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Spatial patterns of subsistence extraction of forest products – An indirect approach for estimation of forest degradation in dry forest

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ABSTRACT

Successful implementation of a forest based climate change mitigation mechanism such as REDD + depends on robust and available methods for measurement and estimation of forest degradation. Currently available methods are for application in single-hit degradation incidents in high density humid forests. However, it has been suggested that gradual degradation, especially in dry forests, is more widespread and that methods are needed for measuring and estimating associated emissions. We assess the applicability of an indirect remote sensing approach for monitoring forest degradation: infrastructure and other indicators of human activities are mapped and used for spatial prediction of degradation activities. For proxy variables we tested distance to forest edge, distance to roads, and population pressure calculated as the sum of inhabitants per pixel in the Landscan 2010 population raster dataset multiplied by an inverse power distance decay function. Wood extraction incidents were counted in 160 plots in two dry forests in Tanzania with infrastructural entry from one side only. We analyzed the spatial pattern of forest degradation as a function of the chosen proxy variables using zero inflated count models which allows for an excess of zero counts. A jack-knife bootstrap using 10,000 runs was applied to optimize the population distance decay function. We found that the impact of forest degradation is highest near high population concentration, above 1000 individuals. Furthermore, distance to nearest forest edge or road was a significant proxy for estimation of the number of wood extraction incidents ($p < 0.001$), where degradation incidents decreased with increasing distance to forest edge or road. At 3000 m from the forest edge towards the forest core the probability of wood extraction is 20% and dropping. The population distance decay function was found to have a steep decline indicating a relative small impact on forest degradation. Further, and perhaps larger, studies are needed to be able to recommend a distance decay function for general application in Tanzania. However, the results are useful for understanding spatial patterns of wood harvesting as a function of distance to nearest forest edge or road in dry Miombo woodland areas with average population pressure at 1685 ± 101 persons within a radius of 4000 m from the wood extraction sites.

Introduction

The success of the implementation of a mechanism to reduce emissions from deforestation and forest degradation, as well as to enhance conservation, sustainable management and forest carbon stocks (REDD+) is strongly linked with the ability to estimate carbon emissions from forests change (GOFC-GOLD, 2010). A significant proportion of emissions results from forest degradation (Asner et al., 2005), but major gaps remain in available approaches for estimation and monitoring of forest degradation (Murdiyarso et al., 2008; UNFCCC, 2009). In spite of recent technological progress, for example in the use of airborne Lidar measurement (Ryan et al., 2012), not all types of degradation can be monitored with high accuracy and many developing countries lack the capacity to provide degradation estimates for historic periods (De Sy et al., 2012). To accommodate the operational challenges in measurement of degradation, each country is allowed to target the most significant degradation activities with higher accuracies (tier levels) and focus on areas with high levels of degradation (Herold et al., 2011). Similarly, operational definitions of forest degradation and the categorizing of degradation activities is decided at national or sub national level (Herold & Skutsch, 2011).

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An indirect approach to measure and monitor forest degradation in dry forest

Forest degradation activities in dry forests will likely lack ground data from historic periods. This type of data is often only widely available from commercial concessions in dense forests. Furthermore, typical degradation activities are 'invisible' to remote sensing techniques although it has been suggested that these activities cause a constant and persistent degradation process that may be more widespread on a global scale than degradation in dense humid forests (Herold & Skutsch, 2011). These areas are significant for national emissions reporting and developing countries engaging in REDD + need to be able to measure and monitor emissions from degradation activities in dry forests. An idea, that originally emerged from the European Joint Research Centre, for baseline establishment was to use proxy variables for demarcation of intact and non-intact forest land (Achard et al., 2005). This 'indirect measurement approach' is fundamental for current guidelines on national Monitoring Reporting and Verification (MRV) under REDD + policies (De Sy et al., 2012; GOFC-GOLD, 2010). The indirect approach uses available remote sensing and GIS data to model forest degradation from measurement of spatial distribution and evolvement of infrastructure including roads and population centers (Mollicone et al., 2007). The indirect approach follows the rules for carbon accounting given by IPCC LULUCF Guidance (Penman et al., 2003) for 'Forest land remaining Forest land' and is meant as an operational tool applicable worldwide (Asner, Herold, Mollicone, & Souza, 2013). We argue here that the indirect approach is especially valuable for capturing degradation by subsistence wood extraction in dry forests. The definition of intact forest land and choice of proxy variables depend on local conditions (Asner et al., 2013). Among these are that intact forest land follows the UNFCCC definition of forest land with a 1 km buffer zone inside the forest area and that there are no signs of significant human transformation or infrastructure (GOFC-GOLD, 2010). Absence of visual indicators of degradation activities can be used as evidence and acceptance of an intact forest area (Aksenov et al., 2002).

