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Modelling agricultural expansion in Kenya's Eastern Arc Mountains biodiversity hotspot

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ABSTRACT

The Taita Hills are the northernmost part of the Eastern Arc Mountains of Kenya and Tanzania, which is one of the most important regions for biological conservation in the world. The indigenous cloud forests in this area have suffered substantial degradation for several centuries due to agricultural expansion. In the Taita Hills, currently only 1% of the original forested area remains preserved. In order to create effective policies to preserve the natural resources and biodiversity of the Eastern Arc Mountains it is crucial to understand the causes and interactions involved in the landscape changes in the most degraded areas. The research presented here aimed to understand the role of landscape attributes and infrastructure components as driving forces of agricultural expansion in the Taita Hills. Geospatial technology tools and a landscape dynamic simulation model were integrated to identify and evaluate the driving forces of agricultural expansion and simulate future landscape scenarios. The results indicate that, if current trends persist, agricultural areas will occupy roughly 60% of the study area by 2030. Agricultural expansion will likely take place predominantly in lowlands and foothills throughout the next 20 years, increasing the spatial dependence on distance to rivers and other water bodies. The main factors driving the spatial distribution of new croplands were the distance to markets, proximity to already established agricultural areas and distance to roads. Other driving forces of the agricultural expansion, as well as their implications for natural resources conservation, are discussed. Further studies are necessary to integrate the effects of population pressure and climate change on the sustainability and characteristics of local agricultural systems.

1. Introduction

The Eastern Arc Mountains (EAM) of Kenya and Tanzania maintain some of the richest concentrations of endemic animals and plants on Earth, and are thus considered one of the world's top 25 biodiversity hotspots (Myers et al., 2000). The EAM comprise a chain of mountains located in southern Kenya and eastern Tanzania and are home for at least 96 endemic vertebrate species and 800 endemic vascular plant species (Burgess et al., 2007). Although this region is among the most important areas for biological conservation in the world, it has already lost approximately 80% of its original forest area (Hall et al., 2009).

Forest loss in sub-Saharan Africa is proceeding at an alarming rate of 2.8 million ha per year; particularly in Afromontane areas the decrease is estimated to be 3.8% annually (Eva et al., 2006). Most of these losses are caused by agricultural expansion. Between the years 1975 and 2000 the agricultural areas increased 57% in sub-Saharan Africa (Brink and Eva, 2009). Although the development of the agricultural sector is essential to improve food security in this region, the expansion of croplands without logistic and technological planning is a severe threat to the environment. Besides the imminent risk to biodiversity, indiscriminate agricultural activities may pose serious obstacles to water resources and soil conservation.

One of the EAM sections most affected by agricultural expansion is the Taita Hills, which is the northernmost part of the EAM. Between 1955 and 2004, the indigenous forest areas in the Taita Hills decreased by 50% (Pellikka et al., 2009). Today, only 1% of the original forested area remains. Although only a small fraction of the indigenous cloud forests is preserved, the Taita Hills continue to have an outstanding diversity of flora and fauna and a high level of endemism. It is home for six endemic vertebrate species, three endemic bird species and at least 13 endemic plant species (Burgess et al., 2007; Brooks et al., 1998). Hence, a detailed study of this specific region is essential to preserve the remaining biodiversity and, most importantly, to expand the understanding of the interactions between human activities and landscape changes in the EAM. Such work can contribute to improving environmental protection policy in the regions of the EAM that are still intact but currently threatened by agricultural expansion.

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The improvement in models and computer capacity during the past decades has allowed an increasing number of studies aiming at the sustainable use of natural resources and land use planning. For instance, land use and land cover change (LUCC) simulation models provide robust frameworks to cope with the complexity of land use systems (Veldkamp and Lambin, 2001; Washington et al., 2010). Such models are considered efficient tools to project alternative scenarios into the future and to test the stability of interrelated ecological systems (Koomen et al., 2008). Understanding the circumstances and driving forces of change is an essential step for elaborating public policies that can effectively lead to the conservation of natural resources.

Among dynamic spatial models, frameworks operating on a cellular automata (CA) basis have arisen as a feasible alternative for the analysis of land use dynamics and in the exploration of future landscape scenarios. CA models consist of a simulation framework in which space is represented as a grid of cells, and a set of transition rules determine the attribute of each given cell considering the attributes of its neighboring cells (Almeida et al., 2003). For instance, CLUE-S is a spatially explicit, multi-scale model that can be applied to describe land change dynamics through the determination and quantification of the bio-geophysical and human drivers of land use (Verburg et al., 2002). Another widely used CA simulation model is Dinamica-EGO (Soares-Filho et al., 2002, 2009). Dinamica-EGO is an environmental modelling platform developed by the Centre for Remote Sensing of the Federal University of Minas Gerais, Brazil (CSR-UFMG). This platform allows the design of static or dynamic simulations involving nested iterations, dynamic feedbacks and multi-scale approaches.

