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

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EDITORIAL

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Biodiversity offsetting – *en vogue* in Madagascar?

In August I attended the International Primatological Society meeting in Mexico. During the session devoted to lemurs, there was an intriguing presentation on lemur conservation in the mining area of Ambatovy, some 80 km east of Antananarivo. Among other fauna, a remarkable 16 lemur species have been recorded there, including the IUCN Critically Endangered *Prolemur simus* and the Endangered *Propithecus diadema*. According to the company website, Ambatovy is a "large-tonnage, long-life nickel and cobalt mining enterprise located in Madagascar. Total project cost is US$ 6.3 billion, making Ambatovy the largest-ever foreign investment in the country – and one of the biggest in sub-Saharan Africa and the Indian Ocean region. Once fully operational, it will have the annual capacity to produce 60,000 tonnes of refined nickel, 5,600 tonnes of cobalt and 210,000 tonnes of ammonium sulphate fertilizer." This will position the Ambatovy project among the world's most productive lateritic nickel mines. Clearly on the payroll of the mining company, the presenter showed a map of the Sherritt mining area, revealing among other features, a conservation area for biodiversity offsetting some 70 km northeast of the mining site. This got me wondering: it seems quite a distance from the mining site, in other words, the biological / ecological conditions may be different. So how exactly is biodiversity offsetting working?

Biodiversity offsets are conservation measures implemented to compensate for the residual biodiversity losses caused by development activities. This entails 'adequate' compensation in form of upgrading the environmental value of other sites. The 'successful' upgrading or reconstruction of valuable habitat is documented through permits which are issued by an authorized agency ensuring that quality standards are met (Wissel and Wätzold 2010). The conceptual assumption behind offsetting is that degraded natural environments can be balanced by conserving 'pristine' nature, or, using Brockington and Duffy's (2010) notion of a "global virtual ledger" on which a quantitative balancing of beneficial and adverse environmental actions is carried out. So, how are compensatory mechanisms applied when dealing with biodiversity? Its conceptual complexity renders delineating physical boundaries of ecosystem functions and services extremely challenging, and to assign virtual price tags to single systemic elements or values and to relatively weight their contribution to the entire 'biodiversity' (Kosoy and Corbera 2010). Common offsetting schemes tend to abstract biodiversity into tangible, itemized proxies such as 'habitat hectares', or they may favor certain flagship species, for example lemurs – hence engaging in what Castree (2003) calls "trading [off] biodiversity elements". Trade-offs can be decided empirically, by identifying ecological thresholds, assessing vulnerability, or defining uniqueness (e.g., endemism, irreplaceability, etc.) of components of elements of biodiversity, such as species. Oftentimes single metrics (e.g., monetary value) are used to quantify biodiversity values in such a context (Hirsch et al. 2011). However, biodiversity trade-offs extend beyond the pure economic value dimension (cf. Gowdy 1997), adding to the complexity analysing and assessing trade-offs. International standards are required to ensure best practice and transparency of biodiversity offsetting. It is similar to the more known Carbon offsetting in that both are trying to mitigate or reduce impacts (of emission for the latter mechanism). However, the greenhouse gases are more uniform and less complex than 'biodiversity' and therefore represent a better tradable commodity on an international level (ten Kate et al. 2004).

Madagascar is extremely rich in minerals as Tsilavo Raharimahefa in this issue depicted when discussing Madagascar's geoconservation and geodiversity (Raharimahefa 2012). During the past decade, large-scale mining has grown considerably in the country (e.g., Cardiff and Andriamanalina 2007). This is partly because of the Large Mining Investment Act (cf. Sarrasin 2006). According to the World Bank 2010 report, Madagascar is only just about to enter a large-scale exploitation phase where relatively easy rentals and revenues for government (Malagasy) are assured from industrial mining since respective transnational industries have sophisticated administrative and governance structures in place. "Companies may be motivated [i.e., by self-interest] to offset the harm they are causing when transforming biodiversity on a purely voluntary basis." (ten Kate et al. 2004: 38). They do so in order to increase efficiency in terms of acquiring necessary permits for development projects (such as industrial mining) and to enhance global reputation ("we are practicing conservation and improving local economy by creating many jobs"), and to secure social licenses with stakeholders (ten Kate and Inbar 2008). Many of these companies aim to reduce rates of biodiversity loss, by promoting a 'no net loss' of biodiversity, or even to achieve a 'net positive impact' following destructive activities (Rio Tinto 2004, 2008, TEEB 2010). Best practices (following the mitigation hierarchy of avoiding, minimizing, restoring, offsetting) to achieve such highly staked goals are formulated by the BBOP (Business and Biodiversity Offsets Programme), an international collaboration between companies of the extractive industries, financial institutions such as the International Finance Corporation (a member of the World Bank Group) or the Global Environment Fund, government and non-governmental agencies (e.g., Birdlife International, Conservation International, International Union for Conservation of Nature, Wildlife Conservation Society), and civil societies (BBOP 2012).

In conclusion, when perusing the list of NGOs active in Madagascar that are engaging with the extractive industries, it is apparent that there seem to be more than just a business opportunity involved to engage in biodiversity conservation (offsetting) in Madagascar. There are two main risks to emphasize in this regard: (i) A great deal of uncertainty remains, i.e., it is not assured that the compensatory mechanisms or conservation activities on a different patch (one which is connected or not with the developed /mined patch) will create a no net loss or even a net positive impact: only time will tell (e.g., Johst et al. 2012). (ii) Land development activities (extractive mining) continues to harm biodiversity. What has changed in the past years is the marketing strategy employed by the extractive industries: it uses the same narrative and presentation as conservation organizations (for in-depth examples and case studies, refer to Seagle 2012, Evers and Seagle 2012). These narratives are too often used to shoulder farmers or the impoverished rural people as culprits of deforestation or other environmental destruction (Horning 2012, this issue) while in reality, land and patch conversions are supported by governments and the conservation community. I do not wish to engage in a blame game, but rather, would like to point out the risks of falling too easily into the one or the other narrative to deflect from actual issues. Biodiversity offsetting in Madagascar seems to be coming into vogue in the years ahead. Therefore, it appears logical to delve more deeply into models such as 'Zones of intermediality', proposed by Sandra Evers in this issue, where all different stakeholders engaged in a resource interaction (such as biodiversity offsetting) are profiled in a holistic and respectful way (Evers 2012).

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SPOTLIGHTS

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Ideology and the self-fulfilling prophecy in conservation and social science research

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ABSTRACT

In this essay, I propose an analytical model, 'zones of intermediality', designed to research socio-cultural dynamics in foreign large-scale land projects. 'Zones of intermediality' refers to the ontological grids of (inter)national-local stakeholder encounters where diverse ideologies, discourses and practices of land use and valuation are mediated. The model was constructed to analyze conceptual similarities and differences between and within stakeholder groups in such land projects. Just as local 'communities' are composed of people with varied social realities, economies, political relations, knowledge, views and perceptions, so are other stakeholder groups. Researchers are not immune to such realities. The subjectivity and epistemological rooting of the researcher impact on what he or she sees in the field and what is eventually reported in research publications. Thus, the essay argues for a reflection on these processes in view of the fact that we ourselves mediate representations of 'local' people to academic and non-academic audiences. I hope that the 'zones of intermediality' model will be useful in facilitating such reflections.

RÉSUMÉ

Dans cet article, je propose de considérer un modèle analytique dénommé 'zones d'intermédialité' conçu pour faire progresser les outils de recherche des dynamiques socioculturelles associées avec des projets d'acquisition foncière de grande envergure en Afrique continentale et à Madagascar. Le modèle 'zones d'intermédialité' s'inscrit dans des grilles ontologiques de rencontres d'intervenants (inter)nationaux à locaux dans lesquelles divers idéologies, discours et pratiques ont une influence sur l'utilisation des terres et sur l'évaluation foncière. Le modèle a été conçu pour procéder à une analyse détaillée des différences et des similarités entre et au sein de tels projets d'acquisition foncière. Au même titre que les 'communautés' locales sont constituées de personnes avec des réalités sociales, économiques et politiques différentes, et que cette diversité a un effet sur leur opinion et leurs perceptions, convient-il de préciser que ces diverses réalités s'imposent également aux autres groupes d'intervenants et même aux chercheurs qui ne sont pas indifférents à de telles réalités. Les racines subjectives et épistémologiques du chercheur influencent ce qu'il observe sur le terrain et ce qu'il rapporte ultérieurement dans ses publications. C'est pour toutes ces raisons que j'invite à une réflexion sur ces procédés dans la mesure où nous sommes nous-mêmes amenés à influencer les représentations des gens locaux destinés à un public universitaire ou non. J'espère que le modèle 'zones d'intermédialité' facilitera de telles réflexions.

In 2010, I was invited alongside other scientists to share my reflections in this journal on the relations between social scientists and conservationists (Evers 2010: 121–122). I expressed my opinion that conservationists and social scientists appear to have a somewhat caricatured view of each other, and commented that "The only way to reconcile contrasting ethical views, concepts and impacts of conservation is through exchange and dialogue." In this essay, I would like to return to this theme and propose an analytical model which hopefully will assist in bridging what I believe to be an undue emphasis placed upon philosophical and epistemological differences at a time when exciting new research is beckoning. In doing so, I will refer to the controversial area of conservation projects in Madagascar – where on one side of the conceptual divide, researchers place conservation at the apex of their values, and on the other, principally social science researchers tend to qualify such projects as cases of 'land grabbing' or 'green grabbing'.

In 2011, with support from The Netherlands Organization for Scientific Research (section WOTRO Science for Global Development), we commenced a research programme on foreign large-scale land acquisitions at VU University Amsterdam with partner institutes in Africa. We have formed a transnational and multidisciplinary team of researchers – including those with expertise in history, anthropology, geography, GIS/spatial analysis, political science, ecological economics, linguistics, cognitive and communication sciences. The research (September 2011–September 2015) has four aims. First, we will analyse the global actors, networks and interests (e.g., political, economic, social, cultural, environmental) driving foreign land acquisitions, examining the role of the state, neoliberal reforms and donor interests in facilitating land access. Second, a grounded stakeholder analysis will detail local impacts, perceptions and responses to land deals. Third, we will map, through our theoretical model, 'zones of intermediality', the ontological grids of (inter)national-local stakeholder encounters where diverse ideologies, discourses and practices of land use and valuation are mediated. Fourth, we will use this model to capture commonalities between stakeholders and potential areas of contestation. The comparative research takes place in four settings ranging from large-scale mining in Madagascar, foreign food production in Ethiopia, REDD initiatives in Madagascar, and agricultural Chinese land investments in Uganda.

The past several decades have witnessed an unprecedented increase in foreign large-scale land acquisitions. It is estimated that over 46 million hectares of land were leased out to or the subject of potential land deals with foreign investors since 2006 (Deininger et al. 2010). Other figures differ; IFPRI (International Food Policy Research Institute) calculated that 20 million hectares had been officially transferred to investors by 2009 worldwide (cf. von Braun and Meinzen-Dick 2009). They are often referred to as 'land grabs' – a label evocative of neo-colonialism – by activists and academics alike who presume that cronyism and corruption taint these acquisitions *ab initio*. However, this view overlooks the reality that many acquisitions are completed within existing legislative, regulatory and policy frameworks. Land is being leased for various purposes such as tourism, mining, infrastructure and agricultural projects. Nature, conservation and climate mitigation schemes have also been characterized as large-scale land acquisitions (Cotula et al. 2009, IIED 2009, Smaller and Mann 2009). This last category of acquisition is often termed 'green grabbing', defined as land and resources which are appropriated for environmental purposes (Fairhead et al. 2012).

Literature on such conservation projects has sharpened the divisions between social science and conservation. Social scientists tend to focus on livelihood shifts, economic changes, dislocation from land and changed human-environment relations. Such research often depicts local people as a unified, victimized, and powerless group. Conservationists argue that Madagascar's biodiversity is under severe threat, often portraying the Malagasy themselves as the main threat to "our world heritage" due to slash and burn practices. Such stereotypical images of local people do a disservice to both the Malagasy and the cause of science. This impasse in part motivated our development of the 'zones of intermediality' model.

It might be useful to ask ourselves whether some commentators haven't made undue concessions to ideology and political correctness in the rush to jump on the land-grab bandwagon or to meet the pressures of "publish or perish". Are we, as researchers, vigilantly investigating data that contradicts our own preconceptions? Are we coming to conclusions prior to checking realities properly on the ground? Rather than comfort our positions, perhaps a brief recollection of the Popper falsification theory might be in order, i.e., an examination of data that goes directly against our own assumptions. Malagasy ideas and practices are varied, intricate, evolving and somewhat transient. Research demands analysis that takes this into account.

Conservationists and social scientists in fact have a similar lexicon when speaking of large-scale acquisitions, but terms are not always vested with the same meaning. This is a good example of what we see as a prevalent variable in a 'zone of intermediality'. Intermediality initially referred to the interconnectedness of modern media of communication. As modes of expression and exchange, the different media depend on and refer to each other, both explicitly and implicitly; they interact as elements of particular communication strategies, and they are constituents of a wider cultural environment (Donsbach et al. 2008).

Culture in fact is profoundly intermedial: people use media to communicate with each other and to mind read each other's thoughts (Bloch 2008, 2011, 2012). They use words, images, text, modern media, practices, etc. to interact with a perpetually changing audience. In the current essay, the focus is on just one of the analytic elements of intermediality: the use of the same medium by various people to unravel conceptual differences between what I will refer to here as stakeholders, who can include anyone claiming a stake in a land project, from the state to local individual NGOs but also researchers who do not have a direct stake in the land deal but who through their publications (reports, articles, books, etc.) are part and parcel of the mediation processes informing audiences outside the land project and therewith fuelling perceptions and imagined communities of what the local Malagasy are like in the minds of people throughout the world (see also Tsing 2005 and *infra*). As scientists, we need to be fully aware of our substantial responsibility when the 'information' we pass on is being disseminated to audiences we may not even be aware of.

The 'zones of intermediality' model addresses the above problematic, focusing specifically on how diverse, culturally-informed stakeholder approaches to the environment are mediated in the context of foreign large-scale land acquisitions. In 'zones of intermediality' various cultural paradigms and land claims meet on the same playing field, and imperatives of local cultural references, practices and discourses encounter those of external actors. The grid of stakeholder engagement in land deals is anything but static; language, lexicons, positions, and postures are deployed interchangeably and for various reasons. A village elder may draw upon the discourses of an NGO to refer to 'synergies', while a conservation group might frame new utopias to local communities – formerly the arena of politicians or religious leaders. Although signs may have become interchangeable, with various actors using a common terminology, what is signified may be entirely different. The same holds true for researchers rooted in divergent epistemological paradigms.

Intermediality necessarily entails media analysis, partly due to the effective use of media by conservation groups to explain and legitimize their work to audiences far beyond local settings. Conservationists also regularly publish their work in academic journals and other publications. Modern communication tools indeed have become most important in justification models of land projects. The increasing frequency of contacts across social strata and geographical regions has multiplied the veins present in physical, social and ideational landscapes. During our research into foreign large-scale land acquisitions, we have observed and are focussing on analysis of some of these mediated ideologies, discourses and practices as they pertain to land use and valuation. Such information is never a neutral knowledge stream but a mediation coloured by political, ideological and particular interests of the messenger.

To date, the Arena model has been the preferred tool to analyze stakeholder interaction in conservation and development programmes. The model was developed by Norman Long (Long 1989, Long and Long 1992, Arce and Long 2000). Researchers adhering to this model have an actor oriented lens in which they depart from a set of central principles: "agency and social actors, the notion of multiple realities and arenas where different life-worlds and discourses meet, the idea of interface encounters in terms of discontinuities of interests, values, knowledge and power, and structured heterogeneity" (Long 1989: 82). Olivier de Sardan groups this model under the social logic approach with a methodological interactionalism point of departure (reminiscent of Goffman (1959) and Blumer (1986)) and praises the model as a milestone in the Anthropology of Development (de Sardan 2005: 13) while deploring its lack of innovation over the last twenty years.

Our approach is designed to address the dichotomy between local and international conservationists' views. Our aim is to distil complexities of cultural variation and "life-worlds and discourses" within each group of stakeholders: not all villagers or conservationists share ideal-typical discourses and lived-realities. There is considerable variation within such groups, not in the least due to power dynamics which can alter and mutate realities, discourses and practices on a daily basis between people within a certain category. Mediation, however, (agendas, messages and audiences) is highly contextual and conducted through political processes of social navigation (cf. Vigh 2009), imagination and interaction between and within stakeholder groups. The Arena model doesn't sufficiently integrate an analysis of the role of media in the justification, legitimating and implementation of conservation projects.

Tsing (2005) also draws our attention to the problem of juxtaposing stakeholder positions as such groups are the result of what she refers to in her book Friction as 'scale-making': "Scale is the spatial dimensionality necessary for a particular kind of view, whether up close or from a distance, microscopic or planetary. I argue that scale is not just a neutral frame for viewing the world; scale must be brought into being: proposed, practiced, and evaded, as well as, taken for granted. Scales are claimed and contested in cultural and political projects" (Tsing 2005: 58). She gives a particularly pervasive example of 'scale-making' when certain definitions of 'community' (which had often little empirical reality on the ground) were created to meet the eye of the beholder, the funding agency of a forest conservation project in Indonesia. Note that researchers indeed are also engaged in 'scale-making' when they publish on the local groups or 'communities' are described in their publications.

In this regard, Tsing asks: "When 'community' is dreamed up and imposed by outsiders, what happens to local assessments and dreams?" (Tsing 2005: 264). As she aptly points out, village elites (Manggur elders) displayed considerable acumen in assuming the cultural paradigms of the international conservationists running the project: "In their cosmopolitan efforts to connect with powerful outsiders, village leaders may endorse forms of knowledge that are wrong or biased when considered in the context of local practices. Manggur elders have been quite capable in making their stories about the Manggur forest match middle class dreams – and in the process, further their own leadership strategies." Tsing rightly warns us however that such instrumental acquisition and use of knowledge is not just in the air.

Information and ideas do not flow smoothly and not everyone has equal access thereto (cf. Ribot and Peluso (2003) on access theory). Tsing therefore cautions against Manichean over-simplifications of local and global (in the same vein as Mosse (1994, 2005) and Appandurai (1996)): "I find myself doing it. Yet we know that these dichotomies are unhelpful. They draw us into an imaginary in which the global is homogeneous precisely because we oppose it to the heterogeneity we identify as locality. By letting the global appear homogeneous, we open the door to its predictability and evolutionary status as the latest stage of macronarratives. We know the dichotomy between global and local detail isn't helping us. We long to find cultural specificity and contingency within the blob, but we can't figure out how to find it without, once again, picking out locality" (Tsing 2005: 58). Tsing's point is well taken, but it is noteworthy that even the local is often depicted as homogeneous in the 'scale making' process of particular types of research: ranging from 'the locals as victims' paradigm to the 'locals as culprits of environmental destruction' paradigm.

Our analytical tool is designed to research these variations of knowledge, views and practices between stakeholders and within stakeholder groups. Just as local 'communities' are composed of people with varied social realities, economies, political relations, knowledge, views and perceptions, so are other stakeholder groups (cf. Evers 2002, 2006). Researchers indeed are not immune to such realities and the subjectivity, and epistemological rooting of the researcher impacts on what he or she sees in the field and what is eventually written down in the research publications.

To summarize, one of the missions of social science research is to penetrate the deeper understandings (and quantitative implications) of interacting cultural practices and discourses. Griswold (1987, 1992, 1993) convincingly argues that most research fails to deal with the problem of meaning analysis altogether. Mohr (1998) thinks that this can be remedied by an approach similar to ours: "The best rule of thumb in this situation is to locate and evaluate the relevant domain of practical activity in which the identified system of cultural meanings is embedded. Differences in practice produce (and are produced by) differences in meaning. Therefore, the goal of an empirical analysis should be to assess how the various cultural elements are differentially implicated in alternative forms of practice" (Mohr 1998: 366). Thus, land use indeed is the embodied practice of discursive and non-discursive expressions of what for example the value of land is, and what concepts like development, conservation and land mean for the stakeholding individuals.

Odden (2011) provides practical references as to how to research the dissemination of knowledge and views in his article dealing with levelling mechanisms of primary schools on the differential distribution of competence in honorific language. This type of research gives us a tool to delve deeper into meaning structures via for example lexicon tests (which can be also orally). Mohr also takes this approach to heart by reiterating his plea for the practice approach (cf. Bourdieu 1977, 1984): "The argument is that any cultural system is structured as an embodiment of the range of activities, social conflicts, and moral dilemmas that individuals are compelled to engage with as they go about negotiating the sorts of everyday events that confront them in their lives. This insight has direct implications for the measuring of meaning structures." (Mohr 1998: 353) Thus when determining a certain set of key cultural concepts (ideally through anthropological fieldwork), it is crucial to ask how they are related to one another, while assessing the question of what type of practical utility such cultural concepts play within a concrete institutional context. This is crucial information to be able to distil local variation, ideological flows and processes of 'scale-making'.

