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Evaluating the trade-off between food and timber resulting from the conversion of Miombo forests to agricultural land in Angola using multi-temporal Landsat data

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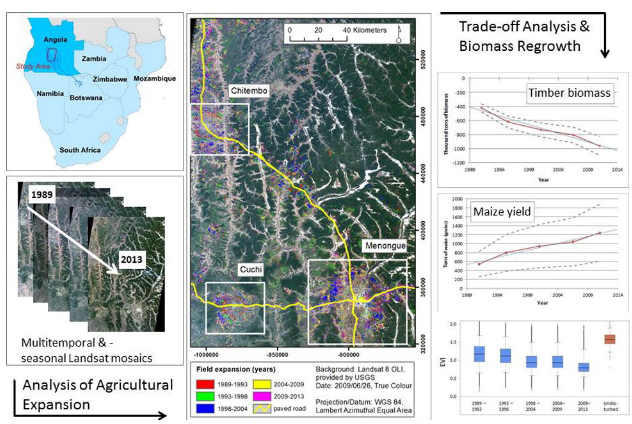
HIGHLIGHTS

- We prove an increase in the rate of agricultural expansion during the last 25 years.
- Biomass recovery on fallows is slow and does not reach the pre-disturbance level.
- We assess the trade-off between woody biomass and crop yield.
- Rising population numbers may require the modernization of agricultural practice.

GRAPHICAL ABSTRACT



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ABSTRACT

The repopulation of abandoned areas in Angola after 27 years of civil war led to a fast and extensive expansion of agricultural fields to meet the rising food demand. Yet, the increase in crop production at the expense of natural resources carries an inherent potential for conflicts since the demand for timber and wood extraction are also supposed to rise.

We use the concept of ecosystem services to evaluate the trade-off between food and woody biomass. Our study area is located in central Angola, in the highlands of the upper Okavango catchment. We used Landsat data (spatial resolution: 30×30 m) with a bi-temporal and multi-seasonal change detection approach for five time steps between 1989 and 2013 to estimate the conversion area from woodland to agriculture. Overall accuracy is 95%, user's accuracy varies from 89–95% and producer's accuracy ranges between 92–99%. To quantify the trade-off between woody biomass and the amount of food, this information was combined with indicator values and we furthermore assessed biomass regrowth on fallows.

Our results reveal a constant rise in agricultural expansion from 1989–2013 with the mean annual deforestation rate increasing from roughly 5300 ha up to about 12,000 ha. Overall, 5.6% of the forested areas were converted to

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agriculture, whereas the FAO states a national deforestation rate for Angola of 5% from 1990–2010 (FAO, 2010). In the last time step 961,000 t per year of woodland were cleared to potentially produce 1240 t per year of maize. Current global agro-economical projections forecast increasing pressure on tropical dry forests from large-scale agriculture schemes (Gasparri et al., 2015; Searchinger and Heimlich, 2015). Our study underlines the importance of considering subsistence-related change processes, which may contribute significantly to negative effects associated with deforestation and degradation of these forest ecosystems.

1. Introduction

The Millennium Ecosystem Assessment (2005) states the conversion of natural land to agricultural areas as one of the main challenges of our time, also because it involves high carbon and biodiversity costs (Searchinger and Heimlich, 2015). In sub-Saharan Africa, it is linked to often ineffective cultivation practices due to missing fertilization and deficient techniques (MEA, 2005b). This is also valid for Angola, where the displacement of the rural population during the civil war led to the break-down of the agricultural sector (Kibble, 2006). After the termination of the civil war in 2002, large numbers of war refugees returned back to their former homesteads (Kibble, 2006). As a result of the armed conflict and the demographic policy, rural areas are nowadays affected by growing population numbers, bad medical and educational supply as well as insufficient road and railway infrastructure and the rising demand for food (BTI, 2014; INE, 2014). Today, the country faces a big economic inequality with high gross domestic product (GDP) growth rates thanks to large oil and diamond sources on one hand and unemployment rates of almost 60% in rural areas on the other (BTI, 2014).

