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

IN THIS ISSUE

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EDITORIAL http://dx.doi.org/10.4314/mcd.v10i2.1

Increasing women's participation in community-based conservation: key to success?

Ensuring that both men and women benefit equitably from conservation and development programs is likely to increase the long-term success of both conservation and development goals. However, despite numerous international agreements and national policies highlighting the important relationship between gender, environment and sustainable development, implementation is often weak and gender is often neglected or inadequately addressed in conservation initiatives (Westerman and Benbow 2014). Since women play critical roles in natural resource use, information transfer, and societal reinforcement of resource use practices (Agarwal 2009), there is a need to ensure that they are as well integrated into community-based conservation projects as men at all levels, from micro-development projects to management and decision-making structures. Cultural practices and traditional gender roles may make this challenging; however, such an approach could substantially improve the outcomes of conservation and development actions.

In Madagascar, there is currently an urgent need and also an opportunity to mainstream the integration of gender in conservation planning and implementation. Madagascar holds some of the most unique and biodiverse ecosystems on Earth, but is currently facing an environmental crisis that threatens both its biological wealth and the human livelihoods that depend on it. Madagascar's forests are among the most threatened ecosystems in the world, and support about 14.5 million people (ca. 65% of the population) who rely on forest resources for their subsistence (Chao 2012). Efforts to stem this crisis have led to a rise in community-based conservation initiatives in Madagascar including the Government's recent earmarking of 94 new protected areas totaling more than 6 million hectares and about 10% of the remaining forest. These new protected areas will each be tied to a community-based conservation effort run through a local or foreign NGO. While this is a giant leap in addressing Madagascar's environmental crisis, there will be significant challenges in implementing and effectively addressing the coupled environmental and human dimensions. Given the high dependence of the nation's people on forest resources (e.g., for food and construction), the successful integration of both men and women into these initiatives will be critical for their success.

The importance of a gender-responsive strategy to conservation is also addressed in decisions and recommendations set forth by the Convention for Biological Diversity (UNEP 2010, 2014), for which Madagascar is a party. As such, there has been a recent increase in gender considerations in conservation initiatives throughout the island. This advancement is promising; however, there is still a great need for better integration of this approach in many of Madagascar's current protected areas and a great opportunity to mainstream this approach as the newly decreed areas for protection become a reality. This article discusses the relevance and challenges of incorporating gender considerations to the conservation and sustainable use of biodiversity in Madagascar and offers some strategies for implementation.

WHY INTEGRATION OF WOMEN MATTERS

The majority of Malagasy people live on under $2 per day; and therefore, they depend heavily on natural resources for their subsistence, for which women play an under-recognized but significant role. Use of forest for rice agriculture, called '*tavy*', forms the basis of subsistence for many rural communities and is practiced by both men and women, who share rights to ownership and inheritance of forest land (Widman 2014), and participate in working the fields and selling their product in the market. Women also use natural resources to directly provide for their families such as fetching water; harvesting crayfish, fruits, and leafy vegetables for consumption and sale; and collecting non-timber forest species to weave mats and baskets, to be sold in local markets or used by the women's families for their everyday needs (Järvilehto 2006). Men, on the other hand, may traditionally collect wood for fuel, construction or sale, harvest honey and medicinal plants, tend to cattle, and in some regions, hunt bushmeat for consumption. When attempting to offset the costs associated with reduced access to these critical resources, it is important for community-based conservation initiatives to consider the needs of both men and women in order to enlist community support and ensure success of the program.

While both genders from rural households will experience costs from restricted use of natural resources, women may be more negatively affected because of their reduced alternative economic opportunities and more limited access to natural resources. For example, Madagascar, currently ranks 120th out of 128 countries listed on the Women's Economic Opportunity Index (Economist Intelligence Unit 2012). This lack of earning alternatives may reduce women's abilities to compensate for restricted access to natural resources, thus reducing their contribution to their family's well-being, which may, in turn, diminish their status and equity in society. Even if the limited jobs within protected areas are staffed by both men and women, protected area management can create or increase gender imbalances in access to natural resources, which may have repercussions for women's status in society and their attitudes about conservation programs. For example, when forest use is restricted in southeastern Madagascar, women have been shown to avoid entering the forest to carry out their traditional resource use practices more than men because of the societal belief that women are more likely to get caught by park agents (Järvilehto 2006). If women are more affected than men in their ability to fulfill their traditional role in providing resources for their families and compensation for resource opportunity loss is also biased towards men, women's perceived value and status in society could fall. This inequity may affect not only gender-structures but the success of development and conservation goals that rely on community support. Thus, if gender issues are not adequately addressed in natural resources management efforts, gender inequities may be unintentionally exacerbated with long-term consequences for women's roles in society and attitudes toward protected-area management may suffer.

Women can also be important actors in conservation and natural resource management in many ways. Through their use of and connection with natural resources in their daily life, women gain extensive ecological knowledge, essential in activities that could strengthen natural resources management. For example, it would be useful for reforestation initiatives in zones made accessible to local villagers to know the attributes of species valued by both men and women, such as medicinal plants, timber and non-timber species. In addition, women have a great potential to spread knowledge and to influence societal views in Madagascar, because they tend to be highly connected socially, and they play an important role in passing on knowledge, culture and values while caring for and raising children. Women can also strongly influence men's roles in the management and use of natural resources. For example, in East Africa, women's verbal and non-verbal behaviors towards men have been shown to encourage bushmeat hunting by men because they place high value on the access to meat and cash as well as to the bravery of male hunters (Lowassa et al. 2012). In Madagascar, there is also a tendency for important household decisions to be made by couples jointly, and women often manage the household money, giving them a strong position on household decisions and activities that may relate to natural resource use and exploitation in protected areas (Järvilehto 2006).

CREATING GENDER-RESPONSIVE STRATEGIES

To integrate the involvement of women in conservation initiatives, there is a need for a clear, strategic, gender-responsive plan that takes into account the specific needs of men and women and the gendered inequities that may prevent women from benefiting from natural resources management (Agarwal 2009). Gender-responsive policies consider the different societal roles and places of men and women, their interests as well as their cultural and traditional settings (Otzelberger 2011). Such approaches have been recently outlined at the conference of the parties to the Convention on Biological Diversity (UNEP 2014), which present valuable tools for natural resources management. The Nature Conservancy (2015) has also developed useful toolkits that outline specific steps organizations can take to create a strategic plan that integrates gender into conservation projects. Essentially, gender integration needs to be made explicit in the development and implementation of conservation approaches, and frequent assessment during and after the project should be done to ensure its effectiveness.

STRATEGIES FOR INTEGRATING WOMEN IN CONSERVATION PROJECTS

The establishment of sustainable micro-development projects for women is a useful strategy that could greatly improve equity in benefits as well as provide incentives for women to be involved in natural resource management. For example, several NGOs working in Madagascar have created opportunities for women living in areas adjacent to protected areas, enabling them to perform profitable income-generating activities, such as producing and selling high-quality silks and embroidered products (e.g., Azafady, Centre ValBio), running business that sell fuel-efficient stoves (e.g., Conservation Fusion), and performing alternative coastal livelihood activities such as aquaculture (e.g., Blue Ventures).

Although micro-developments projects targeted toward women promote gender equality, it is not enough. An important strategy is to empower women in decision-making processes. The settings of community meetings, where management decisions are often made, do not often encourage the participation of women; and although women are usually not formally excluded, they are often reluctant to speak up in mixed-gender meetings because of cultural expectations (Järvilehto 2006, Westerman and Benbow 2014). This is illustrated by the Malagasy saying, "aza manao akohovavy maneno", which means "do not be the crowing hen". It is, therefore, particularly important to find ways to motivate women to actively participate in decision-making structures. For example, park managers could organize separate women-only meetings to discuss issues related to conservation and resource management and encourage the involvement and election of women in park-related committees. This lack of women representation in community meetings also occurs because women are often busy with household duties and childcare, preventing their equal participation (Westerman and Benbow 2014). Thus, one way to increase women's involvement would be to consider women's needs, such as offering childcare during meetings, holding the meetings at times when women have more time (e.g., when they are more likely to be away from domestic duties), providing transportation to meetings or even arranging for venues closer to villages.

Improving women's health and providing them with accessible health care can also represent powerful incentives for women to become more involved in conservation actions. Their dependence on natural resources may intensify specific health issues and safety concerns both for them and for their household. For example, women using firewood as a main source of energy may suffer from chronic pulmonary disease (Wan et al. 2011). Also, women tend to be primary care-givers for sick family members, and therefore have an interest in improving the health of their communities. However, living in remote villages with poor road infrastructure often makes it difficult to access health care services. In addition, given that significant population growth, which is the case in Madagascar (at a rate of 2.62%, Index Mundi 2014), can increase anthropogenic pressures on natural resources (Wan et al. 2011), taking into account women's reproductive health is also a beneficial strategy. This includes providing accessible family planning services to women, and/or training female community-based health agents to provide services at the local level (e.g., Dolch et al. 2015, Robson and Rakotozafy 2015).

Another crucial strategy includes training and educating local women who, in rural areas often have had very limited educational access. This may increase their opportunities to benefit from economic opportunities, and may enhance societal support for conservation and development initiatives given women's propensity to spread knowledge within their communities.

ASSESSING PROGRAM EFFICACY

While several major conservation NGOs and policy makers have begun to incorporate gender into conservation projects in Madagascar, it is unclear how equitable they are or how they have contributed to success in conservation outcomes. Very little research has been published that examines gender dimensions but represents an important direction of future research. There is a need to find a way to quantitatively and qualitatively assess and report the outcomes of such programs in a constructive way that avoids conflict of interest arising from self-assessment of organizations seeking continued donor support. Organizations should be open to learning and sharing knowledge gained from both successful and failed measures with the vision of contributiong and making progress towards a larger conservation goal. Although there are challenges to Madagascar's expansion of protected area networks, the opportunities are greater still, including the mainstreaming of effective approaches and the development of appropriate assessment techniques and results reporting. With these tools in hand, new and established programs may improve their implementation strategies to the benefit of both humans and the ecosystems on which their livelihoods depend.

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Importance, impacts de l'utilisation et gestion rationnelle du *satrana* ou *Hyphaene coriacea* Gaertn. (Arecaceae) près de la baie de Rigny, Antsiranana (Madagascar)

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ABSTRACT

Hyphaene coriacea is a useful palm in tropical Africa which also grows in the grasslands of western Madagascar. A study was conducted on the importance of this species in handcrafts and the ecological impacts in three *Fokontany* around the Baie de Rigny. Ethnobotanical surveys were conducted with women aged between 14 and 70 years old who commonly created baskets, from the collection of leaves until the sale of the finished products. The evaluation of human activities on the production of *H. coriacea* leaves was conducted by counting leaves produced by 175 palm trees subjected to different sampling conditions during one year. On average, one person collects 120 to 160 leaves, produces 60 to 80 baskets and earns 43,200 Ariary per month. The collection of the leaves contributes to sustainable management by using special tools and practices during collection such as not completely cutting down palms. However, collection of leaves negatively impacts production of leaves by reducing their number. Rotating leaf collection, restricting the number of leaves collected on each individual per year, and protection of the vegetation against brush fires are strongly advised while respecting the management techniques already in use.

RÉSUMÉ

Hyphaene coriacea, un palmier d'Afrique tropicale, pousse dans les formations herbeuses de la partie occidentale de Madagascar. Une étude sur l'importance de cette espèce pour la vannerie ainsi que l'impact de son utilisation a été effectuée dans trois *Fokontany* à la périphérie de la baie de Rigny. Des enquêtes ethnobotaniques ont été menées auprès de femmes âgées de 14 à 70 ans sur la pratique de la vannerie, de la collecte des feuilles à la vente des produits finis. Les impacts de l'activité humaine sur la production de feuilles de *H. coriacea* ont été mesurés à partir du nombre de feuilles produites par 175 palmiers soumis à des niveaux de prélèvement différents pendant une année. En moyenne, une personne collecte mensuellement de 120 à 160 feuilles, fabrique 60 à 80 paniers et génère un revenu de 43.200 Ariary. La collecte de ces feuilles de palmier est menée dans le cadre d'une gestion rationnelle car elle est réalisée avec un outil adapté et elle profite de l'interdiction d'abattre les palmiers. Le mode de collecte a cependant un impact négatif sur la production de feuilles en diminuant leur nombre. La rotation de la collecte de feuilles, la limitation du nombre de feuilles prélevées sur chaque individu pendant une année (28,4%) et la protection de la végétation contre les feux de brousses sont vivement recommandées, tout en respectant les techniques positives qui sont déjà pratiquées.

INTRODUCTION

Hyphaene coriacea est un palmier d'Afrique tropicale (Dransfield et al. 2006) utilisé par les populations rurales. En Afrique australe, par exemple, les jeunes feuilles encore enroulées sont utilisées comme matière première pour confectionner des paniers dont la production constitue une importante source de revenus pour les femmes (Konstant et al. 1995). Par ailleurs, du vin appelé *ubusulu* est collecté directement à partir de la sève de la plante et vendu sur le marché local (McKean 2003). Ce produit riche en riboflavine, vitamine B et en acide nicotinique constitue un apport alimentaire important pour les habitants (Campbell 1969).

Cette espèce, connue à Madagascar sous le nom de *satrana*, est largement distribuée dans les zones herbeuses arborées de l'Ouest depuis Antsiranana jusqu'au sud de Toliara (Dransfield et Beentje 1995). Tous les organes de la plante, végétatifs et reproducteurs, sont utilisés par les populations locales dans leur vie quotidienne : les feuilles sont employées en sparterie (e.g., Razakanirina 1994), le cœur est cuit pour être consommé (Razakanirina 1994) ou utilisé comme galactogène (Rakotonandrasana 2014) et les fruits mûrs rentrent dans l'alimentation.

La vannerie est une activité des femmes malgaches dont il est fait cas depuis longtemps (Grandidier 1928). Les espèces et les parties utilisées varient suivant les régions de Madagascar : écorces de *Raphia farinifera* (Arecaceae) à Ambalabe, région orientale de Madagascar (Bussmann et al. 2015), feuilles de *Pandanus guillaumetii* (Pandanaceae) pour les populations vivant autour des forêts humides de basses altitudes, aux environs de Manompana (Fedele et al. 2011), tiges de *Lepironia mucronata* (Cyperaceae) dans la région Tanosy (Randriatafika et al. 2007), et feuilles de *Hyphaene coriacea* dans le Menabe central (Rabefarihy 2007) ainsi que dans notre zone d'étude.

À Madagascar, l'artisanat est pratiqué par environ 30% de la population active et contribue jusqu'à 30% du Produit Intérieur Brut du pays (Fanjanarivo 1998). Par exemple, en 2004, l'exportation des produits de la vannerie et de la sparterie à l'étranger avait représenté 85,919 millions d'Ariary (Andriantseheno 2007). Pour les populations de la périphérie de la baie de Rigny, région DIANA, la confection de paniers est une des activités génératrices de revenus pour les ménages. Il s'agit de la seconde activité pratiquée par la majorité des femmes après la pêche ou l'agriculture. Les feuilles de *Hyphaene coriacea* constituent la principale matière première utilisée dans la confection de paniers.

Dans ce contexte, nous avons examiné le mode d'utilisation rationnelle de *Hyphaene coriacea* aux environs de la baie de Rigny en analysant les points suivants : (i) la place de la vannerie dans la vie quotidienne, y compris la quantité de feuilles utilisée par les femmes de la région ; (ii) l'état de la population de *H. coriacea* dans la zone d'étude ; (iii) le taux de production foliaire annuelle du palmier et l'impact des récoltes par les populations rurales sur la production de feuilles, afin de voir le nombre de prélèvements acceptables par palmier et par an.

MATÉRIELS ET MÉTHODES

SITE D'ÉTUDE. L'étude a été effectuée dans trois *fokontany* de la commune d'Andrafiabe à la périphérie de la baie de Rigny, à savoir Sahankazoambany, Ambolobozokely et Ambolobozobe (Figure 1). La vannerie est largement pratiquée dans cette commune.

Du point de vue géologique, la zone d'étude est constituée essentiellement par des sables non consolidés, des dépôts alluviaux au niveau de l'embouchure des rivières Sahankazoambany et Saharenana, et de grès de Sahafary (Du Puy et Moat 1996). Les sols alluviaux de texture limono-argileuse constituent le substrat du cours moyen et inférieur des rivières de Sahankazoambany et de Saharenana, tandis qu'au niveau des embouchures, les sols sont de type argilo-limoneux, riches en chlorure de sodium (Rossi 1980).

La végétation est constituée d'une mosaïque de formations herbeuses plus ou moins boisées, de formations buissonnantes, de forêts sèches de l'ouest, de zones cultivées et de quelques mangroves sur le littoral (Moat et Smith 2007).

Les données socio-économiques portant sur le site d'étude ont été extraites des enquêtes effectuées de 2005 à 2008 au

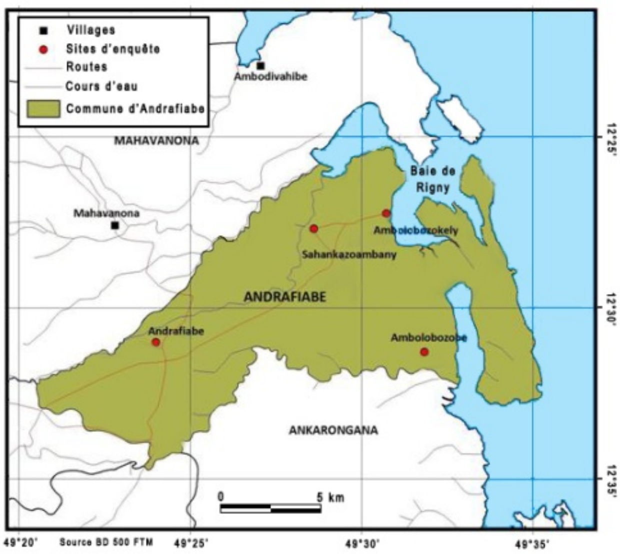

FIGURE 1. Zone d'étude à la périphérie de la baie de Rigny.

cours des travaux ethnobotaniques réalisés à la périphérie de la baie de Rigny (Rakotonandrasana 2014). Les populations villageoises ont majoritairement des origines Antakarana. Des immigrants Antaisaka et Antaifasy se sont installés récemment dans la région. Certaines personnes revendiquent également des origines mixtes Merina ou Betsileo, mélangés à des Antakarana. Selon un recensement de 2007, les trois *fokontany* abritaient 2731 habitants dans 711 ménages dont 576 femmes âgées de plus de 14 ans. La taille moyenne d'une famille est ainsi de 3,8 personnes. La densité de la population est de l'ordre de 21 habitants par km². La population a adapté ses activités économiques aux conditions environnementales existantes. Ses moyens de subsistance sont largement basés sur l'agriculture, la pêche et l'élevage de bovins, de caprins et de volailles. Avec un cheptel de 2512 têtes, l'élevage bovin constitue un véritable potentiel de production avec une moyenne de 3,5 zébus par ménage. Les activités secondaires telles que la vannerie ou la production de trembo, qui est un vin extrait de la sève des cocotiers, améliorent le revenu familial et permettent en grande partie de couvrir les dépenses liées aux produits de première nécessité tels les vêtements, le sucre ou le café.

MÉTHODES

Afin d'examiner la place de la vannerie dans la vie quotidienne, les espèces utilisées en vannerie, les procédés de la confection des paniers et la quantité de feuilles utilisées par les populations locales, des enquêtes ethnobotaniques ont été effectuées pendant les saisons pluvieuses et les saisons sèches de 2006 à 2008. Pour cela, 117 femmes pratiquant de la vannerie, âgées de 14 à 70 ans, ont été interrogées à partir de questionnaires préétablis (Alexiades 1996) et ont été observées directement (Blanchet et al. 1987) depuis la collecte de feuilles de *Hyphaene coriacea* jusqu'à la finition des paniers. Deux agents originaires de la région, capables de bien communiquer dans la langue locale mais aussi dans la langue officielle tout en comprenant la culture locale ont été retenus pour participer à toutes les étapes de l'enquête (Jain 1987, Aktouf 1990, Bernard 2002, Grenier 2003).

Cinq spécimens d'herbier de l'espèce ont été récoltés (Alexiades 1996) puis déposés respectivement dans les herbiers du Centre National d'Application de Recherches Pharmaceutique (CNARP), de la Direction de la Recherche Forestière et Piscicole (TEF), et du Parc Botanique et Zoologique de Tsimbazaza (TAN). Sur le terrain, ces spécimens ont été préparés avec une presse d'herbier, conservés dans de l'alcool dilué à 50% et enfin séchés dans un séchoir à herbier. La vérification du nom scientifique de l'espèce étudiée a été effectuée en utilisant les ouvrages de Dransfield et Beentje (1995) et de Schatz (2001).

Pour évaluer l'abondance de *Hyphaene coriacea*, un échantillonnage suivi de prospection sur terrain a été effectué en utilisant la carte de végétation de Moat et Smith (2007). Trois faciès ou unités (plaine, mi versant, haut-versant) ont été identifiés dans les formations herbeuses à *H. coriacea*. Six parcelles de 20 x 50 m ont été installées (deux relevés dans chaque unité). Tous les individus de cette espèce ont été comptés et classés par stade de développement : stade d'établissement, adulte végétatif et adulte reproductif. Après l'identification des formations herbeuses à *H. coriacea* sur la carte de végétation de Moat et Smith (2007), la surface de ces formations végétales a été obtenue en utilisant l'outil calcul d'aire du logiciel ArcView 3.2. L'abondance des individus de l'espèce étudiée a été estimée en multipliant la surface de la végétation où l'on peut rencontrer l'espèce par le nombre d'individus présents dans les parcelles d'inventaires divisée par la surface totale des parcelles étudiées (Gounot 1969).

Pour suivre la production foliaire annuelle et les impacts des activités locales sur la production de feuilles et le nombre de prélèvements acceptables pour une gestion durable de *Hyphaene coriacea*, 175 palmiers ont été suivis pour lesquels le nombre de feuilles produites a été compté tous les 4 mois pendant une année. Ces 175 individus étaient soumis à des traitements différents : (i) 35 individus n'étaient pas exploités, et ont ainsi servi de témoins pour l'analyse des effets des prélèvements foliaires et pour documenter le rythme de production foliaire annuelle ; (ii) 35 individus soumis à des collectes de feuilles au hasard par les populations locales au cours de l'année ; ces individus ont servi à étudier les impacts des collectes locales sur la production foliaire annuelle ; (iii) 105 individus soumis à diverses conditions de prélèvement foliaire pendant une année ; ces individus ont permis d'appréhender le nombre de prélèvements acceptables pour une gestion durable : (a) le tiers (35 individus) soumis à un seul prélèvement annuel ; (b) le tiers (35 individus) soumis à deux prélèvements annuels successifs avec un intervalle de 6 mois ; (c) le tiers (35 individus) à trois prélèvements annuels successifs avec un intervalle de 4 mois. Les dernières feuilles ouvertes ont été marquées au moment du suivi pour repérer les feuilles nouvellement apparues après 4 mois. Travaillant avec des villageois habitués à la cueillette des feuilles de *satrana*, nous avons suivi la méthode de collecte locale lors des prélèvements. Cette méthode consistait à laisser les deux feuilles les plus jeunes et à collecter deux à cinq feuilles par individu.

ANALYSES DE DONNÉES. Nous avons effectué des analyses de variances (ANOVA) pour déterminer la signifiance de l'effet du prélèvement des feuilles entre les différents types de traitements, avec un seuil de probabilité de 5%, en utilisant le logiciel XLSTAT (www.xlstat.com). L'impact est négatif lorsque les individus témoins sont significativement différents des autres individus.

RÉSULTATS

PLACE DE LA VANNERIE DANS LES ACTIVITÉS VILLAGEOISES. La vannerie consiste surtout à la confection des paniers ; les nattes ne sont fabriquées que sur commande. Dans la zone d'étude, la vannerie n'est qu'une activité secondaire après la pêche et l'agriculture (Supplementary Material, Tableau S1). Les enquêtes ont montré qu'une personne pouvait fabriquer de 60 à 80 paniers par mois ; un panier étant vendu à un prix de 400 à 500 Ariary, l'activité génère un revenu moyen mensuel de 43.200 Ariary. Cette somme permet, en grande partie, de financer les dépenses liées aux produits de première nécessité. Les produits finis sont achetés directement par huit opérateurs locaux auprès de chaque ménage, puis sont acheminés vers les marchés d'Antsiranana, d'Ambilobe, de Nosy Be et d'Ambanja, où les touristes et les gens venant d'autres régions de Madagascar s'approvisionnent.

LES MATIÈRES PREMIÈRES ET LA RÉCOLTE. Les feuilles d'*Hyphaene coriacea* constituent la principale matière pour la fabrication de paniers dans la zone d'étude. Les fibres de *Raphia farinifera* servent à l'assemblage. Le prélèvement des feuilles se fait à l'aide d'une sorte de faucille munie d'un manche pouvant atteindre plus de 4m de long. Cet outil est localement appelé *Afakanijaly* signifiant littéralement 'problème résolu'. La lame de la faucille est appuyée sur le pétiole puis tirée vers le bas (Figure 2).

En fonction des conditions d'accès, les prélèvements sont plus fréquents dans certaines zones, alors que dans d'autres, les individus sont relativement intacts. Ainsi, les femmes arrivent à faire quatre récoltes sur un même pied pendant une année dans les zones d'accès facile. Pour la pérennité du peuplement, les cueilleurs interdisent le prélèvement du cœur de palmier, l'abattage des individus ou le traçage du tronc lors de la collecte ainsi que la collecte de la sève. La collecte des feuilles se fait surtout en matinée sur les individus facilement accessibles. Une fois coupée, les feuilles sont déchirées longitudinalement en deux au niveau du rachis puis séchées sur place pendant une demi-journée. À la fin de l'après-midi, elles sont ramassées et apportées aux villages. Pour réaliser un panier, il faut deux feuilles. Pour un limbe d'environ 93 cm de long, on obtient des morceaux de feuilles prêts à tisser de 63 cm. Le produit fini, c'est à dire le panier, mesure 33 cm de haut (Supplementary Material, Figure S1). En moyenne, les femmes collectent 40 à 50 feuilles par semaine, soit 160 à 200 feuilles par mois (Figure 3). Étant donné que l'effectif des vannières (de plus de 14 ans) pendant l'année 2007 était de 576, le nombre de feuilles coupées pendant cette année est estimé à une quantité comprise entre 1.105.920 et 1.382.400 feuilles.

IMPACT DE LA COLLECTE DE FEUILLES SUR *HYPHAENE CORIACEA*. Le nombre moyen de feuilles produites par les individus soumis à des collectes aléatoires de la part des femmes de la région est de 8,6 feuilles par an (4 à 11). Ces palmiers produisent significativement moins de feuilles que les palmiers témoins qui produisaient une moyenne de 12,3 feuilles par an et qui n'étaient soumis à aucun prélèvement au cours d'une année (ANOVA, p<0.01, Supplementary Material, Tableau S2). Les prélè-

FIGURE 2. Collecte de feuilles à l'aide d'un *Afakanijaly* dans un terroir typique de la périphérie de la baie de Rigny.

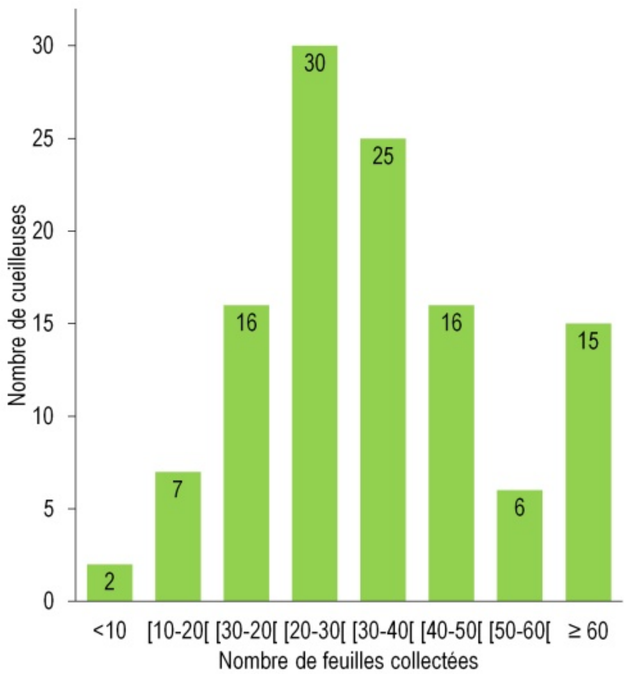

FIGURE 3. Histogramme de l'effectif de femmes cueilleuses en fonction du nombre de feuilles prélevées.

vements répétés tout au long de l'année sur un pied diminuent le nombre de feuilles produites. Lorsqu'un seul prélèvement annuel est effectué, les palmiers produisaient 12,0 feuilles en moyenne, alors qu'ils ne produisaient que 10,5 et 10,4 feuilles lorsqu'ils étaient soumis à deux et trois prélèvements successifs respectivement (Supplementary Material, Tableau S3). La moyenne du nombre de feuilles produites par les individus diminue progressivement en fonction du nombre de prélèvements. La moyenne du nombre de feuilles produites par les individus témoins et celles par les individus soumis à un seul prélèvement sont représentées par une même lettre, ces deux groupes ne présentent pas entre eux une différence significative. Plusieurs prélèvements successifs (supérieurs à deux fois par an) entraînent une diminution significative de la production de feuilles ($p < 0,01$). Un seul prélèvement n'affecte pas la production du nombre de feuilles des individus.

ABONDANCE DE *HYPHAENE CORIACEA* ET PRODUCTION FOLIAIRE ANNUELLE. La surface de la végétation favorable pour l'espèce étudiée est de 6.964 ha. En se basant sur cette superficie pour l'évaluation de l'abondance de *Hyphaene coriacea*, nous estimons la population à 10.144.287 individus (soit 1.456 individus/ha) dont 1.555.302 sont des individus matures (soit 223 individus/ha) dans la zone d'étude. Pour les individus de *H. coriacea* n'ayant pas subi de prélèvement de feuilles, nous avons trouvé qu'un individu produit de 8 à 16 feuilles par an avec une moyenne de 12,3 feuilles par an. Ainsi, par extrapolation, les 1.555.302 individus matures estimés dans notre zone d'étude peuvent produire 19.114.660 feuilles par an. La production foliaire annuelle est alors au moins 17,3 fois plus grande que les besoins annuels des villageois.

DISCUSSIONS

À la périphérie de la baie de Rigny, les feuilles de *Hyphaene coriacea* ne sont utilisées que pour confectionner des paniers en vue d'approvisionner les marchés destinés aux touristes et autres riverains de la région de DIANA. Dans d'autres régions de Madagascar, les feuilles de cette espèce sont également utilisées pour confectionner d'autres produits comme des chapeaux, des cordes, des nattes ou des tapis (Razakanirina 1994, Rabefarihy 2007), comme en Afrique du Sud, au Botswana et au Soudan (McKean 2003).

Cette étude a montré que les prélèvements répétés tout au long de l'année sur un pied de *Hyphaene coriacea* avaient un effet négatif en diminuant le nombre de feuilles produites ; par contre, un seul prélèvement par an n'a aucun effet sur la production de feuilles. Des résultats similaires ont été aussi constatés par McKean (2003) sur le mode de croissance de cette même espèce en Afrique du Sud. Dans la mesure où cette espèce ne produit que 3,8 feuilles par individu et par an (Cunningham 1988), le prélèvement de feuilles ne devrait pas dépasser une feuille par individu et par an (McKean 2003), soit 26,3% de la production foliaire annuelle. Dans notre cas, le mode de collecte local suivi pendant les expérimentations a montré que le nombre de prélèvements acceptables par an par individu est de 28,4% de la production foliaire annuelle.