CONCLUSION

As we are particularly concerned with the role of researchers as mediators about conservation projects, it is important to move beyond simple dichotomies of the local versus international stakeholders because impacts and assessments thereof might be viewed and experienced very differently by local stakeholders. As physical landscape changes so may land practices and assessments. In the same way, ideas of the landscape might evolve as land access and practices change. Analysing land access, practices and mapping meaning of cultural interaction between people coming from varied cultural paradigms, it is crucial that we measure who thinks what and why, and how this impacts on their ideologies, discourses, practices, and navigations in the land projects. We have been assigned the mandate to develop our 'zones of intermediality' model to better track and identify these processes, with a view to designing more effective ways of looking at dispute resolution and mediation. In this essay, I hoped to caution against the lure of clinging to pre-conceived ideological stances at the expense of careful research, which does little to advance the cause of science or to facilitate meaningful dialogue and cooperation between related disciplines. We are confident that our research into 'zones of intermediality' constitutes a step towards avoiding that pitfall while developing a scientific approach to the complex issue of large-scale land acquisitions.

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SPOTLIGHTS

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Debunking three myths about Madagascar's deforestation

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ABSTRACT
After more than three decades of describing, explaining, and tackling deforestation in Madagascar, the problem persists. Why do researchers, practitioners, politicians, and farmers remain perplexed about this problem? This essay offers that our collective thinking of the past three decades has inadvertently perpetuated three myths. The first is that farmers are central agents of deforestation. The second is that the Malagasy state has the capacity and willingness to address the problem. And the third is that Madagascar is unique, especially relative to the rest of Africa. This essay examines each of these established 'truths' in an effort to overcome deforestation and all the degradation – environmental, social, and economic – that accompanies it. It argues that the assumptions behind conservation policies and projects are perpetuated by a class of powerful domestic and foreign individuals whose interests are best served by not questioning their validity. It concludes that fighting deforestation from now on must entail a deliberate, collective effort to question these assumptions and a willingness to open up the thinking to farmers and fellow Africans.

RÉSUMÉ
Le problème de la déforestation persiste à Madagascar et cela malgré les efforts acharnés des chercheurs, des professionnels du développement et de la conservation, des dirigeants politiques et des paysans qui, conjointement ou individuellement, essaient de décrire, d'expliquer et de résoudre ce problème depuis plus de trente ans. Pourquoi restent-ils donc tous désemparés face à ce sujet ? La présente analyse démontre qu'au cours des trente dernières années, nous avons collectivement commis un impair en perpétuant trois mythes. Le premier, selon nous, est d'avoir admis que les fermiers sont les principaux responsables de la déforestation. Ensuite, nous avons crû que l'État malgache avait la capacité et la volonté de remédier à la situation. Enfin, nous avons pensé que Madagascar est différente du reste de l'Afrique. Ce travail examine chacune de ces 'vérités' établies afin de mieux appréhender les problèmes de la déforestation et des dégradations environnementale, sociale et économique qui les accompagnent. Le principal argument est basé sur l'hypothèse qui veut que la politique et les projets de conservation sont défendus par une classe puissante composée à la fois de décideurs nationaux et étrangers qui ne mettent pas en question la validité de ces mythes afin de ne pas desservir leurs propres intérêts. En conclusion, pour combattre la déforestation, il faudra dorénavant remettre en question de manière collective et délibérée ces présuppositions et faire preuve de volonté pour inclure les fermiers et les Africains dans la réflexion.

After more than three decades of fighting deforestation, scholars, foreign donors, politicians, and the public at large remain puzzled as to why the problem persists in Madagascar. The creation of the journal Madagascar Conservation and Development alone attests to the fact that many scholars, domestic and foreign, have invested significant effort, if not entire careers, describing and explaining the issue. Additionally, different Malagasy governments have worked, more or less cooperatively, with foreign donors eager to lend a hand in the pursuit of saving the island's prized biodiversity. As for the Malagasy public, especially forest-dependent farmers who make up a sizeable portion of the island's population, they have adapted their livelihood strategies and living conditions to an ever shrinking resource base as land, forest resources, and water have become scarcer and scarcer for most. In a word, many have, in one form or another, pondered the question of Madagascar's persistent deforestation. Why is it, then, that we remain baffled? The answer is that our collective thinking of the past three decades has inadvertently perpetuated three myths. The first is that farmers are central agents of deforestation. The second is that the Malagasy state has the capacity and willingness to address the problem. And the third is that Madagascar is unique, especially relative to the rest of Africa. These propositions must be re-examined if we want to understand why we have not yet overcome deforestation and all the degradation that has accompanied it.

MYTH 1: DESPERATE FARMERS ARE WRECKING MADAGASCAR'S FORESTS
In Madagascar's history, farmers have often been considered lower-class citizens and they have been treated as such. In the popular discourse, rural dwellers live in remote areas that are hard to reach. To urbanites, they are distant relatives of sorts. Farmers are described as poor and uneducated folks lacking sophistication and the ability to think and act rationally (IFAD 2006). The imaginary line between the world of urbanites (i.e., *les Tananariviens*) and that of rural dwellers (i.e., *les paysans*, or *tantsaha* in Malagasy) has been drawn so many times that

scholars, practitioners, and the public alike have come to think of it as real. This dichotomy has roots in French colonization because the colonial system was designed to identify and privilege *indigènes* most likely to become replicas of French people through a process of assimilation. Since the French colonial headquarters were in Antananarivo, members of the Malagasy-cum-French elite were, for the most part, city dwellers. Consequently, the idea that *les Tananariviens* were different and superior to everyone else in Madagascar was born. Once colonial rule officially ended in 1960, Antananarivo continued to be a prized destination as the island's political and economic capital. Being a *Tananarivien* became a status symbol, one that connoted power and privilege. In this manner, *les Tananariviens* were imagined to pursue life goals different from those of the *tantsaha*. And because the sophisticated and educated were in Antananarivo, it stood to reason, somehow, that rural dwellers were not. Meanwhile, politicians became adept at using the capital vs. rural imaginary fault line to explain, and more often excuse, their failures to deliver political goods to rural areas.

Paradoxically, independent rule in Madagascar has largely consisted of seeking ways to secure foreign support to allow the state to do its job, i.e., provide a measure of security and prosperity to Malagasy citizens. Presenting farmers to foreign donors as a burden or a hindrance to development has been various governments' foolproof strategy to secure aid. Donors have bought it over and over. Of course, one cannot fault politicians for being savvy strategists. Nor can one blame foreigners for reacting to sound bites that validate their claim that assistance is perennially needed. Nowhere is this more apparent than in Madagascar's conservation politics. Exploiting the myth that forest-dependent farmers are incapable of good resource stewardship, various Malagasy governments picture them as poor, ignorant, and multiplying rapidly. In other words, farmers are a hindrance to resource conservation and a threat to development as a whole (Horning 2005). At the same time, representatives of these governments fancy themselves as rational thinkers whose scientific understanding of processes at play best positions them to devise policies, enact laws, and generally analyze the island's deforestation problems in ways deemed scientific. In this way of thinking farmers have little to teach policy makers (Sayer and Campbell 2004). In fact, where and when rural communities are found to be capable of sound resource governance, these communities are portrayed as anomalies!

Undeniably, Madagascar's rural population has swollen in the past fifty years (Index Mundi 2012). Judging from variation in literacy and numeracy rates, access to education is more challenging in rural areas than in cities. Additionally, most rural areas remain out of reach due to the deplorable state of Madagascar's infrastructure. Finally, an increasing portion of the peasantry is experiencing hardship on all measures of development (economic, social, and environmental indicators) (La Gazette de la Grande Île 2012). These are the facts upon which politicians rely when they refer to rural farmers as "trapped in a spiral of environmental degradation" (Repoblikan'i Madagasikara 1990). Yet the scholarship on deforestation, especially tropical deforestation, does not firmly establish causality between demographic pressures and deforestation. Nor is there clear evidence that poverty causes deforestation. Madagascar, in fact, is one of the world's poorest countries, but its deforestation rates are not among the highest on the continent (World Bank 2012). Besides, deforestation patterns vary throughout rural Madagascar: some communities are conserving forests successfully while others are not. If all Malagasy farmers were alike, would we not observe consistent patterns of deforestation throughout rural areas? Since farmers alone cannot be held responsible for deforestation, other culprits must be considered.

Evidence of alarming deforestation where *tavy* is practiced or where poverty is rampant, i.e., in rural areas, is routinely used to convey the gravity of the situation. The problem with concentrating on these snapshots is that doing so distracts from less noticeable yet more devastating practices, ones that involve state actors and private actors keen on profiting from exploiting Madagascar's forests. Even when such practices are denounced or broadcast, the focus is, once again, on villagers who carry out the acts of deforestation. What is easy (or convenient) to miss are two facts: first, villagers are part of the process because public officials and private actors, all acting in their personal interests, rely on them to execute their extraction plans (EIA 2010). Second, not all village farmers are involved in these schemes. Rather, a select few collaborate with outside actors to advance their status locally. Considering that a select few villagers are used, in this context, as tools of deforestation to allow powerful actors – most of whom live in cities – to profit from clearing forests, is it correct to say that farmers are the island's agents of deforestation? A more accurate way to describe and explain deforestation is thus to say that the urban rich and powerful rely on the rural powerless to exploit resources that are supposedly public, i.e., for all to enjoy, for private gain. More often than not, private actors exploit forests with the blessing of state agents who take advantage of their power positions to seek ways to profit personally. The cries against this regrettable collaboration among powerful actors strangely falls on deaf ears whenever there is talk of tackling the problem 'at its source' (Bayart et al. 1999). Instead, politicians routinely propose short-sighted solutions as if unaware of processes at play or struck by attention deficit disorder. And while everyone feigns ignorance or amnesia, forest habitats are destroyed and plant and animal species are disappearing. How much longer can we afford to dance around the truth (Jolly 2009)?

MYTH 2: MIGHTY STATE CAN NEUTRALIZE RECKLESS FARMERS

That the Malagasy state faces chronic challenges in providing public goods and services is an understatement. Statistical and anecdotal evidence abounds to support this claim. Strangely, and despite displaying unmistakable signs of weakness, the state fancies itself as a veritable conservation Goliath, a leviathan of sorts. Forest laws and conservation policies are the clearest manifestation of this illusion of might. In reality, the Malagasy state is a lame leviathan: it hardly controls rural dwellers' behavior vis-à-vis forests. Part of the reason for the state's distorted view of its own capacity relates to the mistaken belief that it is omnipresent. Yet, throughout the island, peasants notice the state for its absence in or poor quality of service delivery, especially in health care and education but also in agricultural extension. The state's prolonged absence in remote areas has been disrupted only by occasional appearances in various forms of abuse and extortion, ranging from tax collection and forced labor recruitment in the colonial era to punishment, intimidation and bribe extraction since independence. As far as farmers are concerned, the state has muscles, but it flexes them in ways that hurt rather than help them live a decent life (Englebert 2009). As a consequence, villagers think it is best to avoid the state.

Lucky for them, farmers are by default autonomous since agents of the state show up in their territories sporadically, if at all. Farmers know this well. So, what do they do to protect the natural resources and meet their food, shelter, and health needs? They devise strategies to conserve forests by skillfully incorporating elements of forest legislation into their own systems of rules and norms regarding proper behavior vis-à-vis forest resources. Notwithstanding occasional rule enforcement, which usually amounts to extortion sprees, the state and its laws are largely irrelevant to forest-dependent farmers. More realistically, the institutions that govern forest access and utilization are hybrids of formal and community-devised rules. And the most effective guardians of the forest are village communities, not the state. In fact, there are multiple instances where village communities protect forests, more or less successfully, against the intrusion of state-sanctioned agents of deforestation such as logging and mining companies. In other words, forest conservation happens despite the state, not thanks to it.

Considering the physical and psychological gap that separates the state from farmers (or the center from the periphery), it is puzzling that conservation models and projects are predicated on the assumption that decisions made at the national level (e.g., conservation laws) affect those made at the local level (farmers' behavior vis-à-vis forests), and vice versa. In reality, these two levels of conservation politics function in parallel, mostly disconnected ways that preclude the development of a symbiotic relationship whereby one level needs the other to function properly (Horning 2008a). Madagascar's national environmental politics are concentrated in Antananarivo and other world capitals, and they lock politicians and foreigners in a relationship of mutual dependency (Horning 2008b). At this level the state and its foreign partners negotiate the place of environmental conservation in the country's development strategies (Corson 2012). Through this process state sovereignty is compromised, but the state does not see this as harmful to its capacity and legitimacy. Hence its insistence that it has a key role to play in protecting the island's forests against its rural citizens.

Another realm of conservation politics exists at the community level. Here the rules governing forest access and uses are negotiated within communities and between communities and external actors including private interests and select representatives of the state. At this level compliance decisions reflect careful, not reckless, calculations that farmers make regarding when, how and how much to use forest resources. Three key factors motivate farmers' compliance decisions: whether (i) they perceive rules and rule enforcers to be legitimate, (ii) rule enforcement is predictable and consistent, and (iii) social cohesion is strong enough to overcome collective action problems (estimated by the degree to which local leaders are deemed legitimate).The state thinks that it has a full role to play in the first two factors because, in the minds of those who represent it, forest legislation applies (as is) and the state has the monopoly of rule enforcement. Evidence from resource-dependent communities points to the fact that both assumptions are wrong: communities go by rules-in-use that combine formal and community-devised rules and, especially where there is cohesion, they rely on their local capacities to enforce these rules. Given this reality, it is baffling that the state and its conservation partners stubbornly think that the state is in control of conservation.

MYTH 3: MADAGASCAR IS UNIQUE

In many ways, Madagascar is like no other place on earth. In terms of cultural makeup and biological richness alone, the island is undeniably unique. This uniqueness is touted and exploited to draw attention to the island's deforestation and threats to its exceptional biodiversity. Equally highlighted is the island's lack of means to tackle its own problems, invariably accompanied by pleas for outside help (Marcus and Kull 1999). External support has, so far, taken two principal forms: technical, because somehow everyone in charge assumes that the West has the knowhow, and financial because the West has the financial means to come to Madagascar's rescue. In the African context this story is disconcertingly familiar, and it strongly suggests that Madagascar's politics are anything but unique.

As it turns out, Madagascar and at least two East African countries have more in common than meets the eye. In the three countries the politics of deforestation play out at two main levels: national, where politicians and donors negotiate development policy priorities, and local, where village communities, on one hand, and public and private actors, on the other, vie for forest control. Admittedly, this sample is small, but research African colleagues and I conducted in Madagascar, Tanzania, and Uganda from 1998 to 2009 includes 170, 120, and 585 respondents from individual households, respectively. The surveys reveal that farmers across the three countries experience similar environmental challenges and react similarly to rules regulating their access and uses of forest resources.

Why does it matter that Madagascar is like the rest of Africa when it comes to its conservation politics? The reason is simple: those facing similar challenges, constraints, and opportunities are more likely to solve common problems by working together than by ignoring each other or, worse, working against each other. When African countries compete for the world powers' attention and resources, essentially they compete against each other. Inadvertently, they fall into insularism, which is the kind of thinking that precludes comparative analysis where it is both appropriate and necessary. This is not just counter-productive, it is dangerous because it reinforces divisions among us Africans and it leaves us vulnerable to foreign domination. Such words may read like a rant against neo-colonialism or environmental imperialism. This is not this essay's intention. Rather, it is an invitation to work collaboratively by opening our 'thinking club' to farmers (Keller 2009) and fellow Africans.

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ARTICLE

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A survey of cardinalfish (Apogonidae) of Antsiranana Bay, northern Madagascar

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ABSTRACT

The cardinalfish of Antsiranana Bay, northern Madagascar, were surveyed over an 11 month period by underwater census employing a simple search pattern using self-contained underwater breathing apparatus. Over this period 15 species were observed including one species not previously recorded in Madagascar, *Siphamia versicolor*. Whilst some species were ubiquitous across sites within the bay others appeared only as single records. Cardinalfish communities were compared between sites within the bay using PRIMER 6 (Plymouth Routines In Multivariate Ecological Research) and on a national scale against existing records. Overall the species richness of cardinalfish in Antsiranana Bay is less than that observed in other regions of Madagascar. The reasons behind these regional variations include oceanic currents, temperature, depth, disturbance and sedimentation, a recognised threat to Madagascar's marine communities. This final point was reaffirmed by comparison of cardinalfish communities between sites within the bay which revealed little variation in species composition between sites, with the exception of highly-sedimented sites in the north-east of the bay that had a significantly different cardinalfish fauna to the rest. As a family that rely on the complexity of the coral reef for shelter, and exhibit high site fidelity, examination of cardinalfish communities may provide a measure of the health of a region's reef.

RÉSUMÉ

L'inventaire des poissons de la famille des Apogonidae de la baie d'Antsiranana, dans le Nord de Madagascar a été réalisé au cours d'une période de 11 mois sous forme d'un recensement sous-marin utilisant un modèle de recherche simple en plongée en scaphandre autonome. Au cours de cette période, 15 espèces ont été observées, dont une espèce qui n'était pas encore connue de Madagascar, *Siphamia versicolor*. Alors que certaines espèces étaient omniprésentes dans tous les sites de la baie, d'autres n'ont été relevées qu'une seule fois. Les communautés d'Apogonidae ont été comparées entre les sites de la baie à l'aide de PRIMER 6 (*Plymouth Routines in Multivariate Ecological Research*) et avec d'autres données existantes à l'échelle nationale. Dans l'ensemble, la richesse en espèces d'Apogonidae dans la baie d'Antsiranana est inférieure à celle observée dans d'autres régions de Madagascar. Les raisons de ces variations régionales peuvent être expliquées par les différences relevées sur les courants océaniques, la température, la profondeur, les perturbations et la sédimentation, cette dernière étant une menace reconnue pour les communautés marines de Madagascar. La sédimentation est ressortie dans la comparaison des communautés d'Apogonidae entre les sites de la baie qui a révélé peu de variation dans la composition des espèces entre les sites, si ce n'est que les sites présentant une sédimentation importante dans le Nord-est de la baie abritaient une faune différente des autres sites. Les Apogonidae ont besoin de trouver refuge dans la barrière de corail pour s'abriter et montrent ainsi une fidélité élevée aux sites ; l'étude des communautés d'Apogonidae peut ainsi constituer une mesure de l'état des récifs d'une région donnée.

INTRODUCTION

Cardinalfish (Apogonidae) form a major component of many coastal fish assemblages, both in terms of species diversity and numerical abundance (Allen 1993). Although small in size, they form a major component of the coral reef fish community due to their high abundance (Vivien 1975). Despite their prominence on reefs, cardinalfish remain one of the least studied of the major families of reef fishes (Marnane and Bellwood 2002). Cardinalfish, which feed almost exclusively on invertebrates, are important prey for large piscivorous fish such as Serranidae, Scorpaenidae, Mullidae and Muraenidae (Vivien 1975, Chave 1978) and as such are an integral component of the reef food chain. Furthermore, as cardinalfish feed nocturnally in a range of habitats and return to restricted sites during the day, they play an important role in concentrating nutrients and energy on reefs (Marnane 2000, Marnane and Bellwood 2002).

The objectives of this study were to (i) record the species of cardinalfish present in Antsiranana Bay, (ii) compare the species in Antsiranana Bay to other regions of Madagascar, (iii) examine patterns in the distribution of cardinalfish within the Bay, and (iv) investigate the relationship between cardinalfish communities and environmental variables.

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MATERIALS AND METHODS

STUDY AREA. Antsiranana Bay is situated in the northernmost part of Madagascar, adjacent to the town of Antsiranana (formerly known as Diego Suarez). The mouth of the bay is at its eastern side, opening into the Indian Ocean (Figure 1). The bay has a variety of coral reef habitats from pristine reef to highly-sedimented areas, impacted by a variety of natural and anthropogenic factors (Browne et al. 2007). The bay experiences variable and severe wind-induced wave action caused by cyclones of varying strengths on a regular basis, and the impact of these can be observed on the coral; exposed sites possess a high percentage cover of fragmented coral and coral rubble, in particular of digitate coral forms (Jabbal et al. 2010). The bay supports an artisanal fishery, as well as a low level of tourist activities (Narozanski et al. 2011). The bay has several industrial uses; Antsiranana town has a fish canning factory, there are extensive salt pans in the south-west of the bay, and it is an important trading port (Cooke et al. 2001).