The case of subsistence degradation activities in dry Miombo woodlands of Tanzania

The REDD + process in Tanzania started when the country became pilot in the United Nations REDD Programme, and received funding from the World Bank's Forest Carbon Partnership Facility as well as the Norwegian, Finnish and German governments (Burgess et al., 2010). Realizing that historic baseline forestry data were inadequate, the national strategy for MRV is based on a network of stratified permanent ground sample plots for emissions factors and historic optical remote sensing to obtain activity data for reference emissions levels (REDDTZ., 2012). More than 35% of the country is covered by forest ecosystems and more than one third of this area is occupied by Miombo woodlands (Munishi, Mringi, Shirima, & Linda, 2010). Tanzania may be internationally recognized for its national parks but at least 85% of the remaining forest is outside the protected parks, e.g. as village forests or partnership reserves, and are often degraded (Burgess et al., 2010). Local case studies estimate above ground carbon levels in pristine Miombo woodlands at approximately 70 Mkg ha^{-1} with an annual average estimated loss of 3 Mkg ha^{-1} due to degradation (Burgess et al., 2010). A study from unmanaged dry Miombo woodlands in neighboring Zambia also finds annual carbon losses from wood extraction and fires of up to 4 Mkg ha^{-1} (Chidumayo, 2013). A list with the most significant proximate drivers of deforestation and forest degradation in Tanzania was identified through the World Bank's Forest Carbon Partnership Facility project: (i) extraction of timber and firewood, (ii) charcoal production, (iii) anthropogenic wild fires, (iv) land clearing, agricultural expansion and human settlements, (v) infrastructure and industry, and (vi) overgrazing (Nguon & Kulakowski, 2013). The underlying drivers are market failures, policy failures, rapid population growth, and rural poverty. For instance, the population increased from 10 million people in 1960 to 42 million in 2008. We therefore argue that the REDD + processes in Tanzania is a relevant case for studying and developing indirect remote sensing approaches for establishment of MRV.

Spatial patterns of subsistence wood extraction

To use the indirect monitoring approach, and in light of the conservativeness principle built into REDD+, where carbon credits are adjusted according to the accuracy of measurement (Grassi, Monni, Federici, Achard, & Mollicone, 2008), it may be beneficial to establish a local understanding of the relationship between proxy variables and forest degradation. The current recommendation for definition of categories of forest degradation has shifted from a division based on forest products to division between subsistence and commercial extraction of wood products as well as a category for wild fires (Herold et al., 2011). To understand which proxy variables link to subsistence degradation patterns we turn to the *Neo-Malthusian* discourse for dry forest degradation (le Polain de Waroux & Lambin, 2012) where population pressure and poverty are seen as the main drivers of degradation. Previous studies from African dry forests have demonstrated decreasing forest degradation with increasing distance to population centres (Shackleton, Griffin, Banks, Mavrandonis, & Shackleton, 1994) as well as increasing distance to nearest road and distance to forest edge inside forest patches (Mertens & Lambin, 1997).

The theoretical models behind von Thünen's marginal productivity and the mathematical formulation of locational rent (von Thünen, 1966) may be used to understand spatial patterns of subsistence extraction of forest products. In the theory of locational rent, a product is valued against travel distance and therefore ultimately total production cost. Locational rent decrease with increasing distance until production (or in this case 'extraction') of a particular product becomes a net cost for the individual. The theory was developed for marketed agricultural products but may also be applied to subsistence product extraction as the assumptions are similar: (i) individuals are rational actors (Holmes, 2004); (ii) there is a possibility to subsidize wood extraction at a cost; and (iii) individuals place an opportunity cost on their own labor which will eventually will be outweighed by diminishing marginal benefits from extraction at increasing distances (Albers & Robinson, 2013). Following this framework, villagers will try to minimize travel distance for subsistence collection of wood products, and extraction will likely cease at the distance from settlements where the opportunity cost exceeds the perceived net value of the product.

To operationalize the use of indirect approaches for estimating and monitoring emissions from subsistence forest degradation in dry forests in Tanzania we analyzed the relationship between spatial patterns of subsistence wood extraction and proxy variables including population pressure and accessibility. The main research objective is to assess the accuracy of estimating the spatial pattern of forest degradation using nationally and historically available remote sensing data. Our hypothesis is that the spatial patterns of subsistence wood extraction can be measured by an inverse power distance decay function applied to the Landscan population dataset and the inside distance to nearest forest edge by Landsat imagery. This decay function is a standard gravity type impedance measure with inverse power as impedance function (Kwan, 1998). Gravity type models have been widely used to describe spatial movement