genus *Ankaranocharmus* was questioned and this genus was placed in the synonymy of *Microcharmus* (Lourenço et al. 2006).

After the description of the first species in the family Microcharmidae in 1995 (Lourenço 1995), the slow pace of new descriptions was largely associated with the difficulties of collecting. In fact, these scorpions are difficult to collect by ordinary methods as rock-rolling, pit-fall traps and even the use of UV light mainly due to their minute sizes, apparently low vagilities and cryptic behaviors. Finally, thanks to precise systematic invertebrate surveys at several sites in Madagascar mainly by B. L. Fisher and colleagues of the California Academy of Sciences, but also a team of Malagasy field biologists, a first global synthesis on this scorpion group was possible (Lourenço et al. 2006). Until this main revision of the group, seven species were recognized in the genus *Microcharmus*, while *Neoprotobuthus* was monotypic. With the new descriptions the number of species and subspecies of *Microcharmus* was raised to 15.

Since this main revision, almost no new element was added to the family Microcharmidae. The single exception being the description of a new species *Microcharmus henderickxi* Lourenço 2009 found however in Copal (Lourenço 2009).

In this paper three new species are described, and some biogeographical aspects are proposed for this family.

METHODS

Illustrations and measurements were produce using a Wild M5 stereo-microscope with a drawing tube and ocular micrometer (at 25 and 50x). Measurements follow Stahnke (1970) and are given in mm. Trichobothrial notations follow Vachon (1974, 1975), and morphological terminology mostly follows Vachon (1952), Hjelle (1990). Hemispermatophore terminology mostly follows Lamoral (1979). Specimens used in this taxonomic contribution are now deposited in the Muséum national d'Histoire naturelle, Paris, France (MNHN).

The characters color and pigmentation are the most conspicuous external ones in scorpions, especially amongst buthoids. These are largely used for in taxonomy of several groups of microbuthoids. It is important to distinguish two aspects of coloration. One is the color of the cuticle itself, which can vary from clear (transparent) to black. Among some scorpions, coloration changes with the age. Juvenile stages of several species are variegated yellow, whereas the adults are black. A second type of coloration is due to the presence of sub-cuticular pigments, which form a variety of configurations or etched-like patterns over the body, pedipalps, and chelicerae. This second type of pigmentation does not normally change with age, but it can be masked by sclerification (Lourenço 1983, Lourenço and Cloudsley-Thompson 1996). In the case of microbuthoid scorpions, color and pigments are very useful characters for species identification, as is the case for other scorpion genera such as *Ananteris* (Lourenço 1982) and *Tityobuthus* (Lourenço 1996a). In the present study, the diagnosis and descriptions of the different new taxa were largely based on precise patterns of pigmentation.

TAXONOMIC POSITION OF THE FAMILY MICROCHARMIDAE

Among the new genera described for the Malagasy fauna since 1995 (Lourenço 1995) *Microcharmus* appears as one of the most remarkable discoveries. Initially, this genus was placed in the family Buthidae, but soon after, and in view of some notable distinct characters, it was accommodated in a new subfamily Microcharminae (Lourenço 1996a). Subsequent new analysis led the subfamily to be raised to the familial rank (Lourenço 1998); this decision was supported by the discoveries of new taxa within the Microcharmidae and in particular a second genus *Neoprotobuthus* Lourenço (Lourenço 2000). Further data to support the position of this family was also provided by the analysis of several characters with the use of Scanning Electron Microscopy technics (SEM). Detailed results based on about ten characters were presented first by Lourenço (2002a) and again by Lourenço et al. (2006).

Subsequently some authors rejected the validity of the family Microcharmidae, but in many cases this divergence of opinion was not globally justified. In a publication treating on the comparative anatomy of the mesosomal organs of scorpions, Volschenk et al. (2008) reached to the conclusion that Microcharmidae presented the same characteristics of several other buthid genera. Consequently, they considered it as a synonym of Buthidae. To justify their opinion, these authors stated as follows: "Our observations on the ovariuterine anatomy also support mounting evidence that the genus *Microcharmus* Lourenço 1996, currently placed in a unique family, Microcharmidae Lourenço 1996, is a buthid (…) We observed the complex open form of the eight-celled ovariuterus in *M. pauliani ambre* and two buthids, *Babycurus jacksoni* (Pocock 1890) and *Lychas tricarinatus. Microcharmus* also lacks lateral lymphoid organs, which is another buthid characteristic. These anatomical characters support numerous external morphological characters (e.g. the presence of the type-A trichobothrial pattern on the pedipalps) otherwise unique to Buthidae, [from which Microcharmidae is separated principally on the basis of size and ecology] (Lourenço 2000b). The balance of evidence does not, in our opinion, warrant continued recognition of Microcharmidae, which renders Buthidae paraphyletic (E. S. Volschenk & L. Prendini, unpubl. data). We therefore propose the following new synonymy: Microcharmidae Lourenço 1996 = Buthidae C.L. Koch, 1837."

It seems obvious that this character taken from the type of ovariuterus found in Microcharmidae and Buthidae attests to the close relationships between these two families. In fact, from the beginning Lourenço (1998, 2000, 2002a, Lourenço et al. 2006) considered Microcharmidae within a buthoid group together with buthids. What, however is not acceptable is the fact that Volschenk et al. (2008) globally ignore all the characters used by Lourenço (2002a) and Lourenço et al. (2006) to justify the family Microcharmidae, stating that the family was based "principally on the basis of size and ecology" what is incorrect. In the publication by Volschenk et al. (2008), other unjustified contradictions can also be noticed. One peculiar example calls the attention: On page 667, the authors stated as follows: "Lourenço (2002) speculated that *Lisposoma* would possess well-developed diverticulae like other scorpionoid taxa, contrary to Stockwell (1989) and Prendini (2000)." This statement is not only incorrect, but can also be considered bizarre since in the article by Lourenço (2002b), or any other article even published by this author, the genus *Lisposoma* was never treated or discussed.

In conclusion, we revalidate the family Microcharmidae at present and the diagnostic characters already used in the previous diagnosis are listed again here below. For some characters, especially those taken from the morphology of hemispermatophores, new observations were done for other species than those cited both by Lourenço (2002a) and Lourenço et al. (2006).

DIAGNOSIS FOR THE FAMILY MICROCHARMIDAE

Scorpions of small size, ranging from 8 to 18 mm in total length. Carapace: anterior margin with a weak concavity or straight; carinae and granulations generally very weak; furrows inconspicuous; median ocular tubercle distinctly located on the anterior third of the carapace; three pairs of lateral eyes (in one case only two pairs). Sternum pentagonal; one median carina moderate or sometimes weak in all tergites. Tergite VII pentacarinate. Pectines, generally moderate to small in size, although may be larger in some taxa; the distal extremity or distal tooth is always rounded (diagnostic character); basal middle lamellae of the pectines not dilated; fulcra absent. Images made with a scanning electron microscope (Lourenço 2002a; Lourenço et al. 2006) show that the peg-shaped sensillae of the pectines have a rounded structure (diagnostic character), somewhat bottle-shaped. Most buthid groups, by comparison, have very short peg-shaped sensillae with a spatula-shaped structure. Sternites with short, oval or semi-oval spiracles (diagnostic character); in only a few species are these completely oval to round. Metasoma: all segments show strongly marked carinae; in some species dorsal and latero-dorsal carinae of segments II to IV present one posterior spinoid granule. Telson with a very elongated pear-shaped structure, smooth with strong setation; aculeus short, weakly curved; subaculear tooth absent. Cheliceral dentition characteristic of buthoid; fixed finger with two well-marked basal teeth; movable finger with external distal tooth shorter than internal distal tooth, and two very weak and sometimes fused basal teeth. Internal face of pedipalp patella with two to six spinoid granules; fixed and movable fingers of pedipalp chela with six to seven almost linear rows of granules; two accessory granules present at the base of each row; extremity of fixed and movable fingers with one long and sharp denticle. Trichobothriotaxy; orthobothriotaxy A-alpha. Legs: tarsus with numerous fine ventrally-located median setae. Pedal spurs reduced in general; tibial spurs reduced to absent on leg III, and moderate to absent on leg IV. Hemispermatophore: Two basic types of spermatophores or hemispermatophores have been initially defined for scorpions (Hjelle 1990): flagelliform and lamelliform. The first one being typical of the buthids and the second type to all the other scorpion families. Stockwell (1989) defined a third type, fusiform, restricted to the family Chaerilidae. A distinct type was also described for the Pseudochactidae family (Prendini et al. 2006). The flagelliform type is defined by a rather long and thin trunk terminating in its distal portion by a long filament referred to as the flagellum. The few studies carried out on the structure of the microcharmid hemispermatophore (3-4 species examined) indicate that it is somewhat different from the typical flagelliform type. The trunk is somewhat elongated, but larger at its base; a truncal flexure is not clearly observed, and two structures, the small hook and the flagellum, appear to be absent from the distal portion; in fact the flagellum if present is clearly reduced (diagnostic character). However, the study of more species would be necessary to conclusively define this kind of spermatophore, but the preliminary results indicates that these are rather simple in microcharmids. The type presented by the species of this family could be the primitive form leading to the evolution of the different types.

TAXONOMY

Family Microcharmidae Lourenço 1996
Genus *Microcharmus*, Lourenço 1996

DESCRIPTION OF THREE NEW SPECIES

Microcharmus andrei sp. n. (Figures 1–6)
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<http://zoobank.org/NomenclaturalActs/C3920C03-C96C-45AE-8358-7CB5FCF11FF9>

Type Material: Madagascar, Mardutsara (= Mandritsara), Wet Forest, IX/1957 (J. Millot leg.), 1 male holotype, 1 male paratype. Types deposited in the Muséum, national d'Histoire naturelle, Paris, France.

Etymology: The specific name honors André Peyrieras (1927–2018) who strongly contributed to the natural sciences knowledge of Madagascar.

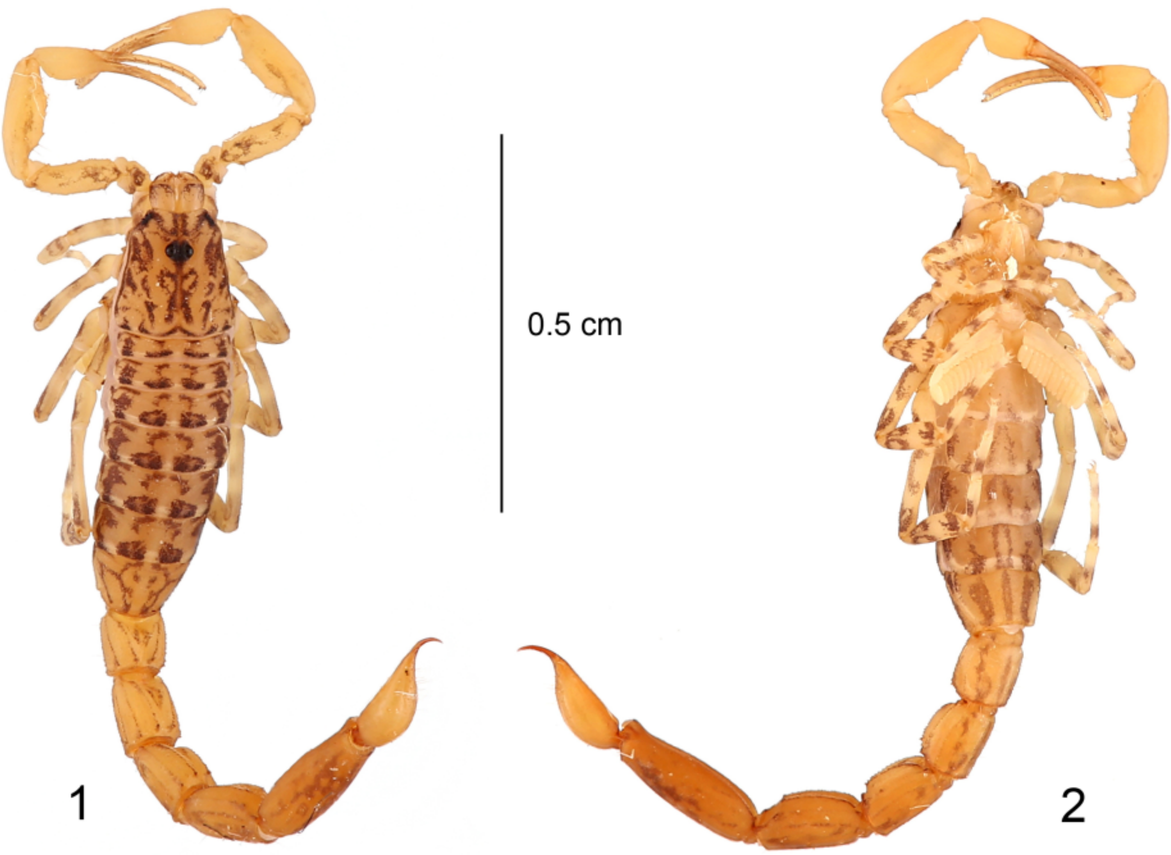
Diagnosis: Scorpions of moderate size when compared with most species of the genus *Microcharmus*, with 14.10 mm of total length for the male holotype (see morphometric values). General coloration yellow with variegated spots over body and appendages. Carinae and granulations moderately marked on body and appendages.