En tenant compte du besoin annuel (1.105.920 – 1.382.400 feuilles), du nombre de feuilles produites par individu et par an (8 à 16 feuilles), du nombre de prélèvements acceptables par individus par an (28,4% de la production foliaire) et du nombre d'individus matures dans la zone d'étude (1.555.302 individus), le nombre d'individus soumis aux cueillettes pendant une année sera compris entre 315.977 et 394.971.

Dans notre zone d'étude, des mesures ont été prises par les populations locales pour atténuer les impacts négatifs des modes de cueillette sur les individus de *Hyphaene coriacea* ; par exemple, en évitant certaines pratiques comme l'abattage des individus, le traçage du tronc lors de la collecte et la cueillette du cœur ou de la sève (Campbell 1969, Rabefarihy 2007). Parmi les bonnes pratiques locales, figurent également l'utilisation de l'*Afakanijaly* qui ne meurtrit pas le palmier lors de la collecte de feuilles ainsi que le maintien des deux plus jeunes feuilles ouvertes. À ces pratiques s'ajoutent la rotation de la collecte, la limitation du nombre de feuilles prélevées sur chaque individu pendant une année et la protection de la végétation contre les feux de brousses. Cependant, pour une bonne gestion de cette espèce, des travaux multidisciplinaires et multisectoriels sont indispensables. La création d'une aire de conservation est également souhaitable pour assurer une bonne régénération du peuplement. La gestion pérenne repose en priorité sur la fréquence de collecte sur les individus les plus accessibles, mais aussi sur l'effet des feux périodiques pratiqués pour le pâturage.

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SUPPLEMENTARY MATERIAL.

Available online only.

Tableau S1. Pourcentage d'activités des femmes dans les trois sites.

Tableau S2. Moyenne de feuilles produites pendant une année dans une parcelle témoin et une parcelle soumise à des collectes répétées.

Tableau S3. Nombre moyen de feuilles produites annuellement en fonction du régime de prélèvement et probabilité.

Figure S1. Travaux de finition des paniers.

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The value of the spineless monkey orange tree (*Strychnos madagascariensis*) for conservation of northern sportive lemurs (*Lepilemur milanoii* and *L. ankaranensis*)

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ABSTRACT
Tree hollows provide shelters for a large number of forest-dependent vertebrate species worldwide. In Madagascar, where high historical and ongoing rates of deforestation and forest degradation are responsible for a major environmental crisis, reduced availability of tree hollows may lead to declines in hollow-dwelling species such as sportive lemurs, one of the most species-rich groups of lemurs. The identification of native tree species used by hollow-dwelling lemurs may facilitate targeted management interventions to maintain or improve habitat quality for these lemurs. During an extensive survey of sportive lemurs in northern Madagascar, we identified one tree species, *Strychnos madagascariensis* (Loganiaceae), the spineless monkey orange tree, as a principal sleeping site of two species of northern sportive lemurs, *Lepilemur ankaranensis* and *L. milanoii* (Lepilemuridae). This tree species represented 32.5% (n=150) of the 458 sleeping sites recorded. This result suggests that *S. madagascariensis* may be valuable for the conservation of hollow-dwelling lemurs.

RÉSUMÉ
De nombreux vertébrés forestiers à travers le monde trouvent refuge dans des cavités et des trous d'arbres. À Madagascar, les taux de déforestation historiques et actuels sont responsables d'une crise environnementale majeure. Dans ce contexte, une disponibilité réduite d'arbres pourvus de cavités pourrait entrainer le déclin des espèces dépendant de ces abris comme par exemple les lépilemurs, un des groupes de lémuriens les plus riches en espèces. L'identification des espèces d'arbres indigènes creusés de trous et utilisés par les lémuriens pourrait faciliter la mise en place d'actions de conservation ayant pour but de maintenir ou améliorer l'habitat de ces lémuriens. Au cours d'une étude réalisée dans le Nord de Madagascar, nous avons observé que *Strychnos madagascariensis* (Loganiaceae) était fréquemment utilisé comme site dortoir par les deux espèces de lépilemurs présentes, *Lepilemur ankaranensis* and *L. milanoii* (Lepilemuridae). Cette espèce d'arbre concernait 32,5% (n = 150) des 458 sites dortoirs enregistrés. Ce résultat suggère que *S. madagascariensis* pourrait être important pour la conservation des lémuriens dépendant de sites dortoirs.

INTRODUCTION
The identification of important interspecific interactions can be of significant value for conservation management (Caro 2007, Berger-Tal et al. 2011). For instance, knowing the major plant species on which an endangered species relies for feeding, resting or dwelling can be of particular importance when establishing conservation, reforestation and/or timber and forest use plans (Rose et al. 2001, Lindenmayer et al. 2006). Sleeping sites are crucial for the survival of terrestrial vertebrates (Anderson 1998), and in particular burrows, nests, tree hollows, and other structures provide protection from climatic extremes (e.g., *Cheirogaleus* sp., Dausmann et al. 2004) and predators (e.g., *Allocebus trichotis*, Biebouw et al. 2009). Tree hollows are a critical structural attribute of native forests worldwide and a large number of vertebrate species (e.g., Cheirogaleidae family of primates, nocturnal birds of the Strigidae family, etc.) are closely associated with these hollows (Newton 1994, Gibbons and Lindenmayer 2002).

Primates spend about half of their life at sleeping sites, and their use has been suggested to be important for understanding the diversity of primates' adaptations to their environment (Anderson 1998). In Madagascar two families of lemurs (Cheirogaleidae and Lepilemuridae) are known to extensively use tree hollows (Mittermeier et al. 2010).

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Lepilemur milanoii and *L. ankaranensis* are two sportive lemur species of the family Lepilemuridae with neighboring and partly overlapping distributions in northern Madagascar (Figure 1, Louis Jr. et al. 2006). They can be very abundant in some forests (e.g., in Ankarana and Solaniampilana, Hawkins et al. 1990, Salmona et al. 2014a), yet, little is known about the biology of these nocturnal species. Apart from several estimates of their population densities and population sizes (Meyers and Ratsirarson 1989, Hawkins et al. 1990, Meyler et al. 2012, Salmona et al. 2014a), their ecology and behavior remains understudied. In particular, while it is known that these species use tree sleeping sites during the day (Mittermeier et al. 2010), no specific study has yet been published that identifies the tree species used as sleeping sites in these regions. However a large body of literature covers the biology and behavioral ecology of several other sportive lemur species. Schmid and Ganzhorn (1996) studied for instance *L. ruficaudatus* and showed that they have the lowest basal metabolic rate of all folivorous mammals, which may allow them to subsist on leaves with a high toxic allelochemicals but low energy and protein content. This further suggests that sleeping sites may provide sportive lemurs shelters to limit energy expenses and maintain low diurnal basal metabolism in adverse climatic conditions. Indeed, the presence of Sahamalaza sportive lemurs (*L. sahamalazensis*) in tree hollows was negatively correlated to rainfall, and tree hollows were reported as not occupied at all in the rainy season (Seiler 2012). This stresses the function of potential tree hollows as a kind of 'dry season residence' in dry regions of Madagascar. Moreover it may also serve as shelter from aerial and terrestrial predators (Fichtel 2007, Seiler et al. 2013). Several studies reported the use of a diversity of sleeping sites per individual and the shared use of sleeping sites by partners or relatives (Rasoloharijaona et al. 2003, Zinner et al. 2003) in some species and solitary in use in others (Rasoloharijaona et al. 2008, Seiler et al. 2013). The spatial repartition of individuals has been repeatedly linked to sleeping site availability for several species (Rasoloharijaona et al. 2003, 2006, Zinner et al. 2003, Rasoloharijaona et al. 2008) and is considered to be an important factor of the low overlap in home ranges of non-mated, unrelated individuals. Rasoloharijaona et al. (2010) suggested that sleeping sites may be limited and defendable resources providing reproductive benefits, and among the main drivers of ritualized aggressive loud call displays and tree gouging behavior used for territory and resource defense.

Forest quality and maturity may affect tree hollow availability as old mature forests are more likely to harbor old and hollowed trees (Gibbons and Lindenmayer 2002). The presence and density of sportive lemur populations may thus depend on the existence of old forests providing suitable food, substrates for locomotion, and sleeping sites (Rasoloharijaona et al. 2008, Seiler et al. 2013).

During an extensive survey whose primary goal was to assess population densities and carry out genetic sampling of sportive lemurs in northern Madagascar, we also noticed the prevalence of the use of one tree species as a sleeping site. As a first step toward describing the roosting ecology of the northern sportive lemurs *L. milanoii* and *L. ankaranensis*, we report in this paper the prevalence of the use of this species, the spineless monkey orange tree *Strychnos madagascariensis* (Loganiaceae) for sleeping sites by these two lemur species. Our aim was not to provide a detailed analysis of sleeping sites or tree species but rather call attention to one particularly striking species.

MATERIAL AND METHODS

STUDY REGION. We visited all 17 major forests within the known distribution of the two *Lepilemur* species (Figure 1) during the dry seasons (April–November) of 2011, 2012, and 2013. Specifically, we visited the Loky-Manambato region (Daraina) and the Andrafiamena-Andavakoera massif, both Category V protected areas managed by the NGO Fanamby, as well as the Ankarana National Park and the Analamerana Special Reserve, both managed by Madagascar National Parks (Figure 1). These study sites have been previously described in detail by several authors (Hawkins et al. 1990, Goodman and Wilmé 2006a, Ranirison 2006, Burivalova 2011). Briefly, these are mainly fragmented dry forests, frequently surrounded and/or connected by riparian corridors or smaller fragments. Yet, some forests in the south of the Loky-Manambato region (Binara, Antsahabe, Bobankora) as well as some valleys of Andrafiamena, and some corridors of the Ankarana Plateau harbor sub-humid forests (Moat and Smith 2007). While most forests of the Loky-Manambato region lie on distinct granito-migmatic blocks separated by alluvium, Ankarana is a typical *tsingy* limestone plateau, bisected by basalt corridors, that extends in the east to the limestone blocks in the northern part of Analamerana and Andrafiamena. The southern part of Andrafiamena forest lies above sandstone soil and Andavakoera basement rocks (igneous and metamorphic, Goodman and Wilmé 2006b).

FIELD PROCEDURES. During diurnal surveys we actively and opportunistically (during other research activities) searched for sportive lemurs. From most of the 36 camp sites, surveys spread, when allowed by the topography, in a star-like manner, and included transects, existing trails, and areas off trail. Additional maps of all surveyed sites and recorded Global Positioning System (GPS) coordinates and other description of the field are available in Salmona (2014), and in Salmona et al. (2013, 2014a,b). When a sportive lemur was spotted we recorded the geographical position of its sleep site using a Garmin® Etrex-H GPS receiver (maximum error: ±5m) and the WGS84 referencing system. The vernacular names of tree species (and scientific names when known) were recorded for all sleeping site trees by trained botanical guides experienced in the regional inventory of native plants. In particular, *Strychnos madagascariensis* was identified on the basis of distinctive characteristics of its leaves and fruits (Schatz 2001). Vernacular names sometimes varied from site to site. For instance *S. madagascariensis* was called synonymously as *vakokoa, vakakoagna, vakakoana, vahipendela*; other vernacular names for single species may have varied similarly.

Our experience was that the two sportive lemur species (*Lepilemur milanoii* and *L. ankaranensis*) are not distinguishable morphometrically. Attribution of these lemurs and their sleeping sites to either sportive lemur species is therefore based on the schematic approximate distribution range (Figure 1) as defined by Louis Jr. et al.'s (2006) taxonomy. According to these authors, however, the two species occur in sympatry in the Andrafiamena forest (Figure 1). Our observations of *Lepilemur* in the Andrafiamena forest hence cannot in theory be attributed without error to either of the two species. To avoid confusion, therefore, we exclude Andrafiamena observations from species-level results, but included it in overall results. Further taxonomic work might help to clarify the exact distribution of these species. For each species and forest we calculated the percentages of sleeping sites in *S. madagascariensis* relative to the total number of sleeping sites. We further compared the proportion of *S. madagascariensis* and other tree taxa used by each sportive lemur species using a Chi-squared test.

STRYCHNOS MADAGASCARIENSIS DISTRIBUTION IN MADAGASCAR. To foster potential interest from other researchers and forest conservation managers within a broader geographic context, we also clarified the distribution of *S. madagascariensis* in Madagascar on the basis of existing collections of this tree species. We used the Tropicos® specimen online data base <http://www.tropicos.org/>, which lists 179 specimens in Madagascar from several institutions. The map of the distribution (Figure 1) was produced using the online SimpleMappr mapping tool (Shorthouse 2010).

RESULTS

Out of 458 sleeping sites, four records (0.6%) were vegetative tangles; the rest were in tree hollows. *Strychnos madagascariensis* represented 150 observations (32.5% of the total, Table 1). There was no difference in the frequency of use of *S. madagascariensis* by the two species of sportive lemurs (*Lepilemur milanoii*: 37.4%, 104 out of 278 observations; *L. ankaranensis*: 35.5%, 43 out of 121 observations, Table 1, Chi-squared test p-value = 1). *S. madagascariensis* was by far the tree species most used by sportive lemurs, with about seven times more records than the second most frequently used category of trees. For *L. milanoii*, *mampay* trees (corresponding to several genera from the Fabaceae family Schatz 2001; 13 observations) were the second-most used species of tree. For *L. ankaranensis*, *hazoatambo* trees (probably *Sarcolaena* spp.; 21 observations) were the second-most used species of tree.

Table 1 and Figure 1 show that the proportion of *Strychnos madagascariensis* is not evenly distributed within and between forests. If we discard sites with very few (≤3) observations, the proportion of *S. madagascariensis* sleeping sites ranges from 12.5% in the wet mountainous forest of Binara to 68.2% in the dry forest of Solaniampilana for *Lepilemur milanoii*, and from 5.1% in Andrafiamena to 45.9% in Analamerana Special Reserve for *L. ankaranensis*. The geographical distribution of observations (Figure 1) shows that the western lowland edge of the Ankarana plateau, covered with very dry forest, the Solaniampilana and Ambohitsitondroina dry forest and the forest of the Analamerana Special Reserve, harbor high proportions of observations of *S. madagascariensis* sleeping sites.

There are a few local exceptions to this regional pattern. The Andrafiamena forest had the lowest frequency of *Strychnos madagascariensis* sleeping sites for *Lepilemur ankaranensis* or *L. milanoii*; rather, most sleeping sites were in *hazoatambo* trees (*Sarcolaena* sp.; 20 out of 21 observations). Since in this area, *Sarcolaena* sp. seems to dominate parts of the landscape, it is possible that *Strychnos madagascariensis* is present at low density. In the core of Antsahabe and Binara forests, where the use of *S. madagascariensis* sleeping sites was low for *L. milanoii*, tree hollows

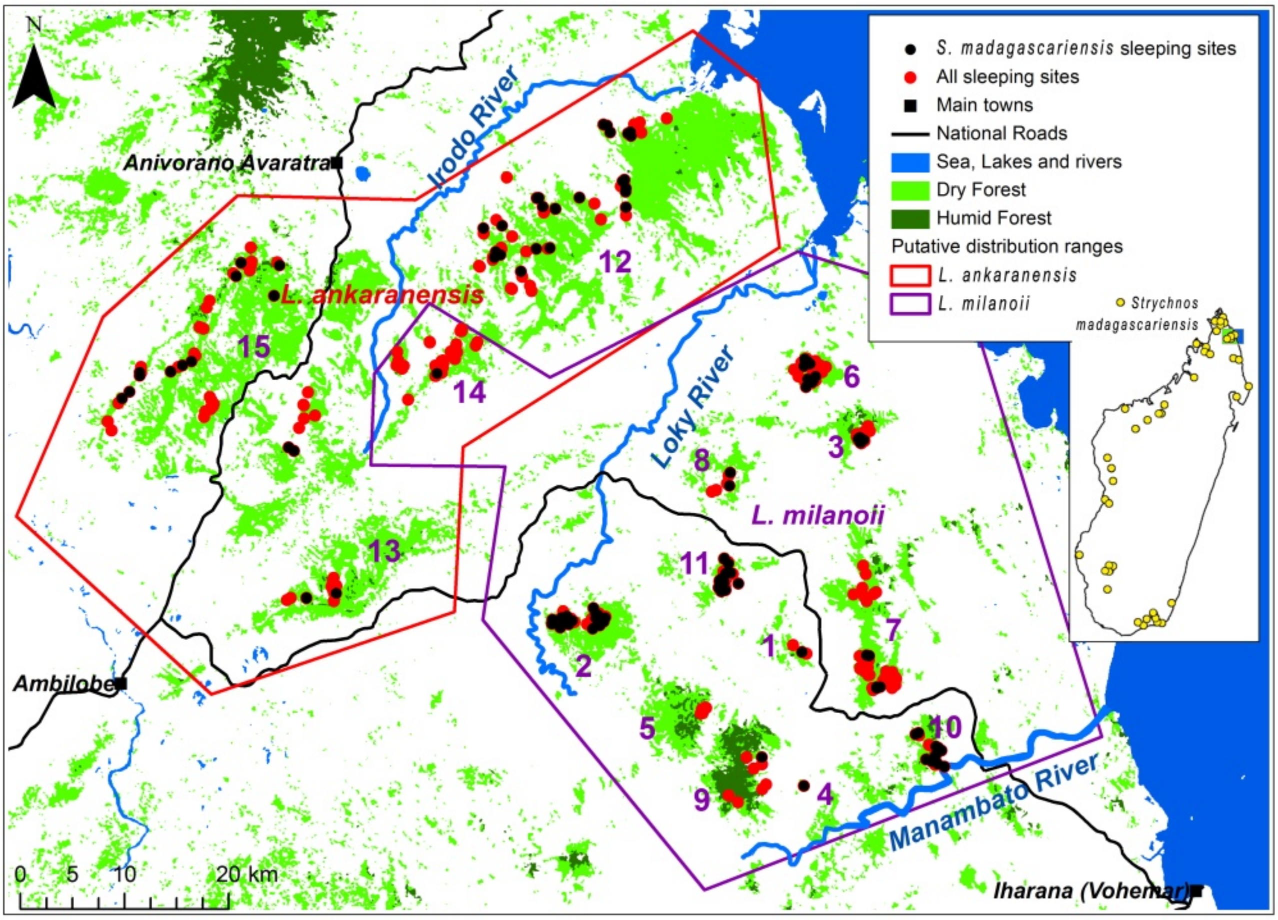

Figure 1. Studied sportive lemur sleeping sites. (Purple numbers correspond to locality numbers (ID) mentioned in Table 1. The schematic approximate distribution ranges are based on Louis Jr. et al. 2006 taxonomy. Tattersall (2007) suggested that the *Lepilemur* species reported by Louis Jr. et al. (2006), all diagnosed exclusively on genetic distance, should be treated with caution. Inset map showing the distribution of *Strychnos madagascariensis* specimens' origin within Madagascar (western areas tend to be the drier areas of Madagascar, eastern areas tend to be wetter; the northern tip of Madagascar tends to be dry or transitional. Modified from: Catalogue of the Vascular Plants of Madagascar. Tropicos.org. Missouri Botanical Garden. 14 May 2015).

Table 1. Number and proportion of *Strychnos madagascariensis* sleeping sites per surveyed forest fragment. (Id = forest identification numbers as purple numbers in Figure 1; *S. mad* = *Strychnos madagascariensis* occurrences; % = percentage of *S. madagascariensis* occurrences out of all sleeping site records; Forest type: D = Dry, T = Transitional, H = Humid, D/T or T/H = site that includes both forest types; Protected Area: L-M = Loky Manambato managed by Fanamby in the SAVA Region, ASR = Analamerana Special Reserve, and ANP = Ankarana National Park, both managed by Madagascar National Park in the DIANA Region, A-A = Andrafiamena-Andavakoera managed by Fanamby in the DIANA Region. Attribution to either sportive lemur species (*L. milanoii* and *L. ankaranensis*) is based on the schematic approximate distribution range (Figure 1) as defined by taxonomy by Louis et al. (2006), with Andrafiamena records assigned to *L. ankaranensis* or *L. milanoii*)

Species	Forest	Id	S. mad	all trees	%	Forest type	Protected area
L. milanoii	Ambilondambo	1	1	3	33.3	D	L-M
L. milanoii	Ambohitsitondroina	2	23	39	59.0	D	L-M
L. milanoii	Ampondrabe	3	12	45	26.7	D/T	L-M
L. milanoii	Ankaramy	4	1	1	100.0	D/T	L-M
L. milanoii	Antsahabe	5	0	3	0.0	T/H	L-M
L. milanoii	Antsaharaingy	6	14	45	31.1	D	L-M
L. milanoii	Bekaraoka	7	2	25	8.0	D/T	L-M
L. milanoii	Benanofy	8	2	8	25.0	D	L-M
L. milanoii	Binara	9	1	8	12.5	T/H	L-M
L. milanoii	Bobankora	10	18	57	31.6	T/H	L-M
L. milanoii	Solaniampilana	11	30	44	68.2	D	L-M
Sub total *L. milanoii*			104	278	37.4		
L. ankaranensis	Analamerana	12	28	61	45.9	D/T	ASR
L. ankaranensis	Andavakoera	13	3	16	18.8	D/T	A-A
L. ankaranensis	Ankarana	15	12	44	27.3	D/T	ANP
Sub total *L. ankaranensis*			43	121	35.5		
L. spp	Andrafiamena	14	3	59	5.1	D/T	A-A
Total			**150**	**458**	**32.8**		

were rare overall (J. Salmona and T. Ralantoharijaona pers. obs.); we rarely observed sportive lemurs during diurnal surveys, and of the five sportive lemur individuals that were observed in Antsahabe, three were sleeping or resting in dense vegetation, not in tree hollows.

Records of collections of *Strychnos madagascariensis*, at an island-wide scale in Madagascar show that the species has been mostly collected in the western parts of the island, where forests are generally drier (Figure 1). However, a few collections of the species have been obtained from the eastern coastal areas, where forests are generally more humid.

DISCUSSION

Consistent with previous research suggesting that some sportive lemurs prefer tree hollow shelters over open sleeping sites in dense vegetation (Rasoloharijaona et al. 2008), we found that northern sportive lemurs chose tree hollow shelters almost exclusively. However, since sportive lemurs resting in dense vegetation may be more difficult to detect than in tree hollows, it would be important to confirm that the observed percentages are not dramatically affected by this possible differential detection.

Strychnos madagascariensis is often used as a sleeping site. However, to state that it is preferentially chosen by sportive lemurs we would need data on both tree species and hollowed tree frequency in all of the visited forests. Given that we did not collect such data, our study remains preliminary. However our findings show that northern sportive lemurs were found in *S. madagascariensis* hollows with much higher frequency than in any other tree species. This occurred for both *Lepilemur ankaranensis* and *L. milanoii*, and occurred in the large majority of forests across northern Madagascar, especially in dry and transitional forest types.

Further study might help determine the hollow characteristics that are associated with *S. madagascariensis* use as a sleeping site. In particular, parameters such as the height of shelter, the width and depth of the hollow, as well as the density of the cover above the tree hollow has been shown to influence sleeping site choice in *Lepilemur sahamalazensis* (Seiler et al. 2013).

A DRY AND TRANSITIONAL FORESTS TREE? The geographic focus of this study was on northern Madagascar, within the ranges of two species of northern sportive lemurs. However, given that *Strychnos madagascariensis* is distributed across the northern, western and southern (e.g., dry and subarid) regions of the island suggests that this tree species is likely used by other *Lepilemur* species. From north to south it is reported and might particularly benefit hollow-dwelling fauna in the following localities: Analamerana (this study), Andrafiamena (Burivalova 2011, this study), Ankarana National Park (Wilson et al. 1989, this study), the Loky-Manambato region (this study), Sahamalaza peninsula (Schwitzer et al. 2007), Nosy Faly Peninsula (Simmen et al. 2007), Anjajavy (JS and LC unpub. data), Ankarafantsika (Rajoelison et al. 2002, Rakotodratsimba 2008), Antrema (Ramanankirahina 2004), the northern banks of the Mahavavy river (Boeny region, JS and LC unpub. data), Kirindy (Ganzhorn 2002, Dausmann et al. 2008), and Berenty, Antserananomby, and Beza-Mahafaly (Simmen et al. 2006). Further, the geographic origins of herbaria specimens of *S. madagascariensis* confirm that it has a wide distribution. Its distribution covers mostly dry and transitional forests on the northern tip and mostly dry forests in the western parts of the island. This is consistent with the deciduous to semi-persistent characteristic of *S. madagascariensis*' leaves (Schatz 2001), which suggest that it is adapted to dry or transitional forests. However the few specimens from more humid localities (e.g., on the Masoala peninsula, Figure 1, Inset) suggest that its presence and role as a sleeping site for Malagasy fauna in humid forests also need further investigation.

A VALUABLE SLEEPING SITE FOR LEMURS? From the 150 *Strychnos madagascariensis* sleeping site observations, we noted that this tree shows a high propensity for hollow formation. It was not rare for trees to harbor several hollows of various sizes, hollows with several entries and sizes corresponding to most of, if not the entire trunk height. Altogether, *S. madagascariensis* could provide important shelter resources for tree-hollow-dwelling fauna in Madagascar. For instance, in what is to our knowledge the only two other studies to date systematically reporting tree species used by lemurs as resting or sleeping sites, *S. madagascariensis* was identified as the most preferentially chosen by *Lepilemur ruficaudatus* (D. Zinner pers. com.) in Kirindy and was among the tree species predominantly used by Cheirogaleus medius (Dausmann 2013) as a resting/hibernating site in Kirindy in southwestern Madagascar. We hope that our study will generate interest among other researchers in improving understanding of other species that may also benefit from *S. madagascariensis* tree hollows.

Apart from protection against predators (Anderson 1998, Biebouw et al. 2009), tree hollow sleeping sites enable some species to tolerate climatic extremes (Dausmann et al. 2004). Hibernation and daily torpor of lemurs of the Cheirogaleidae family and the low resting metabolic rates of sportive lemurs (Lepilemuridae), may have evolved as strategies to counter the challenges of pronounced seasonality with food and water shortage (Drack et al. 1999, Wright 1999, Dausmann et al. 2004, Blanco et al. 2013, Kobbe and Dausmann 2009). Selection of suitable tree hollows as sleeping sites may provide thermoregulatory benefits for these lemur species by shielding them from rain, wind and strong fluctuations in temperature (Dausmann 2013); but see also Seiler et al. (2013) who reported that *Lepilemur sahamalazensis* was not observed in hollows during the rainy season.

In addition, *Strychnos madagascariensis* leaves and fruits were reported to enter the diet of *Lepilemur ruficaudatus* in Kirindy (Ganzhorn 2002), and of *L. edwardsii* in Ankarafantsika (Thalmann 2001). Its leaves are consumed by *Microcebus ravelobensis, Propithecus coronatus* (Ramanankirahina 2004), *P. verreauxi* (Simmen et al. 2003), *P. tattersalli* (Rasolondraibe 2011) and *Lemur catta* (LaFleur and Gould 2009). Its fruits are commonly eaten by *Eulemur sanfordi* and *E. coronatus* (Wilson et al. 1989), and are part of the diet of *E. macaco* (Simmen et al. 2007), *E. fulvus* (Sato 2012, Sato et al. 2014), *E. flavifrons* (Volampeno et al. 2011), *E. rufifrons* (Dausmann et al. 2008), *L. catta* (Simmen et al. 2003, 2006), *M. ravelobensis, M. murinus* (Thorén et al. 2011), *P. verreauxi* (Ralisoamalala 1996 in Dausmann et al. 2008) and *P. perrieri* (Banks 2013). The fruits are also a resource for rodents (*Hypogeomys antimena, Eliurus* spp., *Macrotarsomys* spp. and *Rattus* spp.), bushpigs (*Potamochoerus larvatus*), invertebrates (e.g., *Aphaenogaster swammerdami* ants (Dausmann et al. 2008) and birds (as shown for Southern African brown-headed parrot, *Poicephalus cryptoxanthus* (Taylor and Perrin 2006)). This suggests that the species may be an important food resource for a diversity of Malagasy animals.

More speculatively, a potential hidden benefit to some vertebrate species of these trees could come from the anti-parasitic properties of toxic compounds in *Strychnos madagascariensis* leaves, bark and seeds; the *Strychnos* genus produces strychnine-related alkaloids (Philippe et al. 2004). In particular, *S. madagascariensis* leaves have strong toxic and repellent effects against ticks (Habeeb 2010). Leaf decoctions and/or dry pounded bark of *S. madagascariensis* are traditionally used in eastern Africa against skin sores and ringworm infections caused by bacteria and fungi (De Wet et al. 2013). Additionally, the stem and leaves of several *Strychnos* species exhibit antiplasmodial activity (Philippe et al. 2005). Further study is needed to determine the potential role of this tree species in fighting parasites in lemurs and other vertebrate species, but one could hypothesize that sleeping in a *S. madagascariensis* hollow or (for vertebrates able to detoxify its alkaloids) ingesting its leaves, stems, or seeds may present an anti-parasitic effect.

CONCLUSION

The extensive use of tree hollows by northern sportive lemurs suggests that they strongly depend on the availability of sleeping sites. The extensive historical habitat loss in Madagascar (Harper et al. 2007), coupled with the ongoing (0.4–2.5% per year) and predicted high rates of deforestation in Madagascar (up to +1.17% per year; Vieilledent et al. 2013) are challenging current lemur conservation (Schwitzer et al. 2014). Further, the often fragmented and isolated state of remaining habitat, and ominous threats from global warming throughout the island (Brown and Yoder 2015, Brown et al. 2015), call for further conservation attention to hollow-dwelling species. In particular, inclusion of tree species that offer good quality sleeping sites such as *S. madagascariensis* in reforestation and forest management projects could prove beneficial for these lemur species.

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SUPPLEMENTARY MATERIAL.

Available online only.

Illustrations of *Strychnos madagascariensis* tree hollow hosting a Daraina sportive lemur.

ARTICLE http://dx.doi.org/10.4314/mcd.v10i2.4

Comparison of parasitic infections and body condition in rufous mouse lemurs (*Microcebus rufus*) at Ranomafana National Park, southeast Madagascar

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ABSTRACT
Body condition may be an important indicator for many infectious diseases and parasites, and may ultimately affect an individual's fitness. Although some research has correlated body condition and parasite loads in other nonhuman primates, little information has been investigated in prosimian primates. In this study we compare parasitic infections and body condition in a member of the Cheirogaleidae family (*Microcebus rufus*: rufous mouse lemur) at Ranomafana National Park, southeast Madagascar. This species is characterized by seasonal fattening in preparation for the dry season followed by torpor, and it is important to understand the fluctuation between parasites and infections according to seasonal body condition. We trapped 72 individuals of the species inside Ranomafana National Park (RNP) after the dry season. These individuals were brought to the Centre Valbio Laboratory (CVB) and were subcutaneously micro-chipped with subdermal transponders for permanent identification. We recorded morphometric data, body condition, species richness and prevalence of ectoparasites and gastrointestinal parasites. We found that individuals that had both high number of parasite species as well as high prevalence of ectoparasites and gastrointestinal parasites had better body condition. There is some indication that being in good condition is important in controlling infections.

