Forest Ecology and Management 257 (2009) 968–977

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

# Forecasting hotspots of forest clearing in Kakamega Forest, Western Kenya

Daniel Müller [a,b,*], John Mburu [c,d]

[a] Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO), Theodor-Lieser-Str. 2, 06120 Halle (Saale), Germany
[b] Geomatics Lab, Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany
[c] International Livestock Research Institute (ILRI), P.O. Box 30709, 00100 Nairobi, Kenya
[d] Department of Agricultural Economics, University of Nairobi, P.O. Box 29053, 00625 Nairobi, Kenya

ARTICLE INFO

*Article history:*
Received 10 June 2008
Received in revised form 24 October 2008
Accepted 31 October 2008

*Keywords:*
Tropical deforestation
Prediction
Hot spot identification
Artificial neural network
LTM
Kenya

ABSTRACT

Kakamega Forest is the last remaining rainforest in Kenya and the easternmost remnant of the Guinean-Congolian rainforest belt. As such, it is home to a large number of endemic fauna and flora species. Yet the remaining natural forest is under imminent threat of degradation due to a rapidly growing population in its vicinity and a poverty rate far above the national average. The growing demand for forest resources and ecosystem services will continue to exert great pressure on the remaining forest fragments. In this paper, we predict future hotspots of forest clearing of the remaining natural and old-growth secondary forest in Kakamega Forest. We parameterized an artificial neural network model using resilient backpropagation to simulate the likelihood of forest clearing for each location. Input variables into the network included historic information on forest clearings together with variables capturing the status of forest protection, accessibility to roads and markets, as well as topography and forest density. Simulation results were used to predict future clearings based on observed rates of change. Hotspots of forest clearing were derived by assessing the neighborhood density of predicted clearings.

Our results indicate that forest clearings occurred across all forest fragments. Hotspots of future forest clearing tended to occur near roads and market centers. Most future hotspots were found in areas with a lower protection status, where some forest use is allowed. But our model also predicted considerable pressure on remaining old-growth forest resources in the strictly protected National Reserve. Our predictions of deforestation hotspots contribute to a better geographic targeting of nature protection activities and forest management investments in Kakamega Forest. Thus, it will hopefully help policy makers and land managers to strike a balance between satisfying the needs of local livelihoods and preserving the unique ecological values of Kakamega Forest for future generations.



## 1. Introduction

In the next 50 years, tropical forests are among the biomes projected to lose habitat and species most rapidly (MA [Millennium Ecosystem Assessment], 2005). Yet tropical forests host numerous ecosystem services that provide regional, national, and global benefits (Godoy et al., 2002; Chomitz, 2007). Forests, particularly natural and semi-natural forests, contain diverse flora and fauna species, some of them endemic to particular areas. Furthermore, forests store large amounts of carbon and play an essential role in the global carbon cycle and the mitigation of climate change. On local to regional scales, forests regulate local water cycles, are important to the microclimate, and provide vegetative cover that protects the soil from erosion and retains nutrients in the subsoil (Pearce and Moran, 1994; Chomitz, 2007). At the local level, rural populations often directly depend on the utilization of biodiversity connected to forests and on the benefits derived from forest ecosystem services for their livelihoods (OECD, 2002; Fashing et al., 2004; MA, 2005).

The deforestation of tropical African forests is mainly attributed to forest exploitation for timber, charcoal production or fuel wood for domestic uses (Geist and Lambin, 2002). The high rates of forest product extraction are often underpinned by infrastructural improvements that facilitate access and foster timber trade (Cordeiro et al., 2007). Population growth through both reproduction and immigration may play another key role in the deforestation processes of African forests by increasing the demand for cropland and forest products (Geist and Lambin, 2002; Zhang et al., 2005).

Total forest cover in Kenya decreased by 0.3% each year between 1990 and 2005, to 35,220 km$^2$, which represents 6% of the

* Corresponding author at: Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO), Theodor-Lieser-Str. 2, 06120 Halle (Saale), Germany. Tel.: +49 345 2928 328; fax: +49 345 2928 399.
*E-mail address:* mueller@iamo.de (D. Müller).

0378-1127/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2008.10.032

country's territory according to the Global Forest Resources Assessment (FAO [Food and Agriculture Organization of the United Nations], 2006). Primary forest in Kenya comprises 20% of the total forest cover, but has decreased by 5% since 1990 (FAO, 2006).

The Kakamega Forest in Western Kenya, the country's only remaining tropical rain forest, is particularly an interesting case. The forest forms the easternmost relic of the Guinean-Congolian rainforest belt, which once spanned from East to West Africa. Kakamega Forest is endowed with a rich endemic biodiversity and is known to host a large number of rare animals and endemic plant species (Wass, 1995; Fashing et al., 2004). For instance, with 254 bird species, Kakamega Forest and neighboring Nandi Forest are home to the largest number of bird species in Kenya (Wass, 1995). In recognition of its vital role as a tropical ecosystem, Kakamega Forest was turned into a protected area in 1933. Local inhabitants are, however, allowed to gather non-timber forest products from some sections of the forest. This is mainly done to support the livelihoods of the surrounding human population.