Relationships: The new species shows some affinities with *Microcharmus variegatus* Lourenço, Goodman and Fisher 2006 but can be distinguished from this last species by a much less intense pigmentation on the body and appendages. In particular (i) a ventral aspect much less spotted, (ii) pedipalps almost spotless with only the chela-fingers darker, (iii) chelicerae yellow but much more densely spotted than in *M. variegatus*.

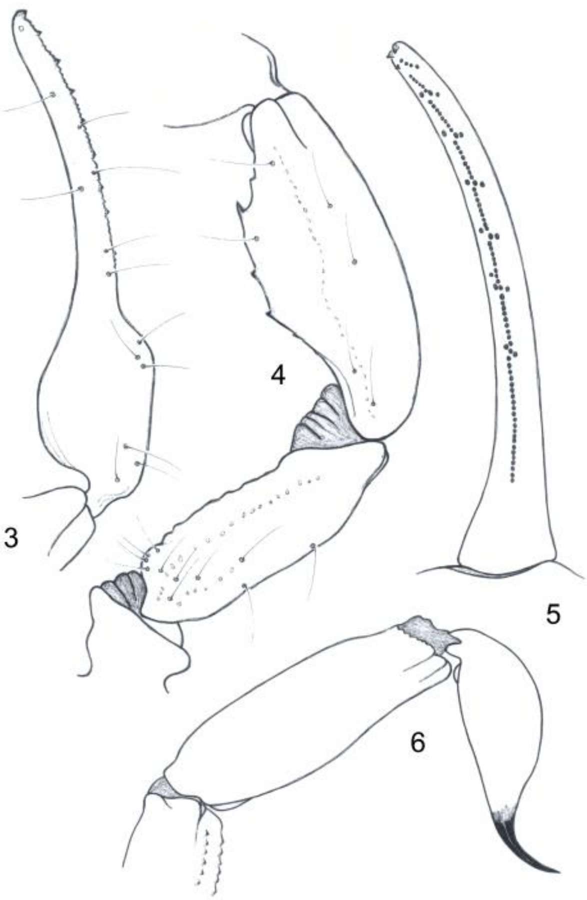
Description based on Male holotype and male paratype.

Coloration. Basically yellow with dark variegated spots over the body and appendages. Carapace, tergites, metasomal segments, and vesicle with variegated spots; pedipalp femur and patella inconspicuously spotted; chela hand yellow without spots; proximal two-thirds of fingers dark and the extremity yellow; chelicerae yellow with variegated spots on its entire surface; fingers and teeth yellow with some dark spots; venter with inconspicuous variegated spots on coxapophysis, sternum and genital operculum; spots better marked on sternites; legs more heavily spotted.

Morphology. Carapace with moderately marked granulation; anterior margin with a moderate concavity. Carinae weak; furrows inconspicuous. Median ocular tubercle located distinctly on the anterior third of the carapace; median eyes separated by approximately one ocular diameter. Three pairs of lateral eyes. Sternum pentagonal. Mesosoma: tergites with a thin granulation. Median carina moderate to weak in all tergites. Tergite VII pentacarinate. Venter: genital operculum divided longitudinally, each plate with a more or less triangular shape. Pectines moderate to small: pectinal tooth count 12-12 for both holotype and paratype; basal middle lamellae of the pectines not dilated; fulcra absent. Sternites with some minor granulations, almost smooth, and with small oval spiracles; VII slightly more granulated and with vestigial carinae. Metasoma: segments I to III with ten carinae, crenulate; segment IV with eight carinae and ventral carinae vestigial; intercarinal spa-



Figures 1–2. *Microcharmus andrei* sp. n. Male holotype. Habitus, dorsal and ventral aspects.



Figures 3–6. *Microcharmus andrei* sp. n. Male holotype. 3–4. Trichobothrial pattern. 3. Chela, dorso-external aspect. 4. Femur and patella, dorsal aspect. 5. Cutting edge of movable finger showing rows of granules. 6. Metasomal segment V and telson, lateral aspect.

ces weakly granular. Segment V rounded with 5 carinae. Telson with an elongated pear-shaped structure, smooth with moderate setation; aculeus short and weakly curved; subaculear tooth absent. Cheliceral dentition characteristic of buthoid (Vachon 1963); fixed finger with two strong basal teeth; movable finger with two very weak but fused basal teeth; ventral aspect of both finger and manus with dense, long setae. Pedipalps: femur pentacarinate; patella with vestigial carinae; internal face of patella with four to five spinoid granules; chela without carinae, smooth; all faces weakly granular to smooth. Fixed and movable fingers with seven almost linear rows of granules; two accessory granules present at the base of each row; extremity of fixed and movable fingers with one long and sharp denticle. Trichobothriotaxy; orthobothriotaxy A-alpha (Vachon 1974, 1975). Legs: tarsus with very numerous fine ventral median setae. Pedal spurs reduced; tibial spurs vestigial on legs III and weak on IV.

Morphometric measurements (in mm) of the male holotype.

Total length, 14.1. Carapace: length, 1.7; anterior width, 1.1; posterior width, 1.7. Mesosoma length, 3.8. Metasomal segments I: length, 0.9; width, 0.9. II: length, 1.1; width, 0.8. III: length, 1.2; width, 0.7. IV: length, 1.4; width, 0.7. V: length, 2.2; width, 0.7; depth, 0.8. Telson length, 1.8; vesicle: width, 0.6; depth, 0.5. Pedipalp: femur length, 1.3, width, 0.4; patella length, 1.5, width, 0.6; chela length, 2.2, width, 0.4, depth, 0.4; movable finger length, 1.6.

Distribution: Only known from the type locality.

Microcharmus antongil sp. n. (Figures 7–13)

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<http://zoobank.org/NomenclaturalActs/646F87DB-6083-48B1-A7FB-09C5011D150C>

Type Material: Madagascar, Baie d'Antongil, Tanjona-Masoala, NW Vinanivao, dense wet forest, XI/1969 (J.-M. Betsch), collected with Berlese, 1 female holotype. Type deposited in the Muséum national d'Histoire naturelle, Paris, France.

Etymology: The specific name is placed in apposition to the generic name and refers to the type locality of the new species.

Diagnosis: Scorpions of moderate size when compared with most species of the genus *Microcharmus*, with 15.8 mm in total length for the female holotype (see morphometric values). General coloration yellow to slightly reddish-yellow with variegated spots over the body and appendages. Carinae and granulations moderately marked on body and appendages. Anterior margin of carapace straight.

Relationships: The new species shows some affinities with *Microcharmus variegatus* Lourenço, Goodman and Fisher 2006 but can be distinguished from this last species by a quite distinct pattern of pigmentation. Both species show a more or less intense variegated pigmentation of the body and appendages but differ in the following aspects: (i) sternites and ventral aspect of metasoma much less spotted in the new species, (ii) coxapophysis darker in the new species, (iii) Anterior margin of carapace straight in the new species whereas in *M. variegatus* it shows a strong concavity, (iv) metasomal segments I-IV with 10 carinae.

Description based on female holotype

Coloration. Basically yellow to slightly reddish-yellow with dark variegated spots over the body and appendages. Carapace, tergites, metasomal segments, and vesicle with variegated dark spots, strongly marked on metasomal carinae; pedipalp femur and patella intensely marked with dark spots, except on the zones where trichobothria are inserted; chela hand yellow without minute spots; proximal two-thirds of fingers dark and the extremity yellowish; chelicerae yellow with dark spots on base of the fingers; fingers and teeth yellowish without spots; venter with variegated spots strongly marked on coxapophysis and sternum; sternites weakly spotted; legs heavily spotted.

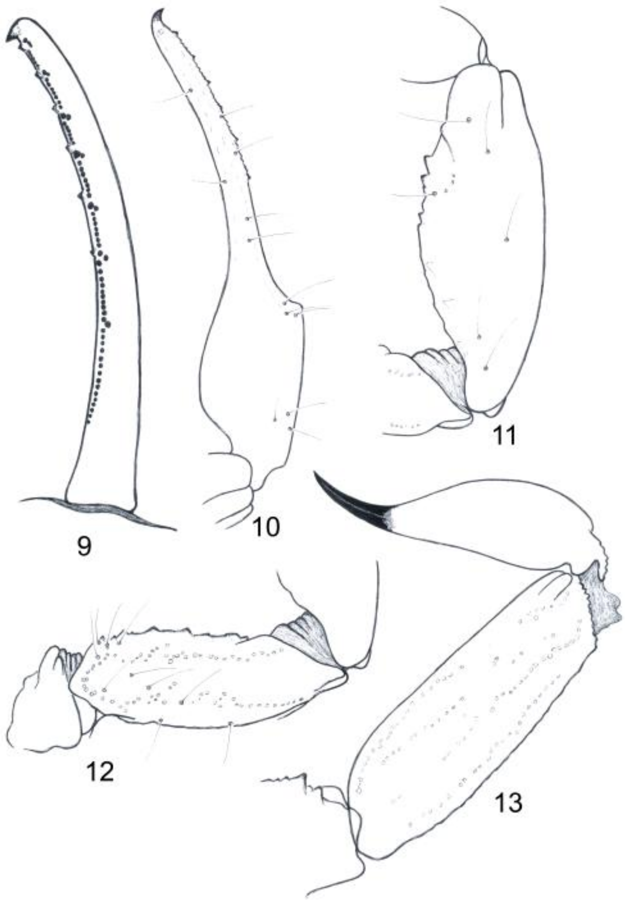
Morphology. Carapace with moderately marked granulation; anterior margin straight. Carinae weak; furrows inconspicuous. Median ocular tubercle located distinctly on the anterior third of the carapace; median eyes separated by one ocular diameter. Three pairs of lateral eyes. Sternum pentagonal. Mesosoma: tergites with a thin granulation. Median carina moderate to weak in all tergites. Tergite VII pentacarinate. Venter: genital operculum divided longitudinally, each plate having a semi-oval to semi-triangular shape. Pectines small: pectinal tooth count 7-8 for female holotype; basal middle lamellae of the pectines not dilated; fulcra absent. Sternites with some minute granulations, almost smooth, and with short oval spiracles; VII with vestigial carinae. Metasoma: segments I to IV with ten carinae, crenulate; intercarinal spaces weakly granular. Segment V rounded but strongly granular and with 5 carinae. Telson with a very elongated pear-shaped structure, smooth with moderate setation; aculeus short and very weakly curved; subaculear tooth absent. Cheliceral dentition characteristic of buthoid (Vachon 1963); fixed finger with two strong basal teeth; movable finger with two very weak but not fused basal teeth; ventral aspect of both finger and manus with dense, long setae. Pedipalps: femur pentacarinate; patella with vestigial carinae; internal face of patella with four to five spinoid granules; chela without carinae, smooth; all faces weakly granular to smooth. Fixed and movable fingers with seven almost linear rows of granules; two accessory granules present at the base of each row; extremity of fixed and movable fingers with one long and sharp denticle. Trichobothriotaxy; orthobothriotaxy A-alpha (Vachon 1974, 1975). Legs: tarsus with very numerous fine ventral median setae. Pedal spurs reduced; tibial spurs absent on leg III and weak on leg IV.

Morphometric measurements (in mm) of the female holotype

Total length, 15.8. Carapace: length, 2.1; anterior width, 1.3; posterior width, 2.2. Mesosoma length, 4.5. Metasomal segments I: length, 0.8; width, 1.2. II: length, 1.1; width, 1.1. III: length, 1.2; width, 1.0. IV: length, 1.4; width, 1.0. V: length, 2.5; width, 0.9; depth, 0.8. Telson length, 2.2; vesicle: width, 0.6; depth, 0.6. Pedipalp: femur length, 1.7, width, 0.6; patella length, 2.2, width, 0.7; chela length, 2.8, width, 0.6, depth, 0.6; movable finger length, 1.8.

Distribution: Only known from the type locality.

Figures 7–8. *Microcharmus antongil* sp. n. Female holotype. Habitus, dorsal and ventral aspects.



Figures 9–13. *Microcharmus antongil* sp. n. Female holotype. 9. Cutting edge of movable finger showing rows of granules. 10–12. Trichobothrial pattern. 10 Chela dorso-external aspect. 11. Patella, dorsal aspect. 12. Femur, dorsal aspect. 13. Metasomal segment V and telson, lateral aspect.

Microcharmus djangoa sp. n. (Figures 14–19)

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<http://zoobank.org/NomenclaturalActs/83BBA31B-FA5B-4FC8-9BB2-08E5ABD29BC9>

Type Material: Madagascar, Road between Djangoa and Maromandia, 3 km S of Djangoa, transition between wet forest and dry forest, IX/2001 (W. Lourenço), 1 female holotype. Type deposited in the Muséum national d'Histoire naturelle, Paris, France.

Etymology: The specific name is placed in apposition to the generic name and refers to the type locality of the new species.

Diagnosis: Scorpions of moderate size when compared with most species of the genus with 14.4 mm in total length for female holotype (see morphometric values). General coloration dark yellow, with moderately marked dark spots; spotting pattern less marked on pedipalps and ventral aspect of metasoma. Carinae and granulations moderately marked on body and appendages. Femur trichobothrium e1, distal in relation to trichobothrium d5.