RÉSUMÉ
La condition physique peut être un indicateur important pour de nombreuses maladies infectieuses et pour les parasites, et peut finalement affecter l'aptitude d'un individu. Si certaines études ont montré la relation entre condition physique et charges parasitaires chez des primates non humains, peu d'informations étaient disponibles en ce qui concerne les prosimiens. Dans cette étude, les infections parasitaires et l'état de santé du microcèbe roux *Microcebus rufus* de la famille des Cheirogaleidae ont été étudiées dans le Parc National de Ranomafana, Sud-est de Madagascar. Cette espèce est caractérisée par sa capacité à accumuler des matières grasses à la base de la queue afin de se préparer à la saison sèche au cours de laquelle elle rentre en torpeur ; il est donc important de comprendre la fluctuation saisonnière entre les parasites et les infections selon l'état de santé des individus. Soixante-douze animaux de cette espèce ont été capturés à l'intérieur du Parc National de Ranomafana après la saison sèche. Les individus capturés ont été rapportés au Centre Valbio où ils ont été marqués avec une puce électronique sous-cutanée servant de transpondeur pour l'identification permanente. Nous avons collecté des données morphométriques pour documenter la condition physique, la richesse spécifique et la prévalence des ectoparasites et des parasites gastro-intestinaux. Nous avons constaté que les individus présentant à la fois un grand nombre d'espèces de parasites ainsi qu'une forte prévalence d'ectoparasites et de parasites gastro-intestinaux avaient une meilleure condition physique. Les résultats semblent indiquer qu'un bon état est important dans le contrôle des infections.

INTRODUCTION
Knowledge of animal body condition is of considerable importance in many ecological studies, as well as in disease research (i.e., Coop and Holmes 1996, Alzaga et al. 2008, Munyeme et al. 2010), and as a wildlife management tool (Ezenwa et al. 2010). It may be an important indicator for many infectious diseases and parasites, and may ultimately affect an individual's fitness (Sheldon and Verhulst 1996). Animals in poorer condition often are more heavily parasitized than individuals in better condition (Wilford 1986, Chapman et al. 2006, Tompkins et al. 2011), as poor body condition can lead to susceptibility to parasites and furthermore lead to "vicious circle" of continuing parasite infections and deterioration of the host (Beldomenico and Begon 2010).

Although studies relating body condition, diet and parasites/disease have been conducted on wild and captive monkeys and apes (e.g., Chapman et al. 2006, Altizer et al. 2007), little is known about the relationships between body condition, and parasites in prosimians primates, especially in the nocturnal prosi-

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mians. Collecting descriptive and analytic baseline data on body condition and parasitic infections is important in determining patterns of health status and will assist in effective disease management and conservation planning.

In this study we compare the extent of parasitic infections and body condition in a member of the Cheirogaleidae family (*Microcebus rufus*: rufous mouse lemur) at Ranomafana National Park (RNP), southeast Madagascar. This species is characterized by seasonal fattening (though not for all individuals at this site) in preparation for the dry season followed by torpor, and it is important to understand the relationship between parasites, disease, and body condition (Wright and Martin 1995). The specific objectives in this paper are to investigate relationships between body condition and multiple measures of parasitism. We hypothesized that i) there is a positive association among body condition indices, ii) there are differences in the measures of body condition index between individuals, and iii) there are differences in measures of parasitic infection between individuals on the basis of sex, site and period of study. Also iv) animals in poorer condition will exhibit higher parasite richness, abundance, and prevalence.

METHODS

STUDY SITE. Mouse lemurs were trapped at two sites from August until December 2012 in RNP, E047°20', S21°16' (Wright 1992, Wright and Andriamihaja 2002). The first is within RNP at the Talatakely trail system (centroid at E047°25'17.0", S21°15'43.5"), which was clear cut in small areas before 1947 and selectively logged from 1986–1990 before the creation of the national park in 1991 (Wright et al. 2009). The second site was at the research station Centre Valbio (near Campsite location, centroid at E047°25'10.7", S21°15'12.1"), which was clear-cut in 2001.

TRAPPING METHOD. Trapping methods were based on methods used by Wright and Martin (1995) and Atsalis (1999). In each site, aluminum live traps (XLR, Sherman traps inc., Florida, USA, 22.2 x 6.6 x 6.6 cm) baited with banana were set in pairs at 25 m intervals, no more than 3 m from the ground along two transects (Talatakely transect is 1.5 km and Campsite 1 km long).

DATA COLLECTION. Data were collected at three selected periods: Period 1 (beginning of reproductive season: mid-August until the beginning of October), Period 2 (mating season: defined as the dates between which the first and the last vaginal opening was observed, from the beginning to the end of October), and Period 3 (gestation period: from November to December). Traps that contained *Microcebus rufus* were taken to the research cabin at RNP or to the laboratory at Centre Valbio. *M. rufus* brought back to the CVB field station or RNP research cabin were put into separate small linen bags to prevent escape, and were sexed, weighed with a digital scale (Fisher Scientific 200GXO), measured for tail circumference at the widest point with a thread (this thread after measured with an electronic caliper), and scanned for microchips. All new captures were microchipped with subdermal transponders (Fecava Eurochips, Vetcare, Finland) for permanent identification. All animals were released on the same night they were trapped at the site of their capture.

We recorded from non-anaesthetized rufous mouse lemur, body weight (BW), crown rump length (CR, from cranium arch to the base of tail), tail length (TL, from the base to the tip of tail), head length (HL, from tip of nose to the prominent point of occipital), head width (HW, between two temporal), circumference of the base of tail (CRT) and circumference of mid tail (CRMT). We measured CR, TL, HL, HW, CRT, CRMT to the nearest of mm using an electronic caliper, and BW to the nearest value in grams using a digital scale. We determine sex on the basis of external morphology.

Individual fecal samples of this species were collected from traps, handling bags or directly from anus for the gastrointestinal parasite analysis. We did a direct analysis without preserved fecal samples and ≈0.3 g of feces were used. Two versions of a modified method, outlined by Gillespie (2006), for the gastrointestinal parasite analysis were used. We performed fecal flotation using $MgSO_4$ solution and quantified the parasite eggs or larvae in McMaster Chamber (Weber Scientific International United Kingdom). We obtained egg count per gram (EPG) by dividing the count by the weight of feces used. Nematodes and flukes are too heavy to float up in the flotation liquid, so the fecal sedimentation method is necessary to identify these helminthes. We used a modified Baermann method (Zohdy 2012). Fresh fecal samples were weighed and folded in tissue paper. Each sample is put in a funnel that has a rubber hose into a glass test-tube containing water, so that the water level reaches the feces. Three days later the larvae are concentrated in the water and we centrifuged the sample and decanted the water. We examined the sediment and made a diagnosis of the nematode larvae, and counted them under microscope. We divided the count by the weight and quantified larvae per gram of feces. Each individual was checked for the ectoparasites. Ectoparasites were counted and scored according to the abundance: 1= no ectoparasites, 2= some (between 1 and 20), score 3= many (over 20).

STATISTICAL ANALYSIS. We calculated three different body condition estimates: body weight (BW), residuals of the linear regression of body weight against total body length (OLS) and tail circumference index (CRT). To estimate the OLS index of *Microcebus rufus*, we performed linear regression of $\log_{10}$ BW against $\log_{10}$ of total body length (TBL=HL + CR + TL) in SPSS 21.0 program. The residual of this analysis were used as the index of body condition and individuals with positive residuals are considered to be in better condition than predicted for their size, while individuals with negative residual are considered to be in relatively poorer condition (Green 2001, Blackwell 2002, Schulte-Hostedde et al. 2005). A log transform data was used to meet the assumption of linearity between body weights against total body length. As *M. rufus* store fat at the base of tail during the period of resource abundance, we computed a transformed index of circumference of tail (CRT index= CRMT/CRT) which reflected an individual's fattening level. We calculated mean ± standard error (SE) for all parameters which indicated body condition index. A bivariate two-tailed Pearson's correlation were used to examine the association between the measures of condition index and a Generalized Linear Model (GzLM) to estimate the difference between individuals on the basis of sex, site and period of study. For model selection, Akaike's information criterion AIC with adjustment for small size AICc (Sugiura 1978) was used for ranking the quality of each model. The AICc value for each model is compared to the lowest AICc value to generate (Δ_i) and to compute the Akaike weights (w_i). As a rule of thumb Δ_i<2 indicate that there is substantial support for the model, while value greater than Δ_i>10 indicates that there is no support for the model (Burnham and Anderson 2002).

We analyzed parasite prevalence, richness and abundance as a measurement of the parasite infection. Parasite prevalence is the proportion of a population infected by a particular parasite. The parasite richness was defined as the total number of species of parasites found in one individual, and the parasite abundance was defined as the total number of eggs and larvae (for helminth parasites) per gram of feces or score for the ectoparasite count that we have quantified. We used Chi-square tests of independence to compare the prevalence of infection between sex, site, and period of study, and a nonparametric test *H* of Kruskal-Wallis for analysis of variance, was used to compare the variation of the parasite abundance and parasite richness through sex, site and period of study. We also used Spearman correlation to assess whether different parasites were independently correlated and to measure the association between parasite infection and body condition index. For all analyses when individuals were sampled more than once for each period, we used the mean mass, mean circumference of tail, and mean parasite load. All statistical analyses were two tailed and $P< 0.05$ was considered statistically significant.

RESULTS

Seventy-two individual *Microcebus rufus* were captured between August and December 2012 (32 females and 40 males) summarized in Table 1. There were 43 captures during the beginning of the reproductive season (Period 1), 37 during the mating season (Period 2) and 40 during the period of gestation (Period 3).

CALCULATION AND COMPARISON OF THE BODY CONDITION MEASUREMENTS. The OLS regression equation of log10 BW against log10TBL was: $y = 0.62\ x + 0.20$ ($r=0.31$, $t=3.41$, $p<0.05$). We have found a negative relation between BW and OLS index ($r=-0.948$, $n=107$, $p<0.05$) and between CRT index and OLS index ($r=-0.28$, $n=107$, $p< 0.05$). The individuals with heavier weight have lower OLS index and those with fat tails have higher OLS index.

To analyze the difference between individuals, we performed an analysis of model selection including the three factors (sex, site and period of study). For OLS and BW indices, model with three factors had the lowest AICc value and had the highest model weight (Supplementary Material Table S1). Model based only on sex were the best model for Log10 CRT index with 92% of probability, Figure 1 shows the variation of the measure of body condition index between sexes, site through the period of study. Female individuals from Talatakely site were heavier than females in Campsite at the beginning of the reproductive season. Both lost weight during the mating season and later their weight increased. Males in both sites lost weight through the period of study.

Table 1. Capture success of *Microcebus rufus* according to season.

Period	Sex	Campsite		Talatakely		Total	
		captured	recaptured	captured	recaptured	captured	recaptured
1	Male	12	0	22	0	34	0
	Female	5	0	4	0	9	0
	Combined	17	0	26	0	43	0
2	Male	2	4	4	13	6	17
	Female	2	3	6	3	8	6
	Combined	4	7	10	16	14	23
3	Male	0	6	0	12	0	18
	Female	12	3	3	4	15	7
	Combined	12	9	3	16	15	25
Total		33	16	39	32	72	48

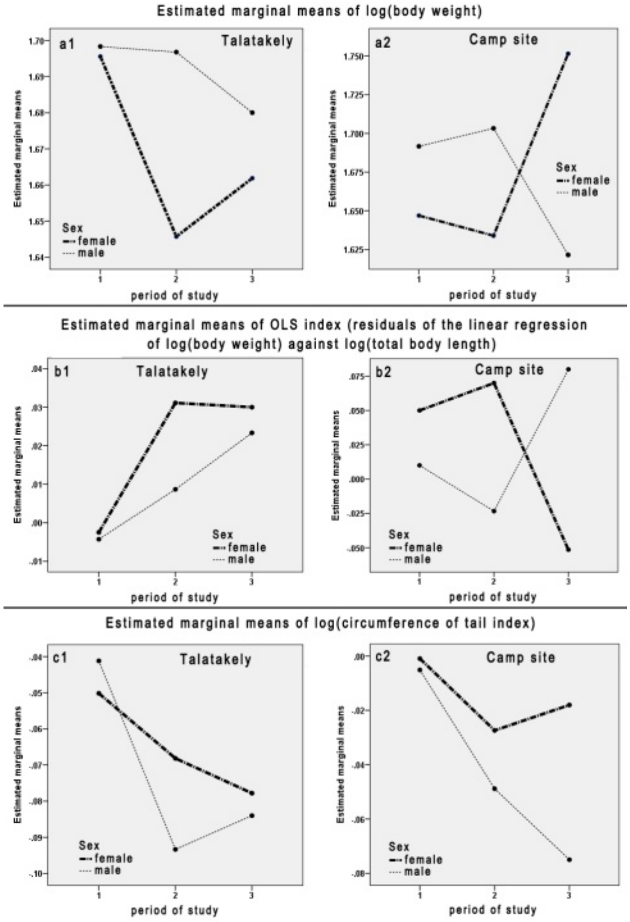

Figure 1. Variation of body condition index between sexes and site through the period of study. Variation based on mean marginal estimated from variable, dark dotted line represent variation in female and light dotted line for the variation in male.

According to OLS index, female from campsite were in better condition until mating season, but beyond this period, their condition became worse. However females in Talatakely had increasing index through these periods as the males in both sites (Figure 1, b1 and b2). Based on the CRT index, males were in better condition than females. During the mating season, individual *Microcebus rufus* were in better condition according to the CRT index (Figure2, c1 and c2). This seasonal difference may be due to increased fat in their tails, as source of energy during the mating period.

COMPARISON OF PARASITIC INFECTIONS AND PARASITE RICHNESS. From the fecal analysis, we identified two gastrointestinal parasite species: one cestode (Platyhelminthes, Hymenolepis sp.) (Figure 2a), and one nematode (Nematoda, Strongyloides sp.) (Figure 2b). We also found the ectoparasite Lemurpediculus verruculosus (Durden et al. 2010) (Figure 2c). Prevalence of infection with Strongyloides sp. and Lemurpediculus verruculosus differed significantly by host sex and site. Male rufous mouse lemur had higher prevalence of nematodes and ectoparasites, individuals in campsite were more parasitized by Strongyloides sp., while those in Talatakely were more parasitized by ectoparasites. In Hymenolepis sp. prevalence, a significant dife

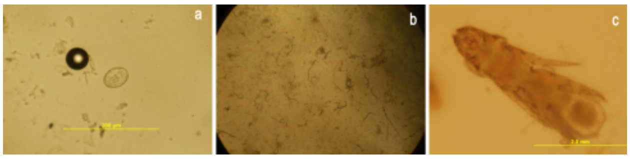

Figure 2. Gastrointestinal parasites (a = *Hymenolepis* sp., Platyhelminthes; b = *Strongyloides* sp., Nematoda), and ectoparasite (c = *Lemurpediculus verruculosus*) identified in *Microcebus rufus* fecal analysis.

rence was found only between sexes, males were more parasitized than females (Supplementary Material Table S2).

The Kruskal-Wallis test reveals that there were effects of sex and site on parasites abundance of *Hymenolepis* sp., and *Lemurpediculus verruculosus*, inspection of the group median suggests that males were an important reservoir for both gastrointestinal parasites and ectoparasites species and individuals in Talatakely were more affected. The difference between two sites concerning the parasite richness wasn't statistically significant (Supplementary Material Table S3). Both sex and site were reservoir of *Strongyloides* sp., and the abundance of this parasite increased by period of study (Supplementary Material Table S3). There was a positive statistically significant association between the abundance of *Hymenolepis* sp. and *Strongyloides* sp. ($r=0.25$, $n=119$, $P<0.05$), and between the abundance of *Hymenolepis* sp. and *Lemurpediculus verruculosus* ($r=0.33$, $n=120$, $P<0.05$).

ASSOCIATION BETWEEN PARASITES INFECTIONS AND BODY CONDITION INDEX. We found a weak significant negative correlation between the CRT index and abundance of *Lemurpediculus verruculosus* ($r=-0.192$, $n=120$, $P<0.05$). Parasite richness was statistically significantly negatively correlated with CRT index ($r=-0.193$, $n=120$, $P<0.05$). We did not find a significant association between body weight, OLS residual index and the parasite abundance and richness (Table 2).

DISCUSSION

COMPARISON OF BODY CONDITION INDEX IN *MICROCEBUS RUFUS*. The calculation and comparison of body condition indices of *Microcebus rufus* were studied for only five months. However, this period encompassed a variety of phases in the biological cycle of *M. rufus*: beginning of reproductive season, mating season, and gestation period. Furthermore, the representation of a wide range of individual condition indices was provided by the large sample. We assessed body condition using standard and non-destructive measures for small mammals (Blackwell 2002), like body weight (Jakob et al. 1996) and the OLS residual index (Green 2001). However, our species experiences seasonal fluctuation in body fat and accumulates fat at the base of tail (Wright and Martin 1995, Atsalis 1999a), therefore we introduced the tail circumference index.

Table 2. Correlation between measures of body condition index and the parasite abundance and richness (n = sample size, r = correlation coefficient of spearman, p = probability, BW = body weight, CRT = crown rump length, OLS =residuals of the linear regression of body weight VS. total body length)

Model	n	*r*	*p*
BW VS. *Lemurpediculus verruculosus* score	120	-0.08	0.38
BW VS. nematode abundance	119	0.13	0.17
BW VS. cestode abundance	120	0.04	0.69
BW VS. parasite richness	120	0.02	0.80
CRT index VS. *L. verruculosus* score	120	-0.19	0.04
CRT index VS. nematode abundance	119	-0.00	0.98
CRT index VS. cestode abundance	120	-0.14	0.13
CRT index VS. parasite richness	120	-0.19	0.03
OLS residual index VS. *L. verruculosus* score	107	0.13	0.19
OLS residual index VS. nematode abundance	106	-0.02	0.86
OLS residual index VS. cestode abundance	107	0.04	0.66
OLS residual index parasite richness	107	0.08	0.44

The two indices OLS and CRT correlated so that those lemurs with higher fat reserves had a higher OLS index. Males at both sites exhibited increased body weight and were in better condition based on indices prior to the onset of the mating season, but lost it soon afterwards possibly as a result of their mate searching strategies which usually involve high activity and defense of habitat already occupied by females (Martin 1972). Individuals in Talatakely had more fat reserve at the base of tail than those in Campsite and females from Talatakely site were also heavier and had higher OLS index than those in Campsite. This could be due to Talatakely being a higher quality habitat than Campsite.

We have found a problem using the OLS residual index, the fit regression was not very high ($r=0.31$), and the scaling theory about the cubic relationships between mass and length was not met in the study. The scaling exponent which equal to the slope in the regression equation ($b=0.62$) was different to the cubic relationship ($b=3.0$) (LaBarbera 1989, Blackwell 2002). Thus we found the residual index from regression of body weight on body length is not appropriate to predict the body condition for this lemur species. It seems that the condition predicted by the circumference of tail index was the best indicator of energy state of this species.

The main limitation of this study was the lack of an absolute measure of body condition. An animal in good condition is assumed to have more energy reserves than an animal in poor condition (Schulte-Hostedde 2005). It is important to estimate the nutritional condition of the habitat, to measure an animal's fitness, and to examine the effect of potential parasites on the host animal (Wilson et al. 2002). The benefit of better body condition for males is that they may be better able to monopolize access to reproductive females during mating season, while also being better able to defend against other males. Males in poorer condition are therefore likely to experience lower reproductive success (Rasoazanabary 2006). Ultimately, body condition is an ability of the animal to successfully reproduce and thus the reproductive success should be assessed (Lewis and Kappeler 2005) which we were not able to do. More parameters are needed to validate the measure of body condition in this species. Specifically, examining the impact of circumference of tail index on reproductive success in this species is likely to reveal important information.

COMPARISON OF PARASITES INFECTIONS IN *MICROCEBUS RUFUS*. *Microcebus rufus* at Ranomafana National Park were found to be co-infected with a combination of two intestinal helminthes (*Strongyloides* sp. and *Hymenolepis* sp.) and one louse species (*Lemurpediculus verruculosus*) through the beginning reproductive season, mating season and gestation period. We detected that males were more infected by parasites than females and had higher parasite diversity. These patterns have been observed in variety of mammal taxa (i.e., Schalk and Forbes 1997, Moore and Wilson 2002, Schulte-Hostedde et al. 2005). Males carrying more parasites than females has often been attributed to the immunosuppressive effect of androgens such as testosterone (Folstad and Karter 1992). However, Zohdy (2012) has reported no significant difference in testosterone level between the sexes in *M. rufus*, the same author showed that this factor is unlikely to be responsible for the high parasite loads seen in males. Other proposed explanations relate to body size dimorphism (Zuk and McKean 1996), and mating system that puts one sex at a disadvantage with regard to transmission of parasites (Moore and Wilson 2002). *M. rufus* is not dimorphic with respect to size. So the best explanation for the sex differences in parasite load and richness may be likely due to the mating system. *M. rufus* have polygyandrous mating system (Atsalis 2008) so the competition and interaction between males could be higher, that pattern leading to increase parasite infestation in males (Nunn et al. 2003).

We have found a difference in parasite infection between sites, individuals in Campsite were more infected by *Strongyloides* sp. However individuals in Talatakely were more infected by *Lemurpediculus verruculosus* and *Hymenolepis* sp. These results could be related to the differences in life cycles of parasites, in host-parasite system, host body condition and ecological factors (i.e., Eley et al. 1989, Coe 1993, Friedman and Lawrence 2002, Gillespie et al. 2005, Mbora and McPeek 2009). *Strongyloides* sp. characterized by its direct life cycles (the parasites is transmitted directly from one host to the next without an intermediate host or vector of another species), so individual *Microcebus rufus* in campsite could be more in contact with the infective larvae of that parasites (Radespiel et al. 2015) because of their sleeping mode and possible territory overlap. And the sleeping site could be contaminated by feces from infected individuals. In addition, Campsite also exhibits higher habitat disturbance with villagers living very near this buffer zone than Talatakely inside Ranomafana National Park (Wright 1992). This might reduce the amount of *M. rufus* habitat and increase possibility of interplay between animals, humans and parasite infection. In contrast, according to Zohdy (2012) the dependence of sucking lice on direct host-host interaction suggests that individuals in Talatakely engage in more physical social interaction and will therefore be the causes of the spread of ectoparasites infestations. Concerning the infestation of *Hymenolepis* sp. this could be related to the diet of the Talatakely *M. rufus* population which may include the intermediate host of the parasites like an arthropod, which we were not able to investigate in this study.

Statistically significant differences in *Strongyloides* sp. larvae abundance in feces were found across periods of study. Abundance varied significantly over the three periods. A lower larvae count was detected at the first period (beginning of reproductive season), while higher abundance was found during the third period (gestation period). This could be indicative of lower intensity of nematode infection at the beginning of reproductive season, which is the end of dry season, and higher intensity infection when gestation period is approaching, which is the beginning of raining season at RNP. This pattern could be related to the life history of this nematode, the seasonal variation of the intensity of infection within individuals and individual vulnerability toward infection under some sort of environmental challenge (Radespiel et al. 2015). The climate during breeding season favors hatching of nematode eggs, which increases the abundance of larvae ready to infect individual *Microcebus* spp. (Ganzhorn and Raharivololona 2010). In this study we used fecal samples from different individuals. However, according to Ganzhorn and Raharivololona (2010), a within-individual analysis across seasons is often desirable.

ASSOCIATION BETWEEN PARASITES INFECTIONS AND BODY CONDITION INDEX. Parasites, by their very nature, derive resources from the host and may affect host survival and reproduction directly, but also indirectly by reducing host body condition (Coop and Holmes 1996, Neuhaus 2003, Gillespie and Chapman 2005). Thus, parasite infections are considered to be a critical component in conservation biology (May 1988). Individuals in poor condition might be unable to resist parasitic infection because of the energetic expense of mounting an immune defense (Martin et al. 2003).

In contrast, our results indicate that individuals who had more parasites species and high prevalence on louse infections and gastrointestinal parasites had more fat in their tail (lower CRT index). This suggests that a good quality host might be able to sustain higher parasite loads (Bize et al. 2008, Seppälä et al. 2008). Furthermore, parasitic infections might not always lead to immediate energetic costs for the host. Rather, the costs might be manifested in longer-term reductions in fitness (Willis and Poulin 1999). For our animal study we could not detect signs of clinical significance, and some parasite-host relationships might be initially commensalistic, but affect animals more severely when intrinsic or ecological stress increases. A long term study examining body condition and parasite infections in this species is needed to support our findings.

CONCLUSION

More parameters are needed to validate measurements of body condition in *Microcebus rufus*, although body condition, predicted by the circumference of tail index, was the best indicator of energy state in this species. Sex and site differences in parasitic infection were found. Male *M. rufus* were more infected by parasites than females and had higher parasite diversity. Individuals in Campsite were more infected by *Strongyloides* sp. However individuals in Talatakely were more infected by *Lemurpediculus verruculosus* and *Hymenolepis* sp. These results could be related to the differences in parasite life cycle, in host-parasite system, or ecological factors. The relationship between body condition and parasitic infection, in this study, reveals that animals in better condition were more infected by parasites because of relatively better quality resources available in that host.

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SUPPLEMENTARY MATERIAL.

Available online only.

Table S1. Seven candidate models for each measures of body condition index in *Microcebus rufus* at RNP. Model selection based on Akaike's information criterion (AIC).

Table S2. Comparison of the prevalence of infection of *Microcebus rufus* between sex, site, and period of study.

Table S3. Comparison of parasite abundance and parasite richness of *Microcebus rufus* between sex, site, and period of study.

ARTICLE

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Understanding deforestation and forest fragmentation from a livelihood perspective

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ABSTRACT

Worldwide, forests provide a wide variety of resources to rural inhabitants, and especially to the poor. In Madagascar, forest resources make important contributions to the livelihoods of the rural population living at the edges of these forests. Although people benefit from forest resources, forests are continuously cleared and converted into arable land. Despite long-term efforts on the part of researchers, development cooperation projects and government, Madagascar has not been able to achieve a fundamental decrease in deforestation. The question of why deforestation continues in spite of such efforts remains. To answer this question, we aimed at understanding deforestation and forest fragmentation from the perspective of rural households in the Manompana corridor on the east coast. Applying a sustainable livelihood approach, we explored local social-ecological systems to understand: (i) how livelihood strategies leading to deforestation evolve and (ii) how the decrease of forest impacts on households' strategies. Results highlight the complexity of the environmental, cultural and political context in which households' decision-making takes place. Further, we found crucial impacts of deforestation and forest fragmentation on livelihood systems, but also recognized that people have been able to adapt to the changing landscapes without major impacts on their welfare.

RÉSUMÉ

Partout dans le monde les forêts fournissent une grande variété de ressources aux habitants des régions rurales, particulièrement aux plus pauvres. À Madagascar, les ressources forestières contribuent dans une grande mesure aux moyens d'existence des populations riveraines des forêts. Cependant, bien que les populations tirent parti des ressources de la forêt, les défrichements ne cessent pas et la conversion des zones boisées en terres cultivables se poursuit. Malgré les efforts entrepris depuis des années par les milieux de la recherche et du développement ainsi que par le gouvernement, Madagascar n'a pas encore connu d'inversion du rythme de la déforestation. Pourquoi les défrichements se poursuivent-ils en dépit des efforts entrepris ? C'est à cette question que nous souhaitons apporter une réponse en essayant de comprendre la déforestation et la fragmentation des forêts en prenant en compte les moyens d'existence des ménages ruraux dans le corridor de Manompana, côte Est de Madagascar. En tirant parti de la méthodologie SLA (*sustainable livelihood approach*), nous avons analysé les systèmes d'existence des populations locales dans le but de comprendre (i) comment évoluent les stratégies de vie impliquant la déforestation et (ii) quel est l'impact de la diminution des surfaces forestières sur les stratégies de vie des ménages. Les résultats mettent en évidence la complexité du contexte environnemental, culturel et politique dans lequel les ménages sont amenés à prendre leurs décisions. La déforestation et la fragmentation des forêts exercent des impacts cruciaux sur les moyens d'existence des ménages. Cependant, il apparait également que les populations sont en mesure de s'adapter à des modifications des paysages sans que cela n'entraîne d'effets majeurs sur leur bien-être. Notre recherche s'est déroulée dans quatre villages, dont deux proches de grands massifs forestiers, les deux autres éloignés des massifs et voisins de fragments de forêts. D'intéressantes différences ont été mises en évidence entre les deux catégories de villages en ce qui concerne l'interface homme-forêt et la perception du rôle joué par la forêt aujourd'hui et à long terme.

INTRODUCTION

Deforestation of tropical forests around the globe has been happening for tens of thousands of years (Malhi et al. 2014). The underlying drivers have shown to be manifold and interacting with each other (Geist and Lambin 2002). While in many countries the main drivers today are the expansion of large scale agribusiness and a rising demand for forest products by urban populations (Lambin and Meyfroidt 2011), the deforestation frontier of eastern Madagascar is still characterized by smallholders' agricultural expansion for subsistence needs (Zaehringer et al. 2015).

Madagascar's tropical rainforests contain a unique biodiversity (Myers et al. 2000) and provide a broad variety of products and environmental services to local populations and their livelihoods (Kremen et al. 1998). Yet, despite their importance, forests have been used since the first human settlement in Madagascar around 2000 B.C. (Dewar et al. 2013); existing evidence documents a general trend of forest loss (McConnell and Kull 2014) and forest

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fragmentation (Harper et al. 2007). The most recent nation-wide deforestation analyses report a decrease from 0.9% deforestation per year from 1990–2000 (ibid), to 0.5% from 2000 to 2005 (MEFT et al. 2007) to 0.4% from 2005–2010 (ONE et al. 2013). However, local scale forest change studies from the east coast have reported overall increases of forest change and deforestation rates above 1% (Eckert et al. 2011, Allnutt et al. 2013).

Along the eastern escarpment of Madagascar, currently the main direct cause of deforestation and forest fragmentation is the land use practice of slash-and-burn to cultivate rain-fed hill rice, a system known as *tavy* in the Malagasy language (Gorenflo et al. 2011). Once the forest is burned, rain-fed hill rice is usually cultivated for only one season, followed by manioc or sweet potato the next (Messerli 2002, Aubert 2008). As a result of the tavy system, soils are heavily washed out and their fertility decreases with every rotation (Pfund 1997, Brand and Pfund 1998). Longer fallow periods maintain better soil fertility. Thus, farmers pursue agricultural expansion as long as forest is available and until enough arable land for long fallow periods is assured (Pollini et al. 2014). At the same time, forest products and resources of remaining forests are used, sold or exchanged. Eventually, however, forests are cleared and converted into complex mosaic landscapes consisting of forest fragments and other mainly agricultural land use types (Pfund 2000, Bennett et al. 2006, Eckert et al. 2011). As described in Urech et al. (2011) forest fragmentation is a dynamic process that reduces larger contiguous forests (called forest massif in this article) into smaller forest patches which become more isolated and increasingly affected by edge effects.

As a consequence, people lose access to forest resources. The reasons why farmers continue to slash-and-burn forested land to grow rain-fed rice, reducing other important forest services and thus undermining part of their own security net, are known to be complex. Multilateral donors and researchers have been engaged for decades in the issue of deforestation in Madagascar, trying to find solutions to stop slash-and-burn agriculture (Messerli 2002, McConnell and Sweeney 2005, Pollini 2009, Freudenberger 2010). Three different approaches have been pursued by these actors as well as the state: (i) attention has been given to testing alternative agricultural practices and finding mechanisms and incentives that would enable land users to adopt those practices (Messerli 2002, Moser and Barrett 2003, Pollini 2009, Freudenberger 2010); (ii) areas reserved for strict nature conservation have been defined (Randrianandianina et al. 2003, Corson 2011); and (iii) a framework for community-based forest management has been implemented by the state with strong support from international donors (Pollini and Lassoie 2011, Bertrand et al. 2014, Corson 2014, Cullman 2015, Rasolofoson et al. 2015).