Sites were selected to provide the most comprehensive coverage practicable in the accessible part of Antsiranana bay. The criteria used in site selection were: (i) Seabed type: based on existing records of habitat type (Browne et al. 2007, Jabbal et al. 2010, Frontier unpublished data) sites were selected that represented the range of benthic conditions present within the bay. (ii) Orientation: sites were selected based on their location relative to the landmass, in order to obtain as comprehensive a spread as practicable. (iii) Practical limitation: sites were only selected that were within recreational dive limits and could be accessed on a regular basis.

SURVEY METHODOLOGY. Between August 2008 and June 2009, Scuba (self-contained underwater breathing apparatus) surveys were carried out in Antsiranana Bay to record cardinalfish presence. Fifteen reef sites were surveyed (Figure 1), which varied in their physical characteristics. Persistent north-easterly winds mean that sites 1–2 and 10–15 are exposed to greater wave energy than the sites close to the northern shores (3–9), which are sheltered by the landmass. The impact of these waves and additional episodic cyclone impacts have left southern shore sites with a higher percentage of coral rubble than the northern shores. As is the case in many Malagasy inshore waters (Cooke et al. 2001), sedimentation as a result of terrestrial activities occurs within the bay, with the more sheltered northeasterly sites 8 and 9 being particularly affected. Each site was visited at least three times over the study period. At each survey site, an area of approximately 800 m^2 was searched for a period of 45 minutes. During this time, the species of cardinalfish observed were recorded. At each site notes were made of the habitat types present. Species were identified *in situ* based on pictorial and photographic references (Froese and Pauly 2000, Lieske and Myers 2002, 2004, Allen and Steene 2007) and literature of apogonid systematics was consulted (Gon 1996, Greenfield et al. 2005, Fraser 2008, Fricke et al. 2009, Fraser and Allen 2010). The taxonomic classification used here follows Eschmeyer (2011). Those species that were not easily identified *in situ* were collected by hand net, using clove oil anaesthetic. These individuals were photographed and morphometric measurements and meristic counts were made before being returned

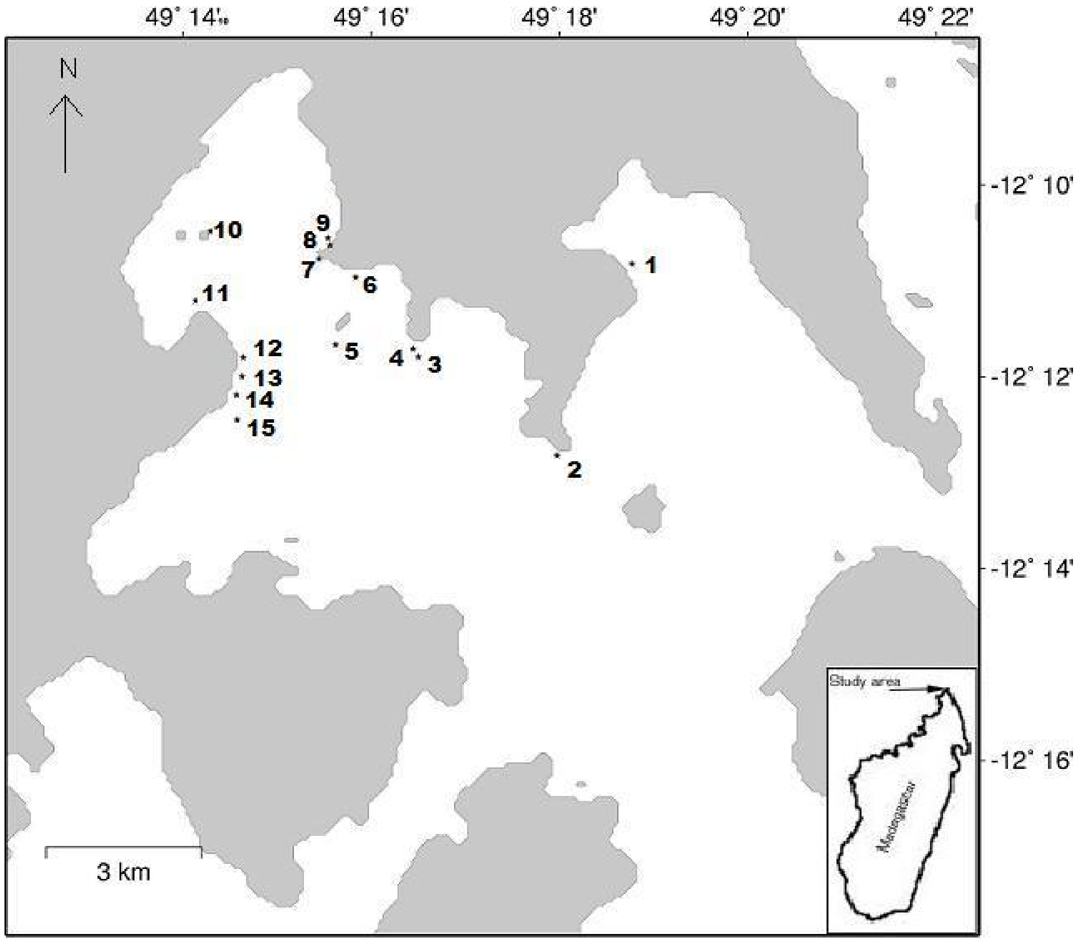

FIGURE 1. Antsiranana Bay showing location of survey sites. Landmasses are shown in grey.

TABLE 1. Mean estimated abundance of cardinalfish at 15 survey sites. Abundance scale: 1= <10, 2 = 10-50, 3 = 50-100, 4 = 100-200, 5 = 200+.

	Site															Abundance at sites where species present	Abundance across all 15 sites surveyed
Species (ranked by number of sites at which species were recorded)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Cheilodipterus quinquelineatus	3	2	3	3	3	3	4			2	3	2	2	3		frequent	occasional
Apogon fragilis	1						4	5	4	1	1				1	occasional	rare
Archamia fucata		2					2			1	1			2		occasional	rare
Siphamia versicolor			2	1				2	2					1		occasional	rare
Cheilodipterus artus	1	2	1		1							2				rare	rare
Apogon thermalis								3	3							frequent	rare
Apogon aureus				2			3									frequent	rare
Apogon cyanosoma					1	1								1	1	rare	rare
Apogon leptacanthus	1										1			2		rare	rare
Apogon savayensis		2										2				occasional	rare
Cheilodipterus macrodon			2				1									occasional	rare
Apogon angustatus					1			1								rare	rare
Apogon fraenatus														1		rare	rare
Apogon kallopterus							1									rare	rare
Apogon taeniophorus	1															rare	rare
Species richness	5	4	4	3	4	2	6	4	3	3	4	3	1	5	2		

alive to the locality from which they were removed. Voucher specimens were not collected.

At each site the number of individuals of each species per 800 m^2 was estimated. Due to the highly territorial nature of cardinalfish and the uniform search pattern employed in the underwater survey, the chance of double counting of individuals was minimised. In some locations, however, cardinalfish were so populous that an absolute count would have been impossible using only visual census, therefore an estimate of abundance, i.e. estimated number of individuals of each cardinalfish species per site was recorded on an arbitrary ordinal scale. The results of repeat surveys at each site were averaged and the rounded means used in the consequent analysis.

DATA ANALYSIS. PRIMER 6 (Plymouth Routines In Multivariate Ecological Research) was used to examine the between-site community variation. PRIMER employs univariate, graphical and multivariate methods to analyse species abundance data in biological monitoring of environmental impacts and show community structure (Clarke and Gorley 2006). In this study we used SIMPEROF, a methodology that identifies the species primarily providing the discrimination between two observed sample clusters. Initially, a pre-treatment was carried out on the data set; a square root transformation was applied to the data in order to downweight any dominant contributions of particularly abundant species in samples (Clarke and Gorley 2006). A resemblance matrix was then produced to show the similarities between pairs of samples using Bray-Curtis similarity; a step necessary prior to any further analysis. Bray-Curtis similarity is the most commonly used similarity coefficient for biological community analysis, as it reflects differences between samples based on community composition and total abundance (Clarke 1993). A CLUSTER dendrogram was produced, showing the hierarchical clustering of samples going into smaller numbers of groups as their similarity to each other diminish

FIGURE 2. *Siphamia versicolor* with *Diadema setosum*. Photograph taken at a shallow sandy site (Site 9) where *Diadema* provided the majority of cover.

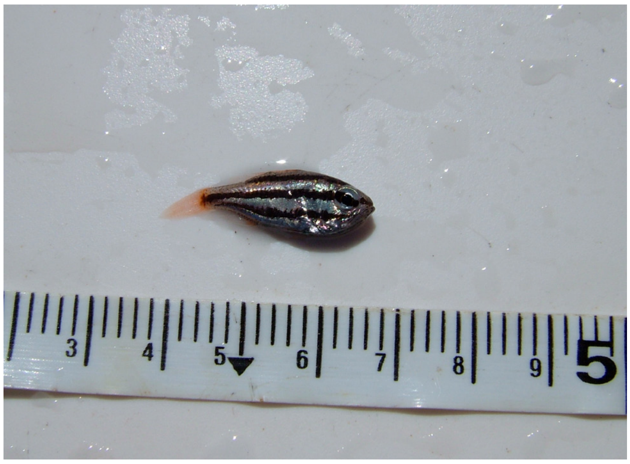

FIGURE 3. *Siphamia versicolor* (same individual as Figure 2). The cardinalfish appears to be red-black in colour until stressed when the lines become visible.

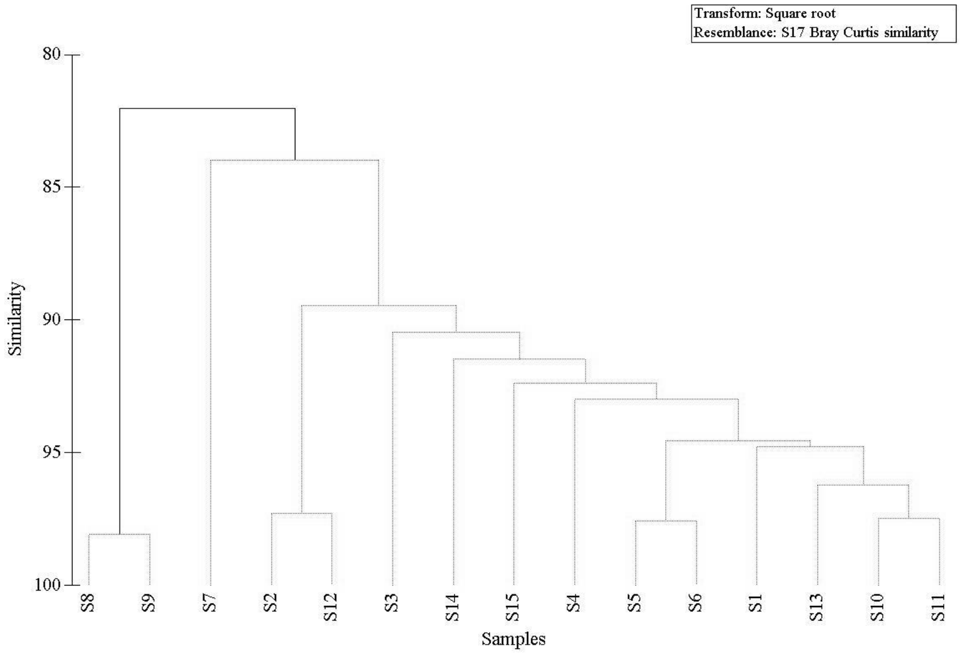

FIGURE 4. SIMPEROF analysis, carried out in PRIMER 6, showing relatedness of cardinalfish communities at the 15 study sites. A figure of 0 indicates no similarity between communities, and 100 indicates identical communities. A continuous black line indicates a significant difference.

(Clarke and Gorley 2006). A SIMPEROF test was applied to the cluster to show the statistical significance of the groupings.

RESULTS

SPECIES RECORDED. Fifteen species of cardinalfish were recorded in the course of this study (Table 1). Of these no previous records exist, to the authors' knowledge, of *Siphamia versicolor* in Madagascar.Individuals of the taxon thought to be *Siphamia versicolor* were recorded amongst the spines of the long-spined sea urchin *Diadema setosum*. They were a dark red-black colour and very well camouflaged amongst the *Diadema*'s spines (Figure 2); when stressed or captured, however, they became lighter and revealed three thick dark stripes on a silver body (Figure 3). They were observed across the bay in the presence of *Diadema* but distribution and abundance were probably underestimated due to their cryptic nature.

SPECIES DISTRIBUTIONS WITHIN ANTSIRANANA BAY. Within Antsiranana Bay there was considerable between-site variation in species composition (Table 1). *Cheilodipterus quinquelineatus* was the most widespread species, occurring at nine of the 12 sites, followed by *Apogon fragilis* that was recorded at seven sites. Three species were recorded only once across all sites: *Apogon fraenatus*, *A. kallopterus* and *A. taeniophorus*. Community structure was complex with in most cases overlap between species and sites: SIMPEROF analysis revealed that whilst in most cases there was a generally high level of similarity between cardinalfish communities within the bay (Figure 4). The communities of sites 8 and 9 were significantly different from those of the rest of the sites.

DISCUSSION

Fifteen species were recorded in Antsiranana Bay including *Siphamia versicolor*. The discovery of this species in Antsiranana Bay is surprising as its distribution is described as Indo-West Pacific from the Maldives to northwestern Australia (Froese and Pauly 2000); if confirmed, this record therefore extends its westerly distribution. The number of species recorded was lower in Antsiranana Bay compared to 21 in northwest Madagascar (McKenna and Allen 2005) and 20 in Toliara, southwest Madagascar (Vivien 1975) (Supplementary Material). Seven species were common to all three regions; *Apogon angustatus*, *A. cyanosoma*, *A. fraenatus*, *A. kallopterus*, *Archamia fucata*, *Cheilodipterus macrodon* and *C. quinquelineatus*. Antsiranana Bay and northwest Madagascar have the highest percentage of species in common (31 %), followed by the two western sites (24%) and Antsiranana Bay and southwest Madagascar, which share the least common species (20 %).

Madagascar waters are dominated by a single current system derived from the south equatorial current (SEC) whose waters encircle much of Madagascar with a quasi-permanent gyre centred to the south of the Comoros which links the waters of northwestern Madagascar with Mozambique (Cooke et al. 2001). However, although dispersal mechanisms are in place, cardinalfish communities around the island are not homogenous as environmental parameters shape the species present. These parameters could include temperature, depth, disturbance and sedimentation.

Madagascar straddles almost 14^{o} of latitude, with mean annual open-water surface temperatures ranging from 22–28 ^{o}C, and reaching extremes of 19^{o}C in Toliara lagoons during winter (Cooke et al. 2001). The difference in shallow-water assemblages of the north and south has been attributed to this large water temperature range; Cooke et al. (2001) observed that coral reef communities of Nosy Be, (within the northwest Madagascar study area of McKenna and Allen (2005)) and Toliara are visibly different, despite no systematic scientific comparison having been made. Results of the present study are consistent with this assertion.

However, despite being on similar latitude, there is still a considerable difference between the northwest community and that of Antsiranana Bay, which may be in part attributed to wind-induced wave action. Previous studies (Vivien 1975, Chave 1978, Greenfield and Johnson 1990) identified high wave energy as a limiting factor in cardinalfish distribution. Ralinson (1991) recorded the differences in winds between coastal regions; Toliara experienced the greatest number of days with winds less than 10 km.h^{-1} (337 days), Nosy Be had 220 days, whilst Antsiranana had only 19 days. The impact of the winds in Antsiranana Bay is considerable with waves of up to 2 m experienced during the windiest months of June, July and August (pers. obs.). Furthermore, cyclones have an episodic impact on Madagascar. These disturbances have been shown to affect the coral community structure; Done (1992) and Lewis (1998) showed specifically that cardinalfish are amongst the species affected by cyclones; These studies showed changes in species and numbers of individuals present following cyclonic events. Cyclonic or severe wind-induced wave action can result in physical damage to, and resultant death of, live coral (Lewis 1998). In northwest Madagascar the ratio of live to dead coral is around 5:1 (Webster and McMahon 2002) whilst in Antsiranana Bay the ratio of live coral to coral rubble is 2:3 (Jabbal et al. 2010) Although it is possible that in the period between these studies a bleaching event may have produced the observed reduction in live coral, there is no record of such an event in the available literature. The vulnerability of corals to physical damage varies between species, yet digitate forms are most impacted (Rousseau et al. 2010), and cardinalfish are most strongly associated with these forms (Gardiner and Jones 2005).

Depth is another important determinant in all marine communities and one that has been shown to influence cardinalfish distribution, including that of the five most abundant species recorded in Antsiranana Bay (Greenfield and Johnson 1990). Although Antsiranana Bay reaches depths in excess of 30 m in places, it has relatively shallow coral reefs, rarely deeper than 10 m, beyond which the seabed is barren sand. In comparison, Vivien (1975) surveyed the Toliara reefs to a maximum of 60 m and McKenna and Allen (2005), in northwest Madagascar, to 40 m. It may therefore be hypothesised that the lower diversity within Antsiranana Bay is due to restricted depth. However, of the 29 species not found in Antsiranana Bay only two, *Fowleria aurita* (in the northwest) and *Apogon flagelliferus* (in the southwest) were recorded exclusively outside the depth ranges surveyed in Antsiranana Bay.

Although the 15 study sites within Antsiranana Bay are relatively closely situated, there is still a variation in the cardinalfish community between them. Within the bay, the most prominent difference, highlighted by the SIMPEROF analysis between cardinalfish populations, was between the sites in the sheltered, heavily-sedimented northeastern section of the bay and the remainder of the sites. The impact of sedimentation in structuring reef communities has been recorded in Madagascar (Cooke et al. 2001) and worldwide (e.g., Mallela et al. 2007). Cardinalfish are active by night, returning to shelter within the reef by day (Marnane and Bellwood 2002). Gardiner and Jones (2005) showed cardinalfish to be strongly associated with live digitate corals; this characteristic, coupled with their strong site fidelity (Marnane 2000), makes cardinalfish a group of fishes vulnerable to loss of habitat complexity. The fact that increased sedimentation reduces the number of reef fissures, which provide cardinalfish with daytime refugia, could explain why in heavily-sedimented areas the cardinalfish population is limited both in total numbers, due to a reduction in available space, and in diversity, supporting only those species tolerant of shelter provided primarily by *Diadema setosum* urchins. As a consequence, observation of cardinalfish may prove a useful tool in monitoring the health of coral reef communities.

The next course of action should be the collection of voucher specimens to validate the identifications made herein, particularly that of *Siphamia versicolor*, an unexpected finding. The comparison between the communities would be greatly enhanced by a contemporary survey of the Toliara reefs of southwest Madagascar. This would also provide an interesting test of the hypothesis that sedimentation alters cardinalfish communities as these reefs have been subjected to heavy sedimentation since the time of Vivien's 1975 census (Cooke et al. 2001).

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SUPPLEMENTARY MATERIAL.

AVAILABLE ONLINE ONLY.

SUPPLEMENTARY MATERIAL S1: Species recorded in three regions of Madagascar.

ARTICLE

http://dx.doi.org/10.4314/mcd.v7i3.5

Geoconservation and geodiversity for sustainable development in Madagascar

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ABSTRACT

Madagascar is well known for its unique and rare natural beauty, and it is one of the biodiversity hotspots for conservation priorities. Many efforts have been made for the protection of biodiversity, yet initiatives towards the conservation of geodiversity are often neglected. Geoconservation refers to the conservation of geological diversity or geodiversity, and it is often applied to a specific location, known as a geosite, where important earth features (geological, paleontological, geomorphological, hydrological and pedological) are protected, preserved and managed. Madagascar is very rich in natural resources and has many spectacular geological features, such as the beautiful gorges and canyons of Isalo, Tsingy de Bemaraha, Ankarana caves, hot springs and volcanic lakes of Itasy, all of which should be conserved and protected by local authorities, the private sector and local communities. Such initiatives can not only help to maintain and protect geological sites of particular importance, but also contribute to sustainable economic development. This essay aims to introduce geoconservation and sustainability in Madagascar, and to increase public knowledge and awareness of geodiversity and its conservation. The creation of geological tourism sites or geoparks is undoubtedly one of the most important steps to promote the conservation of geosites, and the promotion of earth science education should help expand and consolidate their protection.

