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Remote sensing combined with social-ecological data: The importance of diverse land uses for ecosystem service provision in north-eastern Madagascar

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ABSTRACT

Through ongoing deforestation in the tropics, forest-related ecosystem services are declining, while ecosystem services provided by agricultural land uses are on the increase. Land system science provides a framework for analysing the links between land use change and the resulting socio-environmental trade-offs. However, the evidence base to support the navigation of such trade-offs is often lacking, as information on land use cannot directly be obtained through remote sensing and census data is often unavailable at sufficient spatial resolution. The global biodiversity hotspot of north-eastern Madagascar exemplifies these challenges. Combining land use data obtained through remote sensing with social-ecological data from a regional level household survey, we attempt to make the links between land use and ecosystem service benefits explicit. Our study confirmed that remotely sensed information on landscapes reflects households' involvement in rice production systems. We further characterized landscapes in terms of "ecosystem service bundles" linked to specific land uses, as well as in terms of ecosystem service benefits to households. The map of landscape types could help direct future conservation and development efforts towards places where there is potential for success.

1. Introduction

Despite decades of international conservation efforts, tropical forests are still shrinking to make way for agricultural land (Hansen et al., 2013; Malhi et al., 2014). The loss of these important reservoirs of biodiversity and biomass has numerous repercussions for the provision of ecosystem services (ES) to both local and distant human populations (Costanza et al., 2014; Foley et al., 2005). Adopting a sustainability perspective, land system science seeks to understand the links between human activities, land use change, and the resulting socio-environmental trade-offs (Reenberg, 2009; Turner et al., 2007; Verburg et al., 2015). Environmental and agricultural policy and decision-making takes place at different administrative scales beyond the local context. Therefore, knowledge on human-environmental interactions needs to be generalizable to serve specific planning needs at those scales, without oversimplifying highly complex and context-specific social-ecological dynamics (Magliocca et al., 2014). A major challenge of land system science, however, pertains to the difficulty of using remotely sensed land cover information to infer land use and its links to actors' well-being (Verburg et al., 2009). While in spatial analysis new approaches for generalization and upscaling exist that allow a better representation of land use (e.g. Hett et al., 2012; Messerli et al., 2009; Zaehringer et al., 2016), they reveal only one side of the larger picture regarding the linkages between land use and human well-being. The integration of spatially explicit land use data with social science information at regional to national level is crucial for the advancement of land system science (Rindfuss et al., 2007). So far, few examples exist from developing countries: the unavailability of census data at sufficient spatial resolution usually presents a major obstacle to such an endeavour. To tackle this challenge for the biodiversity hotspot of north-eastern Madagascar (Ganzhorn et al., 2001; Myers et al., 2000), we col-

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lected primary data through a regional level household survey to make explicit the links between land use and ES benefits.

The ES concept was proposed almost two decades ago to frame the connections between ecosystems and human well-being (Costanza et al., 1997; Daily, 1997). Despite its holistic focus and widespread application since the Millennium Ecosystem Assessment (MEA, 2005), the concept has shown several weaknesses in terms of understanding the linkages between natural resources and human well-being (e.g. Dawson and Martin, 2015; Villamagna and Giesecke, 2014). Especially in a developing-country context, where poverty alleviation is a major objective to sustainable development planning, we see the following as the most important weaknesses in ES research. First, often only individual ES are selected for assessment based on researchers' main interest and data availability. In tropical forest regions, where ES research is often steered by land managers concentrating on biodiversity conservation, many studies focus their analysis on ES provided by forests only (for Madagascar e.g. Brown et al., 2013; Kari and Korhonen-Kurki, 2013; Kramer et al., 1997; Wendland et al., 2010). However, in multifunctional tropical landscapes, human well-being depends on a range of land use activities and ES, and the interactions between them. To generate meaningful knowledge for the negotiation of trade-offs between conservation and human well-being, we should therefore try to embrace the whole set of land uses and ES linked to them. Second, an individual ES can have various different values to different land users based on its contribution to their well-being (Daw et al., 2011; Jax et al., 2013). This means that a single focus on monetary valuation in ES assessments limits our understanding of the multiple demands that influence local land users' decision-making in terms of land use and management (Turnhout et al., 2013). Third, aggregating land users, their socio-economic characteristics, and demands for ES over landscape or regional scales impedes the development of strategies directed at lifting people out of poverty (Dawson and Martin, 2015; Daw et al., 2011; Fisher et al., 2013). People value ES differently, and their ability to benefit from a specific service – and thus its potential contribution to poverty alleviation – depends on various other factors such as available resources or access (Daw et al., 2011; Leach et al., 1999).