But deforestation continues nonetheless (ONE et al. 2013) with rural farmers perceived to be the main responsible actors (The World Bank 2013). Behind the direct reason of forest clearance for agricultural use, however, lie a variety of intricately linked indirect economic, political, ecological and social factors influencing farmers' actions (Jarosz 1993, Aubert et al. 2003, Casse et al. 2004, Muttenzer 2010). Meanwhile, it remains poorly understood what role local farmers' socio-cultural realm of attitudes, motivations and behavior plays within this network of driving forces and how deforestation affects their livelihood systems.

The aim of our research was to fill this gap by investigating deforestation and forest fragmentation on the eastern escarpment of Madagascar from a livelihood perspective. The objectives were (i) to identify core and context factors of livelihood systems that lead to agricultural expansion at the expense of natural forests and (ii) to analyze how farmers' livelihood systems are affected by deforestation. In order to understand the evolvement of livelihood systems and strategies, we worked in a transect covering different forest landscapes with different deforestation rates over the past decades. With the aim of obtaining a broad understanding we put our own empirical data in a wider context and complemented it with information from other scientific research articles.

METHODOLOGY

STUDY SITE. Geographical situation: The Manompana corridor study site (cf. Urech et al. 2012) is located on the east coast of Madagascar in the region of Analanjirofo, district Soanierana-Ivongo, and comprises the three municipalities of Manompana, Ambahoabe and Antenina. The Manompana corridor comprises a forested area of around 30,000 ha. From 2007 to 2012 a forest project called KoloAla Manompana was implemented in the corridor, aimed at transferring the management rights of the forest resources to the local communities in order to allow local communities to benefit from sustainable timber harvesting and trade (Urech et al. 2013). The nearest town with a bigger market and connected to the town Manompana with a tarred street is Soanierana-Ivongo. This market is accessible in about 1–2 days walking time from the villages within the Manompana corridor. Only small local markets selling staple foods exist along the tarred street in the Manompana corridor, following the coast. From remote villages, the road is reachable in 7–8 hours walking time, across swampy and hilly landscapes. Annually, Manompana experiences several tropical cyclones (Jury et al. 1999), causing serious damage to agriculture and infrastructure.

Population: All households within the study site are involved in a mixed-production system combining subsistence rice and staple crop cultivation, with market-crop production in some cases. Staple crops (rain-fed rice, manioc, sweet potato) are mainly cultivated with slash-and-burn systems on slopes; if households have access to suitable land, they also cultivate irrigated rice in paddies on valley bottoms. Terraces on slopes for crop cultivation are nonexistent in this zone. For income generation, households sell rice surplus and market crops such as cloves, vanilla, coffee or litchi. Most households cultivate 1–3 land slots in an agroforestry system, combining annual crops (manioc, sweet potato, sugar cane, etc.) and trees (clove, papaya, jackfruit and other fruit and non-fruit trees or bushes). The large majority of the study site's population belongs to the Betsimisaraka ethnic group and around 89% of households in the Manompana corridor are living below the national poverty line (INSTAT 2011).

SUSTAINABLE LIVELIHOOD APPROACH. In order to gain a holistic understanding of households' livelihood systems and decision-making processes with respect to deforestation, the Sustainable Livelihood Approach (SLA), as described in Högger and Baumgartner (2004) and Eyhorn (2007), was chosen as the conceptual framework. Compared to other livelihood frameworks, the SLA also takes further dimensions into account, such as the personality characteristics of individuals, their perceptions, emotions, attachments and traditions (Eyhorn 2007). It integrates the analyses of (i) livelihood context factors, (ii) the livelihood core factors and strategy development and (iii) the livelihood outcomes.

Decisions which lead to deforestation in our study site are taken on the individual level, but can be influenced by factors connected to an ethnical group, the village or even the national level. The SLA is the most adequate approach for the analytical distinction of the broad variety of factors that influence households in our study site.

CONTEXT FACTORS. Context factors are the dynamic external conditions influencing the strategy development process of a household. The SLA divides these factors into opportunities, risks and vulnerabilities; policies, institutions and organizations; and processes and services. We analyzed the 'opportunities' that forests provide that could pose incentives to households to decrease deforestation and forest fragmentation; thus, opportunities that could positively influence households' decision-making process towards a more sustainable forest management.

As 'risks and vulnerabilities' we assessed possible events or realities that can negatively impact livelihoods and drive people to clear forests. Risks are in our case mainly biophysical events (e.g., climatic variability, cyclones, disease). Such risks can lead to vulnerability, depending on the household's ability to cope with them. Similarly, we explored 'policies, institutions, organizations and processes' as well as existent and non-existent farmer support 'services' that could influence households' decisions with respect to deforestation.

CORE FACTORS AND STRATEGY DEVELOPMENT. Personal, emotional and spiritual aspects and orientations are considered the core factors of rural livelihood systems which directly influence the decision-making process of a household (Eyhorn 2007). Core factors and the resulting decision-making process are analyzed with the help of the nine-square mandala (Högger 2004). It can be depicted as a house (Supplementary Material 2) with the three floors representing (i) the orientations at the individual, family and community level in the roof layer, (ii) the interactions of socioeconomic aspects as well as family and individual dimensions and (iii) the household's material resources, its knowledge, skills and emotional values as the household's foundation. Livelihood strategies reflect the range of activities and choices that people make based on the given context and core factors (Eyhorn 2007).

LIVELIHOOD OUTCOMES. Livelihood outcomes are the achievements of livelihood strategies (Chambers 1995, NADEL 2007). The outcomes then feedback into the livelihood system and influence all its dimensions (context factors, core factors and strategy development). In this study, we aimed to analyze what outcomes result directly from deforestation and forest fragmentation. We worked in villages along a landscape transect covering different forest landscapes; from scarcely forested areas up to densely forested areas.

Based on satellite image interpretation (Rabenilalana 2011) we know that the villages with scarce forested areas lost a large amount of forest resources in the past few decades, due to deforestation. Working along a landscape transect allowed us to understand how the decrease of forest resources influences livelihood systems.

DATA COLLECTION. Research was conducted in four villages situated at differing distances to the forest massif and with varying forest resource availability (Table 1). We understand the term 'forest massif' as the entire contiguous forest area of the Manompana corridor as well as forest patches with a surface of more than 500 ha and a distance of less than 100 m to the contiguous forest area. In two villages, Ambofampana and Maromitety, forest still covers 75% and 86% of the total village territory, respectively, and villages are situated near the large contiguous forest massif (≤0.5 hours walking time). Thus, deforestation and forest fragmentation are assumed to not yet have had an immediate, measurable impact on local livelihoods. The other two villages, Bevalaina and Antsahabe, are situated far from the forest (>1 hour walking time) and have highly fragmented and degraded forest covers of 20% and 43%, respectively. We know that those villages were also situated near to the forest massif in the past (Green and Sussmann 1990). Thus, deforestation and forest fragmentation are assumed to have already exerted a measurable outcome on local livelihoods. The selection of the two villages near the forest massif and the two villages far from the forest massif allowed us to analyze the direct outcomes of deforestation and forest fragmentation.

Table 1. Characteristics of the four studied villages.

Characteristics	Ambofampana	Maromitety	Bevalaina	Antsahabe
Distance to forest massif (walking time in h)	0.25	0.5	2	3
Category of distance to forest massif	near	near	far	far
Forest cover (% of total village territory)	86	75	43	21
Forest fragments (% of forest cover in village territory)	5	20	100	100
Number of households living in village	27	26	110	65
Market proximity (walking time in h)	6	8	2	1
Primary school is available	no	no	yes	yes
Age of village: (foundation year)	around 1980	around 1998	around 1910	around 1950

In order to limit our investigations to factors and strategies relevant to our research question, we first had to obtain an overall understanding of the local situation. Therefore, open discussions with randomly selected households (total N=20) were conducted in the four villages. The discussions covered were related to major problems and key livelihood strategies, the relatedness between people and natural resources and general core and context factors.

Specific details with regard to forest use, deforestation and agricultural expansion were explored using household surveys (N=110) and focus group discussions (N=24) with five participants each, disaggregated by gender and wealth. Furthermore, we used participatory and direct observation techniques (Marshall and Rossman 2011). Additional semi-structured interviews with resource persons (e.g., village authorities, village elders) allowed for the triangulation of results (Denzin 1970).

QUALITATIVE AND QUANTITATIVE DATA INTERPRETATION. Most data have been qualitatively analyzed and interpreted. We grouped and categorized frequent statements from households and focus groups and took different factors such as gender and wealth into account. This allowed us to identify driving forces of current livelihood strategies of local households. In the analysis, we focused mainly on those household strategies that were common for a larger part of the population or the collective, rather than on single exceptional strategies. However, strategies representing either a potential benefit or a hazard to the collective (e.g., if an individual household does not respect the common community rules) have also been considered. Since our aim was to provide a comprehensive understanding of farmers' complex realities we complemented our own empirical data with the existing scientific knowledge in this region (Jarosz 1993, Brand and Pfund 1998, Styger et al. 1999, Pfund 2000, Kistler and Messerli 2002, Messerli 2002, Aubert et al. 2003, Kull 2004, Hume 2006, Keller 2008, Pollini 2009, Rakotoarison 2009, Muttenzer 2010, Gorenflo et al. 2011).

To test the correlation of quantitative non-parametrical data in relation to the distance of the four studied villages to the forest massif, the Spearman's rank correlation coefficient was used. To test the difference between the two categories near and far from the forest massif for significance, the Pearson's X2-test was applied.

RESULTS AND DISCUSSIONS

CONTEXT FACTORS. Opportunities provided by forests: We found several situations in which forest resources could potentially provide opportunities for simultaneously improving local livelihoods and preserving the forests. Forests provide diverse products that are used for personal consumption and income generation. All interviewed households depend on timber for house and tool construction, and 79% of households use edible non-timber forest products (NTFPs) such as tuber, roots, fruits and palm hearts to complement cultivated crops or to enhance cash income (Table 2). This is especially important during the lean season, when households have consumed all rice from the last harvest and not yet harvested again. However, the quantity of edible NTPFs is very small and insufficient to feed a whole household (mean of five persons). Other products used for household consumption are fuel wood, plants for braiding activities and medicinal plants.

Cash income from NTFPs or timber is generated by 47% (N=49) of all households. However, the annual income per household generated from forest products is only 0.7% (1.6 Euro) to 9.3% (19.7 Euro) of the total annual cash income per household (Urech et al. 2012). This is very low compared to the income generation through forest products in other regions of Madagascar (Shyamsundar and Kramer 1996). In the Manompana corridor, NTFPs as well as timber products are sold at prices that do not match the amount of time and effort people spend for harvest and transport. However, the potential of forest products to increase monetary benefit is exploited only to a limited extent. According to Rabenilalana (2011) the high potential of precious woods, mainly of the genus Dalbergia, in the Manompana corridor could, at least for households in the two remote study villages Maromitety and Ambofampana, provide a maximum annual gross income of up to 40 Euro per household, if harvested sustainably. This corresponds to 19% of the mean annual income per household in the region (Rakotoarison 2009). Thus, the potential is considerably higher than the current earnings from timber trade and NTFPs combined. Nevertheless, limited market access in the two remotest villages hampers the harvest of precious woods for trade. In contrast, in the two villages enjoying better market access, the potential of precious woods is already fully exploited (Rabenilalana 2011). People coming from other territories log the remaining precious woods illegally. For instance, over a ten-day observation period in an accessible forest near one of the study villages, we observed 82 loggers. They transported timber by foot, carrying one timber board on their shoulder. Of the 82 observed loggers, 78 came from neighboring territories. Thus, the benefits from the village's precious wood are lost to households in other territories. Since the management rights for forest resources have not yet been transferred to the villages, they have no legal basis to defend their forest territories.

Table 2. Number and percentage of households (out of 110) collecting different categories of forest products for personal consumption.

Categories of products provided by forests	Household harvesting	
	Number	%
Timber for house construction	110	100
Food (tuber, roots, fruits, palm heart)	87	79
Timber for fuel wood	81	74
Plant leaves for braiding	81	74
Medicinal plants	23	21

Risks and Vulnerabilities: Risks in the Manompana corridor are represented by the highly variable environmental (e.g., natural hazards) and economic context (high price fluctuations) as well as by diseases or death of a family member. Due to extreme poverty, households in the study site are particularly vulnerable to these risks, as they are unable to cope with such changes. Examples would be that they cannot hire additional labor to cope with labor shortages or spend money and time to rebuild irrigation systems if a cyclone has destroyed those.

Despite planting rice and other staple crops for subsistence, 60% of all households have to buy additional food during the lean season because they do not produce enough crops to feed all household members. The majority of households are therefore engaged in casual day labor to generate additional cash. Moser and Barrett (2006) identified dependency on day wages and thus reduced labor availability for the households' own fields as one of the most important factors hindering farmers from improving agricultural practices. In our study site, households do not have enough time, money and flexibility to experiment with risky new technologies and thus prefer to maintain their low-input tavy system. Unfortunately, the main potentiality to escape poverty depends on increasing the productivity of one's one own field (ibid). Thus, households are caught in a poverty trap (Rakodi 2002, Sachs et al. 2004).

Diseases, such as malaria, which is highly prevalent in the region (WHO 2014), constitute another permanent risk as they can fatally reduce labor availability for agricultural activities.

According to the interviewed households, decreasing soil fertility in the whole region further constrains already low yields, and through this increases their vulnerability to natural hazards. Where possible, households thus extend their land under fallow. Cyclones do not only periodically devastate or damage annual rice crops but also destroy irrigation systems and perennial market crops on agroforestry parcels. This deters households from experimenting with permanent agricultural systems and undermines their nutritional and economic security.

With regards to important market crops (e.g., clove trees and vanilla), price fluctuations are another factor reducing motivation to invest household resources into agricultural diversification. Some agroforestry plots were even cleared for this reason. A stable market system that could guarantee a minimum annual income from specific market crops could significantly assist the diversification of households' production and agricultural systems.

Policies, institutions, organizations and processes: According to the policies of the state government, forests are state property and any forest clearance is strictly forbidden. This ban seems to have little effect on local practices. Currently, local customary rights determine forest management and forest clearance in these remote areas. Most commonly, the process of deforestation around our study villages occurs in two steps: (i) forest fragmentation and (ii) forest clearance. By segregating a forest fragment from the large forest massif, households are subsequently considered the rightful owners of the newly created forest fragments next to their arable land, following the local customary right. Consequently, the right to clear the forest fragment is restricted to them (Aubert 2008, Muttenzer 2010, Urech et al. 2011).

As the state forest service has failed to control and assure forest conservation through a centralized forest management policy (Kull 2004), a framework for community-based forest management was established in 1996 (Bertrand et al. 1999). Based on this framework, a local conservation and development project, aimed to establish the necessary local institutions for sustainable and economically beneficial forest management, has been set up in the Manompana corridor. Hence, management rights were transferred to local communities. Local inhabitants should have control of timber logging in allocated areas and can thus benefit directly from the timber trade. The general aim of placing value on existing precious woods, enabling the local population to benefit from them and assuring sustainable forest management through community-based management, is a fundamental opportunity for local inhabitants. However, a recent study by Rasolofoson et al. (2015) showed that commercial community-based forest management can only contribute to reducing deforestation in Madagascar if institutional shortcomings are solved and local participation is guaranteed.

While decentralized community-based forest management could present an opportunity for local people, it is also highly challenging. If the *tavy* practice continues as it has until today, sustainable forest management cannot be realized. For households to be able to reduce their dependence on *tavy*, alternative, productive and sustainable agricultural techniques are needed. Our research shows that officially accepted land tenure rights are also an important barrier preventing households from investing time and labor in the improvement of their agricultural systems. According to the state law very few individuals are recognized landowners. In the two villages near the forest massif, official land ownership does not even exist. Agricultural land for *tavy* is traditionally distributed among children by their parents. As long as parents have not officially distributed their land, descendants have to cultivate another slot of land every year, allocated by the parents. Thus, many young households have little motivation to invest more time and labor in their cultivation systems, than absolutely necessary, as they cannot be sure to reap the long-term benefits of their investments. Additionally, many households have to lease a slot of land from another owner because they do not own land in their family or because they have immigrated. Several households of the same lineage also cultivate some land areas jointly, in which case no one feels responsible for improving production. This complex situation of land tenure combined with the fact that many farmers do not own land hinders the planting of trees for market crops (stated by 40% of the farmers), because households can only plant trees if they traditionally own the land. Thus, households need to own their land to improve yields and to diversify their systems with trees. This, however, can often only be achieved by clearing the forest.

Farmer support services: Manompana's farmers cultivate their hill rice in the same fashion as their ancestors have for centuries. The villages in our study site do not receive support from the government or from NGOs for improving production systems or introducing new agricultural techniques. In regions with better access to roads or rivers, only one organization financed by foreign donors tries to implement a system of intensified rice cultivation (SRI) on irrigated fields. Although experimental studies have shown that, in Madagascar, SRI could increase yields (Barison 2002, Uphoff and Randriamiharisoa 2002), these systems are poorly adopted by local households in ours as well as in other regions (Moser and Barrett 2003). Furthermore, results from interviews and literature review (Hume 2006) show that improved crop yields on irrigated rice fields do not replace the system of *tavy* on slopes; among other reasons, some of the farmers do simply not have access to irrigated rice fields. To improve current agricultural production and to change the current *tavy* system, low-investment technologies that can be applied to steep slopes and small plots are necessary. Such innovative technologies were developed by research institutions in Madagascar, e.g., direct seeding on permanent vegetal cover (O. Husson pers. comm.). However, pest and disease control in the absence of chemical inputs is often a major constraint for the success of those technologies (Messerli 2002). Furthermore, households' flexibility to experiment is strongly restricted by the availability of money (Uphoff and Langholz 1998), time and the fear of cyclones. In any case, replacing traditional systems of *tavy* with a permanent and sustainable cultivation system will require the constant and long-term support of professional technicians (O. Husson pers. comm.).

With regard to forest management, the state forest service is nearly nonexistent in rural areas. The state forest service has one person responsible for the control and monitoring of the whole Analanjirofo region, which includes 1.2 million ha of forests. Considering the remoteness and inaccessibility of most of the region, we can conclude that the control of these forests by a single person is impossible. Community-based forest management might be a step in the right direction, but the local population needs stronger support from the forest service in order to develop the necessary skills to manage forest resources on their own and to resolve possible conflicts among stakeholders.

CORE FACTORS AND STRATEGY DEVELOPMENT. Enhance food security through risk minimization: Producing enough crops to feed all household members is the main aim of households in the study site. The current strategy to maintain soil fertility is to keep long fallow periods. As a result, forests are cleared to make new agricultural land available. In villages close to the forest, fallow periods are up to 10 years, while in villages far from the forest fallow periods have decreased to about five years. Compared to the crop yield of *tavy* systems, traditional irrigated rice cultivation can produce twice as much (Brand 1998). But, as stated by farmers, the latter requires higher time investment to prepare the terrain, to transplant the seedlings and build irrigation systems, and to rebuild them after the damages caused by annual cyclones. Furthermore, farmers explained during interviews that even if irrigated fields produced more than enough rice for personal consumption, they would still continue with *tavy*, in order to diversify their systems and to reduce the risk of crop failure due to cyclones. *Tavy* is known to be a flexible, low-intensive and cyclone adapted system in other regions (ibid). Households stated that they prefer to grow food in slash-and-burn systems in order to enhance food security in the short-term. Moreover, due to the rugged topography, 34% of households in the remote villages do not have access to suitable land to cultivate irrigated rice.

Attain customary land ownership through deforestation: As described above, according to customary law, households can become traditional owners of forest fragments and land through clearing forests. Especially for poorer households or immigrants this is often the only possibility to attain land ownership. Thus, many landless people move to very remote regions where they can find a contiguous forest massif not yet owned by other families. When more land is needed for future descendants or if soil fertility in the tavy system is decreasing, households begin to clear their own forest fragments to bring the forest soil into production.

Attachment to ancestors: The system of *tavy*, as we observed in the Manompana corridor, is an integral part of the culture pertaining to the region's dominant ethnic group of the Betsimisaraka. This is the case also for other regions of eastern Madagascar (Bertrand and Lemalade 2008). Keller (2008) observed on the Masoala peninsula that the conversion of forest into arable land is considered essential for ensuring a connection between the ancestors and future generations. Descendants should be rooted in the land of the ancestors by cultivating their land (ibid), and forests are ancestral land. According to long tradition, deforestation and subsequent cultivation are a means of guaranteeing this connection.

Another important element of the Betsimisaraka's culture, which could be observed in our study site as well as in other regions of the eastern escarpment (Kistler and Messerli 2002), is the duty to honor the ancestral way of life and continue with the same systems of cultivation as were used in the past. Thus, these traditions hinder households from experimenting with new technologies, as they provoke social pressure from other villagers. Many taboos are linked to cultivation systems, especially *tavy*, and village chiefs and other village members control the application of taboos. Village chiefs in our study site noted that if households renege on particular taboos, village authorities must sanction them. This was the case if farmers applied new technologies or if they did not respect the two to three days (according to the individual village) per week during which farmers are not allowed to work in their agricultural fields.

Individual, family and community orientation towards forest conservation: 62 households (N=110) claimed to be very motivated to conserve their remaining forest fragments and to stop forest clearance by *tavy*. These were mainly wealthier households who already own large areas of land and are aware of the finiteness of natural resources (Urech et al. 2012). To enhance sustainable forest management, such individual interests preserving forest fragments must become collective concerns; otherwise communal interventions and regulations will fail (Ostrom 1999).

However, according to Cole (2001), the mobilization of the Betsimisaraka into acting as a community has always been difficult, which is in line with Berkes (2004) who showed that the concept of a 'community' is very heterogeneous. Families are more strongly attached to their lineages than to spatial organizations or administrative structures imposed by the state. Although we could identify communal regulations that predict a sustainable use for some NTFPs (e.g., Pandanaceae) we did not observe any community-based approaches with regard to sustainable forest management as a whole. Forests are ancestral land and accordingly managed by lineage and clans, as observed in other regions of Madagascar (Kull 2004, Muttenzer 2006). Thus, while bans on the clearance of certain forest fragments or restrictions on the use of forest products exist, they are based on clan or lineage-specific taboos. We found several such remaining forests near the two villages close to the forest massif. In the two other villages, however, most of these so called 'sacred forests' have already been cleared by lineages that do not have to respect the specific taboo. Therefore, lineage-specific taboos are no guarantee for forest protection. Moreover, taboos can change within a family as resources become scarce (Fedele et al. 2011, Urech et al. 2011). This shows that orientations which could enhance forest conservation differ between lineages but can be adapted to changing circumstances over time.

Awareness of forest depletion: While exploring households' decision-making processes, we questioned people about the consequences of a landscape without forests on their livelihood systems. Most households living close to the forest massif are unable to envision a landscape without forests and are thus not aware of forest resource's finiteness. Households living far from the forest massif are significantly more aware of the exhaustibility of forest resources. They have witnessed the large-scale disappearance of forest resources and the consequent scarcity of resources. The further households were living from the forest massif, the more able they were to name forest products existing in the past from the village territory (Spearman's correlation, $r=0.305$, $N=88$, $p=0.004$). We also asked households if they would agree to a prohibition of the expansion of *tavy* practice on natural forest in their village territory. The further away the village is from the forest massif, the higher the agreement is to prohibit such extensions in order to preserve remaining forests (Spearman's correlation, $r=0.557$, $N=96$, $p<0.001$).

LIVELIHOOD OUTCOMES AND THEIR INFLUENCE ON LIVELIHOOD SYSTEMS. The number of households collecting timber and NTFPs for personal use does not differ significantly between households living near or far from the forest massif (Table 3). However, there is a significantly higher proportion of households living far from the massif who gain cash with timber (Pearson's $X2 = 7.08$, df=1, $p=0.008$). This can be explained by market accessibility, rather than by proximity to the forest massif. Near the forest massif, people have better access to precious woods but cannot exploit it because of market inaccessibility. In contrast, the number of households selling NTFPs is significantly higher close to the massif (Pearson's $X2 = 15.07$, df=1, $p<0.001$). This is due to the proximity to the forests where NTFPs are still available in high quantities and are of good quality. Moreover, NTFPs are easier to carry over long distances to markets than timber.

Table 3. Number of households (out of 110) collecting timber and NTFPs for personal use or trade, separated by the distance to the forest massif (near and far).

	Near forest massif		**Far from forest massif**	
Answers from questioned households (N=110)	Number	%	Number	%
Timber harvest for personal use	48	100	62	100
NTFP harvest for personal use	47	98	52	84
Timber harvest for trade	7	15	24	38
NTFP harvest for trade	27	59	9	14

Households collect a decreasing number of different NTFPs for personal use or trade the further they live from the forest massif (Spearman's correlation, r=-0.777, N=102, p<0.001) (Figure 1). One reason for this decrease is obvious: the less forest area that exists in the village territory, the less people can collect NTFPs. Another reason is that people living near the forest massif must invest less time in searching for NTFPs that exist only in the massif (e.g., wild pigs, lemurs). A third reason is the decreasing quality of products, as is the case with tsiriky (*Pandanus guillaumetii*), for example. This plant is still well-represented in fragments surrounding villages far from the massif, but due to human population pressure plants of suitable quality for mat weaving are becoming rare. As a result, people do not collect *tsiriky* anymore and replace it with *Lepironia mucronata*, a Cyperaceae growing in marshlands (Fedele et al. 2011).

Close to the forest massif all households still have access to forest products and there is a collective orientation of all households to apply the customary rights of open access to all forest products. In the villages far from the forest massif we could observe growing dissatisfaction with regard to open access to forest products. Fragment owners fear that forest resources will not satisfy their future needs, especially for fuel and timber. Some farmers also began to ask for money from outsiders who want to cut timber in their fragments. Their dissatisfaction may influence the social cohesion of the community and has already resulted in social conflicts among villagers.

Households living far from the forest massif have found ways to adapt their livelihood strategies to the new context of degraded and limited remaining forest resources. Some forest products are replaced with alternative products growing in land use types other than forests. However, the use of alternative products often results in a forfeit of quality. For instance, the leaves of *ravintsira* (*Dypsis* sp.) a palm species growing in forests (Byg and Balslev 2001), are used to build house roofs, but can be replaced by the leaves of *ravinala* (*Ravenala* sp.), growing in secondary vegetation. *Ravinala* is less resistible to rain and lasts only a few years. Other forest products such as high quality timber, certain edible roots or meat (e.g., from lemurs) must be bought at local markets because they are no longer available in the vicinity of the study villages. This adaptation of livelihood strategies has a significant outcome on livelihood systems: if products have to be bought, households become more dependent on cash availability through income generation activities. In turn, this has a negative influence on the social cohesion between villagers. Many households noted that in the past, families helped each other to cultivate their fields. Nowadays, people want to be paid for their work. Forest products such as tubers or fruits are replaced by products growing in crop and agroforestry systems. As a consequence, with decreasing availability of forest products, the increasing diversification of crop and agroforestry systems can be observed. Products from agroforestry systems can also be sold and allow households to increase their cash income. However, as described above, major obstacles for the expansion of agroforestry systems include the risk of cyclone damage, limited market access to sell fruits, and the high price fluctuations of the market crops.

Research results show that households living close to the forest massif depend more on forest resources than households living far from the massif. To explore households' own perception about their dependency on forests, we asked them "What are the consequences of deforestation on your personal well-being?"; 59% of all answering families see negative consequences (details described in Urech et al. 2013). The most frequent negative consequences cited are that families will need more time to find necessary products, that income generation through timber and NTFP will decrease and that forest products will be of lower quality. However, our concluding question after the analysis of the specific consequences was: "Could you survive without forests?", and 79% (N=19) of the households living closest to the forest massif confirmed that they could survive without forests (Figure 2). Considering only the three villages within 0.2 to 2 hours walking distance of the forest massif, the percentage of people answering with "no" increased significantly and correlated inversely with distance (Spearman's correlation, r=-0.324, n=67, p=0.008) to the massif. Surprisingly, in the fourth village furthest from the massif, 85% (N= 23) answered again with yes, they could survive without forests.

We associate the predominant perception close to the forest massif of not being dependent on forest resources with a low awareness of forest scarcity. Moreover, the strategy of households living close to the massif is still to clear forests to gain more arable land. This shows that for the decision-making process, forests are not perceived as very important in terms of their products, but rather as a future land resource for agriculture. However, in the village furthest from the forest massif, people are aware of the consequences of deforestation but have learned that they are able to survive with very limited forest resources.

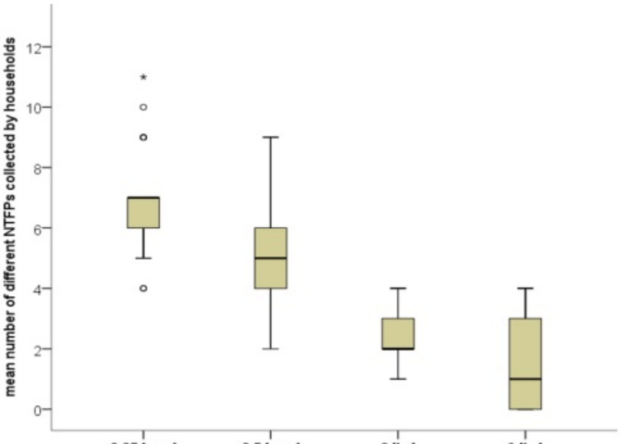

Figure 1. Mean number of different NTFPs collected per household and separated according to the distance of the village from the forest massif.

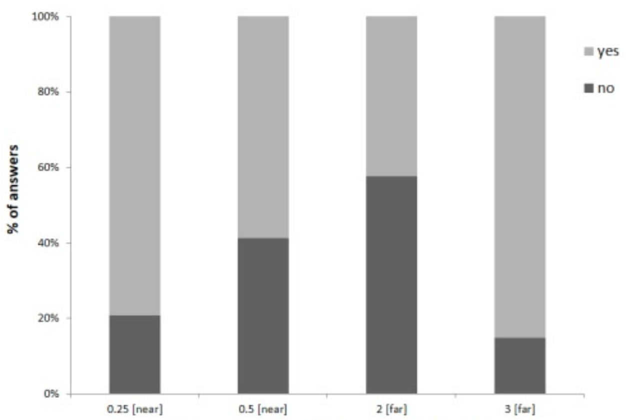

Figure 2. Answers to the question: "Could you survive without forests?", separated according to the distance of the village from the forest massif.

CONCLUSION

The current livelihood strategies of local households are based on the traditional tavy rice cultivation practice, which leads to deforestation and forest fragmentation. The opportunities arising from exploitable forest resources do not seem beneficial enough to make households change their livelihood strategies to preserve those resources for the future. Although there is an existing potential for the commercialization of precious woods and NTFPs, currently it cannot be exploited due to nonexistent infrastructure, limited market access, a lack of an institutional framework and the absence of regulations that would allow a legal, sustainable and profitable trade in forest resources. In addition, the very slow growth of *Dalbergia* species as well as the currently intensive illegal logging (Randriamalala and Liu 2010) considerably reduce the potential for an ecologically sustainable exploitation.

Forest products are used as long as they are available. Once forest resources become scarce, people demonstrate the flexibility to adapt. Products are substituted and cultural values and rules are adapted accordingly. Nevertheless, it must be noted that all of our studied villages still have forest resources left. The *tavy* rotation cycle in these villages is 5–10 years, whereas it has decreased to three years in other regions of Madagascar (Styger et al. 1999, Hume 2006). Households in our study villages have not yet experienced the consequences of the high soil erosion and degradation that have occurred elsewhere on the island. If deforestation continues, the environmental consequences are likely to negatively impact agricultural production systems in the Manompana corridor in the future.

