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Spatio-temporal analysis of forest changes in contrasting land use regimes of Zanzibar, Tanzania

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ABSTRACT

We have estimated forest changes and deforestation trends on the island of Unguja (Zanzibar) over the last three decades based on satellite images, forest cover change trajectory and post-forest land cover analysis. The results show that deforestation has intensified and forest cover change rate has changed from 0.03% to −0.46% between 1975–1996 and 1996–2009. On average 0.88 km^2 of forests were lost annually, which makes altogether 29.9 km^2 during the 34 year study period. Using three distinctive land use regimes prevailing on the island, we are able to show that in reality the changes and their causes were unique in each region. The community forest land use regime was dominated by shifting cultivation related cyclical changes combined with growing deforestation rates. The deforestation rates were also high in agroforest land use regime, but here forest clearings were associated with urban sprawl. Opposite to these two regimes, the cover increased in government forest areas, due to large tree planting schemes. However, forest clearings increased significantly since 1996 in government areas and currently all regimes are facing decreasing forest cover. Population growth, in-migration, urbanization, tourism and increasing demand of agricultural and forestry products were the main underlying causes behind the deforestation. Although, the long-term developments of the forest cover are dictated by these relatively uncontrollable underlying causes, we suggest few actions to restrain deforestation and its effects. These actions include establishment of protected area network with forest corridors, heeding trees in urban and agricultural land use planning, replanting cleared governmental plantations and extending plantations outside the Island.

Introduction

Loss of forested environments, especially in the tropics, is a serious global threat to human well-being. Forests maintain biodiversity and hydrological cycle, improve air, water and soil quality, regulate climate change and reduce flooding and erosion. Equally, they provide essential livelihoods and immaterial values to humans and uphold traditional cultures (Rudel & Roper, 1997; Laurance, 1999; Houghton et al., 2000; Maass et al. 2005; FAO, 2010; Fagerholm, Käyhkö, Ndumbaro, & Khamiz, 2012). Still, around 5.2 million hectares of forests are lost annually and one-fifth of this in Eastern and Southern Africa. In Tanzania, approximately 1% of forests are disappearing each year (FAO, 2010; Tabor, Burgess, Mbilinyi, Kashaigili, & Steininger, 2010; Godoy et al., 2011). This means that already forest-scarce East African landscapes are deteriorating at alarming rate and their multiple ecosystem services are threatened.

The drive for forest changes comes from comprehensive happenings in the society (Geist & Lambin, 2001; Kaimowitz & Angelsen, 1998). According to the Forest Transition Theory, long-term positive forest development trend can be generalized over the globe (Chowdhury & Moran, 2012; Mather, 1992). When economic development, urbanization, share of primary production or forest product prices reach critical thresholds, past deforestation trend is overturned and forest cover increased (Mather, 1992; Meyfroidt & Lambin, 2011; Rudel et al., 2005). Although, the theory is backed up by empirical evidence from several locations, its applicability for rapidly developing countries has been questioned (Rudel et al., 2005; Meyfroidt & Lambin, 2011; Chowdhury & Moran, 2012).

Meta-analyses of case studies have linked deforestation in Sub-Saharan Africa to population growth, in-migration, urbanization, growth of agricultural and forest industries, domestic demand of agricultural and forestry products, economic development, poor land policies and foreign debt (Geist & Lambin, 2001; Brink & Eva,

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2009; Rudel, DeFries, Asner, & Laurance, 2009; DeFries, Rudel, Uriate, & Hansen, 2010; Fisher, 2010). While elsewhere in the tropics deforestation is increasingly caused by export demand of agricultural and forestry products, it is still driven by small holder farmers and domestic demand in many areas of Africa (DeFries et al., 2010; Fisher, 2010; Ryan, Berry, & Joshi, 2014). Direct actions of individuals and communities are practical manifestations of these underlying causes. Shifting cultivation, transmigration related agriculture, cattle ranching, fuel wood collection, charcoal making, pole wood extraction, commercial logging, growth of cities and building of roads are the most typical proximate causes of forest losses in Africa (DeFries et al., 2010; Fisher, 2010; Geist & Lambin, 2001; Rudel et al., 2009).

While these drivers fuel the deforestation process, local biophysical circumstances and political decisions create unique geographical variations for the realized changes (Geist & Lambin, 2001; Kaimowitz & Angelsen, 1998; Rudel & Roper, 1997). Case studies have shown that fertile soils, favorable climate conditions, low elevation, dominance of secondary forest vegetation, fragmentation of forests, flat topography, accessibility and vicinity of settlements promote deforestation, while government protection and community-based forest management ease the pressure (Aguiar, Câmara, & Escada, 2007; Chomitz & Gray, 1996; Geoghegan, Villar, Klepeis, Mendoza, & Ogneva-Himmelberger, 2001; Kok & Veldkamp, 2001; Mertens & Lambin, 1997; Nagendra, Southworth, & Tucker, 2003; Serneels & Lambin, 2001; Tole, 2001).