Relationships: The new species shows some affinities with *Microcharmus maculatus* Lourenço, Goodman and Fisher 2006 but can be distinguished from this last species by a distinct pattern of pigmentation. Both species show a more or less intense variegated pigmentation of the body and appendages but differ in the following aspects: (i) sternites and ventral aspect of metasoma much less spotted in the new species, (ii) pedipalps less spotted in the new species, (iii), in the new species the femur trichobothrium e1, is distal in relation to trichobothrium d5 (iv) tibial spurs absent on leg III and moderate on leg IV.

Description based on female holotype

Coloration. Basically yellow with dark spots over the body and appendages; spots moderately marked on ventral aspect of metasomal segments and pedipalps; vesicle without spots. Carapace with dense variegated blackish spots; tergites with confluent spots; metasomal segments paler than carapace, yellowish with diffused spots. Venter weakly spotted, marbled on coxapophysis, sternum, genital operculum and sternites; pectines with only two minute diffused spots; chelicera yellow with variegated spots over almost the entire surface.

Morphology. Carapace with a weakly marked granulation; anterior margin with a moderate concavity. Carinae weak; furrows inconspicuous. Median ocular tubercle distinctly on the anterior third of the carapace; median eyes separated by less than one ocular diameter. Three pairs of lateral eyes. Sternum pentagonal. Mesosoma: tergites moderately to weakly granular. Median carina moderate to weak in all tergites. Tergite VII pentacarinate. Venter: genital operculum divided longitudinally, each plate more or less triangular in shape. Pectines moderately large: pectinal tooth count 11-11 in female holotype; basal middle lamellae of the pectines not dilated; fulcra absent. Sternites smooth with short oval spiracles; VII with a few granulations and vestigial carinae. Metasoma: segments I to III with ten carinae, crenulate; IV with eight carinae; intermediate carinae incomplete; ventral carinae vestigial on segment IV; intercarinal spaces weakly granular. Segment V rounded with five carinae. Telson with a very elongated pear-shaped structure, smooth with moderate setation; aculeus short, weakly curved; subaculear tooth absent. Cheliceral dentition characteristic of the buthoids (Vachon 1963); fixed finger with two moderate basal teeth; movable finger with two very weak and almost fused basal teeth; ventral aspect of both finger and manus with dense, long setae. Pedipalps: femur pentacarinate; patella with some vestigial carinae; internal face of patella with three to four weakly spinoid granules; chela smooth; all faces weakly granular to smooth. Fixed and movable fingers with seven almost linear rows of granules; two accessory granules present at the base of each row; extremity of fixed and movable fingers with one long and sharp denticle. Trichobothriotaxy; orthobothriotaxy A-alpha (Vachon 1974, 1975). Legs: tarsus with very numerous fine median setae ventrally. Pedal spurs reduced; tibial spurs absent on leg III and moderate on leg IV.

Morphometric measurements (in mm) of the female holotype

Total length, 14.4. Carapace: length, 1.8; anterior width, 1.2; posterior width, 2.0. Mesosoma length, 3.8. Metasomal segments I: length, 0.9; width, 1.1. II: length, 1.1; width, 1.0. III: length, 1.2; width, 0.9. IV: length, 1.4; width, 0.8. V: length, 2.3; width, 0.8; depth, 0.8. Telson length, 2.1; vesicle: width, 0.6; depth, 0.6. Pedipalp: femur length, 1.6, width, 0.5; patella length, 2.0, width, 0.8; chela length, 2.6, width, 0.5, depth, 0.5; movable finger length, 1.8.

Distribution: Only known from the type locality.

BIOGEOGRAPHY

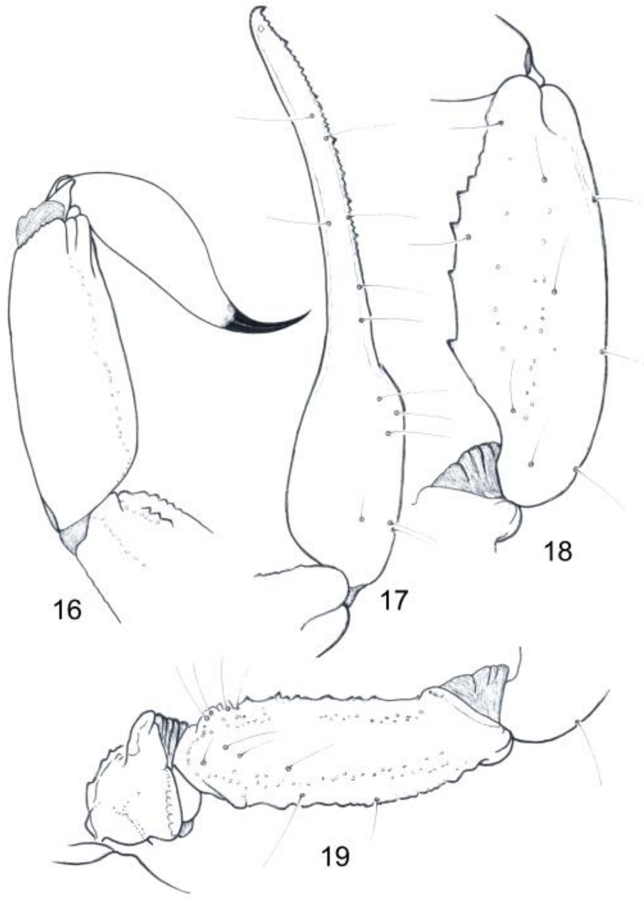
The three new species have been described from localities circumscribed in the known range of the genus *Microcharmus* (Figure 20).

Microcharmus djangoa sp. n. has been collected in a transitional subhumid forest in the Sambirano region. The Sambirano has experienced a monsoon regime with a significant increase in rainfall relatively recently, probably at the end of the Miocene or early Pliocene, about 5–4 million years ago (Wells 2007). The description of this new species brings the number of *Microcharmus* species in the Sambirano region to six. They are all distributed at low altitude over area of less than 150 km².

Microcharmus andrei sp. n. has been recorded from Mandritsara. Mandritsara is a town lying on patches of igneous rocks surrounded by metamorphic rocks. There are two types of vegetation encountered in the region, mainly western dry forests with some patches of humid forests encountered to the east of the city (Moat and Smith 2007). The label indicates a wet forest which could refer to the humid forest of the or the Réserve Spéciale du Tampoketsa d'Analamaitso some 60 km to the southwest of Mandritsara or to the humid forests of the Réserve Spéciale de Marotandrano lying at a similar distance from Mandritsara along a road. More patches of humid forests are also encountered to the northwest of Mandritsara along the Route nationale N. 32. The discovery of the species in this region is nevertheless interesting given that the genus was mainly known from a coastal belt before.

Microcharmus antongil sp. n. occurs on the Masoala peninsula where the mean annual rainfall is one of the highest in Madagascar, nevertheless similar to the rainfall reported on Montagne d'Ambre where *M. pauliani amber* has been collected. The distribution of *M. antongil* sp. n. extends the eastern known range of the *Microcharmus* ca. 100 km to the southeast. Peninsulas, like islands but to a lesser extent, are generally species-poorer (MacArthur and Wilson 1967). Given that the genus *Microcharmus*

Figures 14–15. *Microcharmus djangoa* sp. n. Female holotype. Habitus, dorsal and ventral aspects.



Figures 16–19. *Microcharmus djangoa* sp. n. Female holotype. 16. Metasomal segment V and telson, lateral aspect. 17–19. Trichobothrial pattern. 17. Chela, dorso-external aspect. 18. Patella, dorsal aspect. 19. Femur, dorsal aspect.

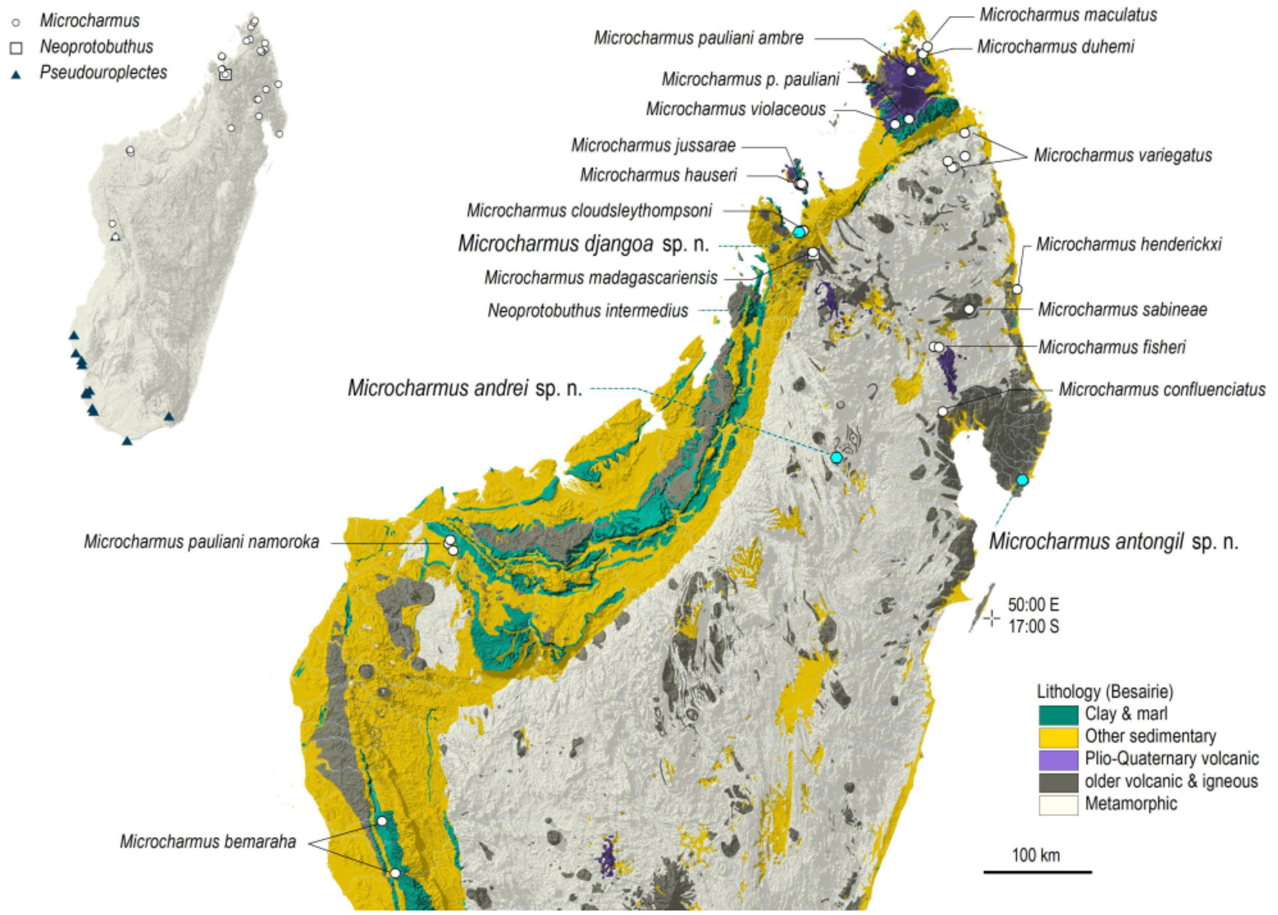


Figure 20. Distribution of the 20 species included in the family Microcharmidae, including the type localities of the three new species. (white circles for the species in the genus *Microcharmus*, white square for *Neoprotobuthus intermedius*, black triangle for the species in the genus *Pseudouroplectes* in the family Buthidae, the later only in the inset top left)

is already known from the island of Nosy Be, with two species, its presence on the Masoala peninsula is therefore not remarkable.

The scorpions belonging to the Microcharmidae and to the genus *Pseudouroplecetes* in the Buthidae family have retained a basal behavior in living in the upper humid soil surface (Lourenço et al. 2016).

The family Microcharmidae, mainly the genus *Microcharmus*, has a distribution that is reminiscent of an evolutionary radiation, with a common ancestor that is likely to have originated from the northern, narrow and elongated, part of the island where the diversity of vegetation types, climate, bioclimates, elevation is by far the highest on a relatively small area (Wilmé and Callmander 2006). *Microcharmus* is encountered in humid, subhumid and dry forests, in most bioclimates ranging from perhumid to almost subarid, including the humid, subhumid, dry bioclimates (Cornet 1974). The ancestral character retained by the Microcharmidae, i.e., the basal behavior in living in the upper humid soil surface (Lourenço et al. 2016), certainly allowed them to adapt to the diversity of environments encountered in northern Madagascar. The northern part of the island has experienced major changes in the last million years with several drastic phenomena, including Quaternary volcanism along the eastern part of the Masoala peninsula and to the northwest of the peninsula, in the southern part of the Sambirano region, and in Montagne d'Ambre (Figure 20). Another major change also occurred when Madagascar exited the Desert belt starting in the Eocene and its northern part entered the monsoon regime with an increase in rainfall, especially the orographic rains some 5 to 4 million years ago (Wells 2007). The great diversity of species in this family, which will certainly increase with new exploration of the island, has in parallel a great diversity in mor-

Table 1. Distribution of the genera in the families Microcharmidae and Buthidae. (colors according to humidity, blue = humid, green = humid—subhumid, yellow = dry, red = subarid)

	Northeast	East	Center	Southeast	South	Northwest	West
Microcharmidae	■					■	■
Microcharmus	■					■	■
Neoprotobuthus						■	
Buthidae	■	■	■	■	■	■	■
Grosphus	■	■	■	■	■	■	■
Neogrosphus					■	■	■
Palaeogrosphus	■						
Pseudouroplectes					■	■	■
Tityobuthus	■	■	■	■	■	■	■
Troglotityobuthus						■	

phology and ecology, also pointing towards a radiation. The range of the family Microcharmidae is limited to the north and to a lesser extent to the west of the island. It is much more restricted than the range of the closely related family Buthidae (Table 1).