In order to improve the overall sustainability of livelihood systems and wellbeing of households, current agricultural practices should be transformed into permanent cultivation systems that (i) do not undermine soil fertility, (ii) produce enough crops to feed the growing local population and (iii) can co-exist with the remaining forests. Such improved production systems have to be designed and tested in close collaboration with the concerned households and farmer communities, so that the new practices are in line with livelihood strategies and the common obstacles to adoption are considered. Those obstacles are manifold: Households' current livelihood strategies are based on experience and risk management, and may be wise with regard to their biophysical environment.

The *tavy* practice is flexible and less vulnerable to damages caused by cyclones than are irrigated rice fields (Brand 1998, Laney 2002). The fact that tavy is deeply anchored in Betsimisaraka culture and that innovation often is hampered by social pressure, adds an additional hurdle to the implementation of innovative technologies. Unsecured tenure rights are another obstacle for local households to diversify their traditional agricultural systems. Moreover, the high vulnerability of local households severely limits their motivation to experiment with and to invest time and resources in new agricultural practices. Therefore, any new technologies that are proposed should be low-input and adaptable to local conditions, and not too susceptible to cyclones. Households need access to additional and alternative income sources in order to allow them a minimal flexibility to experiment with innovative technologies. Moreover, a long-lasting collaboration between local traditional authorities, extension workers and agronomists is needed to adapt new technologies to given cultural factors and social circumstances and to involve local authorities in a common decision-making process.

In order to guarantee forest conservation, it is recommendable to harness the existing potential of forest resources in such a way that preserving forests becomes a more attractive option to households than clearing them. An institutional framework encouraging the sustainable use of these opportunities is vital. The community-based forest management project which was implemented in the Manompana corridor was a significant first step in the direction of beneficial and sustainable forest management and the support of local institutions created in the course of the project should be maintained to ensure their continuity. Income generation from forest products would also allow households to have an alternative source of cash income, which in turn would give them more flexibility to invest in agricultural improvement. It would thus be possible to ensure the future availability of forest resources and environmental services to a greater extent. However, community-based forest management can only be realized if livelihood systems as a whole are considered. Innovative approaches that address the current problems of rural livelihood systems and that can cope with the complexity of rural peoples' realities are needed. The forestry sector should develop a more integrative landscape planning approach, widening the scope to include agricultural land use.

Our research shows that to counter the strategies leading to deforestation, changing one context factor or simply improving one sector of peoples' realities will not be sufficient. National and international organizations are confronted with considerable challenges. They need a broad understanding of the different factors that influence people's decision-making process, including socioeconomic, ecological, and cultural aspects. However, the local population must also contribute to the betterment of its current situation. While the ability of local households to change their livelihood strategies is limited by their given context, their willingness to change some of their habits, customs and traditions is indispensable for a successful collaboration between different institutions and the local population. A holistic understanding is the necessary starting point for further investigations and future interventions. However, particularly in regard to understanding, aspects of cultural attachments, and the dilemma between collective orientation and individual innovation, will require further research by anthropologists or even psychologists.

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SUPPLEMENTARY MATERIAL.

Available online only.

Figure S1. The Sustainable Livelihood Approach, adapted from NADEL (2007).

Figure S2. The nine-square mandala adapted from Högger (2004).

S3. Questionnaires and guidelines for discussions.

ARTICLE

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Historique de la colonisation du milieu de la presqu'île d'Ampasindava : transformations du paysage et système de conservation

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ABSTRACT

In the northwest of Madagascar, the Ampasindava peninsula is home to the essential part of what remains of the forests of the Sambirano phytogeographic domain. The area has great importance in terms of biogeography, ecology, and socio-cultural aspects. The first documented human presence dates back to the tenth century, during the development of the maritime trade in Madagascar, before becoming the first headquarters of the Sakalava kingdom in the northwest of Madagascar. Several facts contributed to the degradation of the landscape, like the practice of the *tavy* and the war between Bemihisatra and Merina. In the peninsula, the western part was the most affected, on contrary to the eastern part where are located the forest massifs which served as refuges during the tribal wars. After the annexion by France, of an important territory including the peninsula (August 6th, 1896), the Merina left the region, and these forest massifs acquired a sacred status and as such were protected against destruction, preserving the characteristics of the primary forests of Sambirano. Elsewhere, a process of natural reconstruction of the vegetation started. These historic facts lead us to conclude that the forests of *Dypsis* spp. (Arecaceae) and Sarcolaenaceae are not primary resulting from a difference in substrate or climate, but are to be interpreted as old secondary forests, deriving from the long-term process of reconstruction of the vegetation. For several years, the analysis of satellite imagery demonstrates that the rhythm of the *tavy* has dramatically increased in the region. This increase stems not only from a population growth, but also from a growing pressure for land to generate income for the purchase of manufactured products. The practice of the *tavy* represents a major threat to forests and different types of residual natural habitats. Secondary forests are the most sensitive and most suitable for rice production. Primary sacred forests have remained so far untouched. Their traditional protection is however recently shaken by the influx of immigrants, who show little respect to traditional ban.

RÉSUMÉ

Dans le Nord-ouest de Madagascar, la presqu'île d'Ampasindava abrite une partie essentielle des restes des forêts du domaine du Sambirano. La région possède une grande importance tant biogéographique et écologique, que socio-culturelle. Elle a connu au X^{e} siècle sa première implantation humaine et il est vraisemblable que l'Homme l'ait parcourue et utilisée régulièrement à l'époque du développement du réseau maritime à Madagascar, avant que le Sambirano ne devienne le premier siège du royaume Sakalava dans le Nord-ouest de l'île. Plusieurs faits ont contribué à la déstructuration du paysage écologique initial, comme la pratique de l'abattis sur brûlis ou *tavy* et les guerres entre les Bemihisatra de la région et l'armée du royaume Merina. Si la zone Ouest de la région a été la plus touchée, celle de l'Est où se trouvent les grands massifs forestiers a servi de refuges durant ces guerres. Après l'annexion par la France, le 6 août 1896, d'un important territoire comprenant la presqu'île, les Merina ont quitté la région, et ces massifs forestiers acquirent un caractère sacré et furent ainsi protégés contre la destruction et le défrichement en conservant les caractéristiques des forêts climaciques intactes du Sambirano. Ailleurs, un processus de reconstitution naturelle de la végétation se mit en route. Ces divers aspects historiques permettent d'avancer que les forêts à Sarcolaenaceae et à *Dypsis* spp (Arecaceae), avec leurs caractéristiques physionomiques, structurales et floristiques, ne découlent pas tant de caractéristiques du substrat ou du climat, mais seraient plutôt des forêts secondaires âgées, issues du long processus d'évolution progressive du dynamisme de la succession végétale. Depuis quelques années, l'analyse des images satellite montre que le rythme auquel le *tavy* est pratiqué s'intensifie dans la région. Cet accroissement découle non seulement de la croissance démographique, mais aussi d'un besoin accru en terres pour générer les revenus nécessaires à l'achat de produits manufacturés. La pratique du *tavy* représente une des principales menaces pour les forêts et les différents types d'habitats naturels résiduels. Les forêts secondaires âgées qui sont si-

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tuées hors des zones traditionnellement protégées sont les plus sensibles car elles sont les plus propices à la production de riz. Les forêts des massifs sacrés, en revanche, ne semblent pas encore réellement menacées mais leur protection traditionnelle est quelque peu ébranlée depuis par l'arrivée récente et massive d'immigrants qui respectent peu les interdits traditionnels.

INTRODUCTION

Pour sa méga-diversité inégalable, Madagascar est considéré comme un 'joyau écologique' ou un 'sanctuaire de la nature' (Joseph-Philibert Commerson In Oberlé 1981 : i). Malheureusement, on observe une dégradation progressive de ses écosystèmes depuis l'introduction du riz et de son système de production, l'agriculture itinérante sur brûlis ou *tavy*, par les proto-Indonésiens. Cette pratique a fait disparaître une grande partie de la forêt, différents types d'habitats et plusieurs espèces animales et végétales majoritairement endémiques de l'île (Goodman et Benstead 2005). Elle est un problème permanent pour le pays, tout comme la pauvreté. Mais c'est justement cette pauvreté qui explique en partie le phénomène de la destruction de la nature, et notamment la déforestation. La plupart des activités de la population se pratique encore sur un mode traditionnel, souvent destructif et très peu rentable. La partie orientale malgache est d'ailleurs connue pour être depuis de longues années un terrain de recherches et d'expérimentations pour trouver et appliquer des alternatives proposées par différentes entités afin de remédier à ce problème.

Le *tavy* est une des causes principales de la déforestation à Madagascar (Scales 2014). Flacourt (1661 : 23) en donne une des premières descriptions au fil de ses observations dans la partie orientale de Madagascar : « Ils plantent leurs riz dans les montagnes et les vallées, après avoir coupé les bois. Lorsque ces bois sont brûlés, toute la terre est couverte de cendres lesquelles se détrempent par la pluie, et au bout de quelque temps ils sèment le riz ». En 1947, Pierre Gourou a alors défini l'agriculture itinérante sur brûlis comme une technique commune aux régions chaudes humides et une solution trouvée par les agriculteurs aux problèmes que leur posaient le sol et le relief (Veyret 1948). Confrontés aux conséquences du *tavy* sur la déforestation, les paysans se justifient par l'idée qu'en l'absence de plaines cultivables, c'est la seule technique adaptée pour la culture (Vicariot 1970). Dans le cadre de ce travail, la définition du *tavy* se rapproche de l'utilisation locale du terme, qui désigne à la fois le système cultural par abattis-brûlis, mais aussi la parcelle de culture. La région Nord-ouest de Madagascar, notamment le domaine du Sambirano, n'échappe pas à la problématique du *tavy* car il est central dans l'économie des paysans, utilisé non seulement pour la production du riz mais aussi comme un moyen d'appropriation des terrains (Aubert et al. 2003, Razafy Fara 2004).

Humbert (1955) a rattaché la forêt climacique de la presqu'île d'Ampasindava au domaine phytogéographique du Sambirano, en la définissant comme un type de forêt dense humide sempervirente de basse altitude. Dans sa cartographie de la végétation de Madagascar basée sur les missions photographiques des années 1950 (Humbert et Cours-Darne 1965), il constate une déforestation ancienne de la majorité de la presqu'île à l'exception de quelques massifs centrés sur des montagnes. Dans une cartographie plus récente également menée au niveau de l'île dans son ensemble sur la base de l'imagerie satellitaire (Moat et Smith 2007), les forêts sempervirentes ont nettement régressé. Ce qui est paradoxal, c'est que d'importantes surfaces de zones cartographiées comme des forêts humides secondaires par Humbert et Cours Darne (1965) correspondent à des zones classées comme des forêts sèches occidentales. Il est important de rappeler que le signal visible des forêts sèches peut parfois être confondu avec celui des faciès de dégradation des forêts humides, particulièrement à l'échelle considérée et si on n'a pas la possibilité de comparer des images de saison sèche à celles de saison humide. Tout en soulignant le remarquable effort, fruit de travaux antérieurs pionniers (Du Puy et Moat 1998), il est par ailleurs inévitable qu'un travail de cette ampleur se soit heurté à une pénurie de données au sol. A notre connaissance, aucune vérification de terrain n'a été menée dans la presqu'île et nous avons tout lieu de penser que la cartographie climatique de Cornet (1974) a joué un grand rôle dans cette interprétation. Malheureusement, cette cartographie se base sur un réseau très lâche de stations climatiques.

Lors de deux campagnes de quatre mois chacune menées entre 2008 et 2010 dans la presqu'île pour en décrire la flore et la végétation, ainsi que lors de missions plus courtes par la suite, nous avons pu faire les constatations suivantes : (i) les forêts denses humides sempervirentes climaciques de superficie importante ne sont effectivement plus rencontrées qu'au niveau des massifs sacrés. Ceux-ci sont entourés par divers types de formations secondaires, de jachères et de friches (Tahinarivony 2014) ; (ii) la région ouest est occupée par des forêts caractérisées par une composition floristique différente, à Sarcolaenaceae et *Dypsis* spp. (Arecaceae) (Tahinarivony 2014) ; (iii) aucune espèce caractéristique des forêts sèches occidentales n'a été trouvée dans cette zone (Ammann 2011) ; (iv) on constate toujours dans ces forêts une proportion de ligneux issus de rejets de souche anormale pour une végétation climacique, ainsi que la présence de nombreux taxons de la reconstitution des forêts secondaires ; et (v) on y trouve régulièrement des lambeaux de forêts denses humides, aux endroits les moins propices à la culture (ravins encaissés ou dominance d'affleurements rocheux) et témoignent vraisemblablement de leur étendue généralisée par le passé.

Nous mettons ainsi en doute l'interprétation de Moat et Smith (2007). Toutes nos observations concourent à considérer que l'interprétation de Humbert et Cours Darne (1965) était la bonne. Dans cette contribution, nous nous proposons d'analyser l'histoire de la presqu'île pour voir dans quelle mesure elle est à même d'étayer l'origine anthropique des forêts à Sarcolaenanceae et *Dypsis* spp (Arecaceae) comme formations secondaires âgées résultant d'une longue reconstitution naturelle du milieu après défrichement ou passage du feu dans la région. Dans ce contexte, il nous semble primordial d'analyser le processus du *tavy*, d'évaluer son rôle dans la société paysanne, d'essayer de comprendre les raisons de sa persistance, afin de pouvoir envisager des alternatives et des solutions pour conserver les reliques des forêts du Sambirano, sans pour autant prétériter le développement du milieu humain.

HISTORIQUE DE LA PRESQU'ÎLE D'AMPASINDAVA

IMPORTANCE DANS LA CIRCULATION MARITIME DEPUIS LE X^E SIÈCLE. Les régions nord et nord-ouest de Madagascar sont riches en éléments historiques concernant la première implantation humaine dans l'île. D'après les découvertes effectuées dans les grottes de Lakaton'i Anja (Montagne des Français) et d'Ambohiposa (Vohémar) (Dewar et al. 2013), les humains étaient présents depuis longtemps (du IIe au VIe siècle) à Madagascar. Selon Wright et al. (2005), le port commercial le plus ancien sur les côtes de Madagascar se trouve à Mahilaka, dans la baie d'Ampasindava ; il atteint son apogée entre le XIe et le XIVe siècle grâce au commerce des Arabes avec la côte Est-Africaine. L'arrivée des premiers Européens date du 10 août 1500 avec le Portugais Diego Diaz, un des capitaines de la flotte de Pedralvarez Cabral en route pour les Indes, séparé de ses compagnons à cause d'une tempête. Il baptise cette terre pour lui inconnue 'Saint Laurent', le nom du saint pour cette date (Grandidier 1902). A la suite de cette découverte, une première reconnaissance a été effectuée par les Portugais entre 1506 et 1507, et des établissements commerciaux se sont installés dans le Nord-ouest de Madagascar.

À cette époque, la région de la presqu'île d'Ampasindava était donc souvent visitée par les navigateurs grâce en particulier à la nature des côtes, adéquate pour le mouillage des grands bateaux et des boutres. La situation de la presqu'île d'Ampsindava en a fait un des grands carrefours pour les Austronésiens, les Arabes et les Anglais, escale idéale entre l'Afrique et l'Asie (Grandider 1902, Beaujard 2007). On rencontrait déjà alors à Anorotsangana des immigrés africains (à cause du trafic lié à l'esclavage), originaires de Malindi (Kenya), de Mogadicho (Somalie) et du Mozambique (Grandidier 1902). Les Russes sont également passés dans la région en 1905, faisant des escales dans le nord, d'où le nom « Baie des Russes ». La presqu'île d'Ampasindava a donc fait l'objet d'un intense trafic maritime depuis plus de cinq siècles.

PREMIER SIÈGE ROYAL DES SAKALAVA DANS LE NORD-OUEST DE MADAGASCAR. La région septentrionale de l'île a connu sa première implantation humaine au IVe siècle, et sur la côte nord-ouest dans la baie d'Ampasindava entre le Xe et le XIIe siècle (Wright et al. 2005). Cette présence humaine ancienne a été confirmée par des fouilles archéologiques dans la baie à l'ouest de l'archipel d'Ambariotelo (Ampasindava), à Nosy Be et à Mahilaka, ainsi que des récits historiques (Poirier 1948, Radimilahy 1998, Wright et al. 2005). Si cette zone était animée par les voyages des marins et des commerçants, elle l'était aussi par la migration des populations indigènes, causée par des conflits internes entre les Merina (ethnie des hautes terres centrales) et les Sakalava (ethnie de la région ouest), et lorsque Madagascar était sous la domination coloniale de la France (Ballarin 2007).

Après le déclin des Portugais vers 1530, Madagascar a entamé des relations avec les Anglais par l'intermédiaire du royaume Merina. Cette situation a marqué un tournant pour l'histoire du peuple malgache et pour le pays, car elle a favorisé et affermi l'ambition du pouvoir royal Merina et sa politique expansionniste. À partir de 1817, le royaume Merina, sous le souverain Radama I, a cherché à conquérir l'ensemble de la Grande Île. Pour y parvenir, et afin que le royaume Merina soit reconnu comme le royaume de Madagascar, il a accepté les conditions imposées par les Anglais, notamment l'abolition de la traite extérieure des esclaves. Par la suite, le roi Radama I a cherché à accaparer toutes les zones importantes de la Grande Île en utilisant des moyens politiques et militaires. En 1824, le royaume Sakalava de la région ouest de Madagascar (région de Mahajanga) était conquis, avec pour conséquence la fuite des dynasties locales Maroseranana (Deschamps 1959), qui étaient formées par les troupes de Zafimbolamena et de Zafimbolafotsy. À cause de la forte pression des Merina, les Zafimbolamena se sont enfuis vers le nord et se sont installés sur la presqu'île d'Ampasimena, sur le territoire d'Anorotsangana, presqu'île d'Ampasindava. La première résidence royale des Sakalava dans le Nord de Madagascar a donc été établie sur la presqu'île d'Ampasindava, avec une concentration de la population dans la zone d'Anorotsangana (Amicale des Journalistes et Écrivains Français de Madagascar 1942).

Plus tard, en 1832, une scission divisa les Bemihisatra en deux royaumes distincts : l'*Ampanjakabe* (roi) Andriantsoly partit à Mayotte et fonda un nouveau royaume, tandis que la reine Oantitsy fonda un royaume sur le littoral de la presqu'île d'Ampasindava. Sa jeune sœur Tsiomeko lui succéda en 1836. Durant cette période, les hostilités entre Sakalava et Merina prirent un nouveau tournant qui marqua l'histoire de la presqu'île d'Ampasindava. L'armée du royaume Merina, forte de deux mille hommes qui furent envoyés par le souverain, était devenue trop puissante pour les Sakalava, et les envahisseurs cherchèrent à capturer Tsiomeko, la reine des Sakalava Bemazava et ses conseillers Antalaotra et Tsimandroho (Ballarin 2000). Ces derniers choisirent de se réfugier au centre de la presqu'île, notamment dans les grands massifs forestiers. C'est pour cette raison que les indigènes considèrent aujourd'hui encore ces massifs comme sacrés, et en particulier le massif de Bongomirahavavy (qui signifie 'montagnes sœurs') qui a probablement servi de cachette aux sœurs Oantitsy et Tsiomeko.

Lorsqu'en 1839 les hostilités reprirent, une grande partie des Bemihisatra, menés par leur reine Tsiomeko, se réfugia sur l'île de Nosy Be. Comme la France, rivale de l'Angleterre dans la conquête de Madagascar, était attirée par la richesse et la beauté de l'île de Nosy Be, la reine des Bemihisatra passa un accord avec la France en lui cédant son territoire, en échange d'une protection de son peuple contre les Merina (Ballarin 2000). Sur la presqu'île d'Ampasindava, cette guerre avec le royaume Merina est restée gravée aussi bien dans les paysages que dans la mémoire et les traditions des gens avec le respect des valeurs culturelles et coutumières des zones à importance historique (Bongomirahavavy, Andranomatavy, Marotony, Ambariotelo ou d'Ambarijeby). Ces milieux sont sacrés pour les natifs de la région de par les liens qui les unissent au royaume Sakalava, en tant que massifs forestiers qui servirent de refuge pendant les guerres. Cette notion du sacré a été renforcée par des règles coutumières qui se sont transformées en interdits ou *fady*. Parmi ces interdits, les plus importants portent sur l'interdiction pour les Merina de fréquenter la région ainsi que sur la conservation de certaines forêts dont : (i) les Merina n'ont pas le droit de circuler dans les massifs sacrés ; (ii) le dialecte merina ne doit pas être parlé à l'intérieur des forêts des massifs sacrés ; (iii) un habit de couleur rouge ou noir (couleur des armées merina) ne doit pas être porté dans les forêts sacrées ; et (iv) il est interdit de couper, défricher ou de pratiquer le *tavy* dans les forêts sacrées.

SYSTÈME ÉCONOMIQUE COLONIAL, FLUX MIGRATOIRE ET EXPLOITATION DES FORÊTS. Le nord-ouest de Madagascar, avec son climat favorable, ses grandes plaines alluviales et ses sols souvent favorisés par leur nature volcanique, a compté parmi les points économiques stratégiques pendant la période coloniale. Plusieurs régions de grande importance économique sont passées sous protectorat français suivant l'annexion du 6 août 1896 dont Nosy Be, la presqu'île d'Ampasindava, la plaine du Sambirano, les plaines de l'Ifasy, de la Mahavavy et du Mananjeba. Une exploitation massive des forêts a d'abord eu lieu pour l'extraction des ressources en bois et des plantes à caoutchouc, ainsi que pour l'aménagement de terrains pour les plantations de rente. Pour développer le système de production économique colonial, les Français ont imposé un système de flux migratoire pour augmenter la main d'œuvre dans le domaine du Sambirano. Madagascar était alors subdivisé en deux types de zones, les zones de départ qui étaient sources de mains d'œuvre et les zones d'arrivée qui étaient les zones de production. Le district d'Ambanja était une zone d'arrivée, où se sont implantées de grandes sociétés agricoles. De nombreuses personnes venant de différentes régions arrivèrent dans la zone, tels les Antandroy en provenance de la région Androy, les Betsileo de la région de Fianarantsoa, les Tsimihety des régions de Mandritsara et d'Antsohihy, et les Antemoro de la région sud-est de Madagascar (Waast 1972). En conséquence, la population active de la région a très vite connu une forte croissance.

Suite aux travaux forcés imposés par les colons, des révoltes eurent lieu et causèrent la fuite de nombreuses personnes qui s'installèrent dans les forêts et commencèrent à exploiter le milieu (Waast 1972). C'est à partir de cette période que le massif du Manongarivo, les forêts du Sambirano ainsi que les forêts de la zone est de la presqu'île d'Ampasindava ont connu de plus en plus le *tavy*, malgré l'existence de lois du 28 août 1913 interdisant les feux en forêt et les feux de brousse.

DE L'INDÉPENDANCE À LA PÉRIODE ACTUELLE. Depuis l'indépendance, la presqu'île est devenue un grand fournisseur en riz, en bois de construction et en charbon pour Nosy Be et Ambanja. Ceci est dû à sa grande richesse en forêts et en mangroves non protégées et accessibles à tous, à l'inverse des régions de Nosy Be et d'Ambanja où les forêts restantes sont limitées aux aires protégées (Lokobe et Manongarivo). Cette grande disponibilité des ressources naturelles attire les paysans de différentes régions, notamment les Tsimihety de la région Sofia (au sud-est de la presqu'île). En plus, pendant la saison sèche, la presqu'île d'Ampasindava accueille un grand nombre d'immigrants, venus principalement pour chercher un emploi comme défricheurs. Ces défricheurs (appelés localement *Karama tetika*) sont en général des Tsimihety payés 5000 Ariary/jour. Leur présence a pour conséquence d'augmenter non seulement le taux de surface défriché par année, mais aussi la densité de la population. Arrivés à l'origine comme employés saisonniers, beaucoup d'entre eux resteront après la fin de la saison des défrichements et commenceront à faire leur propre *tavy*. Ce cas est souvent observé dans les communes d'Ambaliha et de Bemanevika.

Par la présence de la route nationale 6, la population des communes d'Ankaramy, d'Anjiabory, et d'Ankingameloka ont connu une hausse considérable. Puisque la forêt de Manongarivo a un statut de Réserve Spéciale, et est protégée contre toute forme d'activité anthropique, les paysans à la recherche de nouvelles terres à défricher se sont déplacés de plus en plus vers le nord-ouest et sont arrivés dans la région d'Antsirabe et d'Ambaliha. En conséquence de ces déplacements de population, une nouvelle délimitation administrative a élevé le village d'Ambaliha au rang de commune rurale (CR), celle-ci s'ajoutant aux CR d'Anorotsangana, d'Antsirabe et de Bemanevika., La pratique du *tavy* s'est donc intensifiée et a détruit les forêts des massifs d'Ankobabe, de Bezavona, d'Ambilanivy et une partie de celui de Bongomirahavavy.

La crise politique de 2009 a également contribué à la transformation du paysage de la presqu'île d'Ampasindava. Les industries et les grandes entreprises de la région nord-ouest de Madagascar telles que SIRAMA (industrie de production de sucre de Madagascar), MAGRO (Malagasy Grossiste) de Nosy Be, d'Ambanja et d'Ambilobe ont choisi de fermer leurs portes ou ont été obligées de suspendre leurs activités. De nombreux employés se sont retrouvés au chômage et les familles ainsi en difficulté se sont tournées vers la presqu'île d'Ampasindava pour pratiquer le *tavy*, l'exploitation des bois, ou la pêche, simplement pour survivre, accélérant l'intensité de la dégradation de l'environnement de la région au cours de ces cinq dernières années.

LE *TAVY* : ACTIVITÉ PRINCIPALE DE LA POPULATION LOCALE

IMPORTANCE DU RIZ ET DU *TAVY* DANS LA VIE QUOTIDIENNE DES PAYSANS. Comme dans tous les milieux ruraux malgaches, le zébu et le riz représentent les deux grands signes de richesse des paysans. Sur la presqu'île d'Ampasindava, l'élevage extensif est peu pratiqué et le nombre moyen de têtes de bétail par ménage est limité : entre deux et cinq zébus. Le riz en revanche occupe une grande place tant dans l'économie que dans la constitution des rangs des classes sociales des paysans. La quantité de riz produite fait la richesse d'une personne ou d'une famille donnée. Un paysan qui a eu la chance de faire un *tamborôho* ou *valintanana* (une activité sollicitée par un agriculteur qui a pu produire une grande récolte, et demande de ce fait aux voisins ou aux villageois de lui donner une aide pour la moisson sans rétribution mais seulement en échange de la nourriture pendant les jours de travail) et qui a offert un zébu aux membres de la société pendant les jours de la moisson jouit d'une haute considération. Ainsi, celui qui a eu le plus grand *tôha* ou *riha* (une case construite spécialement pour stocker le paddy et dont la taille dépend de la quantité de la production annuelle) devient une personne modèle et respectée dans la société. Cette importance sociale de la production du riz aggrave le phénomène de la déforestation sur la presqu'île d'Ampasindava, car elle génère une concurrence entre les paysans et augmente considérablement le rythme du *tavy*. Par ailleurs, le *tavy* constitue un moyen pour s'approprier des terrains. À cause de la non-application ou le non-respect des lois de législation forestière la forêt primaire est considérée par les paysans comme une ressource communautaire. Par un choix avisé des zones à défricher, l'agriculteur assure la qualité de la production et augmente son pouvoir foncier et celui de sa descendance. Cet aspect foncier de la pratique du tavy concourt également à favoriser la déforestation.

Le *tavy* est pratiqué par tous les paysans, surtout par les hommes. Il est un moyen de montrer une capacité d'autonomie au sein de la société. En effet, celui qui est capable de réaliser et d'entretenir à lui seul son *tavy* devient un homme respectable. C'est pourquoi, dès l'âge de 14–15 ans, les jeunes hommes commencent à avoir leur propre *tavy* en plus de celui partagé avec la famille. Selon le nombre de personnes actives par ménage et le pouvoir de chacun à défricher la forêt, la superficie d'un *tavy* peut varier de 900 m2 à 10 000 m2 par ménage. Une parcelle étant généralement cultivée pendant deux années successives avant la mise en jachère, cette surface correspond à la surface défrichée tous les deux ans. Les parcelles défrichées sont des milieux riches en biomasse, comme des friches et très souvent des forêts secondaires, voire primaires dans le but d'avoir beaucoup de combustion lors de l'incinération et d'enrichir ainsi le sol en substances nutritives. Si l'espace de production vient à manquer, les paysans se tournent vers des forêts secondaires de plus en plus jeunes. Par ailleurs, si les forces manquent pour défricher des forêts âgées, les paysans choisissent les parcelles en jachère, plus faciles à travailler.

CHOIX DES PARCELLES ET PRATIQUE DU *TAVY*. Dans le système d'agriculture itinérante, la fertilité du sol est un élément primordial dans le choix des parcelles de culture. Les paysans identifient les milieux fertiles et propices au *tavy* selon quelques critères, notamment les espèces indicatrices du type de sol et de la structure du substrat, la présence et l'abondance de turricules (dû à l'activité des vers de terre), ainsi que la taille des arbres. Sur la presqu'île d'Ampasindava, la présence de lianes comme *Merremia peltata* (L.) Merr (Convolvulaceae) ou Vahimbalegny. *(Ampelocissus elephantina* Planch. - Vitaceae) ou Menakibongana, et l'abondance d'arbres comme *Parkia madagascariensis* R.Vig. (Fabaceae) ou Fanamponga, *Khaya madagascariensis* Jum. & H. Perrier (Meliaceae) ou Sandramiramy, *Calophyllum* sp. (Calophyllaceae) ou *Lintanona*, ou *Lazalaza* ou *Mongy*, tous deux *Croton* spp. (Euphorbiaceae), qui indiquent une meilleure qualité du sol, font présager d'une grande production. Ces milieux sont préférés pour le *tavy*, et d'autant plus s'ils ne sont pas loin du village et proches de cours d'eau. Les forêts les moins prisées sont celles qui se développent sur des sols minces ou celles où l'abondance en *Rinorea arborea* (Violaceae) ou *Hazondomohina*, *Homalium micranthum* (Boivin ex Tul.) O. Hoffm. (Salicaceae) ou *Janganito* et *Scleria boivinii* Steud. (Cyperaceae) ou *Filelatra* est élevée car elles reflètent des conditions jugées défavorables à la culture de riz. Les forêts riches en *Martellidendron* sp. (Pandanaceae) sont également évitées à cause de la présence de nombreuses racines échasses et épines, très difficiles à défricher.

La production du *tavy* est importante lors de la première année de culture, mais présente une baisse considérable l'année suivante. En effet, il y a une perte en éléments nutritifs du sol par le phénomène de lessivage et de dénitrification, ainsi qu'un accroissement de la concurrence des mauvaises herbes. Lorsque les jachères et les friches ont été au repos pendant 15 à 30 ans, les paysans les reconsidèrent lorsque les espèces indicatrices redeviennent abondantes, indiquant que le sol a retrouvé ses qualités pour la production de riz.

PRODUCTION DE RIZ DANS L'ÉCONOMIE DE SUBSISTANCE. La production de riz par ménage dépend de plusieurs facteurs : le type de parcelle (type de formation, historique), la qualité du sol, et la quantité et la répartition des précipitations. Dans la commune rurale de Bemanevika, la production moyenne annuelle communale est comprise entre 1600 et 1900 tonnes de riz blanc (Missouri Botanical Garden 2014). La consommation moyenne journalière d'une personne active est quant à elle estimée à 0,72 kg, ce qui représente une consommation moyenne annuelle de 1,303 tonne par ménage (avec 5 personnes/ménage). D'après ces chiffres, la quantité de la production serait donc suffisante pour l'autoconsommation. Cependant les paysans sont obligés de vendre une partie de leur récolte pour acquérir divers produits manufacturés, réduisant ainsi les réserves dont ils ont besoin pour boucler l'année. Ils doivent ainsi surmonter une période de soudure annuelle de janvier à mars, durant laquelle ils sont obligés d'acheter du riz, et se tournent vers l'exploitation des bois afin de générer les revenus nécessaires.

