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THE IMPACTS OF CHANGES IN LAND USE ON WOODLANDS IN AN EQUATORIAL AFRICAN SAVANNA

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ABSTRACT

Savanna landscapes are vitally important in providing both ecological and economic services that sustain local livelihoods and national economies, particularly for sub-Saharan African countries whose economies are mainly agrarian. Development prospects in savanna landscapes are however dependent on actions to avoid and to slow or reverse degradation and that are aided with a clear understanding of trends in land use/cover changes, their causes and implications for conservation. We analysed land use/cover changes based on three Landsat satellite images (1984, 1995 and 2000/2001) and the influence of human utilization on the changes in an equatorial African savanna, central Uganda, for the period 1984–2000/2001. The land cover classification and change analysis clearly identified the dominant land cover types, revealing a severe reduction in woodland cover with dense woodlands decreasing by 64%, over a 17-year period. Consequently, medium woodland, open woodland and cultivation/settlements areas cover increased by 31%, 3% and 80%, respectively. The cover change analysis results were corroborated with interview results that also attributed the woodland cover loss to increasing commercial charcoal production, expanding livestock grazing, subsistence crop cultivation and an insecure land use tenure system. Indeed, the major land use types in the savanna are charcoal production, shifting crop cultivation and livestock rearing. The decreasing woody vegetation cover threatens the savanna's ability to continue providing ecosystems services to support the livelihoods of people who mainly depend on natural resources and are vulnerable to the impacts of climate change. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: biomass energy; charcoal production; Landsat imagery; livelihoods; livestock grazing; woodlands; subsistence agriculture

INTRODUCTION

Savanna landscapes in sub-Saharan Africa and elsewhere in the world with their woody cover are vitally important in providing both ecological (e.g. erosion protection, microclimate and carbon sequestration) and economic services (e.g. timber, food, biomass energy, medicine and wildlife habitats) that sustain local livelihoods and national economies (Shackleton *et al*., 2002; Kristensen & Lykke, 2003; Muñoz-Rojas *et al*., 2012). In these savannas, household livelihoods and options for economic development are based on natural resources utilization and directly linked to the quality of the land and its resources. While the provisioning of ecosystem services depends to varying degrees on particular components of biodiversity, and household livelihoods are therefore vulnerable to biodiversity losses and habitat changes as a result of human land use practices and climate change. The increasing human population in most sub-Saharan African countries whose economies are mainly agrarian is increasing the demand for land resources, resulting in unsustainable land use and cover changes, threatening biodiversity and ecosystem service values (MEA, 2005a; Mwavu & Witkowski, 2008; Coetzer *et al*., 2010; Zhang *et al*., 2013). Consequently, this is subjecting natural vegetation types to high rates of change for large regions (MEA, 2005a), and Uganda's equatorial savannas and other natural vegetation types are no exception. Indeed, the way people use and manage land has often been cited as the primary cause of land cover change (Dale *et al*., 2000; Gobin *et al*., 2001) that impact ecosystem stability and functions.

Presently, Uganda's savannas face the challenge of climate change and variability, land degradation, desertification and loss of biodiversity, which are highly linked. The linkage between climate, land degradation and loss of biodiversity is increasingly viewed as highly interactive, requiring a more holistic framework and approaches in order to solve common problems (MEA, 2005b) that impact human well-being. For the case of savannas, these converging viewpoints lead to an increased focus on monitoring the trends in land use/cover changes and the factors responsible for those changes. Moreover, the development prospects in savannas of developing countries such as Uganda are especially dependent on actions to avoid the degradation of ecosystems and to slow or reverse degradation where it is occurring. These actions, however, can only be possible with the aid of a clear

