Impact of land cover change on aboveground carbon stocks in Afromontane landscape in Kenya

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ABSTRACT

Land cover change takes place in sub-Saharan Africa as forests and shrublands are converted to agricultural lands in order to meet the needs of growing population. Changes in land cover also impact carbon sequestration in vegetation cover with an influence on climate on continental scale. The impact of land cover change on tree aboveground carbon stocks was studied in Taita Hills, Kenya. The land cover change between 1987 and 2011 for four points of time was assessed using SPOT satellite imagery, while the carbon density in various land cover types was assessed with field measurements, allometric biomass functions and airborne laser scanning data. Finally, the mean carbon densities of land cover types were combined with land cover maps resulting in carbon stock values for given land cover types for each point of time studied. Expansion of croplands has been taking place since 1987 and before on the cost of thickets and shrublands, especially on the foothills and lowlands. Due to the land cover changes, the carbon stock of trees was decreasing until 2003, after which there has been an increase. The findings of the research is supported by forest transition model, which emphasizes increase of awareness of forests' role in providing ecosystem services, such as habitats for pollinators, water harvesting and storage at the same time when economic reasons in making land-use choices between cropland and woodland, and governmental legislation supports trees on farms.

1. Introduction

Human modification of land has been recognized as a major driver of change influencing the Earth's ecosystems and climate (Rockstrom et al., 2009; Steffen et al., 2015). Land conversions in forested areas are of special concern in the context of climate change. In Africa, significant amount of carbon is also sequestered in woody vegetation outside forests (Baccini et al., 2012). Land use change, deforestation in particular, is the second biggest driver for increased carbon dioxide (CO_2) emissions after the burning of fossil fuels according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Ciais et al., 2013). It has been estimated that land use and land cover change caused 12.5% of all anthropogenic CO_2 emissions from 1990 to 2010, but the estimate is uncertain (Houghton et al., 2012).

Tropical forest regions are currently undergoing rapid changes with direct consequences to aboveground carbon (AGC) stocks (Feldpausch et al., 2012; Saatchi et al., 2011). For recent decades, a remarkable increase in cultivated areas has been detected in sub-Saharan Africa. An increase of 57% in cultivated area was reported between 1975 and 2000, being 2.3% per year (Brink & Eva, 2009), and between 1990 and

2010 in the Horn of Africa 28%, with yearly increase of 1.4%. (Brink et al., 2014). In East Africa, between 2002 and 2008, wooded vegetation cover decreased by 5.1%, 15.8% and 19.4% from forests, woodland and shrubland, consecutively (Pfeifer et al., 2012). Using historical land cover maps, Willcock et al. (2016) estimated 74% forest loss between 1908 and 2000 in Eastern Arc Mountain watershed in Tanzania causing a carbon release of 0.9 Pg C.

Total net emissions of carbon from deforestation and land cover change in tropical regions has been estimated to be 1.0 Pg C per year (Baccini et al., 2012). However, in Asia and Africa the rate of deforestation is expected to decrease in the 21th century compared with deforestation rates in 1990 due to the depletion of forests (Denman et al., 2007). Total AGC stocks in tropical Africa are estimated as 59.8 Pg C, with 45.9% in shrublands and savannahs and 54.1% in forest land (Baccini et al., 2012). Lack of data on carbon densities and land use/land cover changes cause large uncertainties in these estimates (Baccini et al., 2012).

Number of initiatives aim to reduce anthropogenic carbon emissions from changes in land cover. In REDD + program, for example, the changes in forest AGC stocks need to be quantified with scientifically
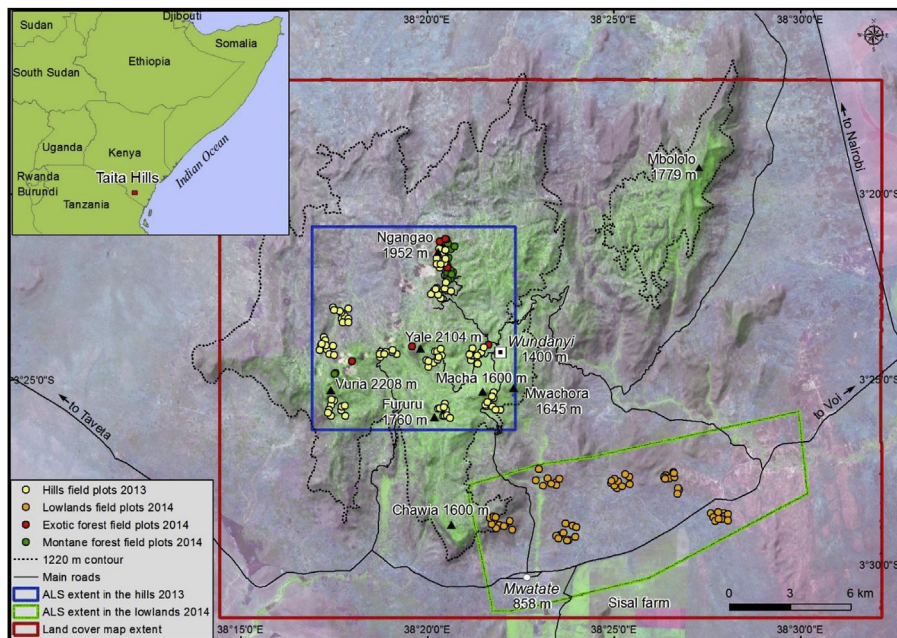
Fig. 1. Map of Taita Hills in southeastern Kenya representing the extent of study area (land cover map) and airborne laser scanning data, and positions of field plots. Background image is a false colour composite of Sentinel-2A MSI satellite image from 8 October 2016. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

