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Identification and quantification of drivers of forest degradation in tropical dry forests: A case study in Western Mexico

Lucia Morales-Barquero[a,b,*], Armonia Borrego[c], Margaret Skutsch[d], Christoph Kleinn[b], John R. Healey[a]

[a] School of Environment, Natural Resources and Geography, College of Natural Sciences, Bangor University, Bangor, Gwynedd LL57 2UW, UK
[b] Chair of Forest Inventory and Remote Sensing, Burckhardt-Institute, Georg-August-Universität Göttingen, Büsgenweg 5, Göttingen 37077, Germany
[c] Posgrado de Economía, Universidad Nacional Autónoma de México (UNAM), 04510, Ciudad Universitaria, Mexico D.F., Mexico
[d] Centro de Investigaciones en Geografía Ambiental, Universidad Nacional Autónoma de México (UNAM), Antigua Carretera a Pátzcuaro 8701, Morelia, CP 58190 Michoacán, Mexico

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ABSTRACT

The intensity of forest degradation is linked to landowners' decisions on management of their shifting cultivation systems. Understanding the processes involved in this land use type is therefore essential for the design of sustainable forest management practices. However, knowledge of the processes and patterns of forest transition that result from this practice is extremely limited. In this study, we used spatially-explicit binary logistic regression to study the proximate factors that relate to forest degradation by combining biophysical and socio-economic variables. Our study region is within the Ayuquila Basin, in Western Mexico, a typical fragmented tropical dry forest landscape dominated by shifting cultivation. Through a survey and semi-structured interviews with community leaders, we obtained data on the forest resources and on the uses that people make of them. Detailed forest cover maps for 2004 and 2010 were produced from high-resolution SPOT 5 data, and ancillary geographical data were used to extract spatial variables. The degree of social marginalization of each community and the ratio of forest area to population size were the main factors positively correlated with the probability of the occurrence of forest degradation. Livestock management and use of fence posts by the communities were also positively associated with forest degradation. Among biophysical factors, forest degradation is more likely to occur in flatter areas. We conclude that local drivers of forest degradation include both socioeconomic and physical variables and that both of these factors need to be addressed at the landscape level while developing measures for activities related to REDD+.

1. Introduction

Determining the proximate and underlying causes of deforestation and forest degradation of tropical forests is a key prerequisite for the development of activities for REDD+ (reducing emissions from deforestation and forest degradation) (Salvini et al., 2014). Developing countries participating in REDD+ are encouraged to report on human-induced activities that are linked to greenhouse gas (GHG) emissions from forest land (UNFCCC, 2010; Hosonuma et al., 2012). The identification of these activities and locating them in a spatially explicit manner may be of utmost importance for effective REDD+ interventions (Kissinger et al., 2012). While there is considerable understanding of the processes causing deforestation (Geist and Lambin, 2002), knowledge of drivers that cause changes in forest carbon stocks in forests that remain forests (i.e. degradation) is quite limited, especially for tropical dry forests (TDFs) (Murdiyarso et al., 2007).

Tropical dry forests have not received as much attention as humid forests in the context of REDD+, mainly because they have lower carbon stocks and increments per area (Blackie et al., 2014). Nonetheless, TDFs cover extensive areas (approx. 42% of the tropics and subtropics worldwide (Murphy and Lugo, 1986; Miles et al., 2006)), and may potentially play an important role in climate change mitigation. They are notably important ecosystem in the Neotropics, where they cover an area of approx. 520,000 km^2 (Portillo-Quintero and Sánchez-Azofeifa, 2010), that corresponds to more than half of the global total extent of TDFs (Miles et al., 2006). Moreover, TDFs provide a variety of ecosystem services

* Corresponding author.
E-mail address: moralesluciacr@gmail.com (L. Morales-Barquero).

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(Maass and Balvanera, 2005) and although holding lower values of species richness than rainforests, they have particularly high levels of endemism and beta biodiversity (Gentry, 1995).

Despite their importance in providing ecosystem services, TDFs are among the most threatened ecosystems in the Neotropics (Miles et al., 2006). They have suffered high conversion rates and the remaining areas are heavily degraded and fragmented (Trejo and Dirzo, 2000; Sánchez-Azofeifa et al., 2005). This is because TDFs often support high human population densities, with many people depending on forest land and forest resources (hereafter forest resources) for their livelihoods (Sunderlin et al., 2008); particularly through shifting cultivation (Saikia, 2014), but also to provide fuelwood, charcoal, house-building materials, fence posts and non-timber forest products (NTFP) (Maass and Balvanera, 2005). In addition, commercial logging and cattle grazing frequently affect the structure and composition of TDFs (Sanchez-Azofeifa and Portillo-Quintero, 2011).