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understanding of the land use/cover changes and their causes. Indeed, understanding the spatiotemporal dynamics of key ecological systems such as the savannas in the face of global change is fundamental to their successful management and conservation (Levick & Rogers, 2011). Although several studies (Dale *et al*., 2000; Gobin *et al*., 2001; Lambin *et al*., 2003; Biro *et al*., 2013) have been carried out elsewhere, the socio-economic factors that influence land use/cover changes may vary from one society to another. However, little is known of the trends in land cover changes and drivers of this change within Uganda's wooded equatorial savanna. Hence, their sustainable management requires an evaluation of the magnitude, pattern and type of land use and land cover changes and the projection of the consequences of these changes to their conservation (FAO, 2004). Furthermore, monitoring the locations and distributions of land cover changes is important for establishing links between policy decisions, regulatory actions and subsequent land use activities (Lunetta *et al*., 2006). We assessed the land use/cover changes and influence of human utilization on the changes in an equatorial African savanna, central Uganda, for the period 1984–2000/2001. This dryland area constitutes the catchment system for Lake Kyoga, and the transboundary water bodies (i.e. River Nile), and habitat to a diverse group of wildlife. These are of global environmental benefits as they contribute to biodiversity and carbon sequestration and are catchments of the transboundary waters. We set out to perform the following: (i) identify and map the major land use/cover types in 1984, 1995 and 2000/2001; and (ii) detect and determine the magnitude, rates and nature of the land cover change between the study dates.

MATERIAL AND METHODS

Study Area

The equatorial savanna of Nakasongola District occurs south of Lake Kyoga, central Uganda (0°40–1°41′N, 31°57′–32° 48′E). The District covers 3,424 km^2, 90% of which is woodland and grass savanna, with 322 km^2 (~10%) of open water and wetlands. It has a total human population of 128,126 (41 people/km^2) of which 95·3% are rural and 4·7% urban (UBOS, 2002). Most (70–80%) of the households engage in charcoal production, with livestock husbandry and subsistence agriculture (mainly shifting crop cultivation), providing 85% of the food supply and >50% of monetary income (DEP, 2002). The major land use practices in this savanna are charcoal production, livestock grazing and subsistence crop cultivation (Kalema & Witkowski, 2012). However, there is a cyclic process in land use over time, which is typical of areas subject to slash and burn agriculture. The annual rainfall range is 500–1,000 mm and is concentrated within two wet seasons (March–May and August–November). The mean monthly maximum temperature range is 25–35 °C, and the mean monthly minimum range is 18–21 °C. Currently, the vegetation is mainly open woodland in transition to thicket/shrubland (Kalema & Witkowski, 2012). The thicket patches are dominated by *Acacia hockii* De Willd., *Acacia gerrardii* Benth., *Acacia kirkii* subsp. *mildbraedii* Harms. and *Acacia senegal* (L.) Willd.

Land Cover Classification and Change Analysis

Land cover change can be observed and monitored using current and archived remotely sensed data at appropriate spatial, spectral and temporal resolutions (Luong, 1993; Rogan & Chen, 2004). Satellite imagery (including Landsat) has, over the years, been used for land cover classification and land use monitoring and assessment of desertification processes (Mwavu & Witkowski, 2008; Biro *et al*., 2013; Trabaquini *et al*., 2013). Land cover changes, specifically the loss of woodland cover, were assessed using ortho-rectified, multitemporal Landsat 5 satellite images (1984, 1995 and 2000/2001) covering a period of 17 years. The Landsat images were used to map vegetation change in order to understand spatial variability and trends. Landsat images consisting of two scenes of path/row 171/059 and 172/059 from the dry and rainy seasons were acquired to classify land cover and distinguish wet and dry, lowland and green areas between different seasons (Table I).

The images were precision orthocorrected to a subpixel accuracy using an image-to-image orthorectification with the 2000/2001 EarthSAT orthoimagery and the Shuttle Radar Topography Mission (90 m, pixel size) digital elevation models for geographical reference. The final orthocorrected image was input as 28·5 m pixels in the UTM (zone 36 North) coordinate system and the WGS1984 global datum.