rigorous monitoring systems (UN-REDD, 2011; GOFC-GOLD, 2014). In these initiatives, agroforestry is an important approach as a carbon sequestration strategy (Montagnini & Nair, 2004). AGC of trees in agricultural land play an important role in mitigating climate change, but agroforestry systems are often not accounted for in national and global assessments (Zomer et al., 2016).

Earth observation contributes to the monitoring of anthropogenic greenhouse gas emission. Remote sensing provides effective methods for observing changes in land cover over large areas with limited data availability or accessibility. Combined with tree measurements in the field, remote sensing data enable the mapping of AGC (Baccini et al., 2012; Willcock et al., 2012). The use of global default values for estimating carbon storage (Aalde et al., 2006) in data deficit areas may result in simplified estimations of local carbon stocks (Baccini et al., 2012). Efforts for more precise carbon estimations have been made on pan-tropical (Baccini et al., 2012; Saatchi et al., 2011), national (Tyukavina et al., 2013) and regional (Gonzalez, Kroll, & Vargas, 2014) scales.

Optical satellite imagery is often the primary data source for monitoring land changes in tropical forest areas (GOFC-GOLD, 2014). However, lidar (light detection and ranging), particularly airborne laser scanning (ALS), has been proven to provide more precise three-dimensional data on vegetation properties, including tree biomass and carbon stocks (Zolkos, Goetz, & Dubayah, 2013). Combining local scale carbon stock estimates from ALS with land cover maps produced from satellite imagery can yield regionally applicable carbon density values in a cost-efficient way (Willcock et al., 2012) allowing also change detection and projection of future scenarios of carbon storage (Gonzalez et al., 2014; Swetnam et al., 2011). It is also possible to extend the carbon storage monitoring backwards using historical land cover maps as in Willcock et al. (2016). A recent study by Baccini et al. (2017) based on MODIS satellite imagery from 2003 to 2014 presented that tropical forests are net carbon source rather than a sink as deforestation and forest degradation (reduction in carbon density) are faster than forest growth. The loss of carbon is the highest in Amazonia, while in Africa there are areas of gain and losses. This study presents a landscape-scale study of carbon stock changes between 1987 and 2011 in the Taita Hills in south-east Kenya.

The Taita Hills were once forested, but during last centuries most of the forests were cleared for agricultural purposes, while on surrounding lowlands, land is used for dryland agriculture, grazing, wildlife conservation and sisal farming to large extent (Pellikka et al., 2013). Despite of the clearance for agriculture, indigenous trees are left and exotic trees are planted for food production and timber on croplands. Trees on farms play an important role providing ecosystem services (Aerts et al., 2011). In the previous studies, land cover changes have been monitored with aerial photographs and satellite imagery (Clark & Pellikka, 2009; Pellikka, Lötjönen, Siljander, & Lens, 2009). According to the projected land cover changes, cropland could cover 60% of the area in 2030 (Maeda, Clark, Pellikka, & Siljander, 2010).

The aim of this study was to assess changes in tree AGC stocks in the Taita Hills and its foothills as a case study of land cover change impact on tree AGC stocks in East Africa. The Taita Hills are like a miniature of Kenya and East Africa having a range on land uses and cover types from grasslands in lowlands areas to indigenous moist evergreen montane forests on the hilltops. The more detailed objectives of this study were 1) to assess land cover change trends in the area from 1987 to 2011 using land cover maps derived from SPOT satellite images from four years, 2) to assess the amount of carbon sequestered across different land cover classes using field measurements and ALS, and 3) to assess the effect of land cover change on tree AGC stocks.

2. Study area and material

2.1. Study area

The study area covers 876 km^2 in Taita Taveta County in SE Kenya (3°25′ S, 38°20′ E). The lowest areas of the study area are at an average elevation of 700 m above sea level (m a.s.l.), while the Taita Hills rise on average up to 1500 m a.s.l. having the highest peaks between 1600 and 2200 m (Fig. 1). The area has two rainy seasons annually, the long rains occurring from March to May and short rains from November to December. The hottest and driest months are January and February, while the dry season from June to October is cooler. According to Maeda, Wiberg, and Pellikka (2011), the average temperature in Voi at 566 m a.s.l. is 27 °C in February and 23 °C in August. Annual rainfall in the Taita Hills is according to Erdogan, Pellikka, and Clark (2011) between 1100 and 1400 mm, while in the lowlands it is between 400 and 600 mm. Rainfall increases with altitude, but the higher elevations in the western parts of the hills receive less rainfall due to rain shadow effect. The reference evapotranspiration is the highest in the lowlands and the lowest in the hills. The maxima (> 7 mm/day) in the lowlands