The evolutionary radiation of the Microcharmidae in the north of the island is reminiscent of another group that could illustrate a similar case: the *Propithecus* for which the distribution pattern in the north is poorly explained (Wilmé and Callmander 2006, Wilmé et al. 2006, 2012, Waeber et al. 2015). In view of the pattern described for the Microcharmidae, one could nevertheless propose an ancestor of the smallest of the *Propithecus*, namely the western and southern species/subspecies *Propithecus verreauxi* sspp. in the north of the island. The events mentioned above over the past few million years could explain a population adaptation in the dry forests of the north-east (*Propithecus tattersalli*), limited to the north and south by the largest *Propithecus perrieri* and *Propithecus diadema*. In this scheme, a population could have adapted to the dry forests of the north-west (*Propithecus coquereli*) which could have disappeared from the Sambirano region or the entire northwest following a cataclysm, like the Quaternary volcanic activity. As in the case of the evolutionary radiation proposed for the Microcharmidae, with ancestral populations diversifying rapidly into several new forms after major changes in the environment and the opening of new niches, it is a hypothesis to test.

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REFERENCES

Cornet, A. 1 974. Essai de Cartographie Bioclimatique à Madagascar Vol. 55. ORSTOM, Paris. Available at <http://www.documentation.ird.fr/hor/fdi:06946>

Hjelle, J. T. 1990. Anatomy and morphology. In: The Biology of Scorpions, G. A. Polis (ed.), pp 9–63. Stanford University Press, Stanford.

Lamoral, B. H. 1976. *Akentrobuthus leleupi*, a new genus and species of humicolous scorpion from eastern Zaïre, representing a new subfamily of the Buthidae. Annals of the Natal Museum 22, 3: 681–691. Available at <https://journals.co.za/content/annals/22/3/AJA03040798_614>

Lamoral, B. H. 1979. The scorpions of Namibia (Arachnida: Scorpionida). Annals of the Natal Museum 23: 497–784. Available at <http://www.ub.ntnu.no/scorpion-files/lamoral_complete.pdf>

Lourenço, W. R. 1982. Révision du genre *Ananteris* Thorell, 1891 (Scorpiones, Buthidae) et description de six espèces nouvelles. Bulletin du Muséum national d'Histoire naturelle, Paris, 4e série 4, section A (1–2): 119–151. Available at <https://www.biodiversitylibrary.org/item/267975#page/1/mode/1up>

Lourenço, W. R. 1983. Importance de la pigmentation dans l'étude taxonomique des Buthidae néotropicaux (Arachnida, Scorpiones). Bulletin du Muséum national d'Histoire naturelle, Paris, 4e série 5, section A, 2: 611–618. Available at <https://www.biodiversitylibrary.org/item/268279#page/1/mode/1up>

Lourenço, W. R. 1995. Description de trois nouveaux genres et de quatre nouvelles espèces de scorpions Buthidae de Madagascar. Bulletin du Muséum national d'Histoire naturelle, Paris, 4e série, section A 17, 1–2: 95–106. Available at <http://bionames.org/bionames-archive/issn/0181-0626/17/95.pdf>

Lourenço, W. R. 1996a. Chelicerata, Scorpions. Faune de Madagascar 87. Muséum national d'Histoire naturelle, Paris.

Lourenço, W. R. 1996b. *Microcharmus hauseri*, nouvelle espèce de scorpion de Madagascar (Scorpiones, Buthidae). Revue Suisse de Zoologie 103, 2: 319–322. Available at <https://www.biodiversitylibrary.org/page/41267885#page/347/mode/1up>

Lourenço, W. R. 1998. Une nouvelle famille est nécessaire pour des microscorpions humicoles de Madagascar et d'Afrique. Comptes Rendus de l'Académie des Sciences, Sciences de la Vie 321, 10: 845–848. <https://doi.org/10.1016/S0764-4469(99)80024-9>

Lourenço, W. R. 2000. Un nouveau genre de scorpion malgache, maillon possible entre les Microcharmidae et les Buthidae. Comptes Rendus de l'Académie des Sciences, Paris, Sciences de la Vie 323, 10: 877–881. <https://doi.org/10.1016/S0764-4469(00)01234-8>

Lourenço, W. R. 2002a. Nouvelles données sur la morphologie et la biogéographie des *Microcharmus* Lourenço avec confirmation de la validité des Microcharmidae (Chelicerata, Scorpiones). Biogeographica 78, 1: 35–47.

Lourenço, W. R. 2002b. Reproduction in scorpions, with special reference to parthenogenesis. In: European Arachnology 2000. S. Toft and N. Scharff (eds.), pp 71–85. Aarhus University Press, Aarhus. Available at <https://bit.ly/2Yl53kS>

Lourenço, W. R. 2003. Humicolous buthoid scorpions; a new genus and species from French Guiana. Comptes Rendus Biologies 326, 12: 1149–1155. <https://doi.org/10.1016/j.crvi.2003.09.003>

Lourenço, W. R. 2004. Humicolous microcharmid scorpions: a new genus and species from Madagascar. Comptes Rendus Biologies 327, 1: 77–83. <https://doi.org/10.1016/j.crvi.2003.12.003>

Lourenço, W. R. 2005. Humicolous buthoid scorpions; a new species from Brazilian Amazon. Comptes Rendus Biologies 328, 10–11: 949–954. <https://doi.org/10.1016/j.crvi.2005.08.004>

Lourenço, W. R. 2009. A new sub-fossil scorpion of the genus *Microcharmus* Lourenço, 1995 from Malagasy copal (Scorpiones, Microcharmidae). Boletín de la Sociedad Entomológica Aragonesa 44: 135–137. Available at <http://sea-entomologia.org/PDF/BSEA44ARACNO/B44135.pdf>

Lourenço, W. R. and Cloudsley-Thompson, J. L. 1996. The evolutionary significance of colour, colour patterns and fluorescence in scorpions. Revue Suisse de Zoologie, hors série 2: 449–458. Available at <http://biostor.org/reference/140435>

Lourenço, W. R., Goodman, S. M. and Fisher, B. L. 2006. A reappraisal of the geographical distribution of the endemic family Microcharmidae Lourenço (Scorpiones) in Madagascar and description of eight new species and subspecies. Proceedings of the California Academy of Sciences, 4th Ser., 57, 26: 751–783. Permalink <http://direct.biostor.org/reference/144003>

Lourenço, W. R., Wilmé, L. and Waeber, P. O. 2016. More about the geographical pattern of distribution of the genus *Pseudouroplectes* Lourenço, 1995 (Scorpiones: Buthidae) from Madagascar. Comptes Rendus Biologies 339, 1: 37–43. <https://doi.org/10.1016/j.crvi.2015.11.001>

MacArthur, R. H. and Wilson, E. O. 1967. The Theory of Island Biogeography. Princeton University Press.

Moat, J. and Smith, P. (eds.) 2007. Atlas of the Vegetation of Madagascar. Atlas de la Végétation de Madagascar. Kew Publishing, Royal Botanic Gardens, Kew, Richmond, UK.

Prendini, L., Volschenk, E., Maaliki, S. and Gromov, A. V. 2006. A 'living fossil' from Central Asia: The morphology of *Pseudochactas ovchinnikovi* Gromov, 1998 (Scorpiones: Pseudochactidae), with comments on its phylogenetic position. Zoologischer Anzeiger 245, 3–4: 211–248. <https://doi.org/10.1016/j.jcz.2006.07.001>

Rossi, A. and Lourenço, W. R. 2015. New comments on the scorpions belonging to the '*Ananteris* group' and description of a new genus and species from Ghana (Scorpiones: Buthidae). Onychium 11: 3–9. Available at <https://bit.ly/2GqD3Sz>

Stahnke, H. L. 1970. Scorpion nomenclature and mensuration. Entomological News 81: 297–316.

Stockwell, S. A. 1989. Revision of the Phylogeny and Higher Classification of Scorpions (Chelicerata). Ph.D. Dissertation, University of California, Berkeley.

Vachon, M. 1952. Études sur les Scorpions. Institut Pasteur d'Algérie, Alger. Available at <https://www.ntnu.no/ub/scorpion-files/vachon.php>

Vachon, M. 1963. De l'utilité, en systématique, d'une nomenclature des dents des chélicères chez les scorpions. Bulletin du Muséum national d'Histoire naturelle, 2e série, 35: 161–166. Available at <https://www.biodiversitylibrary.org/page/55054519#page/167/mode/1up>

Vachon, M. 1974. Étude des caractères utilisés pour classer les familles et les genres de Scorpions (Arachnides). 1. La trichobothriotaxie en arachnologie. Sigles trichobothriaux et types de trichobothriotaxie chez les Scorpions. Bulletin du Muséum national d'Histoire naturelle, Paris, Paris, 3e série, 140, Zoologie 104: 857–958. Available at <http://bionames.org/bionames-archive/issn/0300-9386/104/858.pdf>

Vachon, M. 1975. Sur l'utilisation de la trichobothriotaxie du bras des pédipalpes des Scorpions (Arachnides) dans le classement des genres de la famille des Buthidae Simon. Comptes Rendus de l'Académie des Sciences, Paris, Sciences de la Vie 281: 1597–1599.

Volschenk, E. S., Mattoni, C. I. and Prendini, L. 2008. Comparative anatomy of the mesosomal organs of scorpions (Chelicerata, Scorpiones), with implications for the phylogeny of the order. Zoological Journal of the Linnean Society 154, 4: 651–675. <https://doi.org/10.1111/j.1096-3642.2008.00426.x>

Waeber, P. O., Wilmé, L., Ramamonjisoa, B., Garcia, C., Rakotomalala, D., et al. 2015. Dry forests in Madagascar, neglected and under pressure. International Forestry Review 17, S2: 127–148. <https://doi.org/10.1505/146554815815834822>

Wells, N. A. 2007. Approches paléoenvironnementales du Mésozoïque et du Cénozoïque. In: Paysages Naturels et Biodiversité de Madagascar. S. M. Goodman (ed.), pp 23–56, 89–94. Muséum national d'Histoire naturelle, Paris.

Wilmé, L. & Callmander, M. W. 2006. Les populations reliques de primates: les Propithèques. Lemur News 11: 24–31. Available at <https://bit.ly/30Sl1QY>

Wilmé, L., Goodman, S. M. and Ganzhorn, J. U. 2006. Biogeographic evolution of Madagascar's microendemic biota. Science 312: 1063–1065. <https://doi.org/10.1126/science.1122806>

Wilmé, L., Ravokatra, M., Dolch, R., Schuurman, D., Mathieu, E., Schuetz, H. and Waeber, P. O. 2012. Toponyms for centers of endemism in Madagascar. Madagascar Conservation & Development 7, 1: 30–40. <https://doi.org/10.4314/mcd.v7i1.6>

ARTICLE

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Wildlife hunting in complex human-environmental systems: How understanding natural resource use and human welfare can improve conservation in the Ankarafantsika National Park, Madagascar

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ABSTRACT

Conservation officials work to manage complex and interacting human-environmental systems, where balancing needs between the two systems can become a source of tension. This study presents information on the use of natural resources by, and the health and welfare of, rural communities within and near Ankarafantsika National Park (ANP) in northwestern Madagascar. We focus on behaviors that are difficult for natural resource managers to measure themselves, including the hunting of threatened and protected wildlife and on sensitive information about human wealth, health, and food security. We surveyed 419 households and measured the health of 1860 individuals in 18 communities adjacent to or within the boundaries of ANP. We found a very high prevalence of child malnutrition, illness, and food insecurity and a heavy reliance on natural products to meet subsistence needs. More than 90% of the population reported that they hunted wildlife and harvested wild vegetables at least one day during the prior week as a direct means to cope with their food insecurity. Further, we found a high reliance on the forest for both health care and the building of adequate shelter. Efforts to improve overall food security would likely improve both human welfare and the long-term conservation of the threatened wildlife and habitat of Ankarafantsika. These data can help both conservation and community livelihood programs to find integrated solutions to the shared challenges of improving the well-being of human populations and the protection of Madagascar's unique, endemic, and highly threatened biodiversity.

RÉSUMÉ

Les gestionnaires œuvrant pour la protection de la nature sont généralement confrontés à des systèmes socio-écologiques complexes et interactifs dans lesquels la recherche de l'équilibre entre les besoins de ces deux systèmes peut s'avérer être une source de tension. Cette étude présente des informations sur l'utilisation des ressources naturelles par les communautés rurales riveraines du parc national d'Ankarafantsika (PNA) dans le nord-ouest de Madagascar, ainsi que sur la santé et le bien-être de ces communautés. L'étude s'est en particulier orientée sur les comportements difficiles à mesurer pour les gestionnaires de ressources naturelles, à savoir la chasse d'animaux sauvages menacés et protégés et les informations portant sur l'opulence, la santé et la sécurité alimentaire des gens. Une enquête a été réalisée auprès de 419 ménages et l'état de santé de 1860 personnes a été mesuré dans 18 communautés vivant à la périphérie ou à l'intérieur des limites du PNA. Une très forte prévalence de la malnutrition infantile a été observée ainsi que diverses pathologies, une insécurité alimentaire et une dépendance importante à l'égard des produits naturels pour répondre aux besoins de subsistance. Plus de 90% de la population a déclaré qu'elle avait chassé des animaux et récolté des plantes sauvages au moins un jour au cours de la semaine précédente, à titre de moyen direct pour faire face à l'insécurité alimentaire. Une forte dépendance à l'égard des forêts a également été notée pour les produits destinés à la santé et la construction de maisons. Les efforts visant à améliorer la sécurité alimentaire dans son ensemble pourraient vraisemblablement améliorer le bien-être humain aussi bien que la conservation à long terme de la faune et des habitats menacés de l'Ankarafantsika. Ces données peuvent aider les programmes de conservation et de subsistance de la communauté à trouver des solutions intégrées aux problèmes communs de l'amélioration du bien-être des populations humaines et de la protection de la biodiversité unique, endémique et hautement menacée de Madagascar.