While in many regions the drivers of deforestation have changed from local smallholders' subsistence needs to globalized demands for food and energy crops (DeFries et al., 2010; Gibbs et al., 2010; Lambin and Meyfroidt, 2011; van Vliet et al., 2012), the eastern coast of Madagascar presents a clear exception to this trend (Laney and Turner, 2015; Urech et al., 2015; Zaehringer et al., 2015). The largest remaining continuous surfaces of humid forest in Madagascar are still under threat, mainly due to agricultural expansion (Ganzhorn et al., 2001; Myers et al., 2000; Zaehringer et al., 2015). As global awareness of the importance of biodiversity conservation and carbon sequestration rose, so did attention of international conservation actors to these forests (Kull, 2014; Kull et al., 2007). Several protected areas have been established, the two largest and most recent of which are the Masoala National Park (est. 1997) and Makira Natural Park (est. 2005). To reduce agricultural land expansion and deforestation, intensification of smallholders' irrigated rice production has long been perceived as a solution (in addition to strict protection measures) by conservation and development actors (smallholders being defined as farmers with limited resource endowments who produce mainly for subsistence). Although it has been questioned (Vandermeer and Perfecto, 2007), this approach is based on the assumption that households producing more rice in irrigated paddy fields will abstain from converting any more forests into shifting cultivation rice fields. However, landscapes in north-eastern Madagascar feature highly diverse production systems, and thus the complex links between land use and smallholders' well-being must be understood, for any external interventions to be successful (Brimont et al., 2015; Messerli, 2004; Pollini, 2009; Poudyal et al., 2016).

The overall goal of this study is to reveal the importance of different land uses for the provision of ES benefits to local land users in the biodiversity hotspot of north-eastern Madagascar. To achieve this goal we use a regional-level approach combining information on landscape types, obtained through remote sensing and spatial analysis, with household survey data on ES perceptions. More specifically, we aim to answer the following three research questions:

(1) do different landscape types, classified through remote sensing, reflect households' rice production systems, obtained through survey data?
(2) do "ES bundles" (the sets of ES provided by a certain land use type [Raudsepp-Hearne et al., 2010]) linked to specific land uses vary across different landscape types?
(3) do different landscape types correlate with household types in terms of key ES benefits they obtain?

We also discuss the potential ES trade-offs related to the expected landscape change trajectories in the region.

2. Methods

2.1. Study region

Our study region in north-eastern Madagascar (Fig. 1) comprises mainly the administrative region of Analanjirofo, as this represents the level at which decisions on agricultural and infrastructural development are taken. However, we also added the part of the Masoala peninsula belonging to the SAVA administrative region, due to the pronounced global interest in the conservation of this biodiversity hotspot.

North-eastern Madagascar has a hot and humid climate with an average temperature of 24 °C and about 3600 mm of rainfall per year (Jury, 2003). Rice production is at the very centre of life in the culture of the Betsimisaraka population, the dominant ethnic group in this region. They produce hill rice through shifting cultivation and permanent irrigated paddy rice for subsistence; in addition, they grow a number of commercial cash crops (mainly clove and vanilla). Prices paid for these cash crops show high inter-annual variability (FAO, 2014). Mean annual income from agriculture was about US$ 292 per household and the share of poor people (based on the national poverty line) was estimated at 63.5% in 2013 (Institut National de la Statistique INSTAT, 2014). While large contiguous forests today are restricted to the core zones of protected areas, smaller forest fragments are dispersed throughout the agricultural matrix. Converting forest into agricultural fields is one of the few ways for family elders to bring additional land into production and thus assure food security for their descendants (Keller, 2008).

2.2. Conceptual framework

To frame the link between land use and benefits to households we used the cascading ES model as proposed by Haines-Young and Potschin (2010) and adapted by de Groot et al. (2010). As we aimed at a comprehensive assessment of ES at landscape level, ES linked to agricultural land uses played a major role. We conceptualized the ES actively used by households as ES benefits (Fig. 2).

As highlighted by Zhang et al. (2007), in our study some ES provided by a certain land use can be important for the functioning of another land use (Fig. 2). For example, the ES of water regulation provided by forests was also an important ES to irrigated paddy