Medium-term forest change trends can be quite effectively studied using remote sensing data over consecutive decades combined with methods of change trajectory analysis (Käyhkö & Skånes, 2006; Käyhkö, Fagerholm, Asseid, & Mzee, 2011; Mertens & Lambin, 2000). However, spatio-temporal forest change analyses are sensitive to spatial and temporal partitioning of the data. Analyzing change patterns based on administrative units, forest protection areas or other well defined entities may emphasize different processes behind the deforestation, than analyzing the entire study area as one homogenous block (Aguiar et al., 2007; Espindola, Aguiar, Pebesma, Câmara, & Fonseca, 2012; Godoy et al. 2011; Hall, Burgess, Lovett, Mbilinyi, & Gereau, 2009; Kok & Veldkamp, 2001; Lung & Schaab, 2010; Tabor et al., 2010; Tole, 2001). Also, the forest cover changes can be contradictory even within a small geographical area, if there are clear differences in the land use practices and underlying biophysical qualities of the land (Perz, 2007; Rudel & Roper, 1997).

Similarly, the temporal sampling of the change detection is likely to influence what type of change processes can be captured. Shifting cultivation and silviculture activities explain about half of all forest clearings in Africa (Käyhkö et al., 2011; Mertens, Sunderlin, Ndoye, & Lambin, 2000; Mertens & Lambin, 2000). Therefore, these processes have substantial role in short-term studies. Whereas, medium-term analysis are able to point out how demographic, economic, legislative and policy changes influence deforestation rates (Espindola et al., 2012; Geoghagen et al., 2001; Mertens et al., 2000; Nagendra et al., 2003). This makes intellectual selection and justification of both spatial and temporal partitioning critical for any case study trying to analyze internal and temporal variations of forest changes.

We have analyzed forest cover changes in a Sub-Saharan island of Zanzibar (Tanzania), which is one of the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) pilot areas. Zanzibar is expected to face serious deforestation, degradation and fragmentation of its globally valuable forest habitats (RGZ, 2004; Käyhkö et al., 2011; Indufor, 2013). Population growth, insecure land tenure system, low technological development, weakness of government institutions and limited livelihood and income generating opportunities have been stated as important underlying causes of deforestation (Käyhkö, Fagerholm, & Mzee, in press). However, the deforestation and forest degradation process is not spatially coherent or homogeneous on the island (Käyhkö et al., 2011, Käyhkö et al., in press).

Currently, Zanzibar is renewing its nearly 20 year old national land use plans. Explicit information about the forest dynamics are needed to support this task, but the government and stakeholders are left with fragments of speculations and lessons learned from other areas in the world. Our objective is to estimate forest changes and deforestation trends on the island over the last three decades based on satellite images and forest cover change trajectory analyses. Using three distinctive land use regimes prevailing on the island, we aim to point out internal variations in the changes. Also, post-forest land cover analysis will be used to connect happened changes to proximate causes. We will use these spatially explicit evidences to discuss the possible roles of underlying causes, long-term development of the forests and possible ways to tackle deforestation.

Methodology

Study area

Unguja (Zanzibar) is a tropical island offshore Eastern coast of Tanzania (Fig. 1). The once natural coastal forests of the island have been greatly modified by humans over the centuries and only fragments of the original tropical monsoonal forests are left (Hettige, 1990; Indufor, 2013). Natural forests, which are part of the larger biodiversity hotspot known as East African Coastal Forests, are largely degraded into thickets and scrubs, and form multistory forests only within the protected areas (Burgess & Clarke, 2000; Indufor, 2013). In general, the forests have an essential role in local livelihoods as sources of fuel wood, charcoal, building materials, medicinal plants and fruits (Fagerholm & Käyhkö, 2009; Fagerholm et al., 2012). Over 90% of rural and almost 50% of urban inhabitants use wood fuel as the main source of energy in cooking (NBS, 2004). The wood demand is exceeding the supply and estimations have been made that 99% of timber and 59% of all wood products, including the fuel wood, are imported from mainland Tanzania (SCF, 1997; Indufor, 2013).

The community forest land use area is dominated with naturally regenerating scrubs and forests (coral rag forests) with native tree species such as *Euclea natalensis*, *Trichilia emetic*, *Pandanus rabaiensis, Blighia unijugata, Vitex doniana and Macphersonia gracilis* (Indufor, 2013). Traditional slash-and-burn techniques are still prevailing, but more permanent rotation farming can also be found in most fertile and highly populated areas (Eilola, Käyhkö, Fagerholm, & Kombo, 2014; Käyhkö et al., in press). Coral forest form a quite contrasting landscape compared to the western agroforest land use regime, where native understory scrubs and trees grow mixed with domesticated fruit trees, such as Coconut (*Cocos nucifera*), Mango (*Magnifera indica*), Breadfruit (*Artocarpus altilis*) and Jackfruit (*Artocarpus heterophyllus*) (Indufor, 2013). Most of the remaining old-growth forests are within the three (total 100 km^2) government protected areas in Jozani-Chwaka Bay, Kiwengwa-Pongwe and Masingini (Fig. 1). Additionally, the government manages about 20 km^2 of plantations with Whistling pines (*Casuarina equisetifolia*), Earleaf acacias (*Acacia auriculiformis*), Caribbean pines (*Pinus caribaea*) and Rubber trees (*Hevea brasiliensis*) (SCF, 1997; Indufor, 2013).

Zanzibar Islands have experienced various political and economic changes during the last 50–60 years such as independency, revolution, union as well as land reform (Fig. 2; Shao, 1992; Myers, 1996; Törhönen, 1998). Zanzibar's economic foundation, clove