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INTRODUCTION

National parks are often located in regions of both high biodiversity and high poverty (Barrett et al. 2011, Ngonghala et al. 2016). An unsustainable reliance on these resources can lead to the collapse of both the natural environment and human condition (Dasgupta and Maler 2004, Barrett et al. 2011). If approached appropriately, the local communities near national parks are therefore natural allies in resource protection. Likewise, improving human well-being is an integral part of many conservation programs (Andam et al. 2001, Ferrarro et al. 2011, Naughton-Treves et al. 2011). Growing human populations face strong incentives to use natural resources within parks to meet their subsistence needs (Wilkie et al. 2016, Reuter et al. 2017, Poudyal et al. 2018). Yet, we often lack rigorous quantitative data on natural resource use or human well-being surrounding national parks. Without this information, it is difficult to effectively manage protected areas, implement conservation and livelihoods programs, or to quantify the impact of these activities (Gardner et al. 2013).

Madagascar is a conservation priority because of its high biodiversity, high levels of endemism and threat faced by the species (Myers et al. 2000). Order-, family-, and genus-level endemism occurs in Madagascar's terrestrial mammal species, amphibians, reptiles, birds, insects, and of plants (Vences et al. 2009, Wilmé et al. 2012). One-quarter of the world's primates are found only in Madagascar, second only to Brazil in global primate diversity (Estrada et al. 2018). This incredible diversity is threatened by both unsustainable hunting and habitat loss (Harper et al. 2007, Rakotomanana et al. 2013, Brook et al. 2018). Ninety-three percent of primate species in Madagascar are threatened with extinction, a percentage of threat higher than that of any other keystone country for primate diversity (Estrada et al. 2018). The long-term viability of much of Madagascar's flora and fauna will depend upon the effectiveness of Madagascar's protected area network.

The dry forests of western Madagascar may be one of the nation's most threatened biomes (Waeber et al. 2015). Local people depend on this ecosystem for their livelihoods. Complex interactions of landscape-use and climate change have significantly reduced the size and integrity of these fragile, understudied and biodiverse habitats (Zinner et al. 2014, Waeber et al. 2015). With an area of 135,000 ha, Ankarafantsika National Park (ANP) is one of Madagascar's largest contiguous dry deciduous forests. The park was created to ensure the long-term protection of the unique dry deciduous forest ecosystem in northwestern Madagascar (Andriamampianina and Peyrieras 1972), and is home to a variety of narrow-ranged species of flora and fauna. It contains one important watershed for the nearby agricultural center of Marovoay, one of Madagascar's largest rice production areas (World Bank 2015). The park is immediately surrounded by a human population of over 107,000 people across 133 villages, some of which legally are within its boundaries along a major highway which bisects the park (Madagascar National Parks 2018). Given its ecological importance and its complex human-ecological interactions, understanding natural resource use is important for effective management.

This study presents information on the use of natural resources by, and the health and welfare of, communities near and within ANP. We particularly focus on the behaviors that are important for natural resource managers to understand, but are difficult for managers to measure themselves because of the participants' fear of recrimination and prosecution. This includes data on hunting threatened and protected wildlife and sensitive information on human wealth, health, and food security. These data can help both conservation and community livelihood programs to find integrated solutions to the shared challenges of improving the well-being of human populations and the protection of Madagascar's unique, endemic, and highly threatened biodiversity.

METHODS

STUDY SITE. The Boeny region of northwestern Madagascar is home to Ankarafantsika National Park. The principal ethnolinguistic groups are Sakalava and Betsileo (although ethnic diversity is high) and the primary economic activity of local people is subsistence agriculture. The region is 110 km south of the city of Mahajanga, a district home to >250,000 people (INSTAT 2013). Ankarafantsika was originally classified as a Réserve Naturelle Intégrale in 1927, with the adjacent Ampijoroa Forestry Reserve to its West. These two parcels were combined to create the Ankarafantsika National Park (IUCN Category II) in 2002. Ankarafantsika National Park protects 1,350 km2 of dry deciduous forest and wooded grassland habitats and is bisected by the major highway (RN4) connecting Antananarivo to the port town Mahajanga.

SURVEY PROTOCOLS. Between November 2014 and April 2015 JFR and TRA surveyed 419 households, including 1860 individuals, in 18 communities in Ankarafantsika (15–30 households per village). All surveys were conducted in the native dialect of Malagasy spoken within each village. We consulted with the local community leaders and then held a local community meeting to discuss the goals of the project before beginning household interviews in each community. During community meetings, we described the research as an effort to understand the ways in which natural resource use and agricultural activities contributed to human food security, health and general well-being.

We selected households by one of two methods: (1) if a household census existed at the community level, then the local research team selected every third household to participate; or (2) if no household census existed in the community, then the research team selected every third household that they passed in the community. Each head of household consented verbally to participate in the research survey. We interviewed either the male or female head of each household to gather information on household demographics, diet, food security, agricultural labor, livestock raising and diseases, income generation, commercial good ownership, food taste preferences, forest resource use, and hunting behavior. Commercial goods included shoes, bicycles, radios, watches, flashlights, and guns. In general, we asked interviewees to recall wildlife consumption events over the prior year as this had been demonstrated to be successful with regard to previous wildlife harvest surveys (Golden et al. 2013). We asked interviewees to recall information on their typical diet over the prior day and week. These foods were categorized based on their micronutrient-composition to determine dietary diversity and assign a 'Women's' Dietary Diversity Score (WDDS) (FAO 2010). Food security was determined using the Coping Strategies Index (CSI) (Maxwell and Caldwell 2008), a tool which asks household members to report the number of days during the prior week they used pre-defined coping strategies to deal with household food insecurity. A weighted CSI was then determined by weighting the local severity of each coping strategy (categorical weights) using focus groups of 5–10 individuals in each community, as the cultural appropriateness or severity of coping strategies may vary between villages (for example, in one village norms may dictate it more acceptable to borrow food than in others). During these meetings, we also recorded information on poultry disease, cost, husbandry, and mortality.

In addition to questions administered solely to the head of household, we also collected data on the health of all available individuals in the surveyed households (1860 individuals within these 419 households). We recorded the sex, age (to the nearest year), occupation and educational obtainment (in years) of each household member. We then collected specific health information including anthropometric data (height and weight), history of malaria episodes, history of deworming medication, and hemoglobin and blood oxygen level obtained using a portable hemoglobinometer (Rainbow Pulse CO-oximeter from MASIMO). This simple, non-invasive hemoglobinometer uses photospectrometry rather than a blood sample to assess hemoglobin levels. Our research was approved by the Madagascar Ministry of Health No 253/MSANP/SG/DGS/DPLMT, the Harvard T.H. Chan School of Public Health's Institutional Review Board (IRB13-1862), and from the chef *fokontany* in each local community where we worked.

DATA ANALYSIS. Simple summary statistics were calculated for most forms of environmental resource use and socio-demographic variables. Center for Disease Control (CDC) thresholds were used to calculate the prevalence of stunting, underweight, and a low body mass index (BMI) for their sex and age in children and young adults age 2–20 (CDC 2000). We used WHO (2011) guidelines for hemoglobin cut-offs when determining anemia in children and adults. Children under five years of age were considered anemic if their hemoglobin values were less than 11.0 g/dL, 5–11 year-olds if less than 11.5 g/dL, 12–14 year-olds if less than 12.0 g/dL, women of 15 years and older if less than 12.0 g/dL, and men of 15 years and older if less than 13.0 g/dL. We measured dietary diversity using the WDDS (FAO 2010) and food insecurity using responses from the CSI, which were then weighted for cultural importance using focus group data (Maxwell and Caldwell 2008). We used the statistical software JMP for analysis. We applied a partition analysis to characterize food-secure and -insecure households. For data analysis, wildlife consumption was a Log_{10}+1-transformed continuous explanatory variable and household income per capita was Log_{10}-transformed. Hemoglobin levels, the z-scores for child growth, and CSI values in this population were roughly normally distributed and did not require transformation. At the time of data collection, one United States Dollar ($US) was worth 2,600 Malagasy ariary (MGA).

RESULTS

In the 419 households we surveyed in Ankarafantsika, mean household size was 4.44 ± 2.08 individuals (median 4). Half (46.5%) of our study population was female. Nearly half of the population (44.0%) was 16 years of age or younger and 4.5% were under two years of age.

HOUSEHOLD DEMOGRAPHICS AND ECONOMIES. The heads of 39.5% of all households had been born in the community in which they now resided. Those that were not born in that community, had moved there a median of 10 years ago (mean of 13.43 ± 9.48 years), showing a relatively stable population structure in regards to immigration and emigration at the community-level. Heads of households born in their current community of residence were primarily of the Sakalava (34.5%), Betsileo (16.1%), and Betsimisaraka (10.9%) ethno-linguistic groups. Heads of households who had moved to community after their birth were primarily of the Betsileo (24.7%), Tsimihety (16.5%), and Antandroy (14.4%) ethno-linguistic groups.

The principal economic activity of local people was agriculture, and households earned an average of $US211.38 ± $US184.21 in cash income during the prior year. This provided a median of $US42.31 in cash income per person during the prior year (mean of $US57.99 ± $US110.66). Only two households (0.5% of total sample) had not purchased food during the prior week. Of food expenses, 60.3% were used to purchase meat, fish, or vegetables that would complement their rice staple. Comparatively, only 31.1% was spent on rice, 1.7% on tubers, and 3.6% on snacks. Households spent a mean of $US1.23 per person on a vegetable or meat accompaniment to their rice-staple during the prior week. People in Ankarafantsika ate an average of 554.8 grams (1.8 kapoka) of rice (measured size before cooking) per person per day.

Malagasy people often reside in a seasonal home, or *lasy*, close to their rice fields during the harvest season; 83.1% of the Ankarafantsika population used a *lasy* during the prior year. Living in a *lasy* peaked during September (79.3% of all lasy were occupied during this time). Lasy use was, however, high throughout the year. Even during the lowest month (December), 62.3% of *lasy* owning households occupied at least one of these seasonal homes.

Nearly half of interviewees had earned a wage labor (even if only for one day) during the prior year (43.1% of interviewees, 43.9% of men, and 40.6% of women). Interviewees earned a median daily salary of US$1.15 for wage labor. While both men and women earned a median salary of US$1.15, men had higher earning potential (men earned a mean daily wage of US$1.76 ± 2.57; women a mean daily wage of US$1.35 ± 1.98).

NATURAL RESOURCE USE. Nearly all (99.3%) of the population relied on firewood for cooking and harvested it themselves (98.8%) a median of two times per week (mean of 3.26 ± 3.05). Individuals traveled a median of one hour and 15 minutes (mean of 66.1 min ± 35.9 min) to collect firewood. We found a high dependence on the forest for natural products that can create shelter. Many (69.9%) households had purchased or harvested timber for housing (even if just one piece of wood) and 79.9% had collected thatch roofing in the prior year. Most of the timber and thatch used (96.8% and 91.3%) was collected by that household (and not purchased). Households traveled a median of one hour and 15 minutes to collect housing-timber and thatch roofing (means of 85.5 min ± 33.5 min; 86.4 min ± 60.8 min respectively). Half (57.4%) of households had eaten honey during the prior year. Honey was primarily collected and not purchased (95.8% of households that had eaten honey had collected it themselves). Honey was collected a median of 73 minutes from their homes (mean of 81.9 min ± 33.5 min). Few households had collected trees to build boats (3.1%) or plants for the fermentation of a local alcoholic beverage (6.5%) and none had purchased these items. These collectors traveled a median of one hour (means of 92.5 min ± 63.3 min; 83.5 min ± 38.7 min) to reach these products. Most local people relied on the forest for healthcare through ethnobotanical medicine collection (roughly 84.9% of the population). Those who use these traditional medicines primarily collected them (83.0%) from the forest less than once per week (mean 0.6 ± 0.7) at a median distance of one hour and 15 minutes from the home (mean of 90.5 min ± 52.6 min).

There were distinct gender roles in the collection of natural products. The collection of firewood, timber, roofing, wood for boats, bark for fermentation, honey and traditional medicinal plants were all predominantly male activities (Table 1).