Moreover, geospatial technologies, such as remote sensing and geographical information systems (GIS), have made available an unprecedented opportunity for new studies in terms of data collection, availability and processing capacity. Nevertheless, scientists currently face the challenge of integrating these technologies to better understand the coupled relations between human activities and environmental changes. In this context, land change science has emerged as an interdisciplinary field that aims to understand the dynamics of LUCC as a coupled human – environment system (Turner et al., 2007).

This study addresses this exact issue, aiming to understand the role of landscape attributes and infrastructure components as driving forces of agricultural expansion in the Taita Hills. In order to achieve this objective, remote sensing, GIS techniques and a LUCC simulation model were integrated to identify and evaluate the driving forces of LUCC and simulate future landscape scenarios. Thus, it is hoped that the results of this study may represent an important instrument for households, researchers and policy makers to better cope with future changes in local agricultural systems.

2. Study area

Taita Hills is the northernmost part of the EAM biodiversity hotspot, situated in the middle of the Tsavo plains of the Taita-Taveta District in the Coastal Province, Kenya (Fig. 1). Taita Hills cover an area of 1000 km^2. The population of the whole Taita-Taveta district has grown from 90,146 (1962) persons to over 300,000 (Republic of Kenya, 2001). The indigenous cloud forests have suffered substantial loss and degradation for several centuries as abundant rainfall (annual 1100 mm) and rich soils (cambisols and humic nitosols) have created good conditions for agriculture. The agriculture in the hills is intensive small-scale subsistence farming. In the lower highland zone and upper midland zone, the typical crops are maize, beans, peas, potatoes, cabbages, tomatoes, cassava and banana (Soini, 2005). In the slopes and lower parts of the hills with average annual rainfall between 600 and 900 mm, early maturing maize species and sorghum and millet species are cultivated. In the lower midland zones with average rainfall between 500 and 700 mm, dryland maize types and onions are cultivated, among others. Moreover, the area is considered to have high scientific interest and there is a high potential for succeeding in connecting economic development and community-based natural resource management (Himberg et al., 2009).

3. Material and methods

This research integrated remote sensing, GIS techniques and a spatially explicit simulation model of landscape dynamics, Dinamica-EGO (Soares-Filho et al., 2007), to assess the driving forces of agricultural expansion in the study area and simulate future scenarios of land use. A general description of the applied method is illustrated in Fig. 2.

The model receives as inputs land use transition rates, landscape variables and landscape parameters. The landscape parameters are intrinsic spatially distributed features, such as soil type and slope, which are kept constant during the simulation process. The landscape variables are spatial–temporal dynamic features that are subjected to changes by decision makers, for instance roads and protected areas. The land use transition rates were also considered to be decision variables, given that this modelling exercise was based on the assumption that agricultural expansion rates can be modified by public policies or other external forces.

The model is driven by land use and land cover maps (LULCM) from two selected dates: 1987 (initial landscape) and 2003 (final landscape), which are used as inputs to represent the historical land use transitions in the study area. The dates of the LULCM were chosen based on two criteria. The first criterion was that the landscape changes between the initial and final landscape should accurately represent the ongoing land change activities in the study area. That is to say, the agricultural expansion rates between 1987 and 2003 were assumed to be representative of current trends. The second criterion relied on the availability of cloud free satellite images to assemble the LULCM.

3.1. Landscape variables and parameters

In total, ten landscape attributes (variables/parameters) were used as inputs for the model, nine of which were static and one of which was dynamic. Static inputs are those that are kept constant throughout the model run, while dynamic inputs refer to those that undergo changes during the model run. All landscape attributes were represented by raster images with a 20 m spatial resolution. The description of each layer is as follows:

Distance to roads (DRo): Euclidian distance in meters to main and secondary roads.

Distance to Markets (DM): The markets were represented by main villages in the region; the distance to markets raster was created by calculating the Euclidian distance in kilometers to centre of each village.

Digital Elevation Model (DEM): The 20 m spatial resolution DEM was interpolated from 50-feet interval contours captured from 1:50,000 scale topographic maps, deriving an estimated altimetric accuracy of ±8 m and an estimated planimetric accuracy of ±50 m.

Distance to Rivers (DRi): Represented by the Euclidian distance in meters to main rivers. Two sources were used to extract the river network in the study area. Firstly, GIS tools were used to automatically identify the rivers based on a flow accumulation grid obtained using the DEM. Subsequently, eventual errors in the automatic classification were corrected using a 1:50,000 scale topographic map.