RÉSUMÉ

Madagascar est renommée pour la beauté exceptionnelle de sa nature qui est unique. L'île est classée parmi les sites stratégiques nécessitant la mise en place de politiques de conservation de la biodiversité. Malgré les efforts déployés par les protecteurs de la nature au cours des dernières années pour la conservation des écosystèmes, la géoconservation demeure un nouveau concept de conservation qui est méconnu par la plupart des Malgaches. La géoconservation se réfère à la conservation de la diversité géologique ou géodiversité, qui s'applique généralement à un endroit spécifique désigné en tant que géosite, dans lequel on reconnait des éléments et des dispositifs géologiques importants qui méritent d'être protégés, préservés et gérés comme par exemple dans les domaines de la paléontologie, la géomorphologie, l'hydrologie et la pédologie. La géodiversité de Madagascar compte parmi les plus spectaculaires au monde, allant des rares gisements de minéraux à des paysages et des reliefs spectaculaires, en passant par de belles plages et des grottes qui sont autant de richesses qui pourraient être classées en tant que patrimoine géologique mondial. Face à la dégradation rapide de la géodiversité à Madagascar, il est urgent d'adopter une politique efficace de géoconservation de nombreux sites au profit de la population locale, qui devra aussi permettre de donner un coup de pouce au progrès vers le développement durable du pays.

INTRODUCTION

In the developing world economic growth depends largely on natural resources, and Madagascar is no exception. Madagascar, the world's fourth largest island, lies in the Indian Ocean approximately 400 km off the southeast coast of Africa and is well known for its unique and rare natural beauty (Ganzhorn et al. 2001, Goodman and Benstead 2003, Mittermeier et al. 2004). In Madagascar, nature conservation has been understood as biodiversity conservation (Myers et al. 2000, Rogers et al. 2010), despite the fact that the natural environment includes both biodiversity and geodiversity; both are equally important. Very little, if any, appears to have been done or said about the conservation of geological features and landforms in Madagascar. In fact, because of the strong focus on biodiversity, the importance of geodiversity has been 'pushed aside'. However, geology is a fundamental part of nature and much of the surface biodiversity relies on the underlying soil and rock. In this sense the variety of non-living nature, 'geodiversity', which consists of a wide range of processes, environments and evolution, strongly supports the variety and robustness of biodiversity. As such, geodiversity should be considered carefully for successful nature conservation to be achieved (Semeniuk 1997).

In many developing countries where millions of people are still living in poverty, governments often integrate or try to adopt the principles of sustainable development as a new paradigm for development and poverty eradication. Since most of the population are uneducated or under-educated, the developing world is forced to depend largely on natural capital such as the Earth's resources (e.g., water, land, minerals, oil) and biodiversity. Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987) and it includes safeguarding and managing natural systems for future generations. Over the last decade, Madagascar has increased its knowledge and awareness of conservation. However, appropriate management strategies are still needed to reflect 'Malagasy' cultural philosophy and to ensure the maximum survival of wildlife, landscapes and landforms. Given the limited work and cooperation between current biodiversity conservationists and Earth scientists, it is important to integrate and bond wildlife and geological conservation, for instance, by proposing geoconservation in protected areas that are already recognized by local authorities and the people who live and work in such areas. Madagascar has numerous protected areas (Figure 1) managed by the Malagasy government through associations or by private and non-governmental organizations (Jenkins 1990, Madagascar National Parks 2011). Madagascar National Parks (formerly known as ANGAP or *Association Nationale pour la Gestion des Aires Protégées*) manages 48 protected areas, which include 6 Strict Nature Reserves, 19 National Parks and 23 Special Reserves (Madagascar National Parks 2011).

Earth resources help to fill many human needs which, through time, have become greater. They are used in industry as raw materials (e.g., iron, nickel, chromite, copper) (Figure 2), in construction (e.g., granite, aggregates), as energy sources (e.g., coal, oil) and in making products ranging from women's make-up to home decorations. Madagascar has diverse Earth resources ranging from the extremely rare (e.g., gemstones, landforms like the *tsingy*) to the abundant (e.g., laterite, rivers) upon which biodiversity is linked. Because Earth resources are non-renewable and are limited, they must be used wisely and their conservation should be included in any natural conservation policy. The map in Figure 2 shows the distribution of a few of Madagascar's mineral resources, fossils and fossil-fuel; these may or may not be included in protected areas.

This article is written to initiate and to increase public awareness of geoconservation and geodiversity in Madagascar, and to give background information on geoconservation, geodiversity and geosites, and why they are important. Furthermore, the paper describes some of the critical threats to Madagascar's geodiversity and illustrates the steps leading up to their conservation. It is our hope to develop geoconservation in Madagascar and take action to conserve significant, unique and rare geodiversity in order for it to contribute to the sustainable development of the country.

GEOCONSERVATION, GEODIVERSITY AND GEOSITES

The meaning of the word 'geoconservation' might be seen as self-explanatory, however, several definitions do exist (Sharples 1995, 2002, Prosser 2002, Gray 2004). Geoconservation was defined as the conservation of geodiversity for its intrinsic, ecological and (geo)heritage values (Sharples 1995). More recently, the conservation of Earth features (geodiversity), such as geological features (bedrock, minerals, fossils), geomorphological features (landscapes, landforms), hydrological features (rivers, lakes) and pedological features (soil), and the maintenance of natural rates and magnitudes of change in those features and processes are defined as geoconservation (Sharples 2002). Geoconservation was also defined as the "protection and management of geological sites, areas and specimens for scientific research, education and training, where appropriate, popularization of the Earth's history for a wider public and promotion of

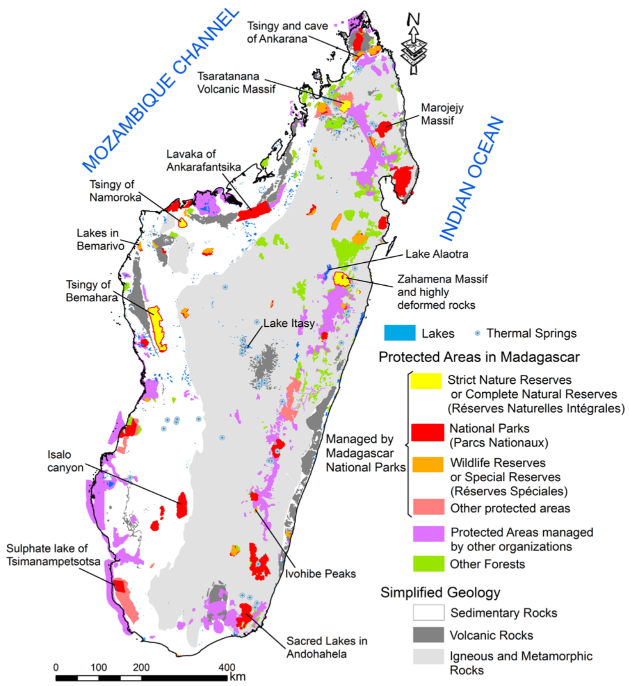

FIGURE 1. Extent and distribution of Protected Areas overlaying a very simplified geological map with lakes and thermal springs locations. The potential areas for geoconservation are labelled; these areas are considered to be at risk and need an immediate attention. Compiled from Foiben-Taosarintanin`i Madagascar BD500 (1998) and BD 200 (2001), Système des Aires Protégées de Madagascar data (2011), and Madagascar National Parks (2011).

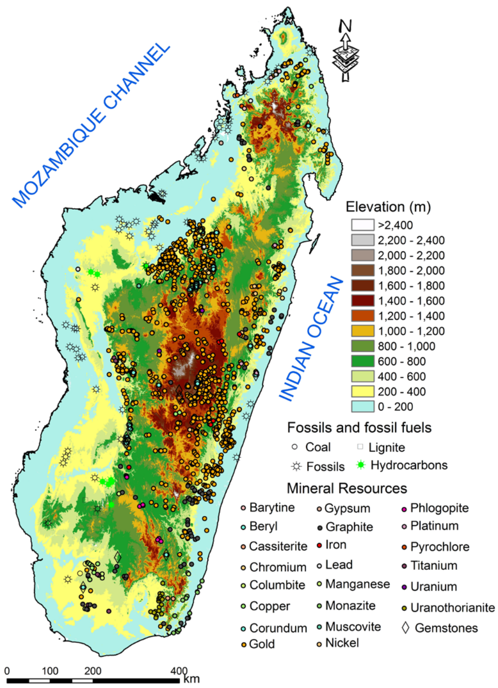

FIGURE 2. Digital Elevation Model of Madagascar computed from Shuttle Radar Topography Mission (SRTM) data showing the topography of the island, together with location of selected mineral resource commodities. Data compiled from Lacroix (1921–1923), Besairie (1964, 1968), Peters et al. (2003), Base de Données pour la Gouvemance des Resources Minérales (2005) and BGS-USGS-GLW (2008).

good conservation practice" (ProGeo 2011). Generally speaking, it can be defined as the intent to conserve, monitor and enhance geological and geomorphological features, processes, sites and specimens (Burek and Prosser 2008).

Areas with specific and significant Earth features are called 'geosites' (geological sites), which may vary in size from a square meter to thousands of square kilometers, and can be very sensitive to human activities. Due to the natural diversity of geological, paleontological, hydrological, geomorphological and soil features, the term 'geodiversity' was introduced by a variety of authors including Sharples (1993), Dixon (1995), Kiernan (1997) and Osborne (2000), and includes their assemblages, properties, relationships, interpretations and systems (Gray 2004). When a geosite is promoted for tourism purposes (geotourism), it becomes a 'geopark'. Geological heritage or 'geoheritage' defines an important geosite that is considered to be of educational, scientific, research, recreational, aesthetic or inspirational value to humans (Legge and King 1992) and need conservation (Osborne 2000).

GEOCONSERVATION AND GEODIVERSITY IN MADAGASCAR

In Madagascar, geoconservation is still in its preliminary stages and it can be considered as a new concept to local authorities and the public. Public awareness of geoconservation depends largely on the educational background of the public. The successful practice of geoconservation will also depend on legislative, political and administrative support from local government. Madagascar's economy is still struggling (BTI 2012) and crippled by the political crisis, and funding and support from international and non-governmental organizations are therefore necessary and unavoidable.

The main island of Madagascar is 587,041 km^2, running 1,577 km from north to south, 600 km from east to west and containing an area of 0.63 x 10^6 km^2 of continental crust. Two thirds of the island is underlain by deformed and metamorphosed Precambrian crystalline basement rocks (>540 Million-years), with the western part covered by a Phanerozoic sedimentary sequence (Devonian-Quaternary) and minor recent volcanic formations (Cretaceous-Quaternary), which have also intruded the central and southeastern parts of the island (Figure 1) (Besairie 1964, 1968). Madagascar was broken up from Gondwana in two distinctive stages, it separated from East Africa ~ 160 million years ago, and broke away from India and the Seychelles between 90–66 million years ago (de Wit 2003, Yatheesh et al. 2006).

Madagascar has a remarkably rich geodiversity that includes exceptional landforms (karst peaks and needles, caves, bays) (Guilcher 1965, Vogt 1965, Duflos 1966, Wilson 1990); rare minerals (betafite, behierite, manandonite) (Lacroix 1921–1923, Behier 1960, Hogarth 1977, Ranorosoa et al. 1989); outstanding gemstones (emerald, ruby, sapphire) (Schwarz and Henn 1992, Rakotondrazafy et al. 2008); considerable industrial non-metallic and metallic ore-deposits (gold, copper, nickel, ilmenite) (Besairie 1964, 1968, BGS-USGS-GLW 2008, OMNIS 2012); fossils (dinosaurs, ammonites, petrified wood) (Boule and Thevenin 1906, Collignon 1962); spectacular structures (canyons, folds and faults) (Guilcher 1965, Arthaud et al. 1990); distinctive hydrological features such as deltas (e.g., Betsiboka delta), fast-flowing rivers passing through spectacular landscapes (Chaperon et al. 1994), volcanic craters lakes (e.g., Lake Tritriva), thermal springs and waterfalls, not to mention the diverse landscapes of rainforest, coral reefs, beaches, and striking mountains and peaks (e.g., Marojejy, Ankaratra, Maromokotra) (Madagascar National Parks 2011).

One of the landforms sculpting the landscape of some protected areas in Madagascar (e.g., Bemahara, Namoroka, Ankarana) is the *tsingy*, unique and spectacular karst limestone formations which consist of ragged, razor-sharp pinnacles (Rossi 1983, Salomon 2006, Veress et al. 2008, 2009). As with typical karst landscapes, the *tsingy* is associated with caves and underground drainage systems such as streams and rivers. These features are largely the result of surface and subterranean erosion. The ragged razor-sharp karst landscape is formed from the dissolution of the limestone beds near the surface by rainwater as it becomes acidic due to the contact with carbon dioxide in the soil. This acidic rainwater percolates into the ground along fractures in bedrock and dissolves away and enlarges the fractures over time. This process may eventually lead to the development of caves and streams that are characteristics of karst.

VALUES OF GEOSITES AND GEODIVERSITY

Geosites and geodiversity are certainly valuable, but they have been given minimal consideration. There are several recognisable values of geodiversity (Harmon and Putney 2003, Harmon 2004, Gray 2005, Henriques et al. 2011) but here I only highlight the most important values relevant to the current issues in Madagascar. I do so knowing these values will also clarify the importance of geoconservation in Madagascar.

ECONOMIC VALUES. Geological heritage sites can play an important role in the economic development of local communities through, for example, geological tourism. Madagascar has a large number of fascinating geosites, which can attract many different types of visitors from all socio-cultural backgrounds. Geotourism may play an important role in poverty eradication of an area, and help to build and empower local communities. More interestingly, many potential geosites are themselves the locations of mineral and energy resources. In addition to the oil that has been recently reported in Madagascar (OMNIS 2012), the island is also renowned for its valuable and significant amounts of industrial minerals (quartz, phosphate, gypsum), gemstones (sapphire, ruby, beryl), fossils (ammonites, *Majungasaurus*), construction minerals/rocks (granites, gabbros, sand, clays), and precious and industrial metallic and non-metallic ore (gold, iron, nickel, copper, aluminium) (Lacroix 1921-1923, Collignon, 1962, Besairie 1964, BGS-USGS-GLW 2008, OMNIS 2012). During the last decades, chromite and graphite are known to be two dominant industrial mineral commodities produced in the country (BGS-USGS-GLW 2008, Yager 2009, 2010, OMNIS, 2012). Today, the nickel-cobalt exploitation in Ambatovy by Sherritt and the ilmenite beach sands in Tolagnaro exploited by Rio Tinto/QIT Madagascar Minerals (QMM) are the largest and the most advanced mineral projects in the country.

AESTHETIC VALUES. The meaning of aesthetic can be broad but here it is used to refer to the beauty of natural landscapes. Several Malagasy tourist attractions are world-class (Christie and Crompton 2003), not only for their biodiversity, but especially for their geodiversity. Tourists visiting the island are drawn to the spectacular beauty of the landscape (e.g., *tsingy*, sandstone canyons of Isalo, volcanic peaks of Tsaratanana), the unique features and stories of lakes (e.g., crater lakes of Tritriva and Andraikiba, and around Itasy volcanic field), hot springs (e.g., Antsirabe and Ranomafana), the mystic and secret of caves (e.g., Ankarana), long and gorgeous beaches and magnificent rivers. While the Malagasy government has promoted and continues to promote tourism, hoping to get more revenue for the country, the importance of geoconservation is always forgotten. Considering that only a few thousand tourists per year visit those geosites, we can only imagine the impact of geotourism on the economy if geoconservation of geosites was truly achieved.

CULTURAL AND ECOLOGICAL VALUES. Madagascar has several spectacular geological and geomorphological features that contribute to the cultural and ecological quality of place, and those have been and could be considered part of its cultural heritage. Good examples are the sacred caves in the north (e.g., Ankarana), the 12 sacred hills in the central highlands, and Isalo National Park in the south. Such valuable areas will not only offer a series of touristic opportunities but also will enhance and deepen the public appreciation of geosites. The exposure to rare minerals, fossils sites, and holy places can be enjoyable and exciting, which may give people insight into the history of the places and thus the science of geology. Some of Madagascar's geological features have even inspired musicians (e.g., the Betsiboka River).

Most of Madagascar's unique landforms and soils support the island's natural ecosystems. Several obvious examples are seen throughout the island such as: (i) in the north, caves in the Ankarana National Park are homes of bats (Cardiff et al. 2009) and cave-living crocodiles (Wilson 1987) – without a safe habitat, these wild animals would be in danger; (ii) the Itremo massif (central Madagascar) is a habitat of small aloe (*Aloe parvula*) endemic to Madagascar (Cactuspedia 2012), as such the plant relies heavily on the soil and bedrock forming the spectacular quartzite-marble-schist massifs of Itremo (Besairie 1964); (iii) the Tsimanampetsotsa National Park in the south has unique fauna and flora (e.g., endemic carnivore (*Galidictis grandidieri*), blind fish (*Typhleotris madagascariensis*) in caves) (Sparks 2011, Wildmadagascar.org 2012,) that need conservation. These examples clearly demonstrate that biological systems (biotic) are inextricably connected to physical systems (abiotic), thus the importance of geoconservation and the ecological values of geodiversity.

INTERNATIONAL SIGNIFICANCE AND EARTH HERITAGE VALUES. There are many exceptional sites worthy of international recognition in Madagascar (Figure 1). Considering only the *tsingy*, the Bemaraha, Ankarana and Namoroka protected areas are among the most visited and known by locals.

The largest *tsingy* is located in Bemaraha in western Madagascar between Morondava and Maintirano. The Tsingy de Bemaraha covers 150,000 hectares of highly karstified limestone formation of the Jurassic age, where the southern part is part of a National Park with public access, while the northern end is a Strict Nature Reserve with no access. The karst is associated with numerous deep canyons and a large river gorge known as Manambolo. The Tsingy de Bemaraha National Park is the first Malagasy site listed as Natural World Heritage and National Cultural Heritage (UNESCO 1990). It also contains vast biodiversity including endemic birds and lemurs (Madagascar National Parks 2011).

The Ankarana National Park is located in the northern part of Madagascar (Figure 1) and it comprises approximately 200 km^2 of *tsingy* (Middleton 2004). The park also includes sacred lakes, canyons, and the largest underground river network in Africa (Madagascar National Parks 2011) with spectacular stalactites and stalagmites, and diverse wildlife including endemic lemurs, bats and crocodiles (Wilson 1987). The Ankarana underground network includes the >18 km long Ambatoharanana crocodile cave, the ~11.5 km long Andrafiabe cave, the 4.5 km long Lavaka Fanihy bat cave, the approximately 10.4 km long Antsatrabonko cave and numerous native tombs (Radofilao 1977, Wilson 1990, Middleton 2004). The caves are unique repositories of information for geologists (e.g., speleothems are important for paleoclimate study, clastic sediments are the focus of mineralogical, hydrological and geomorphological studies) and contain a wide range of biodiversity.

The Namoroka National Park (22,200 hectares) is located in the northwest of the island, within 180 km^2 of Jurassic limestone (Middleton 2004), the same as those seen in the Ankarana. The area also contains a 4.6 km cave, with natural pools and canyons (Middleton 2004, Madagascar National Parks 2011). Because of their unique wildlife and their bio- and geodiversity values, such parks should be treated as exceptional and international earth heritage sites.

EDUCATION AND TRAINING VALUES. Earth science education is one of the most essential aspects of geosites and significantly contributes to the preservation of the environment and cultural heritage. Geosites not only promote conservation of geological heritages, but also serve as tools for education and training activities at all educational levels in Earth science. As pointed out by Modica (2009), geosites and geoparks provide real-world outdoor classrooms where geology can be explained and communicated in a more interactive way. Rocks, minerals, fossils, landforms and landscapes are all products of the long-term evolution of our planet Earth. Teachers and educators can use geosites for practical demonstration of the fundamental principles of geology and the dynamic evolution over geological time, or the processes of landscape formation and evolution, and also to make students aware of how human occupation and activities can affect the physical environment in general. However, because of the low level of knowledge and awareness of geoconservation in Madagascar, there is a tremendous need for more geoscience education in the country. This is especially true in areas with low levels of school education, as is the case in most regions, bearing in mind that the public's lack of understanding and knowledge about the value and meaning of geodiversity strongly contributes to its destruction. In addition, over the last two decades, many people have depended heavily on natural resources for living, particularly mineral resources. There is clearly a need for large numbers of well-trained geologists to do geological surveys, to locate and extract mineral resources (gemstones, metal ores), oil and gas, water and rocks for industrial purposes which will not only contribute to the economic development of the country, but also to avoid the destructive exploitation of natural resources and the degradation of geosites that sustain the unique biodiversity of Madagascar. There is also a need for large number of geologists to locate aquifers and to study groundwater which plays an important role in all socio-economic development. Furthermore, geologists are an important stepping-stone for major engineering projects (e.g., dams and road construction). Thus, geodiversity conservation is undoubtedly vital for promoting education and training, and can be tied into the notion of sustainability. Strengthening of geosciences education is needed to disseminate the values and meaning of geoconservation, and also to produce professional geologists. Increasing knowledge and awareness of geoconservation amongst communities can also be achieved through the uses of available geosites (e.g., organization of guided field trips to selected geosites, TV documentaries and radio programs on *tsingy*, deltas, fossils, gemstones or other interesting Earth features).