Image classification

Land cover classifications were generated for each assessment period using the standard unsupervised iterative self-organizing data analysis technique algorithm clustering procedure as a first-pass solution, and this was refined using

Table I. List of satellite imagery data with final root mean square errors (RMSE in pixel units) used to study the land cover types in an equatorial African savanna, Nakasongola District, central Uganda

Satellite	Path/row	Acquisition date	Season	RMSE (m)
EarthSat US	171-059	27 November 2001	Dry season	Nil
EarthSat US	172-059	23 May 2000	Rainy season	Nil
USGS data archives	171-059	3 January 1995	Dry season	0·79
USGS data archives	172-059	27 February 1995	Rainy season	0·30
USGS data archives	171-059	1 September 1984	Rainy season	0·72
USGS data archives	172-059	20 June 1984	Dry season	0·38

the supervised classification approach based on knowledge of local conditions. Time-dependent stable woodland features with obvious static boundary characteristics were matched in terms of class codes and spectral class groupings in all images, while allowing for all other areas to be coded according to the extrapolation of such characteristics across the study area. The specific approach taken was first to map and delineate the dense woodland and open grassland classes as two extremes of the defined woodland cover gradient and then '*fill-in*' the remaining areas with the medium woodland and/or open woodland classes according to the interpretation of local conditions. The raster calculator in ARCMAP® version 9·0 (ESRI, Redlands, CA, USA, 2004) was used to calculate the changes in woodland cover in areas that persisted with dense, medium or open woodland through the dates 1984, 1995 and 2000/2001.

Classification accuracy assessment

The historical Landsat images used could not be ground-truthed, but because stable spectral features were used in the classification, fieldwork was conducted in 2006 to assess the validity of these stable spectral features. A total of 135 points, 75 from vegetation assessment plots measuring 20 × 50 m (Kalema & Witkowski, 2012) and 60 GPS ground reference points of representative homogenous patches of specific land cover types were used. This number of points compares well with the 132 used by Waite *et al.* (2009) but much higher than the 42 and 40–45 ground-truthed GPS points used by Kamusoko & Aniya (2007) and Mwavu & Witkowski (2008) in evaluating land cover/use change in natural landscapes, respectively. Only nine classes of land cover types based on the 2000/2001 image were included in the final assessment (Table II).

An accuracy assessment of the land cover was conducted for the classified imagery based on how well the image-based classification matched observations at sample points. An error matrix (contingency table) was generated using 135 points for the classified image. Using the error matrix, overall image classification accuracy using the kappa index was calculated as well as conditional Kappa (K_i) (Table II). The Kappa index accounts for chance agreement between the classes represented in the image and on the ground (Foody, 2002; Trabaquini *et al.*, 2013), whereas the K_i provides an individual measure of agreement for each class represented in the classified image (Hudson & Ramm, 1987). Generally, K_i values greater than 0 indicate better than chance agreement, and values near 1·0 are approaching perfect agreement, whereas K_i values ≥0·4 indicate good to excellent agreement (Fitzgerald & Lees, 1994). The validated land cover maps for 1984, 1995 and 2000/2001 were overlaid in postclassification comparison to detect the pixel-by-pixel land cover changes between 1984, 1995 and 2000/2001. The outputs were cross-tabulation matrices showing the pathways and the change maps showing the spatial patterns of the land cover change.

Table II. Conditional kappa (K_i) for land cover types in an equatorial African savanna, Nakasongola District, central Uganda, based on Landsat image 2000/2001

Class	Class names	Conditional kappa (K_i)
1	Cultivated, disturbed and settlement	0·642
4	Woodlots	1
6	Aquatic wetlands	0·318
7	Hydro-morphic grassland	0·718
8	Dense woodland	0·361
9	Medium woodland	0·209
10	Open woodland	0·568
11	Grassland (wetland periphery)	0·701
14	Natural bare ground	1