This paper presents an analytical framework to identify drivers of forest degradation in TDFs and other variables that are correlated with it. Satellite imagery that provides data at a scale fine enough to detect forest degradation due to shifting cultivation is used together with on-the-ground data on the local use of forest resources. It is important to stress that, in our analysis, shifting cultivation (here meaning slash-and-burn agriculture, subsistence farming and swidden cultivation, following the terminology of Mertz (2009)) is considered to cause forest degradation rather than deforestation because its cycle of operation involves clearance followed by regrowth of forest that creates a landscape with lower biomass density that still qualifies as forests, in contrast to deforestation that implies a permanent conversion of land cover from forest to non-forest (Houghton, 2012). As a result, landscapes where shifting cultivation is practiced are complex mosaics made up of patches that are losing or gaining forest carbon stocks (Mertz et al., 2012). However, although there can be carbon gains at the landscape level during particular periods of time, in their early development stages the resulting secondary forests on average usually hold lower carbon stocks than mature forests (Read and Lawrence, 2003; Lawrence et al., 2005; Becknell et al., 2012). Furthermore, lower capacity to store carbon and modified species composition have been observed in secondary forests as an area is subject to more cycles of clearance and recovery (Lawrence et al., 2010). Therefore, they must be considered as degraded forests in the REDD+ context, both in terms of carbon stocks and regarding their ecological characteristics. However, since most of the discussion on forest degradation have been on selective logging (Putz and Redford, 2010); the inclusion of shifting cultivation as a driver of forest degradation within REDD+ is unclear, and this has significant consequences on countries carbon stock estimations (Pelletier et al., 2011). The core questions rely on whether fallows are classified or not as forest land; while the IPCC (Penman et al., 2003) considered fallows as land under predominantly agricultural use, in reality, it is a stage of forest re-growth. Most importantly, the methods used by most countries do not distinguish secondary growth due to shifting cultivation from other types of secondary forest (Houghton, 2012). Consequently, we argue that these stage of secondary re-growth should be considered degraded forest, because it is not a permanent loss of forest cover to be classify as deforestation and it holds less carbon density.

In order to capture the pattern of forest clearance and subsequent regrowth of forests carbon stocks, observations and analysis at suitably fine spatial and temporal scales are required. Previous studies which analyzed multiple dates are limited by coarse and medium spatial resolution (Li et al., 2014) and may not be adequate to detect patches of small-area agriculture (±2 ha) with short cycles of forest clearance and regrowth (3–6 years). Many studies have used spatial scales that are too coarse to detect degradation related to shifting cultivation, e.g. Bonilla-Moheno et al. (2013) used data from MODIS with a pixel size of around 250 m. Multi-date medium resolution Landsat data (30 m) have been used in combination with detailed field inventories to detect shifting cultivation in rainforests where clearings are on average ±2 ha (Pelletier et al., 2012). Clearings and fallows were classified using spectral unmixing analysis, a technique that has been successfully applied to the detection of selective logging mostly in moist and wet tropical forests (Asner et al., 2005; Souza et al., 2005). However, in TDF coarser, spatial and temporal resolution limits the capacity to differentiate between natural open forest areas that have never been cleared and degraded forest or forest recovering after clearance via secondary regrowth, because of overlapping spectral signatures. So far, to the best of our knowledge, only one study (Hurni et al., 2013) has managed to delineate landscape units in which shifting cultivation prevails, by using higher spatial resolution (10 m pixel) satellite data. Nonetheless, this analysis was only done for a single date, i.e. it does not examine change over time.

The scale of analysis is also extremely important in evaluating the human factors that could potentially influence the observed patterns of forest degradation defined by cycles of regrowth and clearance. Typically, proximate causes of forest cover change are hypothesized and tested from national census datasets or data that are aggregated at regional or municipal level because they are readily available. As a result, these analyses may be of limited utility in evaluating local processes in dynamic socio-ecological systems such as shifting cultivation landscapes (Geoghegan et al., 2004). Only a few studies (e.g. Roy Chowdhury, 2006; Getahun et al., 2013) have integrated community-level information or analyzed it across scales from household to regional (e.g. Overmars and Verburg, 2005). Likewise, regional studies that evaluate factors that affect forest degradation at a landscape level are rare (Saikia, 2014).

This situation is not desirable in the context of REDD+, because on-the-ground projects are implemented at a landscape level, and activities are undertaken by individuals and communities on their own parcels of land. To tackle efficiently the causes and consequences of forest degradation, analysis at a scale compatible with the degradation processes is needed. For example, in Mexico, where some studies have claimed that as much as 80% of the forest area is on communal land managed by rural agrarian communities (Bray et al., 2006), data at the community level is required (Skutsch et al., 2013). These agrarian communities are in any case the target group of most REDD+ programs in Mexico (Estrada, 2010) since the policy of the Mexican government is to use REDD+ as a strategy to promote cross-sectoral rural development, as well as to foster the sustainable management of forest ecosystems (SEMARNAT, 2010).

In this paper, we use as a case study a landscape in Western Mexico that contains large areas of TDF in which shifting cultivation is the traditional way of growing crops. We address three main questions: (1) Can the patterns of forest cover change in TDF be associated with forest degradation at the landscape scale? (2) Which factors determine forest degradation in a TDF landscape under a shifting cultivation system? (3) Can variation in the use of, or demand for, forest resources and forest land by communities provide an indication of the probability of forest degradation in a TDF socio-ecological landscape? To explore these questions, a detailed forest cover map was produced through an approach that allows land cover changes due to shifting cultivation to be tracked. Next, the information derived from the interpretation of this map was used in a statistical model that allows the identification and quantification of the probability of forest degradation from an integrated set of biophysical and socio-economic variables. Finally, we further explore the relationship between the use of forest resources such as firewood and poles, and forest degradation associated with shifting cultivation, to explore the utility of using demand for forest