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Beyond deforestation monitoring in conservation hotspots: Analysing landscape mosaic dynamics in north-eastern Madagascar

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ABSTRACT

Due to its extraordinary biodiversity and rapid deforestation, north-eastern Madagascar is a conservation hotspot of global importance. Reducing shifting cultivation is a high priority for policy-makers and conservationists; however, spatially explicit evidence of shifting cultivation is lacking due to the difficulty of mapping it with common remote sensing methods. To overcome this challenge, we adopted a landscape mosaic approach to assess the changes between natural forests, shifting cultivation and permanent cultivation systems at the regional level from 1995 to 2011. Our study confirmed that shifting cultivation is still being used to produce subsistence rice throughout the region, but there is a trend of intensification away from shifting cultivation towards permanent rice production, especially near protected areas. While large continuous forest exists today only in the core zones of protected areas, the agricultural matrix is still dominated by a dense cover of tree crops and smaller forest fragments. We believe that this evidence makes a crucial contribution to the development of interventions to prevent further conversion of forest to agricultural land while improving local land users' well-being.

1. Introduction

Tropical forest landscapes have been modified by humans for tens of thousands of years with increasing intensity (Malhi, Gardner, Goldsmith, Silman, & Zelazowski, 2014). The expansion of agricultural land is a main driver of forest conversion (Gibbs et al., 2010), ranging from large-scale agribusinesses to smallholder subsistence farms (Laurance, Sayer, & Cassman, 2014). In many countries the concern has now shifted to large-scale forest clearance linked to the engagement in international agricultural markets and the growth of urban populations (DeFries, Rudel, Uriarte, & Hansen, 2010; Lambin & Meyfroidt, 2011; van Vliet et al., 2012). Madagascar seems to be an important exception to this trend, with the retraction of its humid forest frontier still due to smallholders' expansion of agricultural land to produce subsistence rice through shifting cultivation (van Vliet et al., 2012). In Madagascar, as in other shifting-cultivation hotspots around the globe (Ickowitz, 2006; Mertz et al., 2009), shifting cultivation has since colonial times been considered irrational and unsustainable, leading to the destruction of biodiversity-rich forests (e.g., Humbert, 1927 in Kull, 2000).

Land change science offers a strong conceptual framework to analyse transitions in land use systems dominated by smallholders (Turner, Lambin, & Reenberg, 2007). Adopting a sustainability perspective, it seeks to understand the dynamics of land cover and land use as a coupled human–environment system (Global Land Project, 2005; Reenberg, 2009). The resulting knowledge should help policy-makers to steer land change processes towards sustainable outcomes, ensuring the provision of ecosystem services for stakeholders at different levels.

A major challenge arises if the investigation of land change starts with the analysis of remotely sensed imagery. This makes it difficult to link land cover information to human influence and thus to understand land use processes (Verburg, van de Steeg, Veldkamp, & Willemen, 2009). This is especially pertinent in the context of shifting cultivation systems, which are characterized by a combination of different land cover types showing high spatial and temporal dynamics (Schmidt-Vogt et al., 2009; Sirén & Brondizio, 2009). Another challenge involves the discrepancy between the different levels at which land use decisions are made. Local land

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users' decisions are increasingly influenced by broad economic, political and environmental processes (Lambin et al., 2001; Verburg et al., 2009) leading to highly context-dependent outcomes (Ostrom, 2007; Rindfuss et al., 2007). The uniqueness of local information makes upscaling and generalization difficult (Magliocca et al., 2014), which hinders its use by policy-makers (Messerli, Bader, Hett, Epprecht, & Heinimann, 2015). In light of these two challenges, it is not surprising that shifting cultivation in eastern Madagascar does not appear on regional or national maps.

Most regional and national land change studies have limited their focus to the binary analysis of changes from forest to nonforest land cover (Grinand et al., 2013; Harper, Steininger, Tucker, Juhn, & Hawkins, 2007; Ministère de l'Environnement, des Forêts et du Tourisme (MEFT), United States Agency for International Development (USAID), & Conservation International (CI), 2009; Office National pour l'Environnement (ONE), Direction Générale des Forêts (DGF), Foiben-Taosarintanin'i Madagasikara (FTM), Madagascar National Parks (MNP) & Conservation International (CI), 2013). The scarce scientific knowledge on the current extent and trajectories of shifting cultivation in this zone is almost exclusively based on a few case studies clustered between the capital, Antananarivo, and the port of Toamasina (Klanderud et al., 2010; Messerli, 2004; Styger, Rakotondramasy, Pfeffer, Fernandes, & Bates, 2007). This presents a considerable omission given the large attention shifting cultivation has received from conservation and development stakeholders (Conservation International, 2011; Freudenberger, 2010; Holmes, Ingram, Meyers, Crowley, & Victurine, 2008; World Bank, 2013; World Wildlife Fund, 2007).