SCIENTIFIC RESEARCH VALUES. The development of geoparks offers a venue for scientific research. Madagascar's unique tectonic position during the amalgamation and breaking-up of the Gondwana supercontinent (Stern 1994, Shackleton 1996, Collins et al. 2000, Reeves and de Wit 2001, Collins 2006), with its long and complex history of geological evolution (de Wit 2003, Collins 2006), has drawn the attention of many international universities and research institutes, and could promote the scientific education and dissemination of geoscience for the public. An understanding of how different geological features form and what processes shaped the topography and the coastline will enable a large number of the public to have more understanding of the evolution of the earth, and will help them to increase not only their scientific knowledge, but also their awareness of the important values of geological features so that these geological features can be protected.

In this sense, natural rock exposures and landforms become crucial and represent potential tools to gain a better understanding of the geological evolution of the island. Future research could be pursued on, for instance, the history of Madagascar, its geological evolution and the processes that shape the topography and the coastline only when physical evidence are preserved and maintained. Environmental research also depends on the availability of the sites. A good example is the temporal evolution of the Betsiboka delta (Raharimahefa and Kusky 2010), where in the near future researchers will be able to look at the increased amount of sediments in the delta and its relation to natural diversity only if conservation will be undertaken.

INTRINSIC OR EXISTENCE VALUES. Sometimes the value of geodiversity doesn't have anything to do with human needs or human approval and judgment; it is simply weighted by its natural value (Kiernan 1997, Gray 2005), i.e., as is. Intrinsic value is already a recognized concept in natural conservation (Fox 1990, Nash 1990). A geological feature has intrinsic conservation value because of its type, for example, it is a representative example of a class of landform and should be protected without human scientific justification (Sharples 2002).

THREATS TO EARTH RESOURCES AND GEODIVERSITY

To protect geodiversity, it is important to understand the potential threats (Table 1). Most people would consider that no management and conservation should be taken for Earth features because they are durable and rugged. However, most of the removal and degradation of Earth resources and features are permanent (e.g., coal, oil, minerals, rocks, landscape). If they do recover, it will take thousands, millions, or even billions of years. Accordingly, such resources are in real danger because of human uses and activities. Earth features need to be managed in such a way, at least, that their destruction is minimized.

In Madagascar, the difficulty of exploiting minerals has important economic and environmental impacts. Some mineral resources are starting to be depleted (e.g., graphite, chromite) (Yager 2009, 2010, INSTAT 2011), making it more difficult and expensive to obtain those minerals. Also, everyone should know that every time a mineral is used, that much less remains. For these reasons, conservation of Madagascar's Earth resources is needed, not just by saving these resources, but also by making sure that there is no waste in using them. Geoconservation policy should also include recycling and modernising factories (e.g., recycling of metal cans), as well as improving mining extraction and processing techniques and production.

MOVING FORWARD INTO GEOCONSERVATION

We are still in the early phases of geoconservation, and the most important steps toward geoconservation are thus listed below; most of them have already been explained by other researchers (cf. Gray 2004, 2005, Burek and Prosser 2008): (i) Public awareness of the importance and value of geology, geoconservation, geodiversity and geosites. This can be done by: (i.1) training the public, especially people who live around and in protected areas, park rangers/technicians, conservation technicians, protected area managers, political leaders, directors of public and private institutions and agencies; (i.2) using mass media: production of TV shows and radio programs dedicated to geological themes, informative web pages, geological booklets, and park guide books; (i.3) raising the importance of geology in school and university curricula, which in part can be enhanced by scientific talks, a variety of publications and magazines, building of educational centres and museums; (i.4) making geological, geomorphological, hydrological, paleontological and pedological resources available (e.g., hard copy maps or through electronic databases). (ii) Inventory and description of Madagascar's geodiversity and geosites, which can be done with local specialists from local universities and collaboration with overseas scientists and academic institutions. (iii) Characterize the values and importance of geosites. (iv) Knowing the threats and make them public, with a commitment to manage and monitor these sites. (v) Establishing geoparks and creating protected areas with the supports of Malagasy authorities (legislation and policy), and local and international non-governmental organizations. This step will need the full approval of the government and their desire to act.

From this step forward, the suggestions will mainly apply to existing protected areas including Strict Nature Reserves, National Parks, Special Reserves and private reserves that contain valuable geodiversity and for which geoconservation has not yet been undertaken but where it should start. (i) Valuing and monitoring of geosites by incorporating geology into natural conservation policies at the same level as biodiversity, in other words, influence local plans to support geoconservation. Clear goals should be established for the geoconservation and management of sites. (ii) Periodic training and seminars for park managers as well as regular discussion between geoconservation specialists and the managers, which will increase the awareness of managers. (iii) Encourage public participation, starting from schools and the communities living around the protected areas. (iv) Creating scientific instruments (e.g., data-

TABLE 1. Examples of principal threats to geodiversity and geosites in Madagascar.

Category	Threats	Examples of principal impacts
Natural	Erosion	Loss of soil
		Formation of Lavaka
		Coastal changes
		Silting and filling of lakes, delta and lowland rivers
		Loss of geological exposure
	Excess Rainfall	Flood
		Slope instability
		Slumping of unconsolidated sediments
		Erosion of sandy shorelines
Human activities	Mining (small and large scale industrial and gemstones extraction, building stones quarries)	Destruction of landscape
		Large-scale removal of soil
		Water and air pollution
		Depletion of mineral resources
		Removal of geological specimens
		Flooding and open holes after mines closure
		Loss of geological exposures
		Damage to geomorphological features and disturbance of natural processes
		Face stability problems
	Urban activities	Land conversion
		Change of topography and visibility
		Loss and damage of important rocks, minerals and fossils
		Waste disposal and Landfill issues
		Damage to groundwater and surface water
		Sewage waste affecting pods, rivers and streams
		Noise and Air pollution
		Loss of geological exposure
		Filling of mangrove, paddy field, streams and swamps
		Re-profiling and leveling affecting landscape (cause interruption of natural processes)
		Dredging of rivers, paddy field and swamps.
		The removal of irreplaceable features such as caves, landforms or finite deposits of fossils or minerals.
	Tourism and visitor	Littering
		Trail degradation
		Soil compaction and degradation
		Loss of vegetation cover
		Episodic sedimentation in lowland river systems
		Inappropriate removal of geological specimens
	Agriculture	Land conversion
		Loss of soil
		Soil contamination
		Inappropriate burning increases erosional processes
	Deforestation	Degradation of landscape and landform
		Temporary increases in sediment yield and run-off
	Lack of public understanding	Inappropriate management causes destruction of geological features
		Graffiti and spray-painted mask potential geological features

bases, maps, manuals, survey materials) to support a sustainable management of the geological or Earth resources. (v) Find funds for geoconservation and establish clear strategies to build human and financial resources for the planning process. One way is seeking integration into the African Geoparks Network and Global Geoparks Network. (vi) Integrating geoconservation with land-use planning and land management, e.g., retaining the integrity of geodiversity in geosites and restoring them authentically where possible. (vii) Develop a nature conservation initiative showing the integration of biodiversity and geodiversity.

BARRIERS TO GEOCONSERVATION

Despite all of the progress Madagascar has made since the introduction of biodiversity conservation in the 1980s and the efforts of conservationists, periodic political crises and instability are the main barriers for any conservation efforts in Madagascar. In addition to deforestation, biodiversity conservation is now facing the most difficult challenges with increasing illicit logging and exportation of rosewood (Schuurman and Lowry 2009, Butler 2010, Innes 2010, Randriamalala and Liu 2010, Randriamalala et al. 2011) as well as the illegal exportation of endangered tortoises (Guanqun 2011) and hunting lemurs for food (Reardon 2011). The current political unrest masks the conservation effort and has raised the number of Malagasy living in poverty to 77 % of the population (Taratra 2012).

From the geoconservation perspective, since very little has been done, no significant damage has been reported except the intensive illegal exploitation of gems (Andrianandraina 2012, Niaina 2012). The current crisis will, of course, disturb the implementation of geoconservation. As such, the inventory of geosites and the integration of geoconservation within state policies on nature conservation would be hampered until the establishment of a stable government; however, geoconservation can be initiated by using mass media to educate the public about the importance and the value of geoconservation. Concurrently, the Ministry of Education should incorporate geoconservation into school and university curricula. Geological surveys should work on the inventory and description of Madagascar's geodiversity and geosites. Conservation and development depend on everyone's participation; as such the public's level of education is the most important factor.

CONCLUSION

Madagascar's geodiversity is threatened by many potentially damaging human activities enhanced by poverty, irresponsible management and unawareness of the public and local authorities. The use of natural resources subsequently leads to the transformation of ecological and geological habitats as well as the loss of flora and fauna. Geoconservation plays a key role in nature conservation and in sustainable development. Currently, it is only in its early stages; however, because of the several threats to Madagascar's geodiversity, conservation action should be taken. One of the most important steps is to educate the public and local authorities. Public understanding of basic science is a must; as such, education plays a vital role in geoconservation. Geosites should be protected under national conservation legislation; however it does not guarantee conservation due to political instability, infringement of regulations, and lack of funding.

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ARTICLE

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Who wants to conserve remaining forest fragments in the Manompana corridor?

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ABSTRACT

Contiguous forests in Madagascar are continuously converted into forest fragments due to deforestation, and dispersed into landscape mosaics dominated by agriculture. These fragments are of increasing importance for biodiversity conservation as well as for the well being of rural inhabitants, providing a high diversity of timber and non-timber forest products. An increasing number of international projects are therefore trying to preserve remaining forests and to transfer the management of these forests to local communities. However, it is not known how important the preservation of forest fragments are to local people. We therefore explore the importance of forest fragments as a source of cash income to different groups separated by wealth level and access to forest resources. A multi-method research approach was taken, based on score application exercises as well as interviews with individual households and focus groups. Our study site was located at the east coast of Madagascar in the Manompana corridor. Results show that some groups are significantly more interested in the preservation of forest fragments than others. Interest is significantly related to the wealth of local inhabitants as well as to the walking distance between villages and forest resources. Nevertheless, interest in resource preservation does not depend on how important fragments are to local people, but rather on the awareness about resource scarcity.

RÉSUMÉ

En raison d'une forte déforestation sur la côte est de Madagascar, de nombreux massifs forestiers d'un seul tenant et de vastes écosystèmes interconnectés ont été détruits, laissant des fragments de forêts qui s'intègrent dans une mosaïque paysagère dominée par l'agriculture. Ces fragments gagnent en importance. Ils jouent un rôle de premier plan dans les réseaux de biodiversité en assurant un certain niveau de connectivité. Mais les fragments sont essentiels au bien-être de la population locale, fournissant produits et services pour la consommation quotidienne ou donnant accès à un revenu monétaire. Sur un plan global, aussi bien les organisations de protection de la nature que les milieux scientifiques essayent d'endiguer la déforestation. Depuis les années 1996 la politique nationale à Madagascar a généré lois et processus visant à transférer la gestion des ressources forestières de l'Etat aux communautés locales. Cependant, il n'a pas été possible, jusqu'à ce jour, d'atténuer l'ampleur de la destruction et de la fragmentation des forêts pluviales de l'île. Plus encore, à l'heure actuelle la perception de l'importance des fragments de forêts n'est pas connue par la population. Un projet de recherche a été lancé pour contribuer à combler cette lacune, dans le corridor de Manompana, sur la côte. Les buts de ce projet étaient (i) d'explorer l'importance des fragments de forêts pour les revenus monétaires de la population locale et (ii) d'analyser la perception de l'importance des fragments de forêts par la population locale. Les recherches se sont déroulées dans quatre villages situés à des distances différentes du grand massif forestier. La population locale a été répartie en différentes catégories de niveau de vie et en fonction de la distance à parcourir entre les villages et la forêt. Cette approche a permis d'étudier le rôle de la forêt quant aux revenus monétaires des différents groupes de la population. Nous avons également cherché à établir un lien entre l'ampleur des revenus monétaires et un intérêt à conserver les fragments de forêts qui subsistent. Nos méthodes de recherche font recours à des exercices de « scoring », à des discussions avec des groupes ciblés et à des enquêtes de ménages. Il ressort des analyses que certains groupes ont un intérêt à conserver les fragments forestiers. Cet intérêt est significativement lié, d'une part, au niveau de vie de la population, d'autre part, à la distance entre le village et le massif forestier. Cependant, l'intérêt à conserver les fragments de forêts est plus fortement lié à la conscience de la finitude des ressources forestières qu'au montant des revenus monétaires que la population peut tirer des produits forestiers.

INTRODUCTION

The planet is gradually losing its original tropical forests (Shvidenko et al. 2008). Most tropical landscapes are not only confronted with severe deforestation but also with forest frag-

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mentation (Laurance et al. 1998, Ranta et al. 1998, Laurance et al. 2002), which often leads to decreasing vitality of remaining contiguous forests (Malanson and Armstrong 1996, Shvidenko et al. 2008). This is also the case in Madagascar, where forests are increasingly fragmented (Harper et al. 2007, Gorenflo et al. 2011) by agricultural activities (Messerli 2002, Pollini 2009). Between 1950 and 2000 more than 40 % of the island's forests were cleared, and between 2000 and 2005 the annual deforestation rate was estimated to be 0.5 % (USAID 2009), resulting in a patchwork of dispersed forest fragments (Harper et al. 2007). Forest fragments are of growing importance, not only for the biodiversity, but also for the well-being (Pfund et al. 2006, Bawa et al. 2007). Rural people are increasingly forced to meet their needs by taking products from the remaining forest fragments (Pfund 2000). In the Manompana corridor, on the eastern coast of Madagascar, people have to walk large distances to reach larger contiguous forests. Thus, they collect forest products for daily life in the forest fragments that are closer to villages. These products, such as fuel wood, timber, medicinal plants, honey, tubers and others, seem to be important for the local population and their livelihood (Fedele et al. 2011, Urech et al. 2011). Despite the apparent importance of forest fragments, forest clearance in Manompana is continuing (Pfund et al. 2011).

With this research we aimed to identify population groups who might be interested in preserving the remaining forest fragments of Manompana. Various studies have shown that a population's dependence on forest resources can influence its interest in conserving these resources (e.g., Gibson 2001). Following Ostrom (1999), people's interest in conserving forest remains low as long as populations do not place strong importance on the forest for their daily livelihoods. Another hypothesis states that with the awareness about the growing scarcity of resources, the interest in conserving them will grow (Behera 2009, Wu and Mweemba 2010). Based on these hypotheses we pursued three research objectives: (i) to develop a methodology that would measure the importance of forest fragments and forest massif for local people's life; (ii) to analyze whether or not people's dependence on forest resources has an influence on their conservation interest; and (iii) to assess what influence resource scarcity has on people's interest in forest fragment conservation. This knowledge should help future community-based forest management projects in the region to meet the differing interests coming from the rural inhabitants and to consider individual perceptions.

METHODOLOGY

RESEARCH AREA. Our research area, the Manompana corridor, is located on the east coast of Madagascar in the region of Analanjirofo, district Soanierana-Ivongo (Figure 1). The area of about 50,000 ha extends over three communes and about 30,000 ha of the landscape are covered by natural forest (Rakotomavo 2009). We worked in four villages situated around the large contiguous forest (Table 1). The villages Ambofampana and Maromitety are situated near the forest massif in very remote and inaccessible areas. To reach the closest small market via road or a river, villagers have to walk six to eight hours. The villages Bevalaina and Antsahabe are less remote but far from the massif in a territory where only forest fragments remain and the next market is reachable in one to two walking hours. In this region and its 30,000 ha of forests, a community-

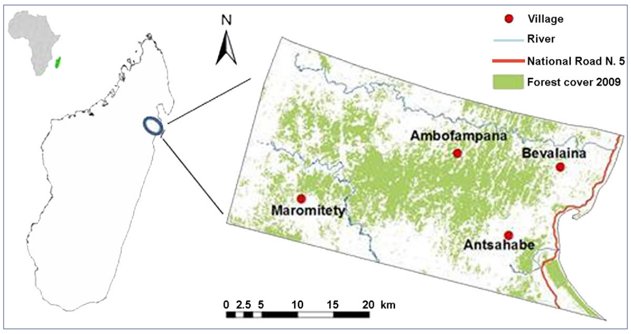

FIGURE 1. Study site with the four analysed villages (data source: KoloAla Manompana 2009)

based forest management project has recently been implemented. With decentralized management legislation, based on the GELOSE principle (Bertrand et al. 2006), the local population receives the right to beneficial but sustainable management of forest resource.

THE DEFINITION OF FOREST FRAGMENT AND FOREST MASSIF. The forest of our study site is classified as evergreen lowland rainforest (Moat and Smith 2007) and is in a continuous process of fragmentation. Nevertheless, it still remains a large part of a contiguous natural forest, which we label 'the forest massif' (Legout et al. 2008, Urech et al. 2011). This forest massif is surrounded by a belt of forest fragments, caused by agricultural activities of the local population such as slash-and-burn cultivation (Harper et al. 2007). Aiming to understand the particular role of forest fragments, we separated all natural forests into forest massifs and forest fragments. In the current literature, there are different definitions for fragments based on differing sizes and shapes (e.g., Laurance et al. 1998, ODEM 2005, Martin 2008). We defined fragments based on a combination of both, current research theories and local understanding. For example, a small forest that is surrounded by agricultural fields and that is still partly connected to the massif would be, following the local understanding, a fragment. Following the definitions of shape and size this forest would be considered as a part of a massif. Considering local understanding is crucial for this research, we aimed especially to comprehend local practices, perceptions and interests. To identify forest cover by satellite image interpretation, a definition of forest fragments and massif was developed by Rabenilalana (2011), based on ODEM (2005). As a result, the whole contiguous natural forest, including larger forest patches of more than 500 ha, has been classified as a forest massif. All natural forests smaller than 500 ha, surrounded by agricultural land or fallows and therefore not connected to the massif are considered forest fragments. Forest cover was identified by satellite image interpretation (Rabenilalana et al. 2010) using LANDSAT-images from the year 2009.

CATEGORIZATION OF HOUSEHOLDS. Aiming to analyze which population groups depend most on forest resources and which may be the most interested in forest conservation, we categorized all households into groups.

The categorization of distance to the forest massif: One categorization relates to forest resource scarcity, which can influence peoples' behavior and thinking (Rustagi et al. 2010). The analysis of forest cover indicates scarcity of forest resources increases with distance from the forest massif. We therefore grouped all villages into two categories of near (≤ 0.5 hours walking time) and far (> 0.5 hour walking time) from the forest massif. For the categorization, we measured the walking time from the village to the nearest edge of the forest massif guided by local farmers. The distance to the forest massif correlates negatively with the distance to markets (Spearman's correlation, r=-0.933, n=106, p< 0.001).

The categorization of wealth: Following other studies wealth has an influence on the dependency on forest resources (Barham et al. 1999, Wunder 2001, Dubois 2003, Tumusiime et al. 2011). Therefore, we separated all households into three categories of wealth: wealthier, intermediate and poor. The criteria for the different wealth levels have been adapted to our region and were the same for all villages. Criteria were based on household characteristics such as land property, livestock, crop diversity, quality of house construction, dependency on day labor and alternative income possibilities, as well as on the household's social status in the village (Gaemperli 1997, Schmidt 2007, Carter 2008).

INTERVIEW AND SCORING EXERCISES. A multi-method research approach (Ormsby and Kaplin 2005) was adopted to gain a broad understanding of peoples' perceptions and interests, based on open-discussions, semi-structured household interviews and scoring exercises with focus groups. Open discussions (N=20) with randomly selected households helped to get a general overview of the relation between villagers and natural forests (opportunities, rules, risks, traditional use, etc.) and to respond to villagers' misgivings and queries with regard to our research activities. Semi-structured household interviews (N=110) were conducted to collect data about the most important forest products (timber and non-timber forest products (NTFPs)), quantitative yields, and qualitative information about the general use of resources as well as about conservation interests.