Drivers of Land Cover Change

The history of land use and causes of land cover change from 1984 to 2006 (when fieldwork was done) were obtained through field observations and individual face-to-face interviews with selected household heads and key informants (KIs), during the period March–August 2006. Observations were made of standing trees and harvested stumps within 75, 20 × 50 m vegetation plots and enumerated to establish whether the area was dense (i.e. with more than 20 trees), medium (i.e. 10–15 trees) or open woodland (i.e. less than 10 trees). Interviews were conducted with a representative total of 45 respondents, in terms of ethnicity, wealth, gender and age classes from the eight subcounties. Three KIs (i.e. the District Resource Officer, District Environmental Officer and District Livestock Officer) were interviewed to obtain information to clarify or to improve information collected in the household interviews. Interview questions generally focused on changes in resource use and availability, causes of woodland loss or change and income-generating activities within the communities. Human population data for the surrounding villages were obtained from the 2002 National Household Census (UBOS, 2002) and utilized to give an indication of the gender, family size, livelihoods and employment situation. Interview data were analysed using both descriptive and inferential statistical techniques.

RESULTS

Land Cover Classification and Accuracy Assessment

The land cover classification clearly identified mixed woodland, hydro-morphic grassland and cropland as the dominant land cover types, with the relative coverage varying between sites and years (Figures 1a–1c; Table III). The overall classification accuracy was 60%, with a kappa index of 0·5. The conditional kappa values (K_i) for the individual classes ranged from 0·209 to 1 (Table II). Hence, the classification was more than sufficiently accurate to show real changes.

Land Cover Change Detection

Trends in woodland cover change showed a severe reduction over the period 1984–2001 (Table III). Over this period, the dense and medium woodlands changed into open