Le calendrier agricole des paysans est chargé (Tableau 1), selon les données des enquêtes collectées. La culture du riz occupe la saison des pluies, et le défrichement et la mise à feu sont réalisés pendant la saison sèche. Entre ces deux saisons, pendant la période de soudure, l'exploitation forestière atteint son maximum. Pour les paysans vivants sur les côtes, la production de charbon, destinée au marché de Nosy Be, est intensive pendant les mois d'août et de septembre, et baisse pendant la saison des pluies.

LE *TAVY*, UN PROBLÈME NON RÉSOLU À MADAGASCAR. Plusieurs dirigeants malgaches, anciens et récents (rois, présidents ou ministres), ont tenté de résoudre les problèmes liés au *tavy*. De nombreux organismes non gouvernementaux ont également déployé beaucoup d'efforts pour gérer ce problème et proposer des solutions à l'Etat (e.g., EPB-BEMA, SAGE, TAMS). Mais la forêt continue à diminuer d'année en année, et la pauvreté augmente toujours.

Le roi Andrianamponimerina (1787–1810) considérait les forêts comme un patrimoine, source de biens pour les orphelins, les veuves et les malheureux, qu'il fallait protéger, car ces derniers n'avaient rien à vendre ni à manger (Lavauden 1939). Les lois de réglementation du code 305 de la reine Ranavalona (en 1881) (Julien 1932) se sont efforcées de donner une base légale à cette intention de protection en interdisant le défrichement. Pendant la colonisation, le décret de 1913 a renforcé cette interdiction, en proscrivant les feux et particulièrement les *tavy*, ou en les soumettant à un régime d'autorisation administrative préalable. Après une première période où ce système a été mis en place et respecté, un certain laxisme s'est développé, et ce surtout depuis que les colons, impliqués dans la première guerre mondiale, n'avaient plus sur place les effectifs nécessaires.

Depuis la première république (1959–1975), le gouvernement a reconnu l'existence des défrichements abusifs. L'article 101 de Ranavalona a été mis à jour pour prendre en compte l'évolution démographique et l'état des forêts. Dans l'article 2 de l'ordonnance 62-121 qui porte à la modification de l'ordonnance 60-127, l'Etat malgache a défini le défrichement comme la suite des opérations destinées à permettre la mise en culture d'un terrain préalablement recouvert d'une végétation avec l'intention de l'incinérer après dessiccation pour y faire des plantations ou des semis d'ordre agricole. Le défrichement ainsi défini est considéré comme un délit et des réglementations furent mises en place pour le contrôler. Comme précisé dans l'article 3, il est interdit de procéder à des défrichements dans les forêts classées, les réserves naturelles, les parcs nationaux et les réserves spéciales, les périmètres de reboisement et de restauration, les stations forestières et les terres affectées au service des eaux et forêts. Il est aussi interdit au niveau des versants des collines présentant une

Tableau 1. Calendrier des cultures et autres activités ajusté aux données climatiques (Station de Nosy Be)

	Mois											
	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI
Précipitations (mm)	17,0	21,5	20,0	25,2	95,6	270,5	275,8	274,8	228,9	80,5	26,7	19,0
Températures moyennes (°C)	25,2	25,5	25,9	27,6	27,8	27,8	27,7	27,7	27,8	27,7	27.0	26,8
Défrichement	++	++	+++	+++								+
Semis					++	+++	+++					
Désherbage manuel							+	+++	++			
Moisson										+	+++	++
Exploitation de bois	++	++	+	+	+	+	+++	+++	+++			++
Charbonnage (Mangroves)	++	+++	+++	+	+	+	+	+	+++	+++	+	+

pente supérieure à 50%, dans les dunes littorales, sur les berges des rivières et cours d'eau sur une largeur de 20 m à partir de la limite des plus hautes eaux, dans leurs coudes et méandres, et aux abords des ouvrages d'art. Ces lois furent confirmées par le Président Didier Ratsitaka suivant la loi n° 97-017 du 8 août 1997 portant sur la révision de la législation forestière (J.O. n° 2449 du 25.08.94, p. 1717), chapitre VI, Art.24 en mentionnant que les dispositions de l'ordonnance n° 60-127 du 3 octobre 1960 fixant le régime des défrichements et des feux de végétation restaient applicables.

En théorie, ces différentes lois et ces décrets seraient amplement suffisants pour protéger les forêts et les aires protégées de Madagascar, s'ils étaient appliqués correctement. Les analyses spatiales et temporelles des changements de la couverture forestière ont montré que le *tavy* commence toujours depuis les environs des zones d'habitation, qui sont principalement aux bords des cours d'eau. Ensuite, le *tavy* se pratique à des altitudes de plus en plus élevées, et sur des terrains de plus en plus accidentés. Les analyses faites par Gautier et al. (1999) sur le pourtour de la réserve spéciale de Manongarivo, dans le domaine du Sambirano, ont démontré qu'avant 1987 la majorité des *tavy* étaient établies sur des pentes comprises entre 0 et 50%, mais que depuis 1995, ont les trouvait de plus en plus fréquemment sur des pentes plus fortes, atteignant 70% à 90%.

CONSÉQUENCES DES FLUX MIGRATOIRES SUR LA TRANSFORMATION DU PAYSAGE

Les données historiques présentées ici, mises en regard avec les observations menées sur le terrain sur la structure et la composition des forêts, permettent d'avancer que la dégradation des forêts de la presqu'île d'Ampasindava a connu une ampleur importante déjà à une époque ancienne. Avec le développement du circuit maritime reliant l'Indonésie, l'Europe, l'Arabie et l'Afrique, la zone nord-ouest de Madagascar, notamment les régions d'Ampasindava, de Mahilaka et de Nosy Be sont devenues un important carrefour pour les commerçants et les marins et le milieu naturel de la région a connu une présence humaine croissante. Des fouilles archéologiques effectuées dans la région de Mahiaka et d'Ampasindava ont permis de trouver des grains de riz carbonisés parmi d'autres restes de constructions et divers matériaux (Wright et al. 2005). En l'absence d'une topographie favorable à la culture irriguée, ceci nous permet de penser que la pratique de la culture du riz par l'agriculture itinérante sur brûlis se pratiquait dans la région à l'ère de l'expansion du commerce au Xe siècle. L'agriculture itinérante du riz sur brûlis ou tavy a ainsi commencé à marquer le paysage.

Au XVIe siècle, dans la région d'Anoratsangana, les troupes portugaises ont chassé les esclaves africains échappés par différents moyens, notamment le feu pour brûler villages plantations. Les escales des commerçants et la fuite des esclaves ont été à l'origine du développement des premières activités humaines (agriculture et chasse) dans la région. Le défrichement a commencé à transformer le paysage de la presqu'île et s'est intensifié avec l'augmentation de la population. Cette transformation du paysage a commencé au sud-ouest de la presqu'île, dans la zone d'Anorotsangana, et s'est déplacée progressivement vers le nord.

Au début du XIXe siècle, la guerre entre les Merina et les Bemihisatra a apporté sa contribution à la transformation du paysage. Fuyant les troupes Merina, les Bemihisatra sont arrivés sur la presqu'île d'Ampasindava depuis Ampasimena et ont continué à avancer vers Ambarijeby, Ambodivoanio, Andrahibobe, situées sur le territoire d'Anorotsangana et sur le littoral nord (Baré 1980) où ils ont exploité le milieu. Le tavy a donc pris de l'ampleur avec l'augmentation de la population. C'est encore le cours de cette histoire qui a sacralisé ces grands massifs de Bongomirahavavy et d'Andranomatavy. Le concept de la conservation des massifs forestiers s'est développé, en l'honneur des services et de la protection qu'ils avaient fournis aux Sakalava. Ce statut a longtemps assuré la protection de ces milieux contre toutes formes de menaces et pressions anthropiques, permettant la conservation de la structure et de la physionomie originelles des forêts denses humides, qu'on peut ainsi qualifier de végétation climacique. Des valeurs culturelles se sont ainsi transmises de génération en génération, avec la notion du respect du *fady*. C'est la raison pour laquelle les forêts de ces massifs sont restées intactes et forment actuellement l'essentiel des reliques des forêts primaires de la presqu'île d'Ampasindava.

Au fil de cette succession d'événements, la région la plus touchée par la déforestation a été la partie ouest de la presqu'île. La déforestation a commencé dans la partie sud-ouest de la presqu'île. La région d'Anorotsangana en a été le point de départ, et la pratique du *tavy* s'est étendue de plus en plus au nord-ouest vers Betsiriry et Komamery jusqu'à Marotony et Maroariva (Figure 1). Le défrichement et l'incendie ont détruit d'importantes surfaces de forêts primaires, laissant ensuite place au processus de la succession végétale. De par l'arrivée progressive des paysans, le paysage est devenu de plus en plus hétérogène à cause de la dégradation et et de la fragmentation des forêts, dont les zones les plus touchées sont surtout situées dans la partie ouest de la presqu'île.

Pendant la colonisation, une population relativement clairsemée et l'application des lois contre l'exploitation des forêts par les colons sont probablement à l'origine d'une baisse du rythme de la transformation du paysage. Il est ainsi vraisemblable que les milieux dénudés ou exploités pendant ces périodes se sont ensuite reconstitués petit à petit pour donner les formations forestières secondaires actuellement observées.

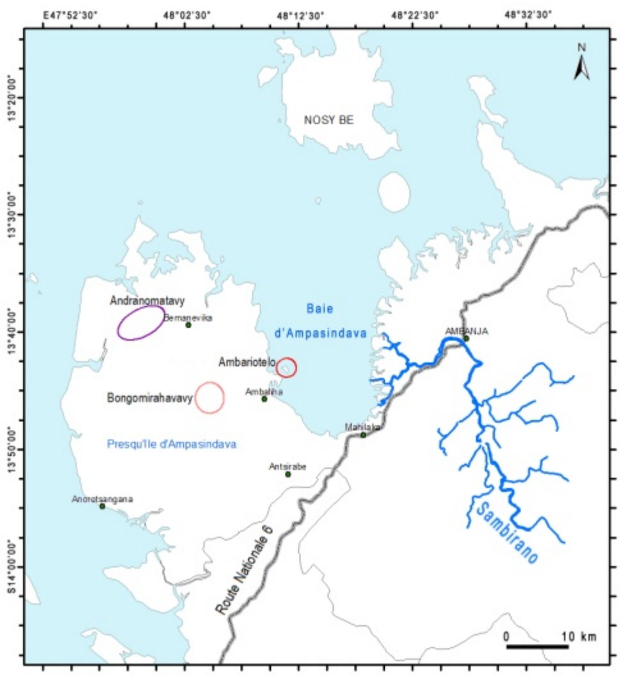

Figure 1. La presqu'île d'Ampasindava dans le domaine du Sambirano.

Pour ces raisons, l'hypothèse émise que nous avançons ici d'une ancienne exploitation et destruction massive du milieu semble être la seule qui puisse donner une explication acceptable de la structure et de la composition floristique de la forêt de la partie occidentale de la presqu'île d'Ampasindava. Les forêts à Sarcolaenaceae et *Dypsis* spp doivent être considérées comme des formations secondaires âgées en plein développement. Leur composition et leur structure, bien que différentes de celles des forêts primaires, en font des sites potentiels de *tavy* pour les générations actuelles.

D'après les données des analyses diachroniques des images satellitaires (1991–2013) la presqu'île d'Ampasindava présente actuellement un rythme élevé en perte de forêt (secondaires âgées et primaires) de 1500 ha par année (Tahinarivony 2014). Si la population malgache présente une augmentation moyenne annuelle de 3% (INSTAT 2014), celle de la région de la presqu'île d'Ampasindava est estimée au-dessus de la moyenne en raison d'un fort taux de natalité et de l'arrivée d'immigrants à la recherche des terres cultivables (Missouri Botanical Garden 2014). La croissance démographique endogène, mais surtout l'immigration, ont eu pour conséquence la réduction importante des forêts rendant le choix des parcelles à défricher pour le *tavy* de plus en plus difficile. Pour ces raisons, le temps de jachère diminue, et la forêt et le sol n'ont plus le temps de se reconstituer pleinement entre deux cycles culturaux. Les paysans sont donc contraints de défricher des parcelles de plus en plus éloignées des villages, atteignent des altitudes de plus en plus élevées et mises en place sur des pentes de plus en plus fortes (Gautier et al. 1999). Ils vont par ailleurs fabriquer des cases près de leur *tavy* pour se rapprocher de leurs zones de production.

La forte dépendance des paysans vis-à-vis des ressources forestières conjuguées à cette réduction de leur surface font donc peser une menace de plus en plus importante sur les massifs forestiers résiduels. Les habitants de la presqu'île sont écartelés entre le respect du sacré et la volonté de produire le riz nécessaire à leur subsistance et à financer leurs besoins. Beaucoup ont commencé ainsi à transgresser les interdits en défrichant des massifs traditionnellement protégés, en particulier les immigrants qui se sentent moins concernés par ces interdits coutumiers d'une ethnie à laquelle ils n'appartiennent pas.

CONCLUSION

LA PRESQU'ÎLE D'AMPASINDAVA DIX ANS APRÈS LA VISION DURBAN. Par la vision Durban en 2003 qui vise à tripler la superficie des aires protégées, allant de 1,7 millions d'hectares à 6 millions d'hectares, une nouvelle directive a été émise, portant sur la mise en place d'un système de Nouvelles Aires Protégées de Madagascar (NAP). Différents spécialistes de plusieurs disciplines ce sont rassemblés pour analyser les données de plusieurs groupes d'espèces, comme les mammifères, les reptiles, les amphibiens, les poissons, certains invertébrés et la flore (Kremen et al. 2008, Allnutt et al. 2009). Les résultats issus de ces analyses ont été combinés avec les données des zones clés de la conservation de la biodiversité et celles des changements climatiques, les analyses ont été affinées et sont devenues de plus en plus pertinentes (Eken et al. 2009) suivant l'approche de zonation de Moilanen et al. (2009). Leur étude a abouti ensuite à la publication des cartes des zones potentielles de conservation qui a montré l'importance écologique de la presqu'île d'Ampasindava, en plus de son degré de priorisation pour la conservation. Malheureusement, entre 2009 et 2013, le pays a traversé une longue crise, ralentissant ou interrompant certains projets de conservation dans le pays.

Il est à présent temps de relancer cette dynamique en développant un projet de conservation innovant, qui prenne en compte d'une part la problématique socio-économique propre à la région, et d'autre part la préexistence d'interdits coutumiers. Avec une démographie en augmentation, il est douteux que la pratique du *tavy* soit à même de répondre seule aux besoins croissants des populations. Il faut donc envisager des solutions qui tendent à sédentariser la production de riz dans des parcelles permanentes. Pour une sauvegarde durable des forêts existantes, une politique de conservation durable doit impérativement se baser sur les interdits coutumiers existants, en renforçant le rôle des acteurs autochtones dans leur application (conservation participative). Il serait par ailleurs salutaire d'envisager un programme d'éducation environnementale qui mette en valeur en parallèle le rôle écologique de la forêt mais aussi sa valeur culturelle pour la communauté locale.

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SUPPLEMENTARY MATERIAL.

Available online only.

Figure S1. Carte simplifiée de la végétation de la presqu'île d'Ampasindava. Classification supervisée sur une image satellite de 2013, projetée sur une teinte relief. Les deux principaux blocs de forêt dense humide sempervirente primaire restants apparaissent au nord-ouest (Andranomatava) et au centre-est (Bongomirahavavy) et correspondent à des massifs sacrés. Le reste de la presqu'île est actuellement dominée par des mosaïques de cultures, de jachères et de jeunes forêts secondaires, à l'exception d'importantes zones de forêts secondaires âgées visibles dans l'ouest.

S2. Tahinarivony, A. J. 2014. Analyse Typologique et Cartographique de la Transformation du Paysage de la Presqu'île d'Ampasindava, Domaine du Sambirano (NW-Madagascar). Mémoire de Certificat en Géomatique. Université de Genève.

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Roles of a forest corridor between Marojejy, Anjanaharibe-Sud and Tsaratanana protected areas, northern Madagascar, in maintaining endemic and threatened Malagasy taxa

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ABSTRACT

Site-based conservation is widely recognized as a fundamental requirement for the maintenance of biodiversity. We carried out a rapid biological assessment from 17 March to 14 May 2011 in the southwestern part of the provisionally protected rainforest corridor between Marojejy, Anjanaharibe-Sud and Tsaratanana protected areas (COMATSA), northern Madagascar, to assess its biodiversity richness and species conservation status. We recorded 248 endemic vertebrate species, including 80 amphibians, 52 reptiles, 79 birds, 27 small mammals and 10 lemurs. Of these 248 species, 36 are threatened including one Critically Endangered (one lemur), nine Endangered (two amphibians, four reptiles and three lemurs) and 26 Vulnerable (10 amphibians, six reptiles, four birds, one small mammal and five lemurs). For herpetofauna species, the pair COMATSA – Marojejy was the only site that had a similarity value greater than 0.50. For birds and lemurs, values of similarity in three pairs of sites COMATSA – Marojejy, COMATSA – Anjanaharibe-Sud and Marojejy – Anjanaharibe-Sud exceeded those of herpetofauna in COMATSA – Marojejy. The inclusion of the COMATSA into the new protected area network in Madagascar is supported by our findings.

RÉSUMÉ

Il est dorénavant largement reconnu que pour maintenir la biodiversité, il est fondamental de réaliser la conservation de la nature au niveau des sites. Un inventaire biologique rapide a été mené du 17 mars au 14 mai 2011 dans la partie sud-ouest du couloir forestier reliant les parcs et réserves du Marojejy, d'Anjanaharibe-Sud et du Tsaratanana (COMATSA). L'inventaire de ce couloir qui bénéficie d'un statut de protection temporaire dans la partie septentrionale de Madagascar, était destiné à évaluer la richesse de sa biodiversité et le statut de conservation des espèces de vertébrés qu'il héberge. Les résultats ont montré que parmi les 248 espèces endémiques de vertébrés recensées, 80 sont des amphibiens, 52 des reptiles, 79 des oiseaux, 27 des petits mammifères et 10 des lémuriens. Sur ces 248 espèces, 36 sont menacées, dont une espèce qui est en Danger Critique d'Extinction (lémurien), neuf en Danger (deux amphibiens, quatre reptiles et trois lémuriens) et 26 Vulnérables (10 amphibiens, six reptiles, quatre oiseaux, un micromammifère et cinq lémuriens). Ce couloir forestier présente un coefficient de similarité élevé, d'une valeur supérieure à 0.50 avec le Marojejy pour les amphibiens et les reptiles. Pour les oiseaux et les lémuriens, les coefficients sont encore plus importants, plus particulièrement dans les comparaisons COMATSA – Marojejy, COMATSA – Anjanaharibe-Sud et Marojejy – Anjanaharibe-Sud. Cette étude confirme l'importance d'intégrer le COMATSA dans le réseau des Aires Protégées de Madagascar pour renforcer la protection des espèces de vertébrés endémiques et menacées.

INTRODUCTION

The in situ conservation of viable populations in natural ecosystems is widely recognized as being important in tackling global biodiversity loss (Nagendra 2008), and is considered to be the greatest hope for the conservation of most of globally threatened faunal groups (Boyd et al. 2008).

The Island of Madagascar is one of the world's highest biodiversity conservation priorities (Ganzhorn et al. 2001, Mittermeier et al. 2005), because of its exceptionally high endemism rate in plants and animals, as well as its relentless pace of forest ecosystem degradation (Myers et al. 2000). Biogeographic studies of several faunal groups in Madagascar show that northern and/or eastern Malagasy forest habitats are important in maintaining many endemic and threatened species of herpetofauna (Glaw and Vences 2007), birds (Hawkins and Goodman 2003) and lemurs (Tattersall 1982, Mittermeier et al. 2008); however, many conservation priority species are not represented within protected areas managed by Madagascar National Parks (MNP) (e.g., Andreone et al. 2001, Durkin et al. 2011). Therefore, the current extension of the Madagascar protected areas system will, undoubtedly, provide

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more survival opportunities for those key species that are suffering from habitat loss outside of protected areas (Rabearivony et al. 2010).

Currently, the MNP protected areas cover about 1.7 million hectares and, in 2003, during the fifth World's Park Congress that was held in Durban, South Africa, the President of Madagascar stated his commitment to triple the amount of national protected area coverage (Mittermeier et al. 2005). Therefore, out of six IUCN's protected area categories adopted for Madagascar, three (IUCN category I = Strict Nature Reserve, IUCN category II = National Park and IUCN category IV = Special Reserve) are under the MNP's management and, after Durban's Congress; three additional categories (IUCN category III = Natural Monument, IUCN category V = Protected Landscape/Seascape and IUCN category VI = Sustainable use area) were adopted under the new protected area system known as SAPM (*Système des Aires Protégées de Madagascar*). As this new protected area system involved many stakeholders, the SAPM sites have to pass two-year provisional protection status to check if there is any resistance from certain concerned stakeholders and to ensure the stability of future reserves before they get definitive protection.

While most field studies in Madagascar are undertaken in MNP's protected areas, this study was carried out in the provisional protected forest corridor between Marojejy National Park, Anjanaharibe-Sud Special Reserve and Tsaratanana Strict Nature Reserve known as COMATSA (Corridor Marojejy, Anjanaharibe-Sud and Tsaratanana, Figure 1) in northern Madagascar. The faunal and floral communities of the southeastern part of COMATSA (Betaolana Forest corridor between Marojejy and Anjanaharibe-Sud) have previously been surveyed (Figure 1, Goodman et al. 2003a, Raherilalao and Goodman 2003, Rakotomalala and Raselimanana 2003, Soarimalala and Goodman 2003) leaving the other parts of the corridor unsurveyed. The COMATSA is known as biologically rich (Garreau and Manantsara 2003, Razafy and Andriamarosolo 2010). This study aims to: (i) assess its biodiversity richness and species conservation status to supplement the previous findings, and (ii) determine its biological similarity with three adjacent protected areas.

METHODS

STUDY AREA. This study was conducted from 17 March to 14 May 2011 in COMATSA (E049°15', E049°15', Figure 1). This corridor comprises one of the largest forest blocks in Madagascar;

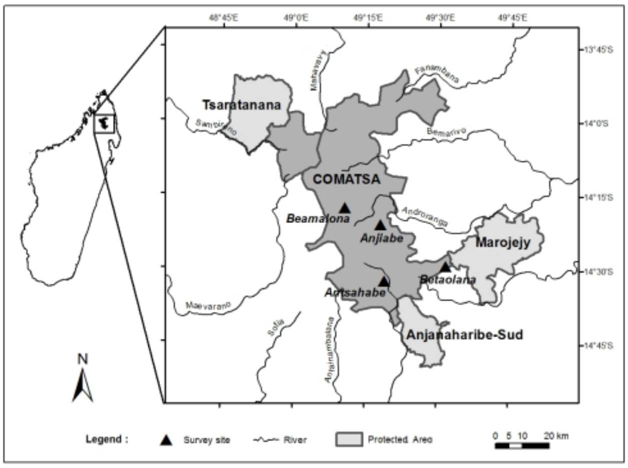

Figure 1. COMATSA area showing the location of survey sites and nearby protected areas.

covering approximately 250,000 hectares and overlaps five Districts in three Regions: Andapa, Sambava, Vohémar within the SAVA Region, Ambilobe within the DIANA Region, and Bealanana within the Sofia Region. The corridor's landscape is formed by a mountain chain interspersed with a series of valleys and with elevations ranging from 75 to 2,800 m. Three specific sites representing the southwestern flank of COMATSA were selected for surveys: Antsahabe Forest (E049°17', S14°34'), Anjiabe Forest (E049°18', S14°20') and Beamalona Forest (E049°11', S14°23') (Figure 1). Global list of floral species in these three sites showed that primary forest habitat is composed mainly of the following trees: *Ocotea* spp. (Lauraceae), *Cryptocarya* spp. (Lauraceae), *Tina* spp. (Sapindaceae), while the species indicating of disturbance such as *Psiadia altissima* (Asteraceae), *Harungana madagascariensis* (Clusiaceae), and *Dionycha* sp. (Melastomataceae) are the dominant trees in the secondary forest (Supplementary Material 1).

The climate in COMATSA is tropical and humid with about 2,500 mm annual precipitation, but can go up to 3,500–4,500 mm. The maximum precipitation is in December whereas the minimum is in July. The rainy season runs from November to April and the dry period from May to October. The average annual temperature is approximately 20°C, with the coldest period in July (16°C) and the hottest in December (24°C). Several rivers (e.g., Maevarano, Sambirano, Mahavavy, Fanambana, Bemarivo and Antainambalana) have their headwaters within COMATSA and flow down to the Indian Ocean or Mozambique Channel (Figure 1).

Since 2008, one of the main activities of the WWF in northern highland of Madagascar is to include the COMATSA within SAPM sites. As such, in December 2010, the COMATSA had got its provisional protection status (Supplementary Material 2). Then, in October 2013, Forestry Department in Madagascar entrusted to WWF one-year management of this forest corridor; but this duration could, probably, be extended up to next five years until the new protected site gets its definitive protection status.

RAPID BIOLOGICAL ASSESSMENT. Rapid biological inventories of amphibians, reptiles, birds, small mammals and lemurs were carried out in the forests of Antsahabe, Anjiabe and Beamalona by a multidisciplinary team of the Association BIODEV. In each site, surveys were conducted at 850–1,000 m, 1,000–1,600 m and above 1,600 m to understand the altitudinal distribution of fauna.

Several types of inventory methods were used to assess the biodiversity of COMATSA. Diurnal and nocturnal observations were conducted for all inventoried faunal groups and survey duration was six days per site. For herpetofaunal surveys, refuge examination and pitfall traps were used. Refuge examination required researchers to search under leaf litter and rocks among dead wood, leaf axils of *Pandanus* palms, and on tree trunks during the day and night to record species (Raxworthy 1988). At each site, over six consecutive trap days, two persons were active about three hours, respectively during the day and night. Pitfall traps consisted of buckets (15 liters in volume), with handles removed, dug into the ground and placed at 10 m intervals along a drift fence 100 m in length. The buckets were drilled with small holes in the bottom to allow water to drain (for more information on pitfall protocol, see Raxworthy 1988, Rakotomalala and Raselimanana 2003). Three trap lines by site were set in different microhabitat along the crest of a ridge and valley during six consecutive days.

Traps were checked twice a day, at 0600h and 1600h. No voucher specimens were taken. The encountered species were identified according to the identification keys and illustrations of Glaw and Vences (2007) and, photographs were also taken to confirm the identification of doubtful species. Photographic records were compared with specimens housed at the University of Antananarivo (Supplementary Material 3).

Forest birds were directly counted using the MacKinnon and Phillips (1993) species-list approach. Researchers walked slowly (about 1–1.5 km per hour) along pre-existing trails and recorded bird species seen or heard. Six days were spent at each site and surveys lasted about four hours in the morning and one hour and half in the afternoon, respectively from 0430–0830h and 1700–1830h when birds were most active and vocal (Scott et al. 1981).

For small mammal surveys, pitfall traps were used for terrestrial species (e.g., Soarimalala and Goodman 2003). A total of 80 Sherman live traps were also used to capture small mammals. Traps were baited with peanut butter and the distance between two consecutive traps varied according to the habitat. Traps were set on the ground, on decomposing trees, under tree roots, on tree trucks, dead leaves or litter and along river shore to maximize the chance of capture. Pitfall and Sherman traps were checked twice a day at 0600h and 1600h.

By using pre-existing trails as transects, nocturnal and diurnal direct observation of lemurs were carried out by two experienced observers. Each transect was slowly walked, about 1 km per hour. Transects were walked once at night between 1900h and 2230h and twice during the day between 0600h and 1030h, and 1500h and 1730h, periods covering peak lemur activity. All species-specific signs or markings were also recorded as indicators of the presence of a taxon. Sherman live traps were also used to capture small nocturnal lemurs as *Microcebus* and *Cheirogaleus*. After identification, trapped animals were released at the site of capture shortly before dusk on the same day. At each survey site, threats and pressures to the biodiversity were recorded through direct observation or by interviewing a local guide.

CONSERVATION STATUS ASSESSMENT. For each faunal group, information from the International Union for Conservation of Nature (IUCN 2014) was used to determine if recorded species were endemic to Madagascar (included regional endemicity for birds), and if they occurred in the Madagascar Protected Areas System (Figure 2), as well as to verify their conservation status. However, for the purpose of conservation prioritization, emphasis was given to those species listed in the three highest IUCN threat categories as Critically Endangered (CR), Endangered (EN), Vulnerable (VU) (Andreone et al. 2005, Rabearivony et al. 2010), although all IUCN categories were considered.

COEFFICIENT OF SIMILARITY CALCULATION. Similarity coefficients (S) are used to compare the degree of association in community composition between sites or samples based on presence/absence of species that areas of comparison contain (Nur et al. 1999). In this study, for conservation purposes, analysis focused only on threatened species. We compared the composition of each faunal group between pairs of sites as follows: COMATSA and Marojejy, COMATSA and Anjanaharibe-Sud, COMATSA and Tsaratanana, Marojejy and Anjanaharibe-Sud, Marojejy and Tsaratanana, and Tsaratanana and Anjanaharibe-Sud. The Jaccard coef

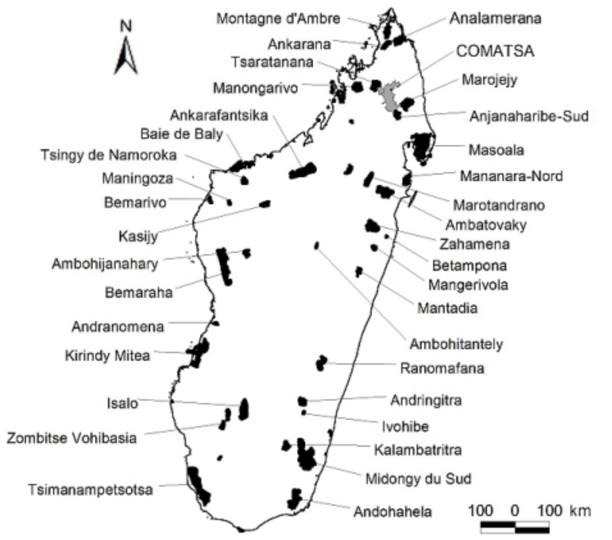

Figure 2. Localities of protected areas in Madagascar cited in the text.

ficient was used to measure similarity between finite sample sets and, according to the formula below, is defined as the size of the intersection divided by the size of the union of the sample sets (Krebs 1989).

$$S = \frac{C}{N_{1+2}}$$

where N_{1+2} is the total number of species encountered in sites 1 and 2, and C is the number of species common to both sites.

This comparison of species composition could also give insight into biogeographical trends between compared sites (Herrera-Campos et al. 2004).

RESULTS

CONSERVATION STATUS OF FAUNA IN THE COMATSA. Rapid biodiversity assessment undertaken in COMATSA and previous findings from Betaolana corridor yielded a total records of 80 species of amphibians and all are endemic (Supplementary Material 4). The COMATSA had two Endangered and 10 Vulnerable species (Table 1). Most of these threatened taxa were found at the altitude lower than 1,600 m and were distributed in only one to four MNP protected sites.