The eastern escarpment of Madagascar holds some of the most biodiversity-rich forests on earth and is therefore a global conservation priority (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). Theoretically, the establishment of two large protected areas in 1997 and 2005 (Masoala National Park and Makira Natural Park, respectively) has closed most of the agricultural frontier in the region. Conservation and development strategy has mainly been directed at the intensification of land use away from shifting cultivation towards permanent irrigated rice production. However, little is known about the success of this approach, and the focus on single components of the agricultural production system has been questioned (Brimont, Ezzine-de-Blas, Karsenty, & Toulon, 2015; Messerli, 2004; Zaehringer, Eckert, & Messerli, 2015). While shifting cultivators are held responsible for rapid deforestation, spatially explicit evidence for this claim is lacking due to the abovementioned difficulty of detecting shifting cultivation on land cover maps. The either/or focus on changes from forest to nonforest also limits our understanding of the processes at work and of how to slow forest loss and lift the local population out of poverty.

The goal of this study was thus to spatially delineate shifting cultivation and permanent land use systems in north-eastern Madagascar and to assess their changes at a regional level; to the best of our knowledge, it is the first such effort. For this study we defined landscape as a spatially heterogeneous area composed of interacting land use systems. We mapped current landscape types, quantified major changes in their extent from 1995 to 2011 and identified the location and magnitude of intensification and extensification at the landscape level. This offers a crucial contribution to policy-making for a more sustainable development of this resource-rich but poverty-prone region.

2. Materials and methods

2.1. The study region

We selected our study region in north-eastern Madagascar (Fig. 1) because it is home to some of the last remaining humid primary forests containing the extraordinary biodiversity for which Madagascar is known (Ganzhorn, Lowry, Schatz, & Sommer, 2001; Myers et al. 2000). Therefore it features a number of protected areas which have the aim to halt deforestation and forest resource exploitation. We chose the administrative region of Analanjirofo as the extent of the analysis, as this is the level at which decision making for regional development takes place. However, the northernmost tip of the Analanjiorofo region is not included as the available land cover data did not extend this far. Instead, the Masoala peninsula, of which part belongs to the Sava administrative region, is included, as it represents a biodiversity hotspot of great interest to many conservation actors.

This region receives about 3,600 mm of annual precipitation and has an average annual temperature of 24 °C (Jury, 2003). Makira Natural Park, established in 2005, encloses one of the largest continuous rainforests in the country and provides a habitat for more than 18 species of lemurs (Golden, Fernald, Brashares, Rasolofoniaina, & Kremen, 2011). Other large forest conservation sites include Masoala National Park (established in 1997), Ambatovaky Special Reserve (established in 1958), and Mananara Nord National Park (established in 1989). Together these protected areas cover 23% of our study region (International Union for Conservation of Nature & UNEP, 2014). Access to these forests by local land users is restricted, but due to their limited accessibility and limited funding, enforcement is rather weak.

Apart from these forests, the region is characterized by small plots with diverse land uses. Rice is the main staple crop in Madagascar. Both rain-fed upland and irrigated lowland paddy rice are produced for subsistence by the local land users, ethnically dominated by the Betsimisaraka people. Also important are commercial crops such as clove, vanilla, coffee, and lychee (Locatelli, 2000). The volatility in prices for these crops creates uncertainty for local farmers (Food and Agriculture Organization, 2014).

Traditional shifting cultivation is used to produce rain-fed upland rice on moderate to steep slopes. Most commonly land users clear and burn small plots, which they plant with rice (often in combination with maize) for a single year. Subsequently, tuber crops such as cassava or sweet potatoes are often cultivated for another one to two years. Thereafter the fields lie fallow for several years (Messerli, 2004). For permanent rice cultivation, land users need access to paddies at the valley bottoms and to irrigation water. Ploughing and weeding the irrigated rice fields is labour-intensive, and external inputs such as fertilizers are rare (Locatelli, 2000). Clove trees, coffee bushes and vanilla lianas are often grown in agroforests together with a diverse mix of fruit trees and tuber crops for home consumption. Monocultures of clove trees are also common. Zebu cattle are used for ploughing and in ancestral ceremonies. They mostly graze in irrigated rice paddies after harvest and along footpaths, as relatively few land users have sufficient land for pastures. Small forest fragments, often family owned, are dispersed throughout the region and provide construction materials, wild food, space for burial grounds and other benefits (Urech, Rabenilalana, Sorg, & Felber, 2011).

Property rights for agricultural land are very complex in this region. Within shifting cultivation systems, all descendants of the person who first clears a forest plot have the right to use it for rice cultivation. From year to year, elders consider the land needs of households within their lineage and then allocate the plots (Urech et al., 2011). The conversion of forest into agricultural land is one of the few ways to assure food security for future descendants (Keller, 2008). The increasing scarcity of natural forests and expansion of protected areas might therefore incite land users to accelerate deforestation. For the cultivation of permanent agricultural land, such as irrigated rice paddies and agroforests, individual or family-based land rights usually prevail. Descendants mostly inherit these