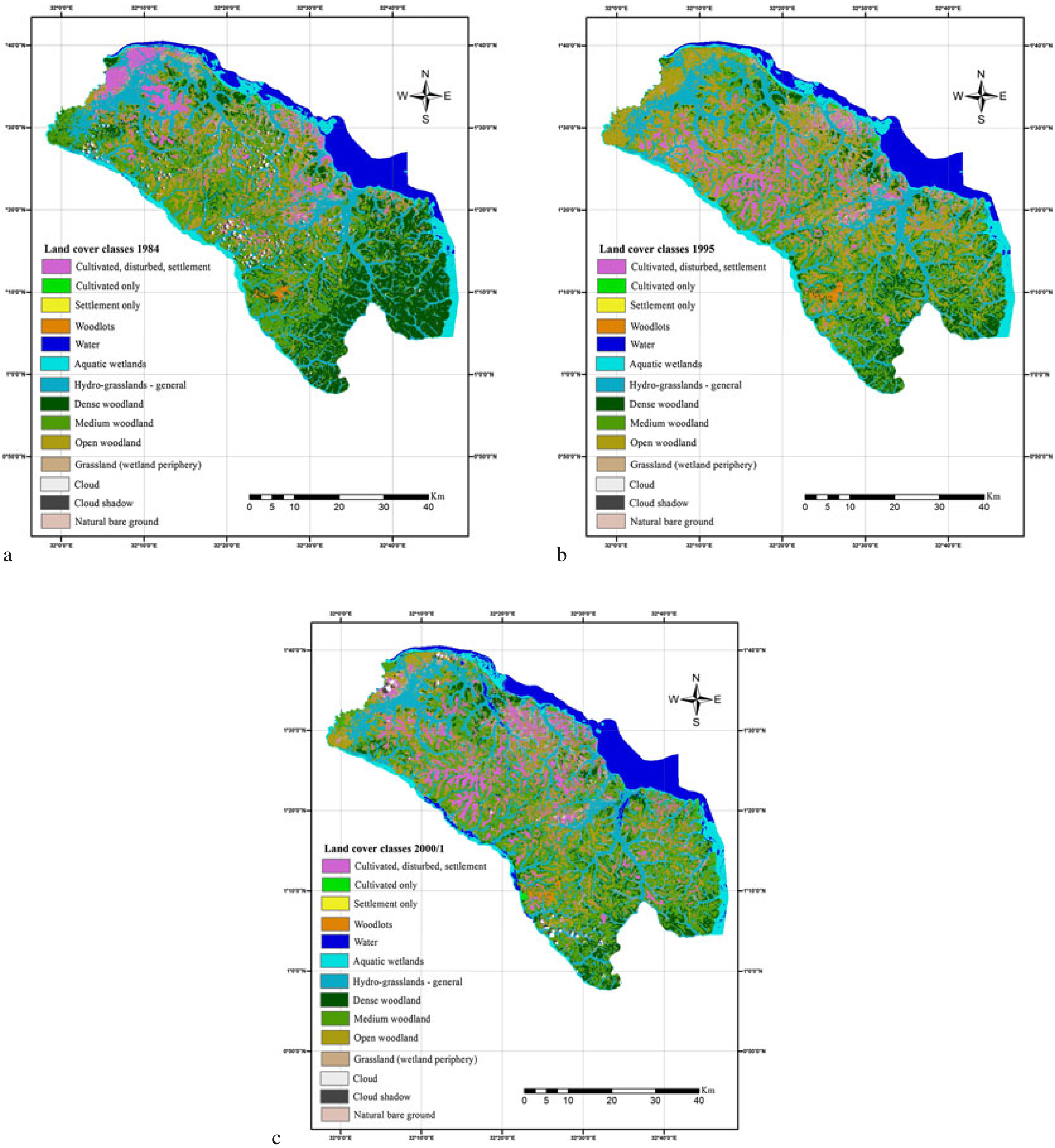

Figure 1. (a) Land cover types of a multiple land use equatorial African savanna, Nakasongola District, central Uganda, in the year 1984. (b) Land cover types of a multiple land use equatorial African savanna, Nakasongola District, central Uganda, in the year 1995. (c) Land cover types of a multiple land use equatorial African savanna, Nakasongola District, central Uganda, in the year 2000/2001. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

woodland, and most of them subsequently changed into cultivated, disturbed and settlement areas (Figure 1c). There was a total loss of 64% of dense woodlands over the 17-year period (Figure 2). Medium woodland cover decreased from 78,517 ha in 1984 to 75,062 ha in 1995 and increased to 102,540 ha in 2000/2001, indicating a 31% overall increase between 1984 and 2000/2001 (Table III, Figure 2). Similarly, open woodland cover increased from 48,876 ha in 1984 to 85,906 ha in 1995 but decreased to 50,237 ha in 2000/2001. Overall open woodland cover increased by 3% between 1984 and 2000/2001 (Table III). Cultivated, disturbed and settlement land rose from 21,434 ha in 1984

Table III. Changes in land cover types in an equatorial African savanna, Nakasongola District, central Uganda, over a 17-year period between 1984 and 2000/2001 as determined from Landsat images of 1984, 1995 and 2000/2001

	Area (ha)			Area loss (−)/increase (+) (%)*		
Land cover class	1984	1995	2000/2001	1984–1995	1995–2000/2001	1984–2000/2001
Cultivated, disturbed, settlement	21,434	23,785	38,478	11⁺	62⁺	80⁺
Cultivated only	1,961	1,464	2,651	25⁻	81⁺	35⁺
Woodlots	952	1,439	1,126	51⁺	22⁻	18⁺
Hydro-grassland-general	72,787	74,331	73,559	2⁺	1⁻	1⁺
Dense woodland	63,488	30,419	22,836	52·1⁻	25⁻	64⁻
Medium woodland	78,517	75,062	102,540	4·4⁻	37⁺	31⁺
Open woodland	48,876	85,906	50,237	76⁺	42⁻	3⁺
Natural bare ground	130	267	431	105⁺	61⁺	232⁺

*The percent loss or increases are calculated from the previous year.