At least three in four households (76.4%) ate wildlife during the prior year. Of the 1387 forest mammals eaten by 419 surveyed households, 49.8% were tenrecs, 26.0% were bush pigs, 13.0% were the small Indian civet Viverricula indica, 5.6% were lemurs, 4.7% were bats, and 0.9% were endemic, Euplerid carnivorans (Table 2). The average household reported eating a median of two forest mammals during the prior year (mean of 3.3 ± 4.4; Table 2). Nearly half of all households ate the meat of tenrecs (48.0%) and bushpigs (48.1%) during the prior year. Of households that ate these meats, each household ate a median of two tenrecs (mean of 3.44 ± 3.64), and ate bushpig-meat a median of two times (mean of 1.8 ± 1.0) during the prior year. More than one tenth of households ate lemurs (10.7%) and bats (10.3%) during the prior year. Of those households that ate lemur or bat meat, members of each household ate a median of one lemur (mean of 1.7 ± 1.0) and one bat (mean of 1.5 ± 0.9). While one in four households ate non-native carnivorans (24.6%). The hunting of endemic Euplerid carnivorans was less frequent (with 2.9% of households participating). Members of the households that hunted these animals ate a median of one endemic and/or one endemic carnivoran during the prior year (means of 1.7 ± 1.0 and 1.1 ± 0.3, respectively). Seven percent (7.2%) of households surveyed reported eating a total of 48 reptiles during the prior year. Members of these households ate a median of one reptile each (mean of 1.3 ± 0.5) (Table 2). The mean and standard deviation of the forest animals each household ate varied between villages (Table S1).

Table 1. The age-class and gender stratification of the collectors of forest resources in households in Ankarafantsika 2014–2015. (expressed as % households; household members self-identified their age-class and gender)

Collector	Female adult	Female child	Male adult	Male child
Firewood	8.6	3	35.3	74.7
Timber	4.5	0.4	14.2	78.9
Thatch	7.4	4.8	34.9	82.2
Honey	3.8	1.4	40.5	79
Wood for boats	0	0	63.6	81.8
Bark for alcohol fermentation	0	0	47.6	85.7
Medicinal plants	17.3	2.6	27.8	54.2
Firewood	8.6	3	35.3	74.7

People used a diverse set of methods to catch wildlife. Trapping (21.5% of all forest animals eaten during the prior year were obtained using traps) was supplemented by opportunistic hunting (21.1%), eating the meat at the household of a friend or family member (19.3%), pursuit hunting using dogs, sling-shots, blow guns, rifles, or spears (18.4%), and purchasing the meat (18.1%) (Table 2). Only 1.7% of surveyed households owned a firearm.

Three species had been purchased during the prior year, the common tenrec (mean price per individual = US$0.82), Madagascar flying fox (US$1.15 per individual), and bushpig (US$1.15 per kilogram).

A step-wise bivariate nominal logistic regression analysis revealed that household size and dietary diversity were the best predictors of whether or not a household had consumed wildlife during the past year (DF = 2 (419), R2 = 0.04, X2 = 18.33, $p < 0.0001$) and a step-wise multiple regression analysis revealed that the most significant predictors of the amount of wildlife members of a household consumed were household size, dietary diversity, and ethnicity (DF = 16 (418), R2 = 0.12, F = 3.48, p = <0.0001). Income did not significantly affect wildlife hunting (DF = 1 (412), R2 < 0.00, F = 0.24, p = 0.62). Larger Betsimisaraka households with less diverse diets ate more wildlife than smaller

Table 2. The volume of mammalian wildlife consumption in communities within Ankarafantsika, disaggregated by hunting method during 2014–2015. (The volume of consumption was reported based on the head of household's recall of number of individual animals consumed during the prior year. Species that exist in the region, but that were not reported to have been eaten during the prior year (e.g., Propithecus coquereli), are not listed here; † local people ate the meat of bush pigs (Potamochoerus larvatus) in pieces ~ 1 kg in weight, this is therefore the number of times the bush pig meat was eaten, and not whole animals)

Species	Local name	Conservation Status (IUCN 2018)	Total consumption (n individuals)	Pursuit hunting	Trapping	Opportunistic hunting	Eaten with friends or family	Purchased
TENRECS								
Tenrec ecaudatus	Trandraka	LC	583	32.6%	14.2%	12.2%	24.9%	12.9%
Setifer setosus	Sokina	LC	112	28.6%	5.4%	59.8%	3.6%	0.0%
BATS								
Pteropus rufus	Fanihy	VU	42	2.4%	9.4%	26.1%	33.8%	23.8%
All insectivorous bats	Kanavy	-	24	0.0%	0.0%	70.8%	30.2%	0.0%
EUPLERIDS CARNIVORANS								
Cryptoprocta ferox	Fosa	VU	13	7.7%	15.4%	61.5%	15.4%	0.0%
Eupleres major	Fanaloka mena	EN/LC	1	0.0%	0.0%	100.0%	0.0%	0.0%
LEMURS								
Cheirogaleus stethi	Matavy rambo	-	15	6.3%	6.3%	81.3%	6.3%	0.0%
Avahi occidentalis	Fotsy fehy	EN	2	100.0%	0.0%	0.0%	0.0%	0.0%
Lepilemur edwardsi	Repahaka	EN	12	33.3%	0.0%	48.3%	8.3%	0.0%
Eulemur fulvus	Gidro	NT	48	8.3%	10.4%	62.5%	10.4%	0.0%
Microcebus spp.		-	1	0.0%	0.0%	100.0%	0.0%	
REPTILES								
Erymnochelys madagascariensis	Rere	CE	7	14.3%	0.0%	71.4%	14.3%	0.0%
Small fresh water turtle	Kapika andrano	-	11	0.0%	0.0%	100.0%	0.0%	0.0%
Small fresh water turtle	Sokatra	-	3	0.0%	0.0%	33.3%	66.7%	0.0%
Small fresh water turtle	Kapidolo	-	5	0.0%	0.0%	100.0%	0.0%	0.0%
Acrantophis madagascariensis	Do	LC	12	0.0%	0.0%	83.3%	26.7%	0.0%
INTRODUCED SPECIES								
Viverricula indica	Jabady	LC	126	8.7%	61.1%	18.3%	15.1%	1.6%
Potamochoerus larvatus†	Lambo dy	LC	363	3.9%	28.4%	1.1%	17.4%	47.4%
Felis sp.	Kary	-	55	3.6%	50.9%	34.5%	9.1%	0.0%

households of other ethnicities with more diverse diets, regardless of whether they were born in that community (DF= 16 (418), R2 = 0.12, F = 3.48, p = <0.0001). While significant, these differences, were however, functionally very minor and may be spurious. Households that consumed wildlife contained a mean of 4.60 ± 2.21 individuals, whereas households that had not eaten wildlife contained a mean of 3.91 ± 1.55 individuals (T = 3.60, p = 0.0002) and the mean dietary diversity score was only very slightly lower in households that ate wildlife (5.22 ± 1.01) than in those that did not (5.52 ± 0.94) (T = -2.69, p = 0.008).

Wildlife consumption was similar between those who were born in their current community of residence and immigrants to the region (T = -0.77, p = 0.78). In terms of consumption of mammals, those born in their current community ate more bats (T = 2.37, p = 0.02; 0.24 ± 0.67 vs. 0.10 ± 0.43 bats per household per year) and reptiles (t = 1.95, p = 0.03; 0.13 ± 0.40 vs. 0.06 ± 0.30 bats per household per year), whereas immigrants ate more bushpig meat (T = -3.23, p = 0.001; 1.00 ± 1.20 vs. 0.65 ± 1.03 portions of bushpig per household per year). Both groups ate similar numbers of lemurs, carnivorans, and tenrecs. By ethno-linguistic group, those with heads of households who self-identified as Betsimisaraka ate significantly more wildlife than any other ethnicity (ANOVA; $R^2 = 0.10$, $F = 3.33$, DF = 14, p = <0.0001) (Table S2).

NUTRITION AND DIETARY DIVERSITY. Most (73.0%) of measured households ate the meat of domestic animals during the prior week, and nearly all (99.0%) had eaten any source of fish, meat, or insect. The diets of most households (87.4%) were moderately diverse during the prior week (Table 3). Most (89.0%) ate a source of fat or oil in the prior week, 43.2% sourced vitamin A from a plant, 43.4% sourced vitamin A from an animal, and 99.5% ate at least one iron-rich food during the prior week (Table 3).

HUMAN HEALTH AND FOOD SECURITY. We found a high prevalence of child malnutrition (Table 4) and a moderate prevalence of anemia throughout all sub-populations measured in the Ankarafantsika region. Just over one-quarter (27.1%) of the cases of anemia were moderate to severe. Approximately 17.6% of children 0–5 years of age (n = 272), 28.6% of children 6–11 years of age (n = 262), 28.9% of women age 12 and older (n = 575) and 44.9% of men age 12 and older (n = 608) were affected by anemia. One-third (32.7%) of all observed subjects (560 of 1715) were anemic. Men were significantly more likely to be anemic than women (X2: DF = 1 (1699), $R^2 = 0.01$, $X^2 = 21.8$; p < .00001; 53.5% of men (909) vs. 46.5% of women (790)). Over half (53.9%) of household members had a feverish illness within the prior three months and 32.6% had seen evidence of intestinal parasites (e.g., worms visible in stools).

Table 3. Foods characterizing diets with low, moderate, and high diversity using a WDDS scale. (Food categories listed were found in greater than 75% of households in that subclass)

Low dietary diversity (WDDS 0-3)	Moderate dietary diversity (WDDS 4-6)	High dietary diversity (WDDS 7-9)
0.5% of households	87.4% of households	1.2% of households
Starchy staples	Starchy staples Dark green leafy vegetables Vitamin A rich fruits and vegetables Fish/seafood, meat, and insects	Starchy staples Dark green leafy vegetables Vitamin A rich fruits and vegetables Other fruits and vegetables Fish/seafood, meat, and insects Dairy Legumes, nuts, seeds

Table 4. Percentages of individuals classified as stunted, underweight, and as having a low BMI for their age and sex in communities in and near Ankarafantsika National Park during 2014–2015. (Children are defined as stunted, underweight, or low BMI if their height-for-age, weight-for-age, or BMI-for-age is more than two standard deviations below the CDC (2000) Child Growth Standards median)

Age range (yrs)	Sex	Sample size (n)	Stunted	Underweight	Low BMI
2<5	Male	98	56.1%	62.2%	34.7%
2<5	Female	67	46.3%	43.3%	26.9%
5<12	Male	217	47.9%	47.6%	23.0%
5<12	Female	164	56.7%	47.6%	22.0%
12<20	Male	188	54.3%	43.6%	16.5%
12<20	Female	146	65.8%	42.5%	16.7%
2<20	Male & Female	791	55.0%	46.1%	21.6%

Nearly all (99%) households had used at least one strategy to cope with food insecurity during the prior week. The median unweighted and weighted household CSI scores were 18 and 44.83, respectively. The most frequently reported mechanisms for coping with food insecurity were to harvest wild vegetables and hunt wildlife (16.1% and 14.7% of all coping strategies used by a household during the prior week). 'Hunting' behavior included all days an individual of the household checked traps and/or carried a weapon in an attempt to catch food. It reflects hunting effort and not hunting success (if they successfully caught a wild animal). Most households (89.7%) reported that they hunted at least one day during the prior week to cope with household food insecurity. Households spent a median of three days hunting during the prior week (mean = 2.67 ± 1.71). Similarly, 95.0% reported that they searched for wild vegetable foods at least one day during the prior week to cope with household food insecurity, and households spent a median of three days looking for wild vegetables during the prior week (mean = 2.92 ± 1.64). Strategies that were used less often included eating next years' seed stock (9.7%), purchasing food on credit (9.2%), borrowing food (8.0%), harvesting immature crops (7.8%), limiting the portion size of all household members (6.6%), reducing the portion size of food given to adults in order to feed children (6.3%), and reducing the number of meals eaten in a given day (5.1%). Rarely reported strategies included eating at friends or families solely as a means to procure food (2.1%), begging for food (0.6%), restricting the consumption of food by non-working household members in order to feed working members (0.2%), reducing the portion size of food given to children in order to feed adults (0.2%), and not eating for an entire day and night (0.1%).

Communities that were farthest from a major road (defined as distance from a rural bush-taxi stop) experienced significantly decreased food security (ANOVA; $R^2 = 0.19$, $F = 48.77$, DF = 2, p = <0.0001). Households who collected many forest products and who used seasonal homes (*lasy*) were less food secure than those who did not collect these forest products or use *lasy* (Table 5).

Table 5. The relationship between food security (weighted CSI) and the collection of natural products (binary) in communities surrounding Ankarafantsika (2014–2015).

Collected/Hunted Forest Product	T	p	Mean Weighted CSI	
			Collected	Did not collect
Plants for Fermentation	3.27	<0.01	54.20 ± 13.55	45.20 ± 17.52
Medicinal Plants	8.53	<0.0001	48.36 ± 16.66	31.24 ± 14.31
Roofing	0.49	0.62	46.00 ± 17.27	44.92 ± 18.08
Honey	7.43	<0.0001	50.88 ± 16.67	38.90 ± 16.02
Timber	5.59	<0.0001	48.70 ± 17.31	39.01 ± 15.79
Firewood	0.35	0.78	45.80 ± 17.45	42.68 ± 15.38
Wildlife	-1.54	0.06	44.99 ± 16.85	48.25 ± 18.97

Table 6. The range and mean of pets and livestock assets per household in communities surrounding Ankarafantsika (2014–2015).