For reptiles, the COMATSA harbors 54 species, of which 52 are endemic, four Endangered and six Vulnerable. None of the existing Malagasy protected areas contain the Endangered chameleon *Calumma vencesi* and the other threatened taxa can be found in one to seven protected sites (Table 1). With the exception of the Vulnerable chameleon *C. tsaratananense*, which was found above 1,600 m, most reptile species were recorded at altitudes lower than 1,600 m.

A total of 96 bird species were recorded in the COMATSA, of which 79 are endemic (included regionally endemic) and, according to the IUCN (2014), four are Vulnerable. The altitudinal range of these Vulnerable species varies from 450 to 1,950 m and each occurs within six to nine protected areas in Madagascar.

Of 28 small mammal species found in the COMATSA, only one species (*Rattus rattus*) is not endemic, and only one species recorded between 1,000 to 1,600 m is Vulnerable: *Microgale dryas* (VU). In Madagascar, this threatened mammal is recorded in only

Table 1. Distribution of Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) species recorded in COMATSA. Taxa: [a] = Species found during this study, [b] = Species found by other authors; Protected Areas: 1 = Ambatovaky, 3 = Ambohitantely, 4 = Analamazaotra, 5 = Analamerana, 6 = Andohahela, 7 = Andranomena, 8 = Andringitra, 9 = Anjanaharibe-Sud, 11 = Ankarana, 12 = Baie de Baly, 13 = Bemaraha, 14 = Bemarivo, 15 = Betampona, 17 = Ivohibe, 18 = Kalambatritra, 19 = Kasijy, 21 = Lokobe, 22 = Mananara-Nord, 23 = Mangerivola, 24 = Maningoza, 25 = Manongarivo, 26 = Mantadia, 27 = Marojejy, 28 = Marotandrano, 29 = Masoala, 30 = Midongy du Sud, 31 = Montagne d'Ambre, 32 = Ranomafana, 33 = Tsaratanana, 35 = Tsingy de Namoroka, 36 = Zahamena. For detailed list of taxa see Supplementary Material and for the location of these protected areas in Madagascar, see Figure 2.

Taxa	Altitudinal range (m)	Status IUCN 2014	Occurrence in pet trade	CITES appendix	Distribution in protected areas
Amphibians					
Mantellidae - Boophinae					
Boophis andreonei	1000–1600	VU			25,33
Boophis axelmeyeri	1000–1600	VU			25,27,33
Boophis sambirano	< 1000	VU			25,33
Mantellidae - Mantellinae					
Gephyromantis ambohitra	< 1600	VU			25,31,33
Gephyromantis schilfi	>1600	VU			27
Gephyromantis klemmeri	810–1600	VU			9,27,29
Gephyromantis rivicola	750–1700	VU			9,27,29
Gephyromantis tandroka	< 1600	VU			27
Microhylidae - Cophylinae					
Platypelis mavomavo	> 1600	EN			9,29
Platypelis tetra	>1600	EN			9,27,29
Rhombophryne coudreaui	200–1000	VU			15,22,27,29
Rhombophryne serratopalpebrosa	800–1200	VU			9,27,33
Reptiles					
Chamaeleonidae					
Brookesia karchei	> 1600	EN	yes	II	27
Brookesia vadoni	< 1600	VU	yes	II	9,27,29
Calumma globifer	1000–1600	EN	yes	II	3
Calumma tsaratananense	> 1600	VU	yes	II	33
Calumma vencesi	700–960	EN	yes	II	
Gekkonidae					
Microscalabotes bivittis	<1000	VU			4,27
Uroplatus ebenaui	810–1600	VU	yes	II	8,9,13,25,27,31,33
Gerrhosauridae					
Zonosaurus subunicolor	<1000	EN			21,25,27
Colubridae					
Brygophis coulangesi	1200	VU			9
Pararhadinaea melanogaster	1000–1600	VU			5,11,27
Birds					
Brachypteraciidae					
Brachypteracias leptosomus	450–1625	VU			4, 6,8,9,29,36
Philepittidae					
Neodrepanis hypoxantha	825–1950	VU			4,6,7,8,9,26,27,28,36
Vangidae					
Euryceros prevostii	825	VU			1,4,9,15,26,27,29,33,36
Oriolia bernieri	450–875	VU			1,9,15,23,27,29,30,36
Micromammals					
Tenrecidae - Oryzorictinae					
Microgale dryas	1000–1600	VU			1,9
Lemurs					
Cheirogaleidae					
Allocebus trichotis	0–1600	VU	yes	I	4,9,22,26,27,28,29,36
Microcebus mittermeieri	1056	EN	yes	I	9
Daubentoniidae					
Daubentonia madagascariensis	450–1875	EN	yes	I	1,4,5,6,8,9,11,13,15,17,18,22,25,26,27,28,29,30,31,32,33,35,36
Indridae					
Avahi laniger	450–1600	VU	yes	I	1,3,4,9,15,22,23,26,27,36
Propithecus candidus	775–1625	CR	yes	I	9,27
Lemuridae					
Eulemur albifrons	450–1625	EN	yes	I	9,15,22,27,29
Eulemur rubriventer	450–1625	VU	yes	I	1,4,8,9,17,23,26,27,28,32,33,36
Hapalemur occidentalis	1000–1600	VU	yes	I	1,5,9,11,12,14,19,22,24,25,27,28,29,33,35,36
Lepilemuridae					
Lepilemur seali	1000–1600	VU		I	1,9,22,27,28,29

two protected sites: Ambatovaky and Anjanaharibe-Sud Special Reserves.

All lemur taxa in Madagascar are endemic to the Island and a total of 10 species were recorded in the COMATSA. In this forest corridor, there was one Critically Endangered, three Endangered and five Vulnerable species. Of these nine threatened lemur taxa, the Critically Endangered *Propithecus candidus* has a very restricted distribution range within Malagasy protected areas. Despite its presence in provisionally protected Makira forest (Patel 2014), it is recorded only in two MNP sites: Marojejy National Park and Anjanaharibe-Sud Special Reserve. The endangered *Daubentonia madagascariensis* has the broadest distribution and has been recorded in 18 Malagasy protected areas. It has been recorded in Betaolana at 820 m (Goodman et al. 2003a).

VALUES OF COEFFICIENT OF SIMILARITY. The comparison of threatened herpetofauna species composition by the similarity calculation showed that COMATSA – Marojejy was the only site that had a similarity value greater than 0.50: 0.67 and 0.60, respectively for amphibians and reptiles (Table 2). This similarity was greater for birds than for herpetofauna: 0.75, 1.00 and 0.75, for COMATSA – Marojejy, COMATSA – Anjanaharibe-Sud and Marojejy – Anjanaharibe-Sud, respectively (Table 2). For small mammal communities, this similarity was not calculated as there was only one threatened species *Microgale dryas* (VU) recorded in the COMATSA. For the same comparison sites, COMATSA – Marojejy, COMATSA – Anjanaharibe-Sud and Marojejy – Anjanaharibe-Sud, lemurs had a greater similarity value than birds, which is, respectively, equal to 0.89, 1.00 and 0.89 (Table 2). For all faunal groups combined, COMATSA – Tsaratanana, Marojejy – Tsaratanana and Anjanaharibe-Sud – Tsaratanana had consistent similarity values less than 0.50. Tsaratanana may have less biogeographical affinity to the southern sites like COMATSA, Marojejy and Anjanaharibe-Sud. Therefore, biogeographical affinity was greater for the herpetofauna species in COMATSA – Marojejy than in others sites whilst, for birds and lemurs, this affinity was much greater in COMATSA – Marojejy, COMATSA – Anjanaharibe-Sud and Marojejy – Anjanaharibe-Sud.

Table 2. Coefficient of similarity for amphibians, reptiles, birds and lemurs. (N1+2 = Total number of species encountered in sites 1 and 2, C = Number of species common to both sites, S = Similarity index).

	COMATSA – Marojejy	COMATSA – Anjanaharibe-Sud	COMATSA – Tsaratanana	Marojejy – Anjanaharibe-Sud	Marojejy – Tsaratanana	Marojejy – Tsaratanana
Amphibians						
N_{1+2}	12	12	12	9	11	9
C	8	5	5	4	2	1
S	0.67	0.42	0.42	0.44	0.18	0.11
Reptiles						
N_{1+2}	10	10	10	7	7	4
C	6	3	2	2	1	1
S	0.60	0.30	0.20	0.29	0.14	0.25
Birds						
N_{1+2}	4	4	4	4	3	4
C	3	4	1	3	1	1
S	0.75	1.00	0.25	0.75	0.33	0.25
Lemurs						
N_{1+2}	9	9	9	9	8	9
C	8	9	3	8	3	3
S	0.89	1.00	0.33	0.89	0.38	0.33

DISCUSSION

COMATSA AS HOME TO ENDEMIC AND THREATENED TAXA. The diversity and high endemism of different faunal groups in northeastern Madagascar have been highlighted by numerous authors (Glaw and Vences 2003, Goodman et al. 2003b, Hawkins and Goodman 2003, Raxworthy 2003). The limited geographical range, combined with continuing decline in the extent and quality of habitat are the main pressures for most of threatened species encountered in this study (IUCN 2014). Given the alarming degradation caused by unsustainable exploitation of rosewood in nearby protected areas of COMATSA such as Marojejy and Masoala, and illegal mining in Anjanaharibe-Sud (Innes 2010, Randriamalala and Liu 2010, Patel and Welch 2013), the establishment of the COMATSA protected corridor would create an additional refuge for these threatened species as it is comparatively safer from these pressures. Selective examples can be taken to illustrate the significant contribution of COMATSA to ensuring the survival of many endemic and threatened taxa. The endangered amphibian *Platypelis tetra* is a *Pandanus*-dwelling species (Lehtinen 2002, Andreone et al. 2003), and is threatened by the collection of these plants for making the roofs of huts (IUCN 2014). It is known from Anjanaharibe-Sud, Masoala and Marojejy at 600–1,250 m (ibid), and its occurrence above 1,600 m in the COMATSA extended its known range to the higher elevation. This higher altitudinal range may provide further protection to this species, especially, when taking into account the recent disturbance in the lowland forests of Masoala and Marojejy during the last political crisis (2009–2013) in Madagascar (Innes 2010, Randriamalala and Liu 2010). There is no formally protected site inhabited by the endangered chameleon *Calumma vencesi* and it is found only in Betaolana Forest corridor with a range of 590 km2 and between 700 to 960 m (Andreone et al. 2001, IUCN 2014). Known as disturbance sensitive chameleon (Andreone et al. 2001), its presence in Betaolana could justify the inclusion of COMATSA in the expanded Madagascar Protected Areas System.

Regarding threatened bird species, the Vulnerable *Brachypteracias leptosomus* was found within six Malagasy protected areas (Analamazaotra, Andohahela, Andringitra, Anjanaharibe-Sud, Masoala and Zahamena), and its declining trend is likely to become rapid over the next ten years (IUCN 2014). For conservation goals, IUCN (2014) recommended the size of the area of suitable habitat for this secretive bird and, according to the present results; COMATSA would be one of the best sites for its protection. As far as small mammals are concerned, the Vulnerable *Microgale dryas* is known only from Ambatovaky and Anjanaharibe-Sud, at the altitude between 500–940 m with an extent of occurrence of less than 20,000 km² (ibid). Its presence in provisionally protected COMATSA extends its northern range and reinforces its protection.

Concerning lemur species, the Critically Endangered *Propithecus candidus* is one the world's 25 most endangered primates and is found, apart from Makira provisional protected area, only in two MNP sites, from 700–1,875 m at Anjanaharibe-Sud and Marojejy (IUCN 2014, Patel 2014). Less than 2,000 individuals of this species remain in the wild, and none ever survived in captivity

(Patel 2014). All lemur species in Anjanaharibe-Sud and Marojejy are currently considered by the IUCN as threatened, except for the greater dwarf lemur *Cheirogaleus major*, due to a variety of new and ongoing threats during the last five years (2009–2013) (Patel and Welch 2013). Therefore, the occurrence of *Propithecus candidus* at the COMATSA, in Antsahabe and Anjiabe sites, would strengthen its protection against such unfavorable circumstances.

In this provisionally protected site, human disturbances to the forest ecosystem and indeed, to the biodiversity, are more severe in its northeastern part (around Bemarivo and Fanambana rivers), although it is still relatively less populated than other parts of corridor (Garreau and Manantsara 2003). This northeastern zone is visited and controlled only by the local forestry representative almost every decade as it is a landlocked area with extremely difficult access (J. Rabearivony pers. obs.). During this study, most threats to biodiversity observed in the COMATSA have previously been reported by Garreau and Manatsara (2003) and Razafy and Andriamarosolo (2010). This includes (i) deforestation due to hill rice cultivation, (ii) habitat degradation caused by the extraction of a variety of products such as wood for construction, and bark of the plant *Evodia* sp. (Rutaceae) for fermenting sugar cane to produce a local spirit known as *betsabetsa*, (iii) lemur-hunting and (iv) artisanal mining. Despite these pressures, the major parts of forest in the corridor keep their primary habitat feature (ibid). Currently, many projects are run by the WWF in the COMATSA to strengthen its protection (ibid). As one significant milestone, the process of definitive protection of 250,000 hectares of forest is now undergone. The delimitation of this provisionally protected forest, entailing some 80,700 hectares of surface area, is surrounded by 33 local associations to ensure the wise use of their forests via management transfer of natural resources program known as GELOSE (*Gestion Locale Sécurisée*). The number of associations is still increasing and reached up to 41 in 2014. The remaining surface of 169,300 hectares of this provisionally protected corridor constitutes the forest core area where found most species of conservation target for the definitive protected site. In peripheral zones of COMATSA, a total of 120 hectares of bare areas around Doany, Ambodipaiso, Mangindrano, Anesika and Analalatsaka villages were reforested, mainly by *Eucalyptus* tree (Myrtaceae), allowing local populations to reduce their dependence on forest wood for energy and construction. The success rate of this reforestation is estimated at 80%. To reconnect the different forest fragments in the COMATSA, about 300 hectares of land between forest blocks was passively restored, allowing natural colonization by shrubs and trees and other secondary succession species.

COMATSA AS A GENETIC BRIDGE. Habitat corridors have been shown to be valuable for the conservation of various groups of wildlife and in various situations, although individual species may vary in their use of corridors (MacDonald 2003). For herpetofauna species in the COMATSA, the values of similarity between COMATSA – Marojejy of 0.67 and 0.60, respectively for amphibians and reptiles, suggested the role played by this corridor in maintaining herpetofaunal diversity between both sites. Large habitat corridors like COMATSA represent a key element for herpetofaunal conservation, maintaining genetic connectivity between fragments and, therefore, reducing the risk of inbreeding depression (Dixo and Metzger 2009, Dixo et al. 2009). This is especially true for the amphibians and reptiles that have very limited dispersal capacity (ibid), and which are extremely sensitive to habitat and microhabitat modifications (Gibbons et al. 2000). As the present results cover only the southern part of COMATSA and the northern and northeastern areas have never been surveyed, this sampling bias may explain the values of similarity less than 0.50 between COMATSA – Tsaratanana for all faunal groups. For all site combinations with Tsaratanana (COMATSA – Tsaratanana, Marojejy – Tsaratanana and Anjanaharibe-Sud – Tsaratanana), a long term monitoring program covering different parts of these forests (Marojejy, COMATSA, Anjanaharibe-Sud and Tsaratanana) should be established to get more representative results and to understand this relatively low value of similarity (S<0.50). This program should take into consideration all factors (biotic and abiotic) that may influence herpetofaunal distributions such as habitat variability, altitudinal gradient, geographical or physical barriers and season. The most updated taxonomy should be used for this, as species misidentification may have significant effects on similarity value.

Many avian studies have shown that landscape corridors play an important role in maintaining biodiversity and ecological processes (Dunning Jr. et al. 1995, Sieving et al. 2000), improving population persistence (Lens et al. 2002), and overcoming the genetic and demographic problems of small and isolated populations (Fahrig and Merriam 1994). Knowing that the effectiveness of corridor's functions depends on the size and disturbance gradient of forest fragments (MacDonald 2003, Pardini et al. 2005), large forested habitat like COMATSA could ensure the genetic exchange of fauna among its surrounding forests (Marojejy, Anjanaharibe-Sud and Tsaratanana), especially for those species of high dispersal capacity as birds (Bélisle and Desrochers 2002). This may explain the high geographical affinity of birds among these forests with respective similarity value of 0.75 for COMATSA – Marojejy, 1.00 for COMATSA – Anjanaharibe-Sud and 0.75 for Marojejy – Anjanaharibe-Sud.

Lemur species are the most studied faunal group among Malagasy vertebrates (e.g., Tattersall 1982, 2013, Mittermeier et al. 2008). They have been researched in almost all protected areas in Madagascar (e.g., Patel and Welch 2013), and this research is now extending to some unprotected forests (Lehman et al. 2006, Axel and Maurer 2011). As COMATSA is separated from its neighboring forests only by seasonal roads or footpaths, lemurs can disperse within forest blocks easily by leaping and/or running on tree branches. Lehman et al. (2006) reported the ability of some lemur species (e.g., *Propithecus* sp.) to traverse the open areas between forest fragments. Therefore, our sampling bias combined with the high mobility of lemurs may explain the high similarity value between COMATSA – Marojejy, COMATSA – Anjanaharibe-Sud and Marojejy-Anjanaharibe-Sud. It is also noteworthy that the high diversity of lemurs in the COMATSA may contribute to the maintenance of ecological process within its natural forest through the frugivory and seed dispersal capacity by these primates (Dew and Wright 1998, Lahann 2007, Razafindratsima et al. 2014).

CONCLUSION

The provisionally protected forest corridor between Marojejy, Anjanaharibe-Sud and Tsaratanana protected areas (COMATSA) contains several endemic and threatened taxa of amphibians, reptiles, birds, small mammals and lemurs. The reptiles and amphibians in the COMATSA showed high similarity with Marojejy. This similarity was more significant between COMATSA – Marojejy, CO-

MATSA – Anjanaharibe-Sud and Marojejy-Anjanaharibe-Sud for bird and lemur species. The high similarity between COMATSA and its nearby reserves corroborate the landscape vision initiated by WWF for considering the COMATSA and several northern protected areas as one important conservation unit. This study confirmed the effectiveness of large forest corridor in maintaining species diversity and, therefore, supports the inclusion of COMATSA to the new protected area system in Madagascar as SAPM. Worldwide, as habitat fragmentation is a major biodiversity issue, connectivity between COMATSA and its three adjacent protected areas (Marojejy, Anjanaharibe-Sud and Tsaratanana) should be maintained permanently to ensure the genetic exchange between these different forest blocks. This will be chivied only by collaboration between and involvement of all concerned stakeholders, including 41 local associations surrounding the COMATSA.

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SUPPLEMENTARY MATERIAL.

AVAILABLE ONLINE ONLY.

S1. WWF 2011. Inventaire Biologique du Grand Couloir Forestier reliant le Parc National d'Anjanaharibe-Sud et la Réserve Naturelle Intégrale de Tsaratanana.

S2. WWF/Foundation GoodPlanet/AirFrance 2013. Programme Holistique de Conservation des Forêts à Madagascar : Quatre années de mise en œuvre, Décembre 2008 à Octobre 2012.

S3. Photographic records of herpetofauna from COMATSA.

S4. List of species recorded in COMATSA, distribution, endemism and IUCN Status.

SHORT NOTE

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Local socio-economic effects of protected area conservation: The case of Maromizaha forest, Madagascar

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ABSTRACT

The vision Madagascar Naturally aimed to triple the size of protected areas in Madagascar from 1.7 million hectares to 6 million hectares before 2008, in order to ensure the safe guarding of Madagascar's natural heritage and the human well-being that depends on it. In 2008, Maromizaha forest was selected by the Ministry of Environment and Forests tobecome a New Protected Area where the delegated manager is the Groupe d'Etude et de Recherche sur les Primates de Madagascar (GERP). One of GERP's strategies is to provide support to the livelihoods of the local people around the Maromizaha protected area in order to reduce the dependency on natural resources. During April 2014, GERP organized a rapid socio-economic survey of 70 households across six villages, in order to make a preliminary, comparison and assessment of this development support and its impact on the main income generating activities of the local people, their highest level of formal education in 2008 and 2014, and their thinking about conservation offsetting. The results showed that in 2014, 70% of local people were engaged in agriculture and less than 40% in cattle farming. Some villagers have benefited from pilot development projects organized by financial and environmental organizations. Other local people benefited from other livelihood activities related to the conservation management of the forest. Most participants were aware of the ecosystem services of the forests (94.3%) and the education level has increased from 2008 to 2014, although even in 2014, 56% of the survey participants were educated only to primary school level; the rate of illiteracy is at 15.6%. We summarize some strengths, weaknesses and recommendations in order to improve the management of the Maromizaha Protected Area.

RÉSUMÉ

La vision « Madagascar naturellement » a été élaborée pour tripler la superficie des Aires Protégées de Madagascar en la portant de 1,7 millions d'hectares à 6 millions d'hectares avant 2008 afin d'assurer le sauvegarde du patrimoine naturel et le bien-être des Hommes. La forêt de Maromizaha avait été retenue par le Ministère de l'Environnement de l'Ecologie et des Forêts pour devenir une Nouvelle Aire Protégée (NAP) depuis 2008. Ce Ministère a nommé un délégataire, le Groupe d'Etude et de Recherche sur les Primates de Madagascar (GERP). L'une des stratégies du GERP est d'améliorer les moyens de subsistance de la population locale vivant à la périphérie de l'Aire Protégée de Maromizaha afin de réduire leur dépendance des ressources naturelles prélevées dans l'aire protégée. En avril 2014, le GERP a organisé une enquête préliminaire rapide sur la situation socio-économique des ménages pour comparer les principales activités génératrices de revenus, le niveau scolaire de la population locale en 2008 et en 2014, et le niveau de leurs connaissances sur les bienfaits de la conservation. Les méthodes de collecte de données ont été basées sur les questions filtre et le focus group. Les données analysées montrent que les principales activités génératrices de revenus en 2014 provenaient de l'agriculture(70%) et de l'élevage (40%). De 2008 à 2014, une différence significative des activités génératrices de revenus a été observée. Certains villageois ont bénéficié de projets de développement financés par des organismes environnementaux. D'autres ont profité des activités alternatives liées à la conservation de la nature comme la restauration des zones dégradées, l'assistance ou le guidage de chercheurs, l'aménagement des infrastructures, les patrouilles périodiques, l'apiculture ou encore l'élaboration de produits alimentaires et industriels. La plupart des participants ont

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conscience des services écologiques rendus par l'aire protégée (94,3%). Le niveau d'instruction a augmenté de 2008 à 2014, mais même si 56% ont suivi l'école primaire, 15,6% des villageois sont analphabètes. Quelques points forts et des limites sont mentionnés et des recommandations sont formulées en vue d'améliorer le système de gestion de l'Aire Protégée de Maromizaha.

INTRODUCTION

The main goals of the protected area system in Madagascar are to maintain environmental services and the sustainable use of natural resources as a step towards reducing poverty and promoting sustainable development (Office National pour l'Environnement 2006). Beginning in 2003, when the national strategy to expand the protected area network was launched, a number of formerly unprotected sites started to receive conservation attention. Through this process, the management of the Maromizaha forest in eastern Madagascar as a protected area category VI by the national primate conservation organization Groupe d'Etude et de Recherche sur les Primates de Madagascar (GERP) was approved by the Ministry of Environment and Forests (MEF) in 2008 (Ratsimbazafy et al. 2008). Since then, GERP, together with technical and financial stakeholders, has provided support to the livelihoods of the local people around the Maromizaha Protected Area in order to reduce the dependency on natural resources.

Located in the southeast portion of the Ankeniheny-Zahamena Corridor, Maromizaha forest is characterized by high fauna and flora species richness (Randrianambinina et al. 2006, Rakotozafy 2011, Razafindravony 2014). The majority of the villages in proximity to Maromizaha forest rely on agriculture. Currently, the main threats to Maromizaha forest are the local demand for timber, charcoal production, and the creation of new agricultural lands (Rakotosamimanana et al. 2004). In addition, timber exportation outside the community illegal logging, harvesting of palm heart, and lemur hunting constitute further pressures. Because of these multiple threats, conserving the biodiversity of Maromizaha forest requires a holistic strategy to deliver conservation and development outcomes effectively and sustainably.

Beginning in April 2014, GERP undertook a preliminary assessment of the contribution that conservation of Maromizaha forest makes to the local socio-economic settingandprepared a rapid survey of households in six villages adjacent to Maromizaha forest. The aim of this survey was to evaluate the development support that had been provided to the villages and assess its impact on the main income-generating activities of the local people, compare the highest levels of education completed by study participants in 2014 to the outcome of GERP survey in 2008 at the same villages, and gauge the thinking of study participants about conservation offsetting, in order to establish a 5-year action plan which will encompass conservation, environmental education, sustainable development, and sustainable ecotourism (Office National pour l'Environnement 2002).

STUDY SITE

The Maromizaha forest is located geographically in latitude 18°57'S and 19°00'S, longitude 48°26'E and 48°31'E, in the Alaotra Mangoro region, Moramanga district and within both the rural municipalities of Andasibe and Ambatovola. There are three main village areas near the forest: Antsapanana, Morafeno and Ambavaniasy (Figure 1). The Maromizaha forest is a 1,880ha expanse of largely contiguous forest located 140km east of Antananarivo and

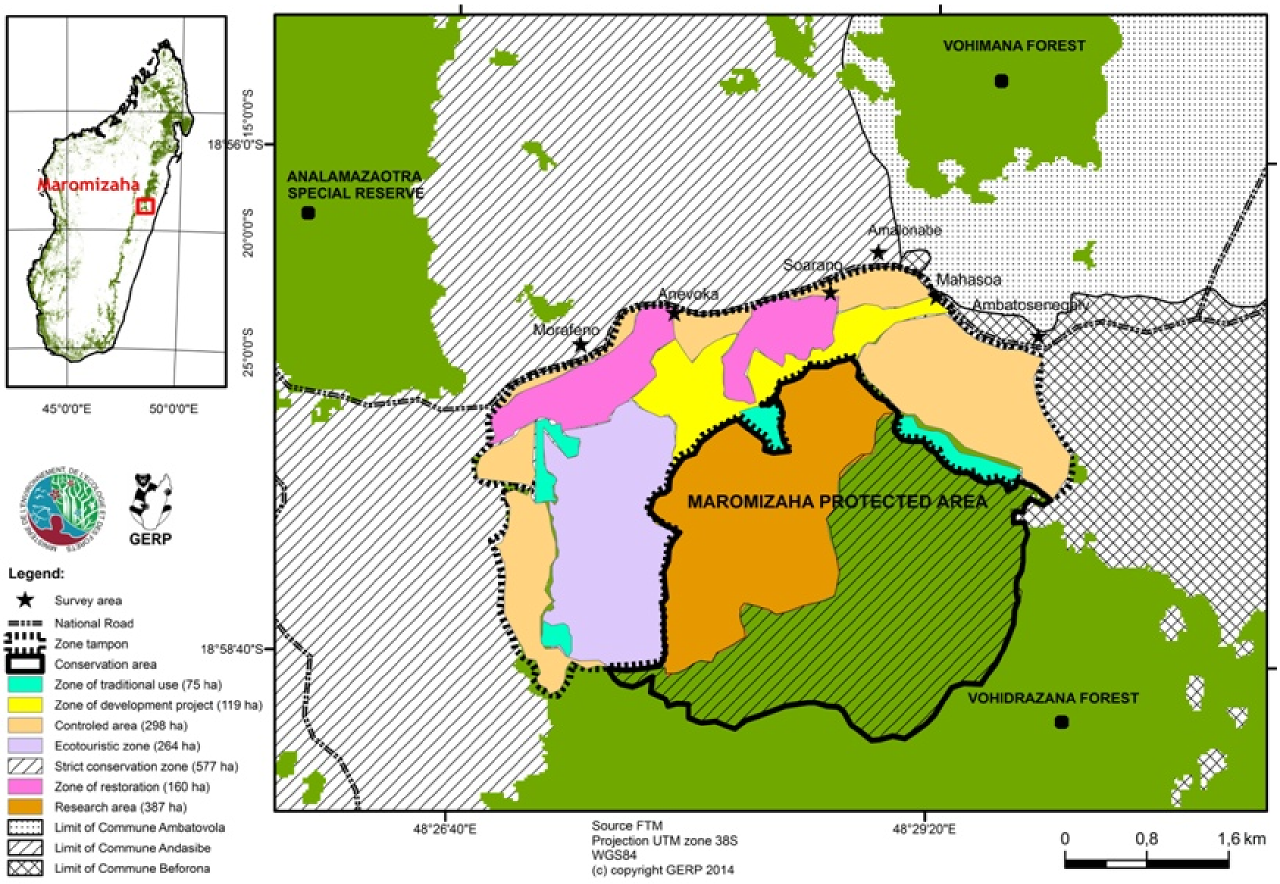

Figure 1. Zones of Maromizaha Protected Area in 2014.

225km from Toamasina. Maromizaha is bordered to the north by the Route Nationale 2, to the east by the Befody hills, to the west by the Madiorano River and to the south by the Ankazomirahavavy River. The forest ranges between elevations of 794m and 1224m (Ramanahadray 2009). The Maromizaha forest is surrounded by three forest blocks, including the Special Reserve (SR) Analamazaotra to the northwest, Vohimana forest to the northeast and Vohidrazana forest to the east (Figure 1).

METHODOLOGY

The main research questions of our study are: What was the impact of development support on the main income generating activities of the local people, and within households what was the highest level(s) of education for the years 2008 and 2014? Additionally, we assessed local people's awareness of benefits gained from conservation offsetting.

The methods employed in data collection included the use of filter questions (Rennekamp et al. 2000) as a means to establish the essential questions for the survey and, thereby, gain focused responses (e.g., Question 2: "Is charcoal production your main income-generating activity?" – if "Yes", go to Question 3: "What are the reasons why you practiced charcoal production; if "None", go to Question 4: "What is your main income-generating activity?"; "Was your household a beneficiary of development project?"),and focus groups to discuss the survey (Rennekamp et al. 2000, Moreau et al. 2004).

We visited six villages: Morafeno, Anevoka, Soarano, Amalonabe, Mahasoa, and Ambatosenegaly. In each village, we collaborated with the chief of the village and asked him to look for more than three beneficiaries of the local support project, and meet at a mutually determined location; once gathered, we conducted one or more focus groups with three to nine participants each. For each focus group, we explained the aim of the survey and we asked individuals the same question one by one, taking note of the replies each person made on their survey sheet. All sessions were also tape recorded.

In total, there were ten questions on the survey. Two questions were about the household economic situation; five questions dealt with the main income generating activities of the household. One question was about income management in the household, one question asked for the highest level(s) of education for members of the household, and one question dealt with their cognition of household members regarding the economic advantages of conservation.

For statistical analyses of the survey data, Chi-Square was performed, using GraphPad Prism (graphpad.com/quickcalcs/).

RESULTS AND DISCUSSION

We interviewed a total of 70 participants from six focus groups in Anevoka, two focus groups in Ambatosenegaly and Morafeno; one focus group was held in each of the villages of Mahasoa, Amalonabe and Soarano. The household size among the six villages varied from one to eight persons, with a mean of 4.2 ± 1.5 persons. The main income-generating activities across the six villages for the years 2008 and 2014 were agriculture, live-stock, charcoal production, logging, breaking stones, bee-keeping, fish-farming, selling, and others (handicraft, teaching).