The area around Kakamega Forest is among the most densely populated rural areas in the world. It had a population density of 578 persons per km$^2$ in 1999 (own calculations with data from the Population and Housing Census of 1999), compared to 54 persons per square kilometer for the whole country (World Bank, 2008). Consequently, Kakamega Forest is under high anthropogenic pressure, which is mirrored by decreasing natural forest cover. Past deforestation rates in the Kakamega Forest were approximated from Landsat satellite images and indicated a decrease of forest area and an increase in the fragmentation of natural, old-growth forest (Mitchell, 2004; Lung and Schaab, 2006). To date, most of the indigenous forest in Kakamega Forest has been cleared (Mitchell, 2004). According to Lung and Schaab (2006), approximately 20% of the forest has been lost in the last three decades. Brooks et al. (1999) further posit that the history of deforestation in Kakamega Forest was characterized by incremental deforestation rather than by sudden changes in forest cover.

High human population densities in the areas surrounding the forest have contributed to the proximate causes of forest decline (Tattersfield et al., 2001; Mburu et al., 2006). Widespread poverty[1] and a high unemployment rate may have further stimulated the demand for land and forest resources (KNBS [Kenya National Bureau of Statistics], 2007). The combination of these factors likely translated into increasing demands for wood extraction, grazing of livestock, charcoal burning, harvesting of medicinal plants, and the expansion of cropland (Guthiga et al., 2006). Given the high population pressure and population growth rates, a bleak future is anticipated for the remaining forest fragments of Kakamega Forest (Fashing et al., 2004; Bleher et al., 2006). Yet no studies are available to date that have forecasted the likely future pathways of forest cover and that have identified areas that are under the highest risks of future forest clearing.

To fill these gaps, the objective of this paper is to simulate spatially explicit probabilities of the decline of natural forest in Kakamega Forest. We accomplish this by using artificial neural networks that simulate forest decreases based on observed past changes. The simulation results serve to forecast forest clearing and to identify future hotspots of forest decline. The aim of hotspot identification is to guide the setting of priorities for conservation efforts on areas that are highly susceptible for change and may therefore warrant special attention (Hansen and DeFries, 2004; Müller and Munroe, 2005; Achard et al., 2007). Geovisualization of the delineated hotspots may greatly enhance the communication and awareness of future developments among forest rangers, stakeholders, and decision-makers. We believe the results contribute to a better targeting of conservation efforts that aim at preserving the remaining old-growth forested areas in Kakamega Forest. Eventually this would lead to strategies geared towards increased efficiency and effectiveness of forest protection and management in the research area.

## 2. Study area

Kakamega Forest is located in the province of Western Kenya, 40 km northeast of Lake Victoria (Fig. 1). The area is approximately 1600 m above sea level, has a mean annual rainfall of 2000 mm, a maximum daily temperature of 26 and a minimum of 11 °C (Glenday, 2006).

At the time of British colonization, Kakamega Forest was a contiguous area that was already under threat of degradation (Brooks et al., 1999). Later, massive disturbances occurred through gold mining, timber logging, timber extraction by saw millers, and uncontrolled harvesting of non-timber forest products by the local people (Wass, 1995; Mitchell, 2004). In the 1970s, the disturbance of the forest was facilitated by the "*shamba*" system, in which local people were allowed to cultivate land in the forest without owning it. However, this was banned in 1987 in most parts of the forest.[2]

Kakamega Forest[3] was first put under government management in 1933 and covered 23,777 ha at the time (Kokwaro, 1988). But the forest continued to be cleared, shrinking to approximately 15,000 ha in 1965 and 8600 ha in 1997. Two small Natural Reserves, Isecheno and Yala, were established in 1967 (Blackett, 1994).[4] In 1986 the northern main forest block (also called Buyangu) together with the adjacent Kisere fragment were established as Kakamega National Reserve (Fig. 1) under the auspices of the Kenya Wildlife Service (KWS). The present management status of the forest fragments is summarized in Table 1. The Forest Department (FD) is in charge of the southern part of the main block and two other small forest fragments (Malava and Kaimosi), which were established as Forest Reserves (Fig. 1, right). The FD allows the local population to use the forest as a source of non-timber forest products such as medicinal plants, forage, and fruits. It has also delegated the management of Kaimosi fragment to the Quakers Church Mission. Conversely, the KWS has adopted a 'fence and fine' approach that strictly prohibits any direct use of forest by the local communities (Guthiga et al., 2008).

A ban on exploiting indigenous tree species in the early 1980s halted commercial logging, but tree poaching and other illegal activities still exist (Bleher et al., 2006). The National Reserve managed by KWS is more heavily patrolled by game wardens, charges entry fees to tourists, and allocates much higher budgets per unit area (Glenday, 2006). In the Forest Reserves managed by the FD, no entry fee is charged. Logging and charcoal burning are illegal, but with a slim budget and a lack of legal and institutional capacity, these activities are difficult to control (Glenday, 2006).

Population density in the areas surrounding the forest increased by approximately 19% from 1989 to 1999 in the sub-locations that have their geographic center less than five

[1] Currently, about 46% of the population in Kenya (52% in Western Province, where Kakamega Forest is situated) is below the international poverty line, that is, live on less than one dollar per day (KNBS, 2007).

[2] The Kenyan government discontinued non-resident cultivation in all indigenous forest in the country in 2004. However, this decision was rescinded in 2007 (Muruingi, 2007).

[3] Since Kakamega Forest is highly fragmented, the term "Kakamega Forest" is used in this study to refer to a combination of all the forest fragments.

[4] Yala and Isecheno are Natural Reserves within a Forest Reserve. They are thus governed under the Forest Reserve protection status under Forest Department (FD). Their boundaries are legally established and they are supposed to be strictly protected. However, the FD usually allows extraction of non-timber forest products just as in other Forest Reserve areas.