To assess how the local population judges the importance of different landscape types and products coming from forests, we applied scoring exercises (Sheil and Liswanti 2006, Sheil et al. 2006). Relative judgements of importance should be subjective and depend on personal experiences (Sheil et al. 2002) and not be expressed in terms of prices and quantities. Exercises were conducted in each village with groups of five people, separated by wealth levels (poor, intermediate, wealthier) and gender (two groups per wealth level) (N=120, 6 groups in 4 villages). The number of five participants allowed for statistical representativeness but also discussions and exchange among villagers. To express their own judgment of importance, each group had to distribute 100 pebbles on nine different landscape types (defined by the participants, see Table 2) according to their value. Each group had to repeat the distribution of the pebbles for eight different categories of goods and products (Table 3), which ultimately totaled 800 distributed pebbles.

ASSESSING DEPENDENCY BASED ON CASH INCOME. All people living within the research area depend on forest resources (e.g., for house construction and fuel wood). However,

TABLE 2. Categories of landscape types.

Landscape types	Categories	Definition
River	Uncultivated	Water and riverside
Irrigated rice fields	Agriculture	Irrigated, permanent rice fields
Tavy	Agriculture	Cultivation of mountain rice and other products on slopes after slash-and-burn
Savoka	Uncultivated	Secondary vegetation after *tavy*, not cultivated
Marsh	Uncultivated	Wet and periodically or permanently flooded ground
Forest massif	Natural forest	Permanent natural tree cover connected to the forest massif
Fragments	Natural forest	Permanent natural tree cover not connected to the forest massif and with a surface of less than 500 ha
Village garden	Agroforestry	Trees and plants cultivated in the village around the houses
Tanimboly	Agroforestry	Traditional agroforestry system with a combination of trees and annual crops

only some farmers rely on a supplementary cash income earned from forest products. Especially during lean periods, before the harvest season when rice is becoming scarce, households are strongly dependent on an alternative income to buy additional provisions (Razafy 2004, Minten and Barrett 2008). During such periods, logging and timber transport, as well as the trade of NTFPs such as honey and handicrafts made from *Pandanus guillaumetii* (Fedele et al. 2011), become fundamental sources for alternative income. Therefore, income from forest products was considered to be the most important variable to assess the dependence of the different population groups on forest resources.

DATA ANALYSIS. Cash income generation from forest resources: To explore possible factors that could influence the cash income from forest resources, we considered two independent variables: distance to the forests massif and wealth level. Dependent variables were cash income from raw timber, cash income from NTFPs (mainly honey, handicraft from *Pandanus guillaumetii*), and total cash income from forest resources (timber & NTFPs). Statistical analysis was conducted applying the non-parametric Kruskall-Wallis test.

Relative judgment of the importance of natural forests: To explore the factors that could influence the relative judgment of forest importance, we used two independent variables, wealth and distance to the forest massif. We then tested the influence of wealth and distance to the forest massif on the dependent variables: (i) importance of forest fragments for income (including both, timber and NTFPs), (ii) importance of forest massif for income (including both, timber and NTFPs), and (iii) importance of the total natural forest (including both, fragment and massif) for income (including both, timber and NTFPs). For statistical

TABLE 1. Village characteristics in terms of distance to the forest massif, forest cover (Rabenilalana 2011) and market proximity.

Village 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 in village territory]	5	20	100	100
Market proximity [walking time in h]	6	8	2	1

TABLE 3. Categories of goods and products.

Categories	Definition
Food	Plants, products or animals which can be eaten
Medicine	Natural products used for medicine and health
House construction	Materials to build houses
Tools	Materials to build tools for agriculture, hunting, fishery
Fire wood	Fuel
Weaving	Plants used for weaving products, such as mats, hats, baskets
Cash income	Cash income generation by products which can be sold (crops, NTFP, timber, handicrafts)
Hunting and fishing	Animals (lemurs, tenrecs, fish etc.)

analysis we used the non-parametric Mann-Whitney-U and Kruskall-Wallis tests.

Conservation interest: To explore the relationship between the categories of wealth and distance and the villagers' responses regarding forest conservation, the Spearman correlation coefficient (ϱ) was applied.

TABLE 4. Scores of importance for all landscape types, including all 8 categories of goods and products, separated by village.

Landscape types	Ambofampana	Maromitety	Bevalaina	Antsahabe
Walking hours to massif	(0.2 h)	(0.5 h)	(2 h)	(3 h)
River	84	64	42	58
Irrigated rice fields	38	43	70	84
Tavy	80	99	90	72
Savoka	150	160	146	115
Marsh	33	20	60	138
Forest massif	215	191	94	0
Forest fragments	127	118	183	209
Village garden	15	38	22	31
Tanimboly	59	69	93	93
TOTAL	800	800	800	800

RESULTS

DIFFERENCE BETWEEN THE IMPORTANCE OF FOREST MASSIF AND FOREST FRAGMENTS. In order to determine the relative importance of forest massifs and forest fragments, we compared how the villages rated their importance regarding the distance of each village from the forest massif. When rated in comparison to other landscape types (including all eight categories of goods and products), forest massifs have been assigned the highest score in the two villages near the massif (Ambofampana and Maromitety), and forest fragments received the highest score for the two villages far from the massif (Bevalaina and Antsahabe) (Table 4). However, forests play a role in almost all categories whereas, e.g., irrigated rice fields are important only for the food category. Thus, forests received the highest score. Moreover, the local population judges forests as important not only because of the products they provide, but also because forests are recognized as a future soil reserve for agricultural food production and are therefore also important for the food category.

The distance from the village to the forest massif has a significant influence on the score for forest fragments ($p= 0.011$) as well as on the score for the forest massif ($p= 0.002$) (Figure 2). In general, people living near the massif seem to be more dependent on natural forests, especially the massif. But they also give a considerable score to fragments, even though the forest massif is very close.

CASH INCOME GENERATION FROM FOREST RESOURCES. The mean income per household and year generated by timber and NTFPs lies between Euro 1.6 (Maromitety) and Euro 19.7 (Bevalaina). Following the analysis of Rakotoarison (2009), who explored general income generation in the remote villages of the Manompana corridor, cash income from forest products (including NTFPs and timber) comprises only 0.7 % to 9.3 % of the total income that a household generates annually. Compared to other regions of Madagascar's rainforests (Shyamsundar and Kramer 1996), the amounts in our study site are very low. This might be attributed to the lack of access to bigger markets.

Influence by distance: The total cash income from forest products does not differ significantly between either the villages or between the two categories near and far from the forest massif (Figure 3). However, cash income resulting from NTFPs does significantly differ between villages ($p< 0.001$), and between the two categories near and far ($p< 0.001$). The income generated by NTFPs is higher in the two villages close to the massif than those far from the massif. On the one hand, the massif provides better quality and higher amounts of NTFPs than fragments. On the other hand, NTFPs are easier to carry for long distances than timber; thus traders may walk to remote villages to buy NTFPs and vice versa.

The income from logging and timber transport differs significantly between villages near versus far from the massif ($p= 0.015$) due to the distance to the forest massif ($p= 0.004$). Interestingly, farmers living far from the massif have higher incomes from timber than farmers living near the massif.

INFLUENCE BY WEALTH LEVEL. The results in Figure 3 (right) show a significant relationship between wealth and the total cash income generated from forest products ($p= 0.020$). The difference is significant between poor and intermediate households and between intermediate and

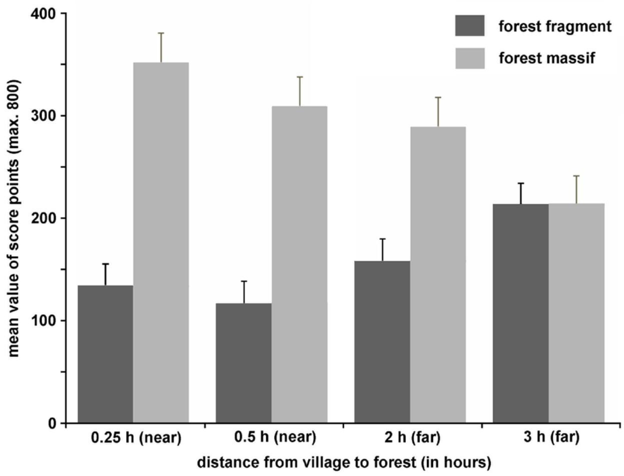

FIGURE 2. Mean values of score points (with standard errors) for the relative judgment of importance for fragment and massif separated by distance to the forest massif.

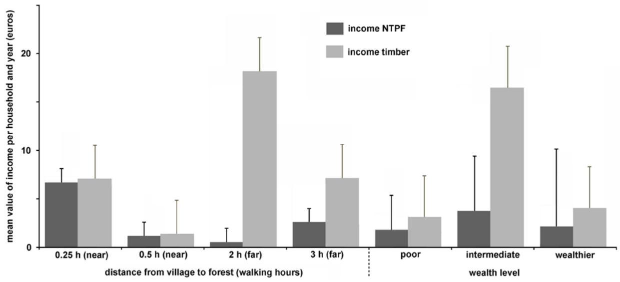

FIGURE 3. Mean cash income per household and year (with standard errors) from timber and NTFP separated by distance to the forest massif (left) and by wealth level (right).

wealthier households. Families with intermediate wealth levels achieve the highest mean income. In this respect, the comparably low income of the poor population class is interesting. With regard to income from timber activities, this can be explained as all of the polled poor farmers work for other families and therefore do not have enough time for additional activities. They also rarely own the necessary instruments to work as loggers. Working as a logger requires a high physical commitment and good health, which members of the poorest households often lack. Nevertheless, in times of shocks and food shortage the poorest are also forced to earn cash by transporting timber. From the questioned poor households, 37 % have an income, although very low, due to transporting activities.

Interestingly, cash income generation does not significantly differ between poor and wealthier groups. Even wealthier households seem to be dependent on cash income from timber. Logging and timber transport activities are mostly performed in times of food scarcity and other crises. Our results indicate the vulnerability of the whole population in our research area, including the wealthier households. Forests can be an important source of income for more than just the poorest households, as has been predicted in other studies (Völker and Waibel 2010).

THE RELATIVE JUDGMENT OF IMPORTANCE FOR NATURAL FORESTS. In this section we examine how peoples' judgment of the importance of forest fragments and forest massif is influenced by wealth and distance to the forest massif. The values resulting from the scoring exercises include only the income category (see Table 3).

Influence by distance to the forest massif: In the previous section, results showed that the total amount of cash income earned from forest products is not influenced by the distance from the village to the forest massif and does not differ significantly. Likewise, how people judge the importance of natural forests for cash income is not influenced by their distance from the forest. Nevertheless, there is a significant difference in how each village judges all natural forests (forest fragments and forest massif combined) (p= 0.029), forest fragments (p = 0.016) and forest massif (p= 0.016) (Figure 4). People living two walking hours from the massif have a significantly higher income than people living only 0.25 walking hours away. However, the importance score of forests for income is exactly the opposite. The score for importance by local residents reflects a more holistic view, including personal experiences and preferences. We therefore asked the different groups why they scored the importance of forests for income generation as they did. The explanation was that the constant availability of forest products is fundamental to them and equal to the importance of income quantity. Products from natural forests are always available and, although to limited extent, tradable. This is a crucial characteristic of forest resources in times of shocks and periods of rice shortage.

The difference for the importance of fragments and massif also differs between villages (p= 0.016 and p= 0.016) and between the two categories near and far (p= 0.007). Farther away from the forest massif, the importance score is higher for forest fragments and lower for the massif.

Influence by wealth level: For all natural forests, forest fragments and forest massif, results showed no significant difference between wealth levels (Figure 4, right). However, it is surprising that the poorest households, which have the lowest cash income generation from forest products (see Figure 3), give the highest score to the importance of all forests for cash income. Households of the intermediate class, which generate considerably more income through forest products than do the other wealth classes, do not place more importance on the forest than do the other wealth levels.

INTEREST IN CONSERVING FOREST FRAGMENTS. The interest of the different population groups in preserving forest fragments was analyzed by means of specific research questions, such as „for what reason did you conserve your fragment until this day?" This question was asked of all families that were, according to local custom (Razafy 2004, Muttenzer 2010, Urech et al. 2011), owners of forest fragments (N = 50). The main answers given by the forest fragment owners concerned either the benefit of the forest for timber and NTFPs, or its role as a soil reserve for future descendants (Pfund 2000, Keller 2008). If farmers see forest fragments as important only as a soil reserve, we assume no long-lasting interest in preserving it. Sooner or later the fragment will be converted into arable land for the family. Interpreting the answer that fragments are important for timber and NTFP, we assume an existing awareness about the finite and predictable supply of the resource and therefore an interest in preserving it. Of course this answer is no guarantee that the family will continue to conserve its fragments, but it demonstrates that there is a certain interest in preserving forests.

Influence by distance: Most farmers living close to the forest massif still believe that forests are not exhaustible and therefore must not be protected because "there will always be forest". However, there is a significant correlation between distance (to the massif) and farmer responses (χ^2= 19.924, df= 6, p= 0.003). We infer that the further the population lives from the massif, the more interest it has in conserving the forest (Figure 5). Farmers living far from the forest massif already experienced a fundamental decrease in forest surface and thus, forest resources.

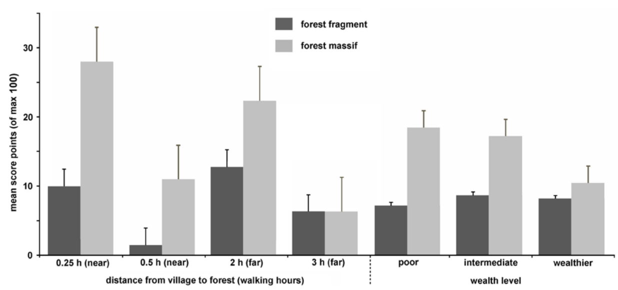

FIGURE 4. Mean value of score points (with standard errors) for the relative judgment of importance of fragment and massif for the income category separated by distance to the forest massif (left) and by wealth level (right).

They are aware, that the last remaining forest fragments may disappear as well if they are not protected in future.

Influence by wealth: The correlation between wealth level and response is also significant (χ^2= 14.375, df= 4, ϱ= 0.006) (Figure 5). The wealthier the population is, the more interest it has in preserving forest fragments for timber and NTFPs. Wealthier households in general have more land than poor farmers, higher crop diversity and more alternatives to generate cash income, thus they are less dependent on slash-and-burn cultivation systems to plant crops and to gain more arable land.

DISCUSSION

MEASURING IMPORTANCE. The importance of forests in local livelihood systems includes different facets. Scoring exercises for eight categories of goods and products show that forests play a role in almost all categories. But most of these products can be replaced by products coming from other landscape types without having significant impact on local wealth (unpubl. data). Fuel wood can be collected in agroforestry systems, medicinal plants are replaced from swamps or secondary vegetation. However, income generated from forest products (timber and NTFPs) can hardly be replaced, as possibilities for alternative income generation are scarce. Therefore, cash income from forest products seems to be a good indicator to measure how depending on forest resources people really are.

Using the single metric of economic importance, this article shows the very complex reasons that influence how the local population judges the importance of natural forests to generate cash income. Importance can be measured with quantitative information resulting from income surveys or scoring exercises. However, to develop reliable reasons and explanations for the given quantitative information, the data must be evaluated in the context of peoples' livelihoods (lean seasons, individual wealth and health, knowledge, etc). Our results show that income generated from forest products is very low if compared with other regions. Although very low, it is nonetheless of importance. Especially during the lean-season, the availability of NTFPs and timber as commodity can always be assured. However, our results showed as well that even though natural forests offer considerable opportunities for income in some cases, they are rated as more important by people who do not necessarily benefit much from them. A very low income can be of high importance during a lean period, especially in case of a household's high vulnerability. We therefore conclude that the importance of forests for local residents is not only related to the quantitative opportunities arising from forests, but also to local livelihood systems and strategies. Other factors, such as

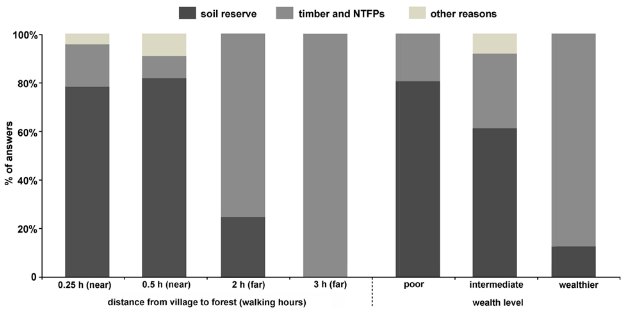

FIGURE 5. Reasons for forest fragment conservation, separated by distance to the forest massif (left) and by wealth level (right).

the possibility to generate cash income through other landscape types or alternative activities, could influence people's perception of the importance of a cash income from forest products. Moreover, wealthier households generally produce enough crops for personal consumption, while poor households are forced to buy food during the lean period and are therefore more dependent on alternative sources of income.

In our study site, people make a clear differentiation between the importance of the forest massif and forest fragments. Even in villages close to the forest massif, forest fragments have a fundamental value. This can be explained by the fact that, following the local customary rights, forest fragments have a recognized traditional 'owner' (Urech et al. 2011); thus, forest fragments are valued for their soil reserves. Moreover, families prefer to collect particular products in their own forest fragments next to the rice fields instead of the forest massif. This distinction between fragments and massif becomes even more important with increasing distance to the forest massif, where only forest fragments remain to satisfy local peoples' daily needs, especially the generation of income. Thus, we recommend that the different understandings of forest massif and forest fragment must be integrated into future forest management.

THE INFLUENCE OF DEPENDENCY ON CONSERVATION INTERESTS. At the outset we introduced Gibson's (2001) hypothesis that people who depend on forest resources have more interest in conserving them. Categorizing people by the distance from the village they are living in to the forest massif, results show that people judge forest resources significantly more important the closer they live to the forest massif. This can be explained if one considers the livelihood context of the people living near the massif. Firstly, households close to the massif have fewer alternative possibilities for generating income because they are situated in a very remote and inaccessible area. Secondly, they are also more vulnerable to natural disasters such as cyclones, which increase the dependency on forest resources. Nevertheless, the concerned households are not interested in preserving forest fragments for NTFPs or timber products that could be sold or used for personal consumption. Rather, villagers close to the forest massif consider forest fragments as soil reserves for the future. This is not surprising as farmers depend much more on agriculture than natural forests. Conversely, the majority of people far from the forest massif seem to be much more interested in preserving forest fragments for NTFPs and timber, even though they do not significantly rely more on income from forest products and judge the overall importance of natural forests with lower scores than villagers close to the forest massif. We therefore cannot confirm the hypothesis that peoples' dependency influences their interest in conserving forests (cf. Gibson 2001) in our research area.

Possibly the variable of proximity to markets has the higher influence on how much interest people have to conserve their remaining forest resources. Timber is much more tradable far from the massif where resources are scarce and population density is high. Additionally, farmers do not have to walk very far to sell their timber, while people living close to the forest massif have to walk up to eight hours, carrying timber planks on their shoulder and traverse landscapes that are often steep and hilly or swampy. Therefore, people close to the forest massif seem to be more dependent on cash income from forest products, but do not perceive for example timber to have high potential for income generation. Meanwhile, people far from the forest massif and close to the markets see the important potential of the remaining forest fragments containing still high amount of precious woods (Rakotomavo 2009). We can therefore conclude that forest fragments are currently of greater importance for timber trade than the forest massif.

Considering different wealth levels, we concur with Gibson (2001) that dependency does not precipitate conservation. Wealthier households gain little income from forest products, but how such households score the importance of forests does not differ significantly from the two other wealth categories. Nonetheless, wealthier families have significantly more interest in preserving forest fragments for timber and NTFPs. Additionally, 78 % of the wealthier households want an end to the system of slash-and-burn for the whole village, even though they are not very dependent on forest products. We therefore reason that dependency on the forest does not have much influence on conservation interest in our study site. We have to point out that in this article we only refer to dependency with regards to income. Dependency on forests includes much more than just income (e.g., medicinal plants, food, material for house construction, fuel wood, etc.). Nonetheless, we think that cash income represents very well the difference between households, as most other products are collected by all households independently of wealth or distance to the massif. Likewise, environmental services are important for all households equally, as all families depend on water provision and agricultural production.

THE INFLUENCE OF RESOURCE SCARCITY ON CONSERVATION INTERESTS. In exploring the hypothesis that resource scarcity enhances interest in forest preservation (Behera 2009, Wu and Mweemba 2010), we find more coherence in our study site. Villagers living far from the forest massif and thus living in landscapes with only forest fragments remaining seem to be aware of resource scarcity and finality. In the village the farthest from the forest massif, 100 % of the villagers conserved their remaining forest fragments because of the need for NTFPs and timber. People are aware that this need cannot be fulfilled if forests are converted for agriculture. As noted earlier, while this awareness and interest is no guarantee that villagers will continue to conserve forest fragments, it does at least demonstrate an awareness that does not exist in villages close to the forest massif. This fact has to be considered in future management activities, as former studies have shown that the more individuals are aware of the degradation of the environment and its consequences, the more likely they will try to ameliorate the situation (Wu and Mweemba 2010). Additionally, greater environmental awareness leads to greater involvement in resource management programs (Wu and Mweemba 2010).