The shortage in food supplies inevitably leads to more than two-third of the labour force being employed in the agricultural sector (World Bank, 2013). But due to the lack of good infrastructure and the high costs of transportation, it is currently cheaper to consume imported food than buying from local or regional farmers (BTI, 2014; Kibble, 2006). The population in Angola especially in the cities is hence very dependent on global food prices and rising prices would especially affect the poor (World Bank, 2013). The effect of an increase in cultivation areas due to population growth, the return of former war refugees and the improvement of infrastructure on forests has not yet been assessed although it is currently the most dominant land use change process in our study area. The study is situated in a mainly rural area in central Angola, where intact forest systems occur along with steadily growing cities and where recently paved roads border and cross the natural woodlands. With only irregular access to cash and the strong dependency on natural resources, the local population relies on fertile areas for cultivation as well as on intact forests to cover their demands for timber products, like fire or construction wood. Further indirect resources that are constrained to the forest and which provide small income are the production of honey and charcoal (Domptail et al., 2013). The predominant slash-and-burn agriculture, honey and charcoal production already put a high pressure on natural resources in the study area and challenge land use sustainability (Finckh et al., 2015). There is hence a potential for conflicts rising from essential need for food but also for the provision of intact woodland areas. On one hand, people rely on farming and on a sufficient yield of food products. This is currently done by clearing intact forest areas to expand agricultural areas for new fields. On the other hand the cleared forest provides the essential products named above.

We use the concept of ecosystem services (ESS) to transfer the forest loss due to agricultural expansion into an analysis of the trade-off between crop growth (maize yield) and tree growth (woody biomass). The concept of ecosystem services and their categorization into four different groups (provisioning, supporting, regulating and cultural) is described by the Millennium Ecosystem Assessment (MEA, 2005b). Furthermore, they explain the influence of ESS on human well-being and present a framework for the evaluation of human impact on ecosystem services (MEA, 2005a). But still, there is a lack of standardized approaches to monitor ESS and to predict their development regarding different scenarios (Daily et al., 2009; Sharp et al., 2014).

Remote sensing can contribute to an ecosystem service assessment by providing detailed information on land use, land cover and the corresponding changes. This information can be provided at different scales (from local case studies to global analyses), which enables a variable study area extent of human impacts on the environment (Kerr and Ostrovsky, 2003). This adaptation is essential, since on one hand, important details may be missed with a low spatial resolution covering a large area and on the other hand small scale detailed studies can lead to misinterpretations of the problem because interlinkages on larger scales are missing (DeFries et al., 2004). The spatial and also the temporal scale of a study should hence be carefully defined to provide the best support for decision makers (DeFries et al., 2004). This can also be a connection of land use or land cover types to reliable and meaningful indicator values to produce maps and data (De Groot et al., 2010). An overview of the implementation of remote sensing data to evaluate ecosystem status and its trend via land use/change can be found in DeFries et al. (2005).

Our objectives to support ecosystem service valuation with spatial and temporal information can hence be summarized as followed:

- Locate areas of deforestation for the establishment of new fields for the last 24 years
- Quantify the rate of agricultural expansion between 1989 and 2013 and connect it to ecosystem service valuation and the corresponding trade-off
- Estimate regrowth on fallows and evaluate the long-term impact of slash-and-burn practices

To analyse this change and its development we chose Landsat data (30 × 30 m resolution) from 1989–2013 with an unsupervised classification approach. Landsat data has two major advantages, which is on one hand the resolution of 30 × 30 m, which allows detecting management changes and on the other hand the long term archive that support the retrospective analysis of land use changes. Many studies of deforestation in tropical forests incorporating remote sensing data and particularly Landsat data have been conducted. They mainly concentrate on South America and Asia (e.g. Broich et al., 2009; Grogan et al., 2015; Hamunyela et al., 2016; Miettinen et al., 2011). For Miombo forests on the other hand, deforestation has hardly been studied with remote sensing data, except for Prins and Kikula (1996) who used the Landsat MSS sensor to detect cleared and regrowth areas. Miombo forests in general were mainly studied in the countries of Zambia (e.g. Chidumayo, 2002; Holden, 1997; Syampungani, 2009), Tanzania (e.g. Abdallah and Monela, 2007; Lund and Treue, 2008; Malimbwi et al., 1994) and Mozambique (e.g. Nhantumbo et al., 2001; Williams et al., 2008), and also remote sensing applications were implemented for different scopes (e.g. Carreiras et al., 2013; Ribeiro et al., 2008; Sa et al., 2003). For Angola itself, only little spatial information is available on deforestation on a medium resolution (Cabral et al., 2011; Hansen et al., 2013; Schneibel et al., 2013).

We furthermore linked the results to field data and expert knowledge. This retrospective view allows the definition of spatial and temporal trends of this specific process during an observation period ranging from the civil war until nowadays. The impact of the population on