Statistical analyses revealed a significant difference in the main income-generating activities between both years (χ^2=31.62, df=8, p=0.0001). Between the years 2008 and 2014, agriculture (38.4% vs. 46.0%), live-stock (20.0% vs. 29.4%), and handicraft and teaching (4.6% vs.6.4%) activities had increased, whereas activities such as logging (4.6% vs. 3.2%) and stone breaking (6.2% vs. 5.6%), and in particular charcoal production (13.9% vs. 2.4%) had decreased. Most people grew food crops, such as rice, cassava, maize, sweet potatoes, cucumbers, potatoes and beans, whilst a few grew cash crops such as sugar cane, the leaves of *ravintsara* or *Cinnamomum camphora* (identification by Razakamalala 2015 In litt., Supplementary Material) for producing essential oils, and ginger.

Since 2008, the local population had the opportunity to get involved in occasional activities (guides,cooks, guards, and porters) during the visit of researchers, students and tourists to the Maromizaha protected area. In addition, forest restoration of the Mantadia-Maromizaha-Zahamena Corridor from 2008 to 2010 benefitted the local population of Maromizaha protected area. One hundred people found jobs as tree planters and nurserymen. In 2012, the passage of the cyclone Giovanna destroyed food crops and bananas. In 2013, a plague of rats destroyed more food crops of the villagers. Therefore, in 2012 and 2013, the local population was beyond their means to survive.

In 2013, GERP/Global Environment Facility Small Grants Programme Madagascar (GEF-SGP) shared one hundred kilograms of improved seeds of kidney beans with a close collaboration between GERP and the National Center of Applied Research to Rural Development (FOFIFA), fertilizer and three tons of gingers to fifty peasants. This project also provided beehives and honey extractors, as well a professional beekeeper to monitor twenty pilot beekeeping operations for a fortnight.

A bee disease called *varois* (*Varroa* sp., Acari: Varroidae), common in the area near the forest of Maromizaha, has been negatively affecting the honey harvested by the farmers since 2011. To combat the disease, beekeepers around Maromizaha forest started using a biological treatment that was shared by a beekeeping specialist. The effective treatment uses the scent of the wild thyme plant (*Thymus serpyllum*), which has been soaked in a vinegar concentrate.

The study found that in 2014 some people were participating in new income generating activities, such as fish farming and beekeeping. Fish farming was tried and carried out by a small number of individuals (<2%). Beekeeping activities and forest protection have been noted to have a mutually beneficial relationship. Maromizaha forest has many benefits for beekeeping when compared to a beekeeping area with *Eucalyptus* trees. The types of tree species within Maromizaha forest have qualities that improve the honey harvest that beekeepers get from their hives. Smoke from slash and burn agriculture and charcoal ovens are the main enemies of bees, as they force the bee populations to move around and change hives. Because of this, beekeepers are more willing to participate in forest protection and encouraging people to not use charcoal ovens. The incomes generated from honey sales are enough to support the livelihoods of beekeepers.

The rate of auto-consumption of crops was at 100%. Some 44% of villagers saved at least a part of their income for their children's education. Investing in livestock was done by 21.4% of people, 18.6% of people spent income to improve their house (shifting from a traditional to a modern house), while 10.0% bought furniture.

From 2008 to 2014, illiteracy decreased from almost 40% to just 13.6%. The percentage of people finishing the final class of primary school increased from under 20% to 25.4%, and those completing the final class of secondary school rose from under 5% to 8.5%. The difference between 2008 and 2014 in highest level of education achieved was not statistically significant (χ^2=11.98, df=8, p=0.1521). Since the development program started in 2008, educational opportunities for children have improved. The study participants noted that they will help support their children through higher school levels, instead of not allowing their children to study.

The 2014 survey results showed that 94.3% of the participants understood that the forest provides important ecosystem services (e.g., drinking water, fresh air, water for their agriculture, traditional medicine, suitable habitat for wildlife, timbers in the areas of use; Figure 2, Supplementary Material). Only 38.6% considered conservation offsetting to produce tangible outcomes in terms of employment, while 17.1% of respondents noted tourism as a benefit from conservation offsetting. In general, the villagers feel that forest protection benefits their communities. The communities already know the laws and regulations regarding forest protection and the consequences of destroying the forest. There are, however, some people who are not permanent community members and who continue to cut down forest and make charcoal in order to generate income. This behavior is not put up with or condoned by long-term community members in the area around Maromizaha. The development programs have incorporated local and traditional authorities to help deal with this problem (Ingram et al.2012)

CONCLUSION

One strong point of the development work made clear by the study is that the development projects were able to continue through the political turmoil in Madagascar that started in 2009. There were also community members ready and willing to participate in forest protection and modern, effective farming and animal husbandry practices.

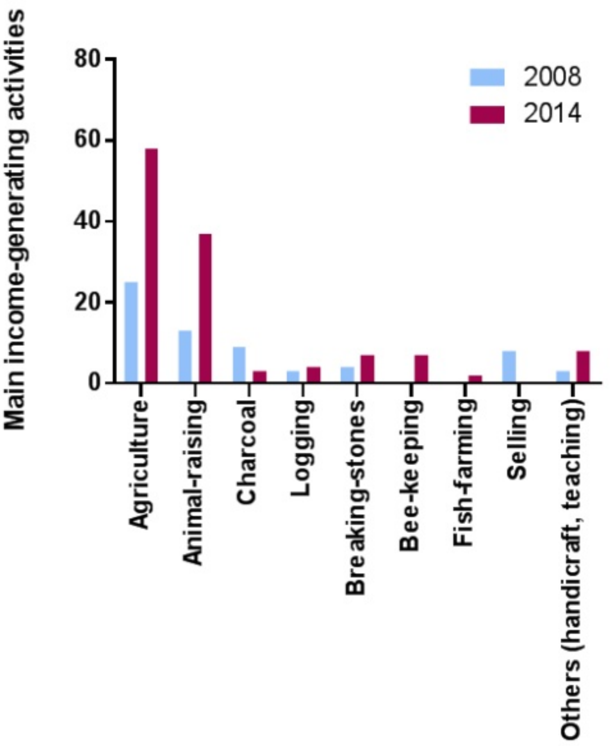

Figure 2. Breakdown of knowledge about the conservation offsetting.

A weakness of the project is that the number of people who are able to participate in the development projects is very small compared to the total number of households in the three communes around the forest. Another weakness or difficulty is promoting behavior change, especially regarding agricultural techniques like slash and burn agriculture.

Furthermore, improvement of materials and supplies needed for the development program to help a large number of community members is possible only by partnering with national initiative and Madagascar investment. These collaborations can help improve the development work around Maromizaha to reach a larger number of people by increasing the quantity of agricultural equipment available to the development project and increasing the frequency and intensity of effective development projects. Also greatly needed is the improvement of partnerships with local authorities in order to decrease and eliminate harmful practices and behaviors such as charcoal production and slash and burn agriculture.

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Our sincere thanks go to the Ministry of Environment, Ecology and Forests for classifying Maromizaha forest as a new protected area. Our gratitude goes to the reviewers and to Chia Tan, Tony King, Steven Goodman, and William Dreyer for suggesting improvements to this manuscript. We also thank the beekeeping technician, Edouard Ranaivo, the traditional and local authorities at Ambavaniasy, Morafeno, and Ampangalatsary located in the Rural Municipality of Andasibe for having provided the access to demographic data and visits to villages. We extend our thanks to Global Environment Facility Small Grants Programme Madagascar (GEF/SGP) for founding the developmental projects, to Missouri Botanical Garden (MBG) in Antananarivo for the "Ravintsara" determination and to Houston Zoo for having funded this socio-economic survey.

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SUPPLEMENTARY MATERIAL.

Available online only.

Table S1. Distribution of the population of *Morafeno*. (Source: 2013 census Morafeno).

Table S2. Location of villages, the number of focus group and participants.

Figure S1. Main income-generating activities of villagers living in and around the Maromizaha Protected Area on the years 2008 and 2014.

Figure S2. Income use of villagers living in and around Maromizaha Protected Area.

Figure S3. Highest level of education completed by study participants.

Figure S4. Breakdown of knowledge about the conservation offsetting.

Figure S5. *Ravintsara* tree or *Cinnamomum camphora*, Lauraceae, planted near Maromizaha Protected Area, an allogenous species also known as the camphor tree.

Figure S6. Syntype of *Cryptocarya aromatic*, Lauraceae, an endemic species in the Lauraceae family, also known in Madagascar by its vernacular name *Ravintsara*.

ESSAY

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Madagascar's future climate change intensified actions and policy reforms: fostering local initiatives or business as usual?

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ABSTRACT

As Madagascar, like all other countries on the globe, is gearing up for the meeting of the 21st Conference of Parties (COP21) of UN's Framework Climate Change Convention (UNFCCC), we reflect on the persistent failure of development policies in Madagascar, and suggest that there may be fundamental flaws in perceptions about development interventions and transferability of solutions, resulting in a country in permanent crisis despite the island's great potential. The major official donors claim that they had left the island to itself since the 2009 crisis. However, World Bank statistics show that, in current terms, Madagascar was receiving US$400 million in 1990 and US$ 500 million in 2013. In the same interval, the Gross National Product (GDP) per capita remained basically the same (equivalent to 440 US$/capita in 2013). Should COP21 produce a momentum for massive investment in carbon emission reduction and in adaptation to climate change (CC), we propose that, at a minimum, these new projects, plans, programs and policies should aim for sustainability by applying Environmental and Social Assessments at all required levels and that, preferably, this should be the opportunity to approach development differently. In particular, we advocate focusing on enhancing the generative capacity (i.e., the capacity to generate unplanned-for new development options) of Malagasy people to better take advantage of the natural resources and the information and communications technologies (ICT) infrastructure already in place. Such an ambitious program is not without risks and pitfalls, but it is one way of thinking about breaking out of Madagascar's current self-reinforcing cycle of under-performance. The purpose of this essay is to question the *status quo* to stimulate discussion and new thinking, short of which observers, 20 years from now, will find themselves echoing the same frustrations that observers and inhabitants alike experience when faced with the present state of development in Madagascar.

RÉSUMÉ

Au moment où Madagascar, comme tous les pays de cette planète, se prépare à participer à la 21e Conférence des Parties (COP21) de la Convention Cadre des Nations Unies sur les Changements Climatiques (CCNUCC), nous considérons les échecs récurrents des politiques de développement à Madagascar pour souligner de possibles biais fondamentaux dans les perceptions des interventions de développement et la transférabilité de solutions, avec, comme résultat, une crise permanente malgré le grand potentiel de l'île. Alors que la plupart des bailleurs de fonds officiels font état d'une cessation de leurs activités dans le pays depuis la crise de 2009, les statistiques de la Banque Mondiale montrent que, en termes courants, Madagascar recevait US$400 millions en 1990 et US$ 500 millions en 2013. Au cours de la même période, le Produit intérieur brut par habitant a stagné (équivalent à 440 US$/capita en 2014). À supposer que la COP21 ait pour résultat des investissements massifs dans la réduction des émissions de carbone et dans l'adaptation au changement climatique, nous proposons que, a minima, ces nouveaux projets, plans, programmes et politiques devraient viser à plus de durabilité en appliquant les Évaluations environnementales et sociales à tous les niveaux requis et que, de préférence, cet afflux de capitaux représente l'opportunité d'une nouvelle approche du développement. En particulier, nous proposons une focalisation sur la capacité générative (définie somme la capacité à générer spontanément de nouvelles options de développement) des citoyens malgaches de mieux tirer parti des ressources naturelles et de l'infrastructure des technologies de l'information et des communications (TIC) déjà en place. L'ambition d'un tel programme n'est ni sans risques ni sans embûches, mais nous estimons qu'il s'agit d'un moyen de sortir du cycle actuel et auto-entretenu de sous-performance qui existe à Madagascar. Cet essai propose ainsi de mettre en cause le *statut quo* afin de stimuler la discussion et une nouvelle approche. À défaut et sans changement, les habitants comme les observateurs connaitront, dans 20 ans, les frustrations d'aujourd'hui, face à l'état du développement de Madagascar.

INTRODUCTION

The Conference of Parties of the United Nations Framework Climate Change (CC) Convention (UNFCC), 21st of its kind (COP21) has the primary mandate of being the concluding act of a series of preparatory actions. These actions provide the foundations for a possible historical consensus allowing the Framework to turn into an actual Convention, of the same authority and application as

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the 1992 Convention on Biological Diversity, for instance. COP21 will also be the starting point of intensified efforts by the international community to help stakeholders around the world achieve the targets set and recorded in the preparatory documents. If the Convention is signed and ratified, Madagascar will be responsible for reaching the targets that it will set for itself in its "Intended Nationally Determined Contribution" (INDC), presently under preparation. As of 24 July 2015, very few Sub-Saharan African countries had submitted their INDC. Exceptions were Ethiopia (Federal Democratic Republic of Ethiopia 2015), Benin (République du Bénin 2015) and Kenya (Republic of Kenya 2015). The typical INDC presents a catalogue of activities in various economic sectors along with quantitative and dated targets for carbon emission reductions (CER) and for CC adaptation activities. The 13-page INDC for Ethiopia takes stock of the present annual carbon emission of 150 Mt of Carbon-Dioxide Equivalent (CO_{2e}) and offers a program to reduce its 2030 emissions by 64% compared to the 'Business As Usual' (BAU) scenario. This would be achieved by actions and policies in six sectors/sub-sectors: Agriculture, Forestry, Transport, Electric Power, Industries and Buildings/Urban planning. In the field of adaptation to climate change, pending more research required, the INDC focuses on droughts and floods and gives a key role to farmers and pastoralists, although it touches upon other segments of the population too. It is likely that Madagascar's INDC will contain some or all of Ethiopia's concerns in its upcoming INDC.

In parallel to these country-led efforts, the developed countries are gearing up to establish a massive Green Investment Fund that will ideally consolidate a myriad of existing financing mechanisms with a short-term goal of delivering as much as 100 billion US$ of financial assistance every year to developing countries. The current scenario is simple: countries prepare and post their INDC, the Convention is signed in December 2015, and money is released to the countries to fund the priority policy reforms, programs, plans and projects described in the INDC. The mandatory monitoring of the implementation of the INDC will also make it a 'live' document. The real overall chain of events may actually be different from this current scenario, but it is generally accepted that large amounts of additional money will flow as a follow-up to COP21, whether the Convention is adopted or not.

The sheer volume of the funds that will be required and requested to fully implement the commitments made in the INDCs is significant and targeted at getting results on the ground. CC policies, plans, programs and projects are far from being environmentally and/or socially neutral (e.g., at the project level, carbon sinks like reforestation may lead to land grab, similarly with large scale solar/wind projects). Consequently, there are few differences between making regular development activities economically viable and environmentally/socially sustainable on the one hand and doing the same with post-COP21 activities on the other hand. The INDCs contain commitments intended to curb carbon emissions and increase adaptation compared to the BAU scenario. Here, we question whether future CC actions and policies in Madagascar should continue to apply the present approaches to international development (what we call BAU) in this context or whether the shift in development paradigm called for by many should indeed start now, using CC actions and policy reforms as a springboard.

In order to implement its INDC commitment, Madagascar will probably be offered the technical and financial assistance of the international community. The corresponding resources will likely be substantial, and, as such, might have a significant impact on the island's development. Beyond the mechanical aspects of this new potential manna, we question what effects can/will this have on Madagascar's future and does it constitute an opportunity for the island to generate and implement new forms and shapes of development?

CONTEXT

Madagascar is a global biodiversity hotspot, but its economy, as reflected in its poor overall performance indicators, is far from healthy: it has currently a GDP/capita of around 440 US$/year, barely above 1 US$/capita/day, and its Gini Coefficient (a favourite measure of income inequalities at the national level: the higher the coefficient, the "more unequal" the income distribution is) of 44.1 is close to the average in Sub-Saharan Africa. The Human Development Index (HDI), a particularly important composite indicator of demographic and economic data popularised by the UN Development Program (UNDP 2015) of 0.5, ranks Madagascar 155/187 worldwide, just above Zimbabwe. A low HDI, like Madagascar's, and especially a degrading or sluggishly improving HDI can be interpreted as a strong handicap for any form or shape of truly sustainable development. Looking at the distant past (in international development terms), Razafindrakoto et al. (2013) have shown the worsening of economic conditions in the country with an approximate 35% decrease in the GDP/capita between 1960 and 2008.

In passing, benchmarking Madagascar with Africa may be the usual practice and it is bad enough to see the country in such a low ranking there, but it fares even worse in benchmarking with other islands in the Indian Ocean. If Madagascar has ambitions other than being a laggard in development, it should set its vision and goals on the better performers like Mauritius or the Maldives. Furthermore, whilst the statistical apparatus in Madagascar is almost non-existent, the modest evidence that is available for disaggregating data between the pockets of recent economic growth in the cities and stagnating rural areas is even more disheartening. According to Word Development Indicators (compiled, for instance, at Knoema 2015), poverty in rural areas rose steadily from 78% in 2001 to 81.2% in 2010 (latest statistics available) while poverty in urban areas rose from 46% in 2001 to 55% in 2005, but went down to 51% in 2010.

We propose to visualise Madagascar as a series of nested Russian dolls. There is Madagascar on the planet, with its rich and bright diaspora, its wide and rich Exclusive Economic Zone and its interesting geographical setting and biodiversity features (Rakotomalala 2012, Ganzhorn et al. 2014), there is the island itself, the sixth largest on the planet, and then the actual terrain, with highlands in the centre and lowlands around. At the lowest geographical level, there is a mosaic of extremely diverse landscapes and people, from the community living in quasi-autarchy to the bustling Antananarivo with international standard beach resorts in between. At the individual level, stereotypic of these contrasting life styles would be the 35 year old professional without any dependents in Antananarivo, and the farmer's family on the highlands with 6 to 8 children fighting for their share of the daily rice dish. The geo-spatial dispersion coupled with limited transport infrastructure and cultural heterogeneity also explains why many communities barely have a sense of belonging to a single nation.

Madagascar's economic, social and environmental under-performance has generated a series of well-meaning interventions over the years. In the environmental management realm, Madagascar was, worldwide, one of the developing countries that tried, with a strong push from the World Bank, to develop a National Environmental Action Plan (NEAP) (Mercier 2006). Madagascar's NEAP adoption was followed by a series of Environmental Projects that literally cost hundreds of millions of US$, with some of the millions having to be repaid by Malagasy taxpayers for several decades. For instance, the Environmental Program II, approved 9 January 1997 and closed 30 June 2003, was funded to the level of US$110 million (462 billons Malagasy Francs at the then exchange rate), of which US$ 30 million were in the form of an IDA credit (10 year grace period, 40 year repayment, in this case approximately 2007-2036) (World Bank 2003). Reading the ex-post evaluations (World Bank 2003, 2007) of these projects can be salutary for avoiding pitfalls in the design and implementation of future CC-related large scale projects and policy reforms in Madagascar.

OVERVIEW AND CRITIQUE OF INTERVENTIONS: ARGUING FOR MORE BOTTOM-UP STRATEGIES

The history of the many and abundant external interventions has given rise to a familiar pattern of relationships where nothing that the interventionists introduce or propose is challenged and nothing that they introduce is challenging. Consequently no strong activist movements are provoked, and the *status quo* is not threatened. It is not only the international donors and lenders/investors who have this familiar relationship: for organisations like Conservation International (CI) Madagascar is a lucrative venture, and the development of CI and its commercial activities have actually paralleled the Madagascar NEAP and its sequels. The total revenue of CI has jumped from US$ 116 million for fiscal year 2009 to US$165 million for fiscal year 2014 (Conservation International 2010, 2015). In particular, CI has helped create carbon reduction emissions (CERs) for the corridor Ankeniheny-Zahamena. Researchers have established that, on this particular project, conflicts occurred between forest conservation and access to resources affecting local livelihoods (Ratsimbazavy et al 2013). Thus, the 50% of the CERs going to the local communities include a fair compensation for the negative local impacts of forest conservation.

The present and past interventions in Madagascar as in many other developing countries are all predicated on a flawed superior and arms-length perspective and behavioural script which we can characterise as follows: (i) a failure to recognize the importance of contextual features for the implementation of development agendas, which may be captured as "Madagascar is a developing country like any other and what the international community has made work elsewhere should work in Madagascar"; (ii) a failure to follow through the consequences of failed interventions to examine causal factors: the observation that Madagascar's economic base is not diversified enough and relies too much on the exploitation of natural resources (land and sub-soil) and the primary sector, leads to the premise that attempts should be made, top down, to help that economy to diversify. When these attempts fail, the next round of negotiations and programming will start the wheel spinning again; (iii) assumed inaptitude of the recipients: an assumption that there is nothing political nor cultural about Madagascar's permanent and deepening crisis, just a failure by the Malagasy Government to comply with the advice provided by the International Monetary Fund (IMF) or the World Bank; (iv) complacency about the expert role of western donors; and (v) an amalgam between financial growth on the one hand and sustainable development on the other hand: the fact that the Chinese and others have rolled up their sleeves, circumvented or corrupted further the Government, made direct infrastructure investments and thus helped create some economic growth, should not be misconstrued as sustainable development (Duffy 2007, Schuurman and Lowry 2009).

However, because, Madagascar is a system that can be described as a complex network with intertwined social, economic and ecological dimensions, any transplant or graft is unlikely to be totally compatible with the parts/dimensions that are retained. Perhaps an alternative paradigm is called for, and COP21 follow-up may be the catalyst for its inception.

The Post 2015 High Level Panel (United Nations 2013) has ventured that one key direction the world should take is to put sustainable development at the heart of development and one of the visible effects of this powerful statement is that the 17 or so Sustainable Development Goals will soon replace the 8 Millennium Development Goals adopted by the General assembly of the UN in 2000. Fulfilling peoples' needs in a sustainable manner should be at the heart of the coming development efforts. For Madagascar, harnessing the opportunities created by COP21 and its sequels should include new development dimensions, and, in particular, an emphasis on generative capacity, which the authors define as an effort to innovate using indigenous knowledge and resources co-specialised with requisite external inputs to develop distinctive, locally rooted development trajectories, rather than westerners trying to replace what exists with what they think they know works elsewhere.

Bringing in climate change opens the field for increased activities in all areas, but more particularly in most of the conventional sectorial approaches. What the authors are looking into is the possibility of integrating these sectors at various (and nested) levels of territories or landscapes. This raises the interesting question of the lessons learned from the failures (or in United Nations' terminology the 'limited successes') of past efforts towards Integrated Rural Development (IRD – the 1970s and the 1980s) and of Community Driven Development (CDD, the late 1990s and thereafter). If this integration does not occur, the focus will remain on the promotion of disjoint 'smart' sectorial policies. 'Climate smart agriculture' (CSA) is one of the present buzz words. It is defined in very technical terms by, e.g., targets in terms of the content of organic matter in the soil. CSA may lead to a significant take-off of organic farming. However, many NGOs already question CSA's foundations, seeing in it a Trojan horse for multinationals and other international companies coming in and grabbing the land of family farmers. The Sustainable Agriculture Initiative Platform, for instance, states that "In theory, practices that are unsustainable when looking at them through social, economic or even other (than climate) environmental lenses, could potentially be covered by the term [Climate Smart Agriculture]" (Sustainable Agriculture Initiative 2015). Deciphered in layman's terms, this means that NGOs fear a very negative impact on family farms by applying CSA without effective social and environmental safeguards. Raising these questions may lead to a healthy challenging of indigenous and imported knowledge claims and opens up a debate that goes beyond how to re-arrange the chairs on the Titanic.

THE BEST OF BAU IN IMPLEMENTING THE FUTURE CC STRATEGIES

Environmentalists and social scientists have invented and tested tools and methods to marginally improve the way international development is conducted. The major tool to 'green' a project, plan, program or policy is the Environmental and Social Assessment (ESA). Project-level ESA is currently defined as methods and tools used "to identify and assess the potential environmental and social risks and impacts of the proposed project" (World Bank 2015a). Well known and mastered at the project level, Environmental and Social Assessors are now attacking one of economists' strongest fortresses: plans, programs and policies, with the ESA variety known as "Strategic Environmental and Social Assessment" (SESA).

Project-level ESA has permeated and influenced project design and shown successes and failures. The latter include mobilising public involvement too superficially and too late in the project cycle. Successes, however, have included, for the largest projects (mainly in the infrastructure/industry sectors: roads, dams, mining, airports, etc.), the requirement by many financiers of Free, Prior and Informed Consent (FPIC) from the affected communities. SESA has a much longer way to go to become mainstreamed, let alone effective. The authors have shown, however, that COP21 sequels, be they in the form of projects, plans, programs and/or policies, should benefit from being subjected to ESA at the relevant levels (Mercier 2010). By balancing economic, environmental and social interests and by providing a platform for the potentially affected populations, ESAs improve the processes, both at the planning and implementing stages. They also provide horizontal (territory, landscape) and vertical (sectors, tiers) linkages. But, as tools at the service of decision makers, ESAs in themselves cannot turn the overall development strategies around and they fall short of correcting the fundamental flaws that lead to the present 'development breakdown' in situations like Madagascar's.

One of the fundamental issues is the way in which the governance of development initiatives drives towards compartmentalisation of effort and outcomes, with large projects predicated on short-term gains. The planned trajectories of such projects are often designed to fulfil donor-specified goals efficiently in a relatively structured fashion with linear progression from one step to next 'move'. However in reality, it is quite possible that as the project advances, new capabilities are developed, new contextual dimensions are perceived and new options are generated for the next move. Attending to this generative capacity for development entails attending to the dynamic nature of evolutionary trajectories and looking for synergies between what exists in the local context and what can be usefully imported from other countries. For example, Kenya's long-drawn journey to establish its Information and Computer Technology (ICT) policy was a failure in terms of meeting the short-term expectations of the World Bank. However, it resulted in the self-organised emergence of a potent local network of public sector champions, entrepreneurial ICT firms, NGOs and civil society (Njihia and Merali 2013). This network embodied the generative capacity which spawned, among other things, the 'invention' of Kenya's pioneering mobile money application (M-pesa) and its rapid uptake and diffusion throughout the country and globally (initially via the diaspora). Whilst the ICT companies were commercially motivated, the societal outcome of this development was rapid penetration of financial services to a rural population that was not served by banks and did not enjoy conventional terrestrial telecommunications, and the ability to make micro payments with mobile money made it viable for the poor to transfer modest funds without incurring prohibitive bank charges.

POSSIBLE PATHS TO FUTURE CC STRATEGIES IN MADAGASCAR

We suggest that a focus on the sustainable use of the island's natural endowments coupled with its significant human and social capital would lead us to investigate further the relationships between the generation and distribution of wealth and the organisation of work in the global, climate-conscious digital economy.

The prevalent vision for growth in the economy of Madagascar is predicated on agricultural production, extracting and exporting minerals, and on tourism. With regard to the first two, given that Madagascar incurs the ecological costs of production of crops and minerals, merely exporting them for integration into the higher end of the value chains situated elsewhere means that it foregoes the opportunity to fully realise its generative capacity. We suggest that Madagascar's comparative advantage of access to natural resources for the generation of renewable (wind, solar and hydro-electric) energy may make local small-processing plants an attractive alternative, both from an ecological perspective and an economic one.

With regard to agriculture- when climate change comes into the equation, it is well worth exploring whether Schumacher's concept of "small is beautiful" (Schumacher 1973) begins to make sense as a viable alternative to large scale monoculture plantations. For example, when we add energy conservation into the equation, it may make sense to deploy modern technologies and smaller scale farming methods with more complete recycling, and local production food and energy for local consumption, possibly with renewables-based energy production driving small cooperative local processing plants. The aspiration of many around the world – developed and developing – is to attain food sovereignty and to have confidence in the provenance and quality of the food they consume, as well as food security: perhaps this is something that should be defended in Madagascar.

Given the advancing affordances of ICTs, it no longer makes sense to be operating a model of economic growth that is predicated on migration of human capital from the countryside to the city – with the production of food distanced from the consumers, and the attendant overheads of packaging and transport. The equivalent of the 'industrial revolution' in Sub-Saharan Africa and island states does not have to follow the trajectory set by history of Western development -it can, at least in part, be predicated on the ICT-based industry of software development and information work, and ICTs can also enable the development of novel, greener business models for the development and delivery of physical goods and services. The potential for deploying ICTs for innovative products, services and business models is demonstrated in Kenya by the emergence of Safaricom and M-pesa to dominate the mobile telephony and mobile money transfer market. If these capabilities are then coupled with ICT-based delivery of education and training, we can begin to see how the investments in CC initiatives, if integrated with human, technological and natural capabilities can realise synergies that may enable Sub-Saharan Africa to leapfrog some of the challenges that the developed nations are currently grappling with. We do not overlook the present lack of generalised access to electricity in Madagascar (only 15% of Malagasy according to World Bank (2015b)), but half of the population now has a portable telephone and the trend is for a continued rapid growth with ad hoc battery charging solutions and portable phones increasingly allowing access to ICT services of the same kind as tablets and computers.

If diversification efforts were focused on the development of capabilities for competing in the digital economy, it may be viable to replace the popular hub-and-spoke model of the city as the locus of wealth management with an intelligent network model. Consistently with Schumacher's vision of using appropriate technologies to empower people, we could conceive a model of local food production and consumption coupled with an ICT industry which has all the benefits for quality of life as 'cottage industry' whilst effectively constituting a large integrated virtual enterprise, with workers based at home or at local community centres with good internet connectivity.

We appreciate that there is a long way to go for Madagascar to come out of the present crisis with more sustainability and equity. However, in terms of building the right set of institutions needed for sustainable development, the Malagasy may not have to look much further than the network of locally managed marine protected areas (Mayol 2013), the rural electrification cooperatives in South America, and the organisations capable of setting up mass demonstrations against land grab in Asia, Africa and elsewhere.

OBSTACLES AND CONSTRAINTS IN MODIFYING THE DEVELOPMENT COURSE IN MADAGASCAR

Doing away with the sectorial and top-down approaches, all at once, is not without risks, nor will it happen overnight. The key risk is raising too many short term expectations. Changes in development patterns do not happen overnight and are more a series of trial and error. Industry lobbyists and their friends will be quick in pointing out the 'errors' part. Social learning (as recommended in Scherr et al. (2012)) is at the heart of any new development strategy as proposed here. The importance of social networks and discourse is clear for this aspect of development, and for healthy co-evolution across the rugged terrain of stakeholder interests, there needs to be a platform and mechanism for heterogeneous knowledge claims to be visible, challenged and defended top-down and bottom-up. First the 'pipes' need to be in place (in the form of the Internet and mobile phones and their networking infrastructure, etc.), but providing the appropriate information and knowledge flows in the pipes takes time, resources and political will. These ingredients may turn out to be missing, even if they represent a fraction of the cost of many white elephants, virtual or physical, that can be visited in Madagascar. Passivity from the local populations may contribute to increasing this cost. Since the Malagasy Government has a huge trust and effectiveness handicap to compensate for, there will be the need for vocal and effective pioneers and grassroots organisers. They are probably already around, and some may even be reading this essay.

RECOMMENDATIONS

It is likely that more funding will be made available to Madagascar as a follow-up to the COP21. Though these funds will be earmarked and processed as CC related, because the actions and policy reforms that will be financed will pertain to many economic sectors, chances are that this opportunity may be treated as being little different from conventional international development assistance and funding. Thus it is recommended that these additional CC funds be treated with extreme care when it comes to sustainability, equity and local empowerment. In particular, ESA for project level and SESA for plans, programmes and CC policies should be the norm. Other sustainability assessment and management/monitoring tools should also be used. The overall objective is to accelerate the path to a green economy and inclusive development putting the local communities in the driver's seat. The technologies exist to build and maintain distributed networks and should be put to general and better use for not only 'smart' individuals, villages, towns and island, but also a more robust and sustainable development at all the levels.

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Daraina sportive lemur, *Lepilemur milanoii*, resting in a hollow tree during the day. By Tantely Ralantoharijaona.

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