CONCLUSION

We conclude that with regard to our study site, one of the hypotheses introduced in the introduction can be affirmed and the other must be rejected. The two categories of population groups in the Manompana corridor which are the most interested in conserving forest fragments are: the wealthier households that are less dependent on forest resources; and families living far from the forest massif which are aware about the resource scarcity. It has to be pointed out that this conflicting interest in resource conservation within one community-based forest management area can be an important source of social conflict between the concerned villages. Therefore, we suggest assuring an equal involvement and participation of villages far and villages close to the massif in future forest management. A formal structure of governance is required which would communicate and resolve conflicts between different interest groups and villages in order to integrate differing needs. The involvement of villages far from the massif has the advantage that residents far from the massif have a greater awareness of resource scarcity and thus greater interest in involvement in resource management. However, farmers living close to the forest should also be involved in the decision-making process as most of the forest area lies within their traditional village territory.

Furthermore, the difference between forest fragments and forest massif with regards to their importance and customary rights should be respected in future management plans. For local peoples' livelihoods, the value of forest fragments increases with distance from the massif to where the villages are situated, as natural forests are becoming scarce. Moreover, because forest fragments are traditionally owned by families they play a significant role for families' land reserve, more than the forest massif. If elaborating a forest management plan, these differences must be considered in order to meet local interests and to respect customary understanding of forest ownership.

Another point is that the poorest households currently earn a very limited income from forest products. Only a few of the poorest people work as loggers because most lack the knowledge, instruments and health to do so. If future forest management is to reduce poverty by increasing local people's participation in the trade and management of forest products, the involvement of the poorest households should be greatly improved.

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ARTICLE

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Air photo evidence of historical land cover change in the highlands: Wetlands and grasslands give way to crops and woodlots

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ABSTRACT

Madagascar's high plateau – where people farm, graze cattle, and set periodic fire in a grass dominated landscape – receives disproportionately little conservation attention. An aerial photograph-based analysis of land-cover change in the latter half of the 20th century, based on a stratified random sample of twenty eight sites, reveals dramatic trends associated with an increasing human population that is building a cultural landscape of villages and agro-ecosystems to assure its livelihoods. On average across the sample sites, about 23 % of grassland areas present in 1949–1950 were converted to crops fields, farm trees and built-up areas by the 1990s. Of all land-cover transitions, the most dramatic changes included the loss of approximately 60 % of wetlands and 37 % of riparian forests. These land covers, which are dispersed along the fine-grained dendritic stream network, are habitat for crayfish, frogs, and other fauna, yet are also prized locations in the rice-based Malagasy agricultural system. The results of this study suggest that attention be given to highland grassland, wetland and riparian forest ecosystem restoration and conservation; however, any on-the-ground initiatives should incorporate respect for local needs and allow sustainable use of these ecosystems, given their cultural and subsistence importance.

RÉSUMÉ

Les hautes terres malgaches, dominées par une végétation herbacée, sont des paysages fortement marqués par la gestion productive qu'y exerce l'Homme ; qu'il s'agisse des pratiques culturales, de l'élevage ou de la manipulation des régimes du feu. Cette région ne reçoit généralement pas d'intérêt pour la conservation de la biodiversité. Cet article présente les résultats d'une étude régionale de changement d'occupation des sols et des dynamiques des formations végétales des hautes terres au cours de la deuxième moitié du XX^{e} siècle. L'étude est basée sur l'analyse de photographies aériennes prises entre 1949–1950 et 1990–1993 de 28 parcelles de 10 km^2 sélectionnées dans un échantillon aléatoire et spatialement stratifié. Les résultats confirment plusieurs tendances liées à l'implantation d'une population agricole croissante : 23 pourcent du terrain qui était couvert de formations graminéennes (herbeuses) en 1950 ont été remplacés par des champs pour l'agriculture, des plantations arborées et des zones résidentielles. Mais la catégorie de couverture végétale qui a été transformée le plus fortement est les zones humides (les marécages), dont la superficie a diminué de 60 pourcent. De plus, 37 pourcent de la superficie des forêts ripicoles ont disparu. Ces deux catégories de végétation humide, qui sont représentées par des parcelles de faible superficie distribuées le long du réseau hydrographique des hautes terres, sont des habitats importants pour les écrevisses, les amphibiens et d'autres éléments de la faune et de la flore. Ce résultat suggère que les efforts de conservation sur les hautes terres devraient se concentrer plus sur les zones ouvertes, les zones humides et les forêts ripicoles qui subsistent, au lieu de se concentrer sur les îlots de forêt sempervirente (qui, dans notre analyse, ont perdu 33 pourcent de leur superficie, mais qui sont bien représentés et protégés dans l'est du pays) ou de se focaliser sur les forêts sclérophylles (les bois de tapia, pour laquelle notre analyse confirme la stabilité). Étant donné l'importance culturelle et alimentaire des zones humides pour le système agricole (et surtout rizicole) des Malgaches, toute action de conservation doit d'abord chercher à respecter les besoins et les droits des habitants des zones rurales.

INTRODUCTION

Highland Madagascar – with its hilly grasslands, irrigated rice paddies, eucalyptus groves, and red adobe villages – gets relatively little conservation attention. For biodiversity enthusiasts, it is a landscape to be crossed *en route* from the capital city to the wet and dry forests skirting the east and west of the island, respectively. What research on biodiversity loss and conservation does exist in this region focuses either on peripheral montane closed canopy forests like Ambohitantely (Ratsirarson and Goodman 2000, Pareliussen et al. 2006), on large wetland areas in the mid-elevation Mangoro-Lake Alaotra basin (e.g., Rasoavarimanana 1997, Ralainasolo et al. 2006), or, after recent prioritization exercises (Kremen et al. 2008), on the highly-modified sclerophyllous tapia woodlands found on lee slopes (Kull 2003, Alvarado et al. 2010). The majority of the highlands landscape is thought to have been heavily modified through a long-term history of farming, domesticated grazing, and anthropogenic fire regimes, and constitutes a cultural landscape home to a significant part of Madagascar's population (Coulaud 1973), traditionally of lesser conservation interest (Raison 1984, Rakoto Ramiarantsoa 1995, Kull 2004, 2008).

This study aims to assess and quantify historic patterns of landscape change across the Malagasy highlands. In particular, which types of vegetation cover – distinguished by physiognomy and by relative anthropogenic influence – are increasing, which are stable, and which are decreasing? From its findings, it then seeks to determine the implications for rural livelihoods and biodiversity.

Most land-cover change studies in Madagascar, which typically involve the analysis of remotely sensed data, have focused on biologically rich forest zones and forest margins, seeking to document large scale conversions between forest and non-forest categories (Green and Sussman 1990, McConnell 2002, Vågen 2006, Harper et al. 2007). Other studies have taken farmers or villages as their unit of analysis, describing land use changes in the context of rural demography, cultural land use, market stimuli, or institutional arrangements in particular highland case studies (Raison 1984, Rakoto Ramiarantsoa 1995, Kull 1998, Blanc-Pamard and Rakoto Ramiarantsoa 2000, McConnell and Sweeney 2005). In contrast, few studies using remotely sensed data to assess land-cover change have focussed on the regional vegetation cover dynamics outside major forested areas and at scales of investigation appropriate for studying rural land users and their livelihoods. This is in part the result of the reliance by remote sensing analysts on satellite-based data, which only became available in the 1970s (at relatively poor spatial resolution); it is also an outcome of the emphasis of the social science studies of land use dynamics or agrarian change on village case studies.

In order to analyze more detailed land use and vegetation categories, and to provide increased historical depth, this study employed manual interpretation of air photos. A trained aerial photograph interpreter can exploit the high spatial resolution and three-dimensional landscape representation offered by stereo pairs of photos in tandem with field experience to produce detailed and accurate maps of localized areas of interest, including minor patches of village trees, small wetlands in stream valleys, or fallow crop fields in grassland zones. It is sometimes even possible to distinguish between dominant species in forest and scrub patches. Historical aerial photograph archives exist for Madagascar as far back as 1949–1950, a half a century before satellite-based remote sensing provided similar levels of resolution. By comparing air photos from this period with the latest photos, from the 1990s, this study aimed to quantify land-cover trends across this highly modified landscape and consider the broader implications for both biodiversity and rural livelihoods.

STUDY AREA

The area of interest for this study is the central highlands of Madagascar, defined as the contiguous zone west of the rainforest escarpment within the former provinces of Fianarantsoa and Antananarivo, wherein valley bottoms exceed 800 meters in elevation (Figure 1). The reasons for this definition are as follows. First, the requirement for contiguity excludes outlying islands of higher elevation like Isalo or Bongolava that are arguably ecologically and culturally less similar. Second, the study area was bounded at the escarpment due to the much more humid climatic conditions east of the escarpment. Third, the 800 m contour has long been used as a biogeographic division (Humbert and Cours Darne 1965, Conservation International et al. 1995), though it is based more on a climatic than a fundamental phytogeographic split (Lowry et al. 1997). Finally, within

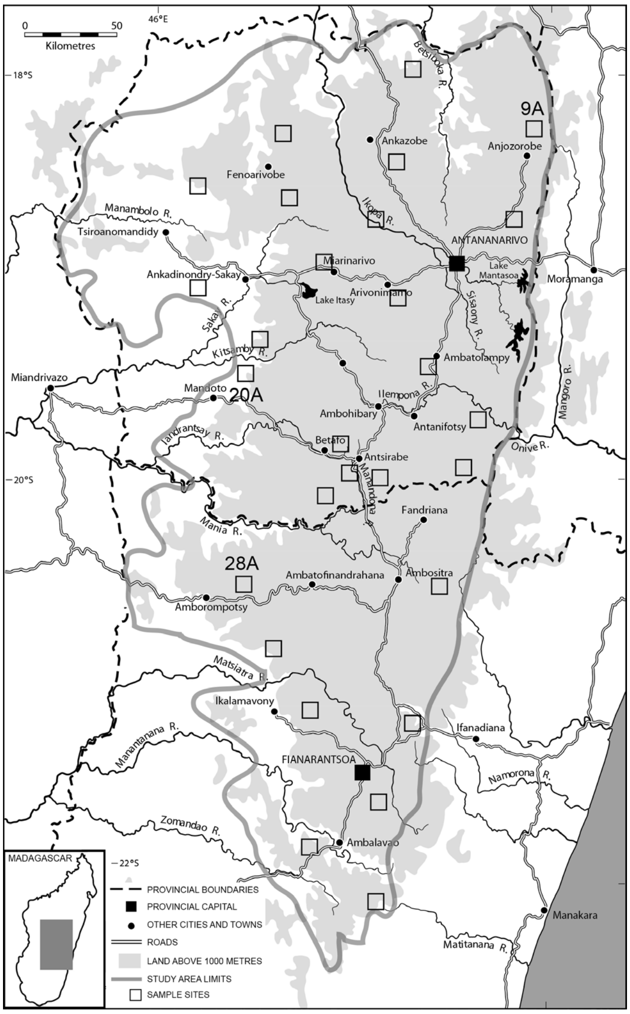

FIGURE 1. The central highlands of Madagascar, showing the study area limits (defined as the contiguous zone west of the rainforest escarpment, within Fianarantsoa and Antananarivo ex-provinces, wherein valley bottoms exceed 800 m), and the locations of the stratified random sample sites.

this area, restriction to upland Fianarantsoa and Antananarivo ex-provinces maintains relative ethnic uniformity (the study area touches much of the current administrative regions of Analamanga, Bongolava, Itasy, Vakinankaratra, Amoron'i Mania, and Haute Matsiatra).

The resulting study area forms a rough triangle from Andringitra in the south, past Tsiroanomandidy towards the northwest, to the Anjafy plateau in the northeast. The region is dominated by herbaceous vegetation cover, with grasses like *Heteropogon contortus*, Aristida spp., *Ctenium concinnum*, and *Loudetia simplex*. The tropical highland climate varies from the warmer and drier mid-elevation west to the cool, wetter higher elevation east. The study area covers 80,000 km^2, or 14 % of the island.

METHODS

Aerial photographs were purchased from the national cartographic agency, *Foiben-Taosarintanin'i Madagasikara* (FTM), for the two temporal increments with full regional coverage: 1949–1950 (the oldest available) and 1991–1994 (the most recent available). The black and white photos measure roughly 20 by 20 cm (slightly smaller for the older series, slightly larger for the recent series), with a spatial scale of roughly 1:40,000. Camera focal lengths were obtained from FTM.

Owing to the high costs of time and labour associated with aerial photograph interpretation, stratified random sampling was employed to adequately represent variability within the area of interest. The study area was divided into a large grid based on half degrees of latitude and longitude. Each resulting grid square was then divided into 2' by 2' parcels (n = 225 per grid square, n = circa 4,050 for overall study area) and a parcel was chosen for each grid square using a random number generator. The choice of 2' by 2' was based the correspondence of this dimension (approximately 3.2 by 3.8 km) with the feasible area of air photo analysis from two or three overlapping air photos from two different overflights. If a sampled parcel was outside the area of interest, it was excluded from the sample and not replaced. The result was 28 sample sites.

For pragmatic purposes, some adjustments were made to the sample coordinates. First, for seven sample sites, the original parcel fell between two lines of air photos. These parcels were systematically displaced to the closest possible point (less than 1.5 km) that provided photo coverage from a single line of photos. Second, key maps to the 1949–1950 air photo coverage affecting two sample sites were missing from FTM offices; in these cases an alternative sample site was created at the nearest point of air photo availability. Third, 1991–1994 air photo coverage is incomplete in northern and western Analamanga and Bongolava administrative regions; as a result, seven sites were moved to the nearest possible covered site. A final site had no nearby alternative, so oblique photographs were taken by handheld digital camera (3.2 megapixels) during a chartered overflight on 4 June 2003, making three passes at 2,400 m altitude and noting coordinates with a GPS (Garmin 12) (Warner et al. 1996).

Standard approaches to air photo analysis were followed (e.g., Vanacker et al. 2000), aware of many of the challenges that apply (e.g., McCusker and Weiner 2003). These include the fact that analyses based only on two time points can only surmise what happened in between, the fact that lumping together analyses from different years as a single time point may obscure short-term events, and awareness that seasonal and annual climate variability, time of day, and degradation of photo quality over time may affect the comparability of photos. Seasonality, in particular, is a factor not captured by the dry-season air photos, but which could be particularly relevant for wetland areas.

First, scanned air photos were orthorectified in ArcGIS using 1:100,000 topographic map sheets purchased from FTM, using numerous specific landscape features as tie points. Next, pairs of photos were analysed using a stereoscope, and land cover categories (Table 1, see also explanation below) manually mapped onto an A3 printout of an orthorectified air photo. All photos were analysed by the same observer (the author) to ensure consistent results. Finally, these classifications were digitized into ArcGIS, used to produce maps and areal coverage statistics for each class. Class conversion analysis based on pixel-to-pixel spatial registration was not undertaken, as the high topographic relief in the region causes geometric error making this unreliable (cf. McConnell 2002). The accuracy of the land cover statistics from this study is to within 0.01 km^2 per 10 km^2 sample site. This was assessed by spot check comparisons of the sums of the classification polygons between the 1949–1950 images and the 1990s images. This is at least an order of magnitude smaller than any changes in land cover found, lending confidence to the interpretation that these changes are not a result of operational error.

The land cover categories used (Table 1) warrant comment. The selection of categories is an artifact of what is visible and distinguishable on the photos, of traditions in remote sensing analyses, and of the interests of the researcher. The choice to separate or lump certain land cover types, the criteria by which they are distinguished, and the labels they are given can represent political agendas and have political implications (Robbins 2001, McCusker and Weiner 2003). In this study, the goal, as stated before, was to assess and quantify historic patterns of landscape change in the context of significant farmer-led land transformation and of interest in the potential impacts on native biodiversity. As a result, the categories seek to distinguish between, for example, natural and anthropogenic formations (recognizing the interpenetrated nature of these categories), and between specific physiognomic types of vegetation communities. The categories reflect to a large extent the opportunities and limits of the air photos and the conventions established in the science of aerial photography (Lillesand and Kiefer 1994) and in previous studies of Madagascar (Lowry et al. 1997). Yet they also in part reflect the distinctions made by farmers living in the landscape (like between categories C1 and C2, or *tanimbary* and *tanety*: Blanc-Pamard 1986, Kull 2008) as well as the author's research interests in fire (category BP: Kull 2004) and in the spread of Australian forestry species (category T9a: Kull et al. 2007). Except for the distinction of exotic and anthropogenic trees, the categories do not address floristic (or chorological) differences, like between different kinds of grassland vegetation communities, for this was not only beyond the scope of the

TABLE 1. Land cover classification categories used in the analysis.

Code	Name	Notes
P	Pasture	Grassland or pasture; may include isolated crop field or tree
BP	Burned pasture	Recent fire scars in grassland; combined with P in analysis
C1	Irrigated crops	Irrigated fields (usually rice) on valley bottoms or terraced slopes
C2	Rainfed crops	Mostly continuous (>75%) cover of dryland rain-fed crop fields (includes fallow)
T1	Riparian trees	Trees/bushes along streams or in mountain side hollows
T2	Native forest	Continuous (>75% canopy cover) non riparian native forest
T3	Native woodland	Discontinuous (25 % -75 % canopy cover) native savanna or woodland, e.g. tapia forests
T6	Farm trees	Anthropogenic trees including fruit orchards, village trees, and especially pine and eucalyptus woodlots
T9n	Natural scrub	Shrubby native vegetation, often heath or bracken fern, usually on hilltops away from crops and habitation
T9a	Anthrop scrub	Shrubby anthropogenic vegetation, often wattle or coppiced eucalypts, usually near settlements
B	Built-up	Settled areas, including houses and bare ground; may incorporate minor garden areas
E	Erosion	Active bare soil erosion, especially lavaka gullies
L	Lakes	Lakes, ponds
W	Wetland	Non-woody areas of visibly humid vegetation in topographic depressions
V	Rivers	Large rivers
R	Roads	Roads and tracks

study but also not possible without extensive fieldwork (Lowry et al. 2007). Identification of the different land cover types was based on analysis of textures and shades, 3-D topographic interpretation, and diverse clues in the landscape, relying on the author's familiarity with highland landscapes from previous fieldwork, and brief field visits to 12 of the sample sites.

The final step was the land cover change analysis, which involved comparing percentage cover of each land cover category in each sample site at the two time points. As the area of the sample sites varied slightly, changes in land cover across the collected sample sites were analysed using percentage change instead of actual areas, in effect normalizing the data. Average percentage changes, and their standard deviation, were calculated for each category across the 28 sample sites. A one-way analysis of variance test was used to test for statistical significance (Table 2).

RESULTS

The air photo analysis documents an expansion of anthropogenic land covers. This occurred largely at the expense of grassland, but proportionately wetland areas are the most affected (Table 2, Figure 2). While many sample sites display similar trends, there is considerable variability from site to site, reflecting accessibility, demography, state interventions, and biophysical context (three examples are illustrated in Figure 3). Below, the results are reviewed by category.

Grasslands [P and BP] dominate land cover in the highlands. Grassland area declined, on average, by 23% across the sample sites. The loss in grasslands areas is fully accounted for by a growth in crop field area, farm trees, and, to a lesser extent, built up village areas (houses, bare ground, and minor gardens). Irrigated rice fields [C1] and rain-fed crop fields [C2] occupied an eighth of all land in 1950, and had doubled to one quarter of land cover by the 1990s. Settlement areas of houses, bare ground, and minor gardens [B] and roads and tracks [R] more than doubled. Farm tree coverage [T6, which incorporates forestry plantations, private woodlots, fruit orchards, and village trees] quintupled, accompanied by a modest growth in anthropogenic 'scrub' [T9a, including harvested eucalyptus woodlots or spontaneous *Acacia dealbata* growth]. The vast majority of the area in these two categories is limited to a few species of eucalyptus, pine, and acacia (Rakoto Ramiarantsoa 1995, Carrière and Randriambanona 2007, Tassin et al. 2009a). These trends, except in the case of T9a, are all statistically significant (see Table 2).