	Median	Mean
Cows	3	6.07 ± 10.70
Pigs	0	0.49 ± 1.76
Ducks	9	13.19 ± 15.13
Chickens	9	10.17 ± 9.45
Geese	0	0.12 ± 1.15
Cats	0	0.21 ± 0.50
Dogs	1	0.98 ± 1.03

On average, ducks were the most commonly owned domestic livestock, followed by chickens (Table 6). Focus groups in each community reported that chicken and duck meat cost a mean of $US2.40 per kilogram. All communities reported that chickens had died from disease epidemics during the prior year. Deaths were reported to be caused by diseases locally referred to as *barika*, *koropoka*, and/or *kopinda*. The reported symptoms of the diseases indicated the presence of Newcastle disease and/or avian cholera. Ducks were also reported to be affected by *ramoletaka* (symptoms consistent with fatty liver disease) and *gripam-borona* (symptoms consistent with avian cholera).

DISCUSSION

Effective conservation policy must be based on an understanding of the choices humans make within their dynamic social and ecological system contexts (Gibson et al. 2000). Conservation officials need to be able to identify what natural resources are being used, address the underlying reasons for using that resource (e.g., hunger), as well as the specific goals users have when using that resource (e.g., to eat a filling, fatty, nutritious, and/or good tasting meal), and how these and other factors affect their incentives for resource use. Yet, it is often difficult for conservation managers to gain accurate information on the behaviors that affect the resources they aim to protect.

We found a very high prevalence of child malnutrition, illness, and food insecurity both, bordering and within the Ankarafantsika National Park in Madagascar. Madagascar's national prevalence of children who are stunted, underweight, and have a low BMI is amongst the worst in the world (UNICEF et al. 2018, WHO 2018). In Ankarafantsika, one in every two children was stunted, one in two was underweight, and one in three had a severely low BMI. These rates are similar or higher than national averages, placing the region in the WHO's highest severity category for child malnutrition (WHO 2018). Nearly all (99%) households had used at least one strategy to cope with food insecurity during the prior week. An astonishing majority of the population (90% and 95% of households respectively) reported that they hunted for wild meat and/or searched for wild vegetables at least one day during the prior week, as a direct means to cope with this food insecurity. Households spent three days hunting or searching for wild vegetable foods during the prior week. In fact, in contrast to the central plateau or northeast of Madagascar (Golden et al. 2014ab, Borgerson 2015, 2016, 2018ab), the most frequently reported mechanisms for coping with food insecurity were to harvest wild vegetables and hunt wildlife. Yet, much of this hunting is conducted simultaneously while completing agricultural and other types of labor, and is often unsuccessful. While 90% reported hunting to cope with food insecurity during the prior week, only three quarters of interviewees had eaten wild meats during the prior year, reflecting either poor success rates in hunting effort, or under-reporting. Further, while food insecurity increased hunting, hunting may be an insufficient coping mechanism. Households that hunted were less food-secure than those that did not hunt. Because we collected data at a single time point, we do not know if households stopped hunting once food security was achieved or if current wildlife densities are simply too low to support sufficient catch.

Wild meat is commonly eaten in the region. While more than three-quarters of people had eaten wildlife during the prior year, they ate on average fewer wild animals per household than in many other regions of Madagascar. Wild meat eating households ate two forest mammals during the prior year, an amount similar to that of southeastern and central Madagascar, but only half to one-fifth of the number of wild mammals consumed per household in the northeast (Golden et al. 2014ab, Borgerson 2015, 2016, 2018a,b). While still uncommon, people also purchased more wild meat in Ankarafantsika than other regions of the country, even at its comparably higher price (Golden et al. 2014a,b, Borgerson 2015, 2016, 2018a,b). This may be due to the comparatively higher income and greater access to markets and transportation routes found in this area. Similar to other regions across Madagascar, the most frequently eaten mammal was the common tenrec (*Tenrec eucadatus*; IUCN Least Concern (Stephenson et al. 2016)), and the lemur genus *Eulemur* (Garcia and Goodman 2003, Golden et al. 2014a,b, Borgerson 2015, 2016, Reuter and Sewall 2016, Borgerson et al. 2018a,b, Merson 2018). Although the *Eulemur* eaten in this survey was *E. fulvus*, it does raise concern for *E. mongoz*, which is also found in the region and is Critically Endangered.

Garcia and Goodman (2003) suggested that common Sakalava taboos for lemur hunting may be eroding in the region with increasing immigration from other areas, and that this may explain the high levels of lemur hunting found in the region. We found high diversity in the ethnolinguistic composition of Ankarafantsika residents. We tested the effect of ethnicity and found that while ethnicity is significantly associated with current levels of hunting (with those who self-identify as Betsimisaraka eating significantly more wild meat than members of other ethnolinguistic groups), most Betsimisaraka had been born in the community in which they reside today. Furthermore, at the time of our survey, recently arrived households and long-term multi-generational households ate similar amounts of wildlife overall. This finding supports those of Golden and Comaroff (2015) and Reuter et al. (2016a,b) who found that immigration did not lead to increased hunting, and that taboos were not eroding. It also supports Garcia and Goodman's (2003) finding of differences in hunting rates of different ethnolinguistic groups. However, we found that while non-Sakalava did eat more wildlife, these individuals were born in these communities and were not immigrants.

An interesting deviation from hunting driven directly by food insecurity was the hunting of the endemic euplerid carnivoran, the fosa (*Cryptoprocta ferox*). Similar to findings in other regions, the hunting of fosa is primarily driven by human-wildlife conflict over poultry (e.g., Kotschwar-Logan et al. 2014, Borgerson 2016, Merson 2018), with fosa subsequently disliked by many rural households as a result (Merson 2018). Three percent of households reported eating 13 fosa in total during the prior year. Two-thirds of these fosa were caught opportunistically within a community's residential area, and not in nearby forests, when they approached or preyed upon community poultry. However, people hunted more fosa per household in Ankarafantsika than in southeastern, central, and northern Madagascar (Golden et al. 2014a, Borgerson et al. 2018a,b), but only half that of people on the Masoala Peninsula. Fosa are found in Ankarafantsika at a density of 0.2 adults per square kilometer. Thus, the Ankarafantsika National Park may contain as many as ~ 270 adult fosa. Approximately 107,000 people live within or on the border of the Ankarafantsika National Park. Given our data on hunting in rural households, we suspect current hunting levels significantly exceed sustainable harvest. It is unclear from our data, whether the increased fosa hunting in the Ankarafantsika and Masoala regions reflects a higher density of fosa in these areas, or greater human-wildlife conflicts over livestock (as livestock ownership was higher in Ankarafantsika than many other areas we have surveyed (e.g., Golden et al. 2014, Borgerson et al. 2018a,b)).

Extreme poverty and biodiversity loss are intimately related and can result in biodiversity related poverty traps (cf. Barrett et al. 2011). Parks created in areas with poverty traps are capable of potentially improving the livelihoods of the poorest subset of the population. If managed well, parks can maintain essential ecosystem services that the poorest households rely most heavily on, including providing refugia for plants and animals that can be sustainably collected in their buffer zones, and support local communities through human-livelihoods initiatives, both reducing poverty and deforestation (Andam et al. 2001, Naughton-Treves et al. 2011, Ferrarro et al. 2011). In practice, however, this potential benefit is often not realized. Assessments of other protected areas in Madagascar have shown that a remote, food insecure, household has a 2% probability of receiving the benefits from a livelihoods program, whereas more accessible and food secure households in influential positions have an 85% chance of being in those same programs, even though they were less likely to be negatively impacted by the protected area or have used forest resources (Poudyal et al. 2016). The potential for a household to participate in livelihood programs is also influenced by their proximity to the center of a park's administrative activities, or their exposure to park staff. In Ankarafantsika, villages with a permanent Madagascar National Park agent are the most supportive of the park's conservation, with other villages within the park's boundary supportive but also divided, and villages on the park's boundaries least supportive, typically perceiving conservation as burden (Aymoz et al. 2013). This lack of equitable benefit sharing of livelihood programs in and around protected areas, could also explain the lack of effectiveness of many protected areas in Madagascar to reduce deforestation once other confounding factors have been accounted for (Elkund et al. 2016).

We found that both resource use and food insecurity were higher in households closest to, or within, the Ankarafantsika National Park. Remote households often rely on the ecological capital of subsistence crops, livestock, forests, wildlife and fisheries, many of which depend on intact forest systems (Ngonghala et al. 2016). Generally, in the face of deforestation less-remote households often have more economic capital to help shift to other sources of livelihood whereas rural households may simply spiral further into poverty. If efforts to improve human-livelihoods are focused in the communities closest to Ankarafantsika National Park, they are likely to have a greater effect on conservation targets.

CONCLUSIONS

People relied heavily on forest products in Ankarafantsika, including materials for shelter, ethnomedicines, and subsistence wild foods. In the face of high food insecurity, the majority of households inside and outside the park boundaries have cleared forests and fallow lands far from their homes to grow a sufficient quantity of staple crops to feed themselves, and have hunted wild animals to add essential fats and micronutrients to their diets. Conservation managers can decrease unsustainable hunting in Ankarafantsika National Park by removing the barriers to achieving food security by developing alternatives to eating wild meats and expanding agricultural fields. Efforts to improve overall food security, while reducing human-wildlife conflict over poultry, would likely improve both human welfare and the long-term conservation of the threatened wildlife and habitat of Ankarafantsika. Additional locally-specific research is needed on what local barriers prevent people from accessing preferred, high quality, and affordable food and housing in sufficient supply throughout the year. It is our hope that our findings help both conservation and community livelihood programs find integrated solutions to the shared challenges of improving the well-being of human populations and the protection of Madagascar's unique, endemic, and highly threatened biodiversity.

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REFERENCES

Andam, K. S., Ferraro, P. J., Sims, K. R. E., Healy, A., and Holland, M. B. 2010. Protected areas reduced poverty in Costa Rica and Thailand. Proceedings of the National Academy of Sciences 107, 22: 9996–10001. <https://doi.org/10.1073/pnas.0914177107>

Andriamampianina, J. and Peyrieras, A. 1972. Les Réserves Naturelles Intégrales de Madagascar. In UICN, Union Internationale pour la Conservation de la Nature et de ses Ressources, Morges, CH (ed.). La Conservation de la Nature et de ses Ressources à Madagascar. Conférence Internationale, 7-11 octobre 1970, Tananarive. Publications UICN, nouvelle série, document supplémentaire 36: 103–123. Available online <http://tiny.cc/v28fhz>

Aymoz, B. G., Randrianjafy, V. R., Randrianjafy, Z. J. and Khasa, D. P. 2013. Community Management of Natural Resources: A Case Study from Ankarafantsika National Park, Madagascar. Ambio 6, 42: 767–775. <https://doi.org/10.1007/s13280-013-0391-9>

Barrett, C. B., Travis, A. J. and Dasgupta, P. 2011. On biodiversity conservation and poverty traps. Proceedings of the National Academy of Sciences of the United States of America 108, 34: 13907–13912. <https://doi.org/10.1073/pnas.1011521108>

Borgerson, C., Vonona, M. A., Vonona, T., Anjaranirina, E. J. G., Lewis, R., et al. 2018a. An evaluation of the interactions among household economies, human health, and wildlife hunting in the Lac Alaotra wetland complex of Madagascar. Madagascar Conservation & Development 13, 1: 25–33. <https://doi.org/10.4314/mcd.v13i1.5>

Borgerson, C., Johnson, S. E., Louis, E. E., Holmes, S. M., Anjaranirina, E. J. G., et al. 2018b. The use of natural resources to improve income, health, and nutrition within the forests of Kianjavato, Madagascar. Madagascar Conservation & Development 13, 1: 45–52. <https://doi.org/10.4314/mcd.v13i1.6>

Borgerson, C. 2015. The effects of illegal hunting and habitat on two sympatric endangered primates. International Journal of Primatology 36, 1:74–93. <https://doi.org/10.1007/s10764-015-9812-x>

Borgerson, C. 2016. Optimizing conservation policy: The importance of seasonal variation in hunting and meat consumption on the Masoala peninsula of Madagascar. Oryx 50, 3: 405–418. <https://doi.org/10.1017/S0030605315000307>

Borgerson, C., McKean, M. A., Sutherland, M. R. and Godfrey, L. R. 2016. Who hunts lemurs and why they hunt them. Biological conservation 197:124–130. <https://doi.org/10.1016/S0006320716300556>

Brook, C. E., Herrera, J., Borgerson, C., Fuller, E., Andriamahazoarivosoa, P., et al. 2018. Population viability and bushmeat harvest sustainability for Madagascar lemurs. Conservation Biology 33, 1: 99–111. <https://doi.org/10.1111/cobi.13151>

Centers for Disease Control and Prevention. 2001. National Center for Health Statistics CDC growth charts, United States. Available online <http://www.cdc.gov/growthcharts/>

Dasgupta, P. and Maler, K. G. (eds). 2004. The Economics of Non-Convex Ecosystems. Kluwer, Dordrecht. The Netherlands.