to 38,478 ha in 2000/2001, an 80% increase (Table III). Mixed open woodland, shrubs and grassland patches occurred in close proximity to patches of cropland and human settlement, indicating that those were patches of high disturbance. Bare ground increased by 232% from 1984 to 2000/2001 (Table III). The increase in cultivated, disturbed and settlement and bare ground land cover types generally indicate a decrease in woodland cover. Only a small percentage (i.e. 0·4% and 2%) of open woodland turned into medium then dense woodland between 1984 and 2001 (Table IV). Between 1984 and 2001, 57% of dense woodland was converted to medium woodland and 26% of medium woodland into open woodland (Table IV). There were observed major conversions of woodlands (i.e. open, medium and dense) to cultivated, disturbed and settlement cover types from 1984 through to 2001. For example, over 37% of what were woodland areas in 1995 had by 2001 been converted to cultivated, disturbed and settlement cover types (Table IV). However, 12,413 ha (20%) of dense woodland, 21,345 ha (27%) of medium and 8,732 ha (18%) of open woodland cover persisted from 1984 through to 2000/2001 (Table IV), which is low compared with the overall area of woodland lost from 1984 through to 2000/2001.

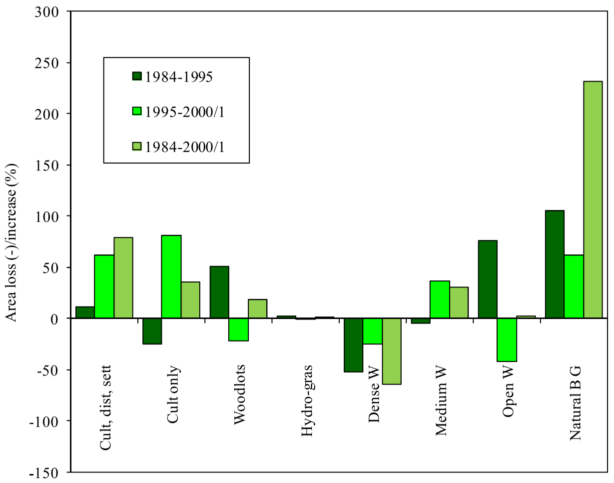

Figure 2. Land cover loss (−)/increase (%) in a multiple land use equatorial savanna, Nakasongola District, central Uganda, over a 17-year period between 1984 and 2000/2001 as determined from Landsat images of 1984, 1995 and 2000/2001. (Cult, dist, sett: cultivated, disturbed, settlement; cult only: cultivated only; hydro-gras: hydro-grassland-general; dense W: dense woodland; medium W: medium woodland; open W: open woodland; natural B G: natural bare ground). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Socio-economic Drivers/Causes of Land Cover Change

Both the households/resource users and KIs concurred that the savanna woodlands have been rapidly decreasing in cover and tree density because of unsustainable harvesting. This corroborates the change analysis results (Table III). All respondents (45; 100%) reported the following: (i) uncontrolled harvesting of trees and shrubs for charcoal production; (ii) overgrazing and clearing of woody vegetation for establishing/rehabilitating farms/ranches and unplanned seasonal bush fires; (iii) expanding shifting crop cultivation; and (iv) insecure land use tenure systems as the major drivers of dense woodland cover loss in the studied equatorial savanna. Twenty-four woody species were reportedly utilized for charcoal production including three (i.e. *Mangifera indica* L., *Artocarpus heterophyllus* Lam. and *Senna siamea* (Lam.) H.S. Irwin & Barneby) which, were nontraditional charcoal production trees (Table V). The 24 species were reported by respondents (30–100%) to also serve over ten other uses, including firewood, poles, medicine, shade, wind breaks, fencing, timber, food/fruits, and making of mortar and pestle boats. Similarly, households reported to derive these uses from woodland resources to meet their daily livelihood needs. Most households (56%) derived all these resources from natural woodlands, 16% derived resources from forest plantations whereas 31% did not respond. None of the respondents, however, owned a forest plantation or woodlot. They also mentioned that resource utilization was not only for local residents, with 35 (78%) respondents revealing that woody plant resources are not only utilized by local residents for charcoal production, but also by commercial harvesters from neighbouring districts (e.g. Luwero) and distant ones (e.g. Lira). In addition, the majority of respondents (39; 87%) concurred that the land available for cultivation per household has decreased over the years, as a result of the ever-increasing human and livestock populations in the district. This is pushing people into clearing new areas with a resultant loss of woody vegetation cover. The District Veterinary Officer revealed that between 1985 and 2004, six new ranches covering about 23,624 ha were established, and that by 1998, the population