TABLE 2. Average percentage extent of land cover categories in 1949–1950 and 1991–1994, and gain or loss between these two temporal increments, across 28 randomly sampled sites in highland Madagascar. Standard deviation are in parenthesis; cf. Table 1 for description of land cover categories. *Gain or loss is statistically significant at $p < 0.05$ based on one-way analysis of variance between 1950 and 1990s data for each category (from summary data, n = 28).

Land cover category	Average % cover ~1950	Average % cover 1990s	Average gain or loss in % cover, 1950 to 1990s	p-value*
P + BP	73.6 (17.9)	56.9 (26.2)	-16.7 (15.6)	0.007*
C1	5.8 (6.4)	9.7 (7.6)	+3.9 (3.6)	0.043*
C2	6.4 (11.5)	15.7 (16.2)	+9.3 (10.0)	0.016*
T1	1.9 (3.3)	1.2 (2.3)	-0.7 (1.2)	0.361
T2	0.2 (0.6)	0.2 (1.0)	0.0 (0.4)	0.855
T3	0.6 (2.0)	0.4 (0.9)	-0.2 (1.2)	0.631
T6	1.7 (2.9)	8.6 (12.4)	+6.9 (11.6)	0.006*
T9a	0.5 (1.8)	0.7 (2.3)	+0.2 (1.1)	0.719
T9n	1.9 (3.4)	1.6 (2.6)	-0.4 (1.7)	0.712
W	5.1 (4.8)	2.0 (2.0)	-3.1 (4.7)	0.003*
B	0.2 (0.3)	0.6 (0.6)	+0.3 (0.4)	0.003*
R	0.3 (0.5)	0.6 (0.8)	+0.3 (0.5)	0.098
other (L + V + E + unclassified)	1.8 (3.7)	1.9 (3.7)	+0.2 (0.6)	0.92

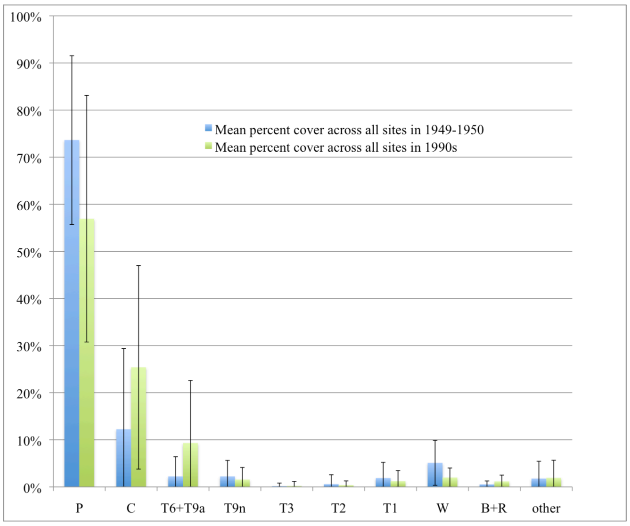

FIGURE 2. Gain, loss, or persistence of different land cover categories in highland Madagascar in the second half of the 20th Century. Shows average percentage of each category (labels explained in Table 1) across the 28 sample sites. Error bars indicate standard deviations.

The highland's small patches of natural forest [T2, closed canopy, non-riparian] declined by one third over the study period, whereas the *tapia* woodlands [T3], found in five sample sites, were stable. There was a slight loss in scrubland consisting of native ferns and heather [T9n]. None of the above trends are statistically significant. Proportionally, the most dramatic losses are of riparian forest (37%) and wetlands (60%); the latter is statistically significant. The former category [T1] includes vegetation ranging from gallery forests along streams to dense forest in mountainside hollows, and various intermediate categories, while the latter [W] includes non-woody vegetation areas in valley bottoms (seen in the air photos as visibly darker, thus moister, than surrounding grasslands).

DISCUSSION

The results largely correspond to what one would expect from a grassland region populated by a growing number of subsistence-oriented farmers: an expansion of anthropogenic land covers (Ellis and Ramankutty 2008), in particular crop fields, farm trees, and built up areas. The population of the island more than doubled during the study period, from 5.9 million in 1951 to 12.1 million in 1993 (SSG 1953, Repoblikan'i Madagasikara 1993), and the intensification of existing areas and conversion of new agricultural lands has been a primary occupation for much of the farming-based population (Raison 1984, Rakoto Ramiarantsoa 1995). The quintupling of farm trees that accompanied this activity reflects concerted efforts by farmers, government officials, and development agents to provide wood resources for fuel and construction, and to 'green' a perceived barren landscape (Carrière and Randriambanona 2007; Kull et al. 2007; Tassin et al. 2009b).

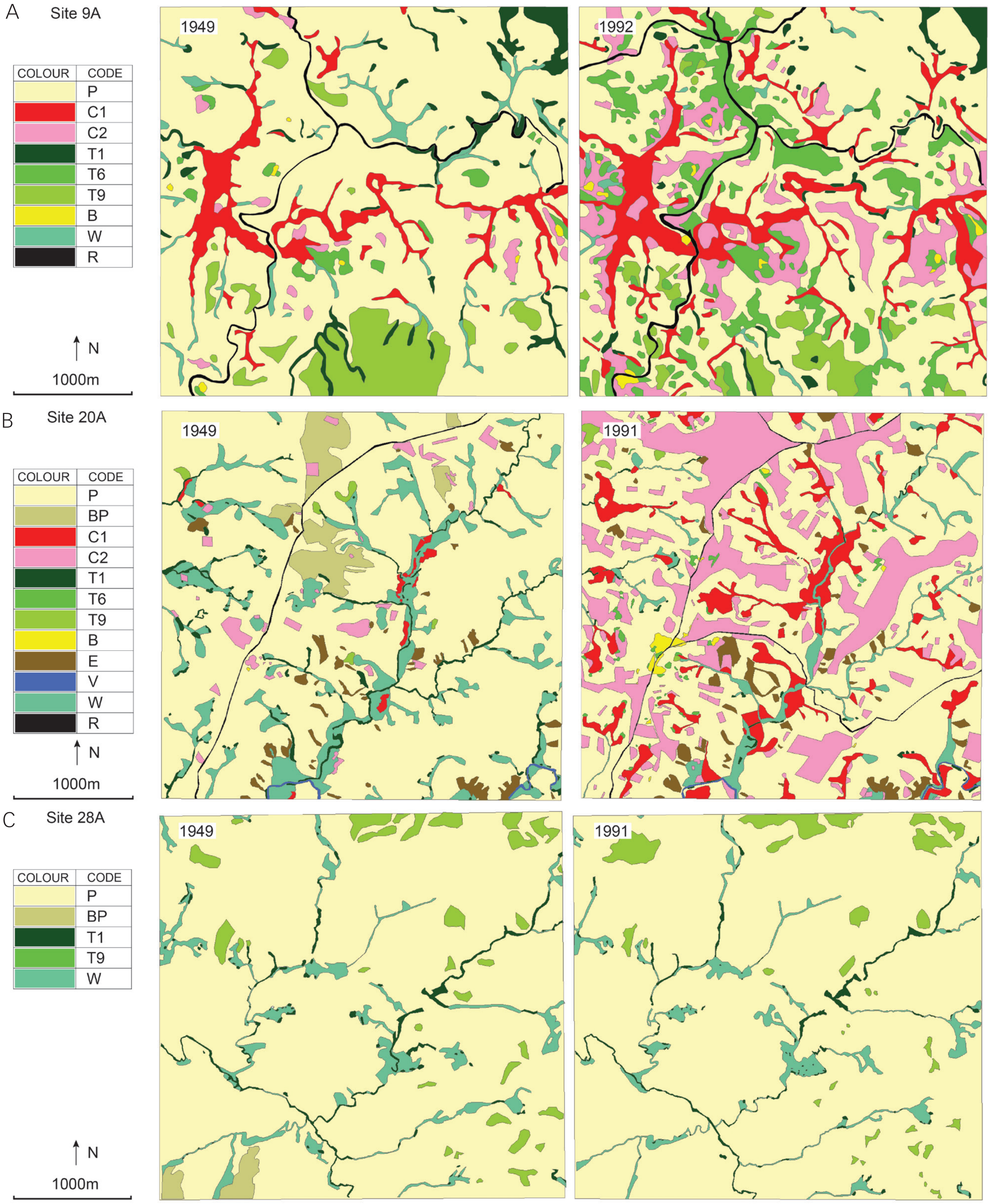

FIGURE 3. Land cover classification maps for three illustrative sample sites with different levels of human intervention (locations indicated in Figure 1; label codes explained in Table 1). (A) Site 9A, in the northeastern highlands, north of Anjozorobe, a zone of spontaneous agricultural and woodlot expansion; (B) Site 20A, in the western highlands near Mandoto, an area hosting several planned agricultural development projects; (C) Site 28A, an uninhabited area in the southwest of the highlands near the Col d'Itremo.

Malagasy farmers are creating cultural landscapes, using the constraints and opportunities of the landscapes, plants, technologies, and socio-economic relations they encounter (Kull 1998, Blanc-Pamard and Rakoto Ramiarantsoa 2000). These anthropogenic land covers incorporate many introduced plant species, some of which also blend into the spontaneous flora of grasslands and forests (Lowry et al. 1997, Kull et al. 2012).

The loss of natural closed canopy forest, though not statistically significant, corresponds with a trend broadly documented for Madagascar as a whole (Harper et al. 2007) as well as for the highlands at the edge of the forest escarpment near Ambositra (McConnell 2002, Vågen 2006) and at the outlying forest of Ambohitantely (Ratsirarson and Goodman 2000, Pareliussen et al. 2006). Forests likely succumbed to the combined pressures of tree cutting, crop field clearance, and fire. The relative stability, indeed slight increase though also statistically insignificant, of *tapia* woodlands corroborates findings reported in my previous studies of the woodlands south of Antsirabe (Kull 2003, 2004).

Grasslands, the dominant land cover, lost the most surface area during the 40-year study period: an estimated 13,000 km^2 if one extrapolates from the sample sites. This broad land cover category includes a variety of herbaceous vegetation communities, in parts highly affected by human activities like grazing, fire and species introductions. The grasslands have long been described in many publications as a degraded, secondary formation characterized by a relatively small number of pan-tropical grasses and derived from woodier, richer pre-human land cover (Bosser 1969, Koechlin 1993, Gade 1996). However, recent research suggests that some Malagasy grasslands are of ancient origin and contain more diverse flora and fauna than previously recognized (Bond et al. 2008, Willis et al. 2008). Indeed, there is considerable debate over the origins of the grasslands, the nature of prehistoric highland vegetation, and the ways in which this history is framed (Lowry et al. 1997, Burney et al. 2004, Kull 2004, Gade 2008, Pollini 2010). This study reminds us that many grasslands are being transformed into other land covers in the creation of settled rural farming landscapes, and that much remains to be learned about their ecology and their historical dynamics in the face of climate swings, species arrivals, and human management. As Bond and Parr (2010) note, conservation attention to grasslands is long overdue.

The land cover categories that in percentage terms lost the most surface area during the latter half of the 20^{th} Century are the wetlands and riparian vegetation. These humid vegetation zones appear in the air photos as a dispersed, patchy, and veined network more or less following the dense, dendritic drainages of the highlands. They were part of the vegetation mosaic that at least partly characterized the pre-human Holocene period in the now grass-dominated highlands (Gasse and Van Campo 1998).

These humid vegetation zones are diverse in character. They include scattered patches of moist forest growing in the wet soil of mountain hollows and along first order streams where they are protected from free-ranging grassland fires (Figure 4A, B). Such forests are assumed to be floristically similar to the montane rainforests of the eastern escarpment, with genera *Tambourissa* and *Weinmannia* traditionally considered as indicative (DEF 1996). Downstream, thin gallery forests occasionally line riverbanks, including *Mangifera indica*, *Ficus* sp., and *Breonadia salicina* (Figure 4C). Finally, wherever the topography is flatter and impedes drainage, edaphic wetlands, marshes, and bogs have developed, featuring various native and introduced grasses, sedges, rushes, and herbs (Figure 4D).

These vegetation categories are frequently overlooked in mapping exercises, largely due to issues of scale. Their typically small size and thin shape is not conducive to satellite image-based remote sensing classifications (e.g., Conservation International et al. 1995, DEF 1996, Moat and Smith 2007). Some previous remote sensing-based studies of highland Madagascar land use do not even include wetlands as a land cover type (Razafindramanga Minoniaina 1994, Vågen 2006). The advantage of air photos lies in their higher level of detail and the potential for easy 3D viewing, which helps in identifying these vegetation types based not only on shade and texture, but also via topography.

Biologically speaking, several aspects of these dispersed, diverse humid vegetation types are poorly known, including their aquatic flora and the biology of freshwater invertebrates and fishes (Benstead et al. 2003). There are indications, however, that they are important. For instance, 30 % of the vascular aquatic plants in Madagascar are found only in the island's Central phytogeographic domain (Andrianasetra Ranarijaona 2003), and all six species of freshwater crayfish (*Astacoides*) on Madagascar are found only above 800 m elevation in the eastern and central highlands (Jones et al. 2007). While the humid vegetation zones are widely altered by humans and the plants and animals we have introduced, they still serve important roles. For example, riparian forests can support the survival of some of the island's highly endemic montane frogs (Andreone et al. 2008, Vences et al. 2009).

Upland wetland conservation has not really found a place on the national conservation agenda outside of the long-standing efforts at Lake Alaotra – which is distinguished by the presence of a unique lemur population (Rasoavarimanana 1997, Ralainasolo et al. 2006, Copsey et al. 2009) and at Torotorofotsy marsh, which is a sizeable wetland site close to the popular Perinet/Andasibe protected areas complex (Rasoavarimanana 1997, Dolch et al. 2008). The lack of attention to other highland wetlands and riparian areas comes despite recognition in the literature that wetlands have been disproportionately fragmented, transformed, and modified by a long history of human land management (Durbin et al. 2003), with detrimental impacts on birds (Langrand and Wilmé 1993, Rabarisoa et al. 2003), aquatic flora (Andrianasetra Ranarijaona 2003), aquatic fauna (Elouard and Gibon 2001, Benstead et al. 2003), amphibians (Andreone et al. 2008), and freshwater fish (Benstead et al. 2003).

Several reasons might explain the lack of attention. Despite the fact that early colonial explorers noted the existence of the very localized, small, and dispersed network of humid vegetation in the otherwise grass-dominated highlands (e.g., de Cointet 1897), they do not show up easily in today's remote sensing analyses. These zones understandably attract less interest than the larger, iconic, lemur-hosting forests encircling the island. The tiny, dispersed patches would not fit easily into the dominant protected areas model for conservation.

Furthermore, wetland conversion is a culturally awkward topic, given the central role of irrigated rice farming to highland culture and food security. In all corners of the highlands, one of the first things that farmers do when settling new lands – which is an ongoing practice – is to establish rice fields in the most accessible marshes or floodplains (Delenne 1970, Rakoto Ramiarantsoa 1995, Kull 2008). In forest areas, conservationists (and colonial foresters before them) have long encouraged farmers to abandon slash-and-burn techniques in favor of more intensive, irrigated rice. So to discourage wetland conversion for conservation confronts the alimentary and cultural needs of a growing population and even the previous messages of government officials and conservationists. Fortunately, a fair number of first order catchments with humid vegetation remain in higher altitudes, in places far from roads, or in the lightly populated western highlands. Any conservation efforts in these areas would need to be based on further study in collaboration with local

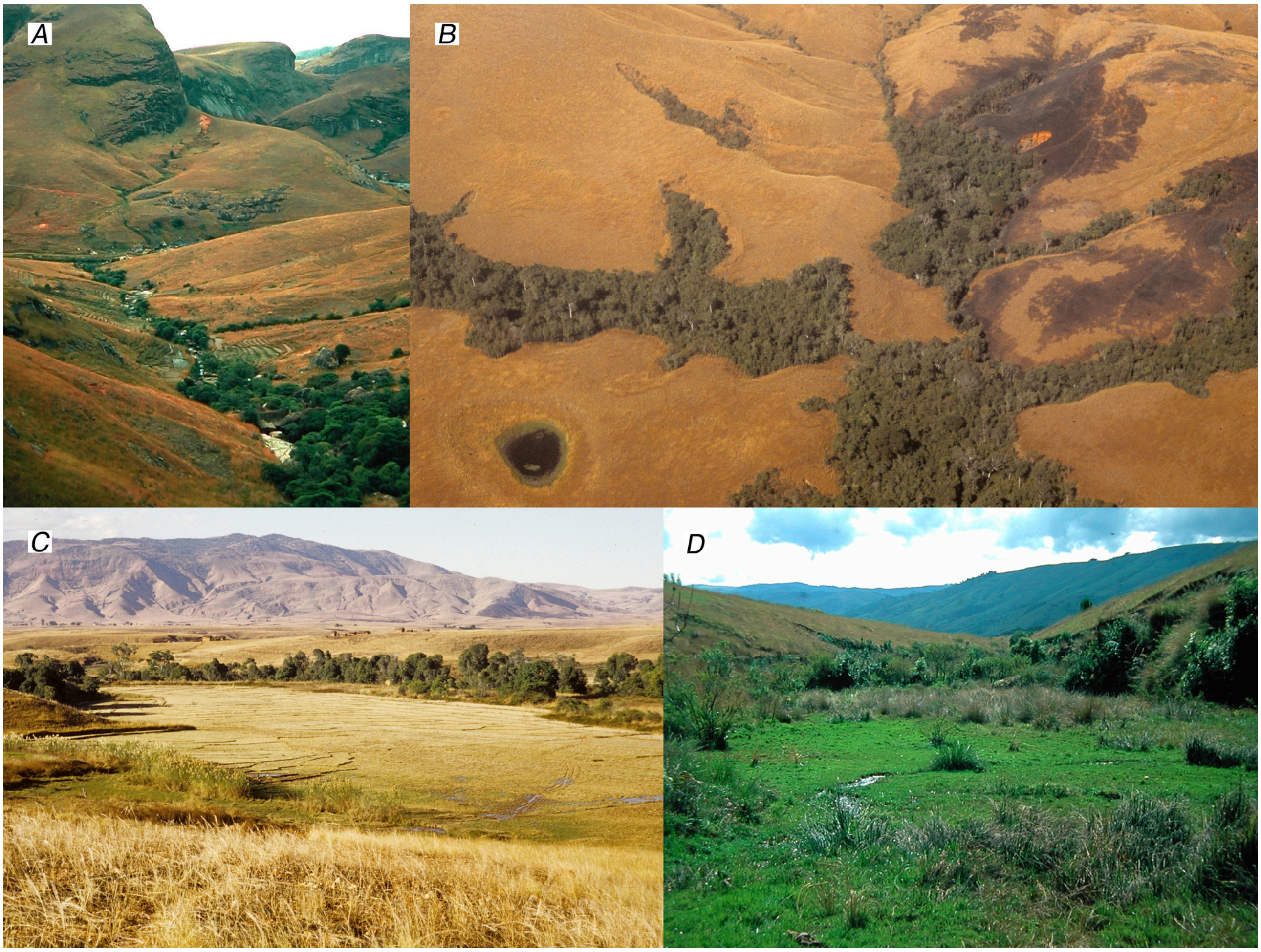

FIGURE 4. Photos of diverse humid soil vegetation formations. (A) Native woody vegetation lining a mountain stream in the southern highlands near Ambalavao. Note also rice terraces along and above stream, and traces of fallow cropfields in grassland. (B) Dense riparian forests in fire refugia stream hollows, as well as a rare pond, in the remote western highlands (towards Bongolava). (C) Gallery forest typical of the middle-west near Tsiroanomandidy. Note floodplain seasonal wetlands developed as irrigated rice fields. (D) Minor moist soil area of poor drainage in small mountain stream hollow in central highlands (near Antsirabe).

villagers, and on locally negotiated forms of sustainable resource management.

In conclusion, this research demonstrates that studies of environmental change based on aerial photography can offer a level of detail (in scale, and in topography) as well as a depth of history (almost half a century before high resolution satellite images) that provides useful and novel insights. Based on such research tools, the study suggests, in particular, that conservation attention in the highlands should focus more attention on grasslands and remnant small-scale wetlands and gallery forests, rather than just on closed forest patches (which have shrunk, but are better represented to the east) or sclerophyllous woodlands (which appear stable). Grassland and wetland environments are both specialized habitats likely to be valuable to biological diversity as well as crucial building blocks for Malagasy cultural landscapes and food security. In the highlands, agricultural expansion takes place preferentially in these environments. As a result, more research attention should be focused on the biology of these environments (Bond et al. 2008), on their place in rural society (Blanc-Pamard 1986, Rakoto Ramiarantsoa 1996), and on the socio-ecological dynamics of the new landscapes created out of them (Martin et al. 2009, Carrière et al. 2012).

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