Estrada, A. Garber, P. A., Mittermeier, R. A., Wich, S., Gouveia, S., et al. 2018. Primates in peril: the significance of Brazil, Madagascar, Indonesia and the Democratic Republic of the Congo for global primate conservation. PeerJ 6: e4869. <https://doi.org/10.7717/peerj.4869>

FAO. 2010. Guidelines for measuring household and individual dietary diversity. Rome: Nutrition and Consumer Protection Division, Food and Agriculture Organization of the United Nations. 60 pp. Available online <http://www.fao.org/3/a-i1983e.pdf>

Ferraro, P. J., Hanauer, M. M., and Sims, K. R. 2011. Conditions associated with protected area success in conservation and poverty reduction. Proceedings of the National Academy of Sciences 108: 13913–13918. <https://doi.org/10.1073/pnas.1011529108>

Garcia, G. and Goodman, S. M. 2003. Hunting of protected animals in the Parc National d'Ankarafantsika, north-western Madagascar. Oryx 37: 115–118. <https://doi.org/10.1017/S0030605303000206>

Gardner, C. J., Nicoll, M. E., Mbohoany, T., Oleson, K. L. L., Ratsifandrihamanana, A. N., et al. 2013. Protected areas for conservation and poverty alleviation: experiences from Madagascar. Journal of Applied Ecology 50: 1289–1294. <https://doi.org/10.1111/1365-2664.12164>

Gibson, C., McKean, M. A. and Ostrom, E. 2000. People and Forests: Communities, Institutions, and Governance. MIT Press, Cambridge. 274pp.

Golden, C. D. 2009. Bushmeat hunting and use in the Makira Forest north-eastern Madagascar: a conservation and livelihoods issue. Oryx 43, 3: 386–392. <https://doi.org/10.1017/S0030605309000131>

Golden, C. D., Bonds, M. H., Brashares, J. S., Rasolofoniaina, B. J. R. and Kremen, C. 2014a. Economic valuation of subsistence harvest of wildlife in Madagascar. Conservation Biology 28, 1: 234–243. <https://doi.org/10.1111/cobi.12174>

Golden, C. D. and Comaroff, J. 2015. Effects of social change on wildlife consumption taboos in northeastern Madagascar. Ecology and Society 20, 2: #41. <http://dx.doi.org/10.5751/ES-07589-200241>

Golden, C. D., Fernald, L. C. H., Brashares, J. S., Rasolofoniaina, B .J. R. and Kremen, C. 2011. Benefits of wildlife consumption to child nutrition in a biodiversity hotspot. Proceedings of the National Academy of Sciences of the United States of America 108, 49: 19653–19656. <https://doi.org/10.1073/pnas.1112586108>

Golden, C. D., Gupta, A. C., Vaitla, B. and Myers, S. S. 2016. Ecosystem services and food security: assessing inequality at community, household and individual scales. Environmental Conservation 43, 4: 381–388. <https://doi.org/10.1017/S0376892916000163>

Golden, C. D., Rabehatonina, J. G. C., Rakotosoa, A. and Moore, M. 2014b. Socio-ecological analysis of natural resource use in Betampona Strict Natural Reserve. Madagascar Conservation & Development 9, 2: 83–89. <https://doi.org/10.4314/mcd.v9i2.4>

Golden, C. D., Rasolofoniaina, B. J. R., Anjaranirina, E. J. G., Nicolas, L., Ravaoliny, L. and Kremen, C. 2012. Rainforest Pharmacopeia in Madagascar Provides High Value for Current Local and Prospective Global Uses. PLOS ONE 7, 7: e41221. <https://doi.org/10.1371/journal.pone.0041221>

Golden, C. D., Wrangham, R. W. and Brashares, J. S. 2013. Assessing the accuracy of interviewed recall for rare, highly seasonal events: the case of wildlife consumption in Madagascar. Animal Conservation 16, 6: 597-603. <https://doi.org/10.1111/acv.12047>

Harper, G. J., Steininger, M. K., Tucker, C. J., Juhn, D. and Hawkins, F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation, 34, 4: 325–333. <https://doi.org/10.1017/S0376892907004262>

INSTAT. 2013. Madagascar in Numbers. Accessed online 25 Jan 2019 <https://www.instat.mg/madagascar-en-chiffre/>

Kotschwar-Logan, M., Gerber, B. D., Karpanty, S. M., Justin, S. and Rabenahy, F. N. 2014. Assessing carnivore distribution from local knowledge across a human-dominated landscape in central-southeastern Madagascar. Animal Conservation. 18: 82–91. <https://doi.org/10.1111/acv.12137>

Madagascar National Parks. 2018. Ankarafantsika National Park.

Maxwell, D. and Caldwell, R. 2008. Coping Strategies index: Field Methods Manual. Second Edition. Available online <http://tiny.cc/jh8fhz>

Merson, S. D. 2018. Bushmeat hunting, retaliatory killing, habitat degradation and exotic species as threats to Fosa (*Cryptoprocta ferox*) conservation. DPhil Thesis, University of Oxford, Oxford. Available online <http://tiny.cc/fc8fhz>

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853–858. <https://doi.org/10.1038/35002501>

Naughton-Treves, L., Alix-Garcia, J. and Chapman, C.A. 2011. Lessons about parks and poverty from a decade of forest loss and economic growth around Kibale National Park, Uganda. Proceedings of the National Academy of Sciences 108, 34: 13919–13924. <https://doi.org/10.1073/pnas.1013332108>

Ngonghala, C. N., De Leo, G. A., Pascual, M. M., Keenan, D. C., Dobson, A. P. and Bonds, M. H. 2016. Genereal ecological models for human subsistence, health and poverty. Nature Ecology and Evolution 1: 1153–1159. <https://doi.org/10.1038/s41559-017-0221-8>

Ngonghala, C. N., Plucinski, M. M., Murray, M. B., Farmer, P. E., Barrett, C. B., et al. 2014. Poverty, disease, and the ecology of complex systems. PLOS Biology 12, 4: e1001827. <https://doi.org/10.1371/journal.pbio.1001827>

Poudyal, M., Ramamonjisoa, B. S., Hockley, N., Rakotonarivo, O. S., Gibbons, J. M., Mandimbiniaina, R., et al. 2016. Can REDD+ social safeguards reach the 'right' people? Lessons from Madagascar. Global Environmental Change 37: 31–42. <https://doi.org/10.1016/j.gloenvcha.2016.01.004>

Poudyal, M., Rakotonarivo, O.S., Razafimanahaka, J. H., Hockley, N. and Jones, J. P. G. 2018. Household economy, forest dependency & opportunity costs of conservation in eastern rainforests of Madagascar. Scientific Data 5: #180225. <https://doi.org/10.1038/sdata.2018.225>

Rakotomanana, H., Jenkins, R. K. B. and Ratsimbazafy, J. 2013. Conservation challenges for Madagascar in the next decade. In Conservation Biology: Voices from the Tropics. N. S. Sohdi, L. Gibson, P. H. Raven, P. H. (eds), pp 33–39. John Wiley & Sons, Ltd.

Razafimanahaka, J. H., Jenkins, R. K. B., Andriafidison, D., Randrianandrianina, F., Rakotomboavonjy, V., et al. 2012. Novel approach for quantifying illegal bushmeat consumption reveals high consumption of protected species in Madagascar. Oryx 46, 4: 584–592. <https://doi.org/10.1017/S0030605312000579>

Reuter, K. E. and Sewall, B. J. 2016. Taboos and sustainability of tenrec hunting in Madagascar. Afrotherian Conservation 12:11–15.

Reuter, K. E., Randell, H., Wills, A. R., Janvier, T. E., Belalahy, T. R. and Sewall, B. J. 2016a. Capture, Movement, Trade, and Consumption of Mammals in Madagascar. PLOS ONE 11, 2: e0150305. <https://doi.org/10.1371/journal.pone.0150305>

Reuter, K. E., Randell, H. R., Wills, A. R. and Sewall, B. J. 2016b. The consumption of wild meat in Madagascar: drivers, popularity and food security. Environmental Conservation 1, 3: 1–11. <https://doi.org/10.1017/S0376892916000059>

Reuter, K. E., Sewall, B. J. and Di Minin, E. 2017. Drivers of present and lifetime natural resource use in a tropical biodiversity hotspot. Animal Conservation 21: 127–136. <https://doi.org/10.1111/acv.12355>

Reuter, K. E., Clarke, T. A., LaFleur, M., Ratsimbazafy, J., Holiniaina Kjeldgaard, F., et al. 2018. Exploring the Role of Wealth and Religion on the Ownership of Captive Lemurs in Madagascar Using Qualitative and Quantitative Data. Folia Primatologica 89: 81–96. <https://doi.org/ 10.1159/000477400>

Stephenson, P.J., Soarimalala, V., Goodman, S. 2016. Tenrec ecaudatus. The IUCN Red List of Threatened Species 2016: e.T40595A97204107. Accessed 18 June 2018. <http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T40595A97204107.en>

United Nations Children's Fund, World Health Organization, The World Bank. 2012. UNICEF-WHO-World Bank Joint Child Malnutrition Estimates. (UNICEF, New York; WHO, Geneva; The World Bank) Washington, DC. Available online <https://www.who.int/nutgrowthdb/estimates2012/en/>

Vences, M., Wollenberg, K.C., Vietes, D. R., Lees, D. C. 2009. Madagascar as a model region of species diversification. Trends in Ecology & Evolution. 24, 8:456–465. <https://doi.org/10.1016/j.tree.2009.03.011>

Waeber, P.O., Wilmé, L. Ramamonjisoa, B., Garcia, C., Rakotomalala, D., Rabemananjara, Z.H., Kull, C.A., Ganzhorn, J.U., Sorg J.-P. Dry forests in Madagascar: neglected and under pressure. International Forestry Review 17(S2): 127–148. <https://doi.org/10.1505/146554815815834822>

WHO. 2011. Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. Vitamin and Mineral Nutrition Information System. Geneva, World Health Organization, 2011 (WHO/NMH/NHD/MNM/11.1) Available online <http://www.who.int/vmnis/indicators/haemoglobin.pdf>

WHO. 2018. WHO Global Database on Child Growth and Malnutrition. Ed. May 2018. World Health Organization. Available online <https://www.who.int/nutgrowthdb/database/en/>

Wilkie, D.S., Wieland, M., Boulet, H., Le Bel, S., van Vliet, N., Cornelis, D., Briac Warnon, V., Nasi, R. and Fa, J.E. 2016. Eating and conserving bushmeat in Africa. African Journal of Ecology 54: 402–414. <https://doi.org/10.1111/aje.12392>

Wilmé, L., Ravokatra , M., Dolch, R., Schuurman, D., Mathieu , É., Schuetz, H. and Waeber, P. O. 2012. Toponyms for centers of endemism in Madagascar. Madagascar Conservation & Development 7, 1: 30–40. <http://dx.doi.org/10.4314/mcd.v7i1.6>

World Bank, 2015. Reversing the Red Sand Tide: A Call for New Solutions to Land Degradation. Accessed on 17 Oct 2018. <http://tiny.cc/my8fhz>

Zinner, D., Wygoda, C., Razafimanantsoa, L., Rasoloarison, R., Andrianandrasana, H., Ganzhorn, J. U. and Torkler, F. 2014. Analysis of deforestation patterns in the Central Menabe, Madagascar, between 1973 and 2010. Regional Environmental Change 14: 157–166. <https://doi.org/10.1007/s10113-013-0475-x>

SUPPLEMENTARY MATERIAL

Table S1. The variation in the mean number of forest wildlife eaten by households during the prior year between communities surveyed within Ankarafantsika (2014-2015).

Table S2. Differences in the amount of wildlife consumed during the prior year (2014–2015) within Ankarafantsika by ethnolinguistic cultural group. (Minority ethnolinguistic groups with fewer than twenty-five households surveyed in our study population are not represented in this table)

ADDENDA

http://dx.doi.org.104314/mcd.v14i1.2

Addenda to the article Three new species of *Grosphus* Simon, 1880, (Scorpiones: Buthidae) from Madagascar; possible vicariant cases within the *Grosphus bistriatus* group of species. Madagascar Conservation & Development 11, 2: 52–65.

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In the recent paper by Lourenço and Wilmé (2016), three new species of *Grosphus* Simon, 1880 were published without the Zoobank registration number. Here we add the numbers in order to make the new taxa valid according to the International Code of Zoological Nomenclature regulations (ICZN 2012).

Grosphus eliseanneae sp. n.
urn:lsid:zoobank.org:act:D3E27F0F-D606-4758-8525-04591ABFA537
<http://zoobank.org/NomenclaturalActs/D3E27F0F-D606-4758-8525-04591ABFA537>

Grosphus sabineae sp. n.
urn:lsid:zoobank.org:act:E44B1A72-3626-4C92-BD01-E7E22E80D422
<http://zoobank.org/NomenclaturalActs/E44B1A72-3626-4C92-BD01-E7E22E80D422>

Grosphus waeberi sp. n.
urn:lsid:zoobank.org:act:A07D3CB3-0ADC-4739-ADE2-CF2DB1A5ABBC
<http://zoobank.org/NomenclaturalActs/A07D3CB3-0ADC-4739-ADE2-CF2DB1A5ABBC>

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REFERENCES

ICZN 2012. Amendment of Articles 8, 9, 10, 21 and 78 of the International Code of Zoological Nomenclature to expand and refine methods of publication. ZooKeys 219: 1–10. <http://dx.doi.org/10.3897/zookeys.219.3944>

Lourenço, W.R., Wilmé, L. 2016. Three new species of *Grosphus* Simon 1880, (Scorpiones: Buthidae) from Madagascar; possible vicariant cases within the *Grosphus bistriatus* group of species. Madagascar Conservation & Development 11, 2: 52–65. <http://dx.doi.org/10.4314/mcd.v11i2.2>

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