Table IV. The change detection matrix showing the patterns of major land cover changes in an equatorial African savanna, Nakasongola District, central Uganda, through 1984, 1995 and 2000/2001

1984	1995	2000/2001	Area (ha) in 1984	Present area	% area cover*
Dense	Dense	Dense	63,488	12,413	20
Medium	Medium	Medium	78,517	21,345	27
Open	Open	Open	48,876	8,732	18
Dense	Medium	Open	63,488	2,040	3
Dense	Medium	Medium	63,488	21,237	33
Dense	X	Medium	63,488	36,393	57
Dense	Open	Open	63,488	3,569	6
Dense	X	Open	63,488	6,066	10
Medium	Dense	Dense	78,517	2,560	3
Medium	X	Dense	78,517	5,199	7
Medium	Open	Open	78,517	13,196	17
Medium	X	Open	78,517	20,477	26
Open	Dense	Dense	48,876	201	0·4
Open	X	Dense	48,876	982	2
Open	Medium	Medium	48,876	6,706	14
Open	X	Medium	48,876	15,964	33
Dense	X	Cultivated	63,488	2,743	4
Medium	X	Cultivated	78,517	9,045	12
Open	X	Cultivated	48,876	13,955	29
Open	Medium	Dense	48,876	469	1
X	Dense	Cultivated	63,488	309	0·5
X	Medium	Cultivated	78,517	3,176	4
X	Open	Cultivated	48,876	15,925	33
Cultivated	Cultivated	Cultivated	21,434	4,803	22

X, year not included in a specific cover change analysis.
*The percent area covers are calculated based on the year 1984.

of cattle increased by 30%. Of the 45 households interviewed, 25 (56%) were under *mailo*, 14 (31%) under customary, 4 (9%) under freehold and 2 (4%) under leasehold land tenure system. The respondents also revealed that prior to 2006, dense and medium woodlands mainly persisted in forest reserves and some other areas that were under the protection of government agencies (e.g. National Forestry Authority). They confirmed that the three major land use practices in the district were charcoal production, subsistence crop cultivation and livestock grazing.

DISCUSSION

Land Cover Change

The Landsat imagery analyses clearly showed woodland to bushland/thickets vegetation transition, with significant losses of dense woodland cover and increases in open woodland, grassland and settlement land cover types. Most woodland cover has been and continues to be cleared for charcoal production, expansion of crop fields and infrastructure. Other studies in African savannas (Biro *et al*., 2013) and the Mediterranean landscapes (García-Orenes *et al*., 2012) have similarly reported a significant spatial expansion in cultivated land and a large decrease in woodland cover. The overall classification accuracy of 60% and a kappa index >0·5 recorded in this study is within the acceptable range and indicates that the classification was sufficient for the evaluation of land cover changes (Wulder *et al*., 2006).

The studied savanna experienced a relatively high loss of woodlands and an increase in land degradation during the 17-year study period (1984–2001). This is contrary to the global trend towards tree densification in rangelands and savannas in general, with the assumption that open woodland would have become dense woodland (Bond *et al*., 2005). Indeed, none of the major land use practices in the area does encourage the development of vegetation into dense woodlands. The study period overlapped with the 1990–2005 period during which Uganda reportedly lost about 24·7% of its forest and woodland habitat (NEMA, 2007). On the other hand, the 76% increase in open woodland between 1984 and 1995 overlapped with a period of road network development and improvement in the study area probably facilitating settlement establishment and the charcoal production business in previously inaccessible areas; thus, facilitating illegal harvesting of timber and nontimber forest products (MEA, 2005b). The observed trends (i.e. land use and cover changes) in this savanna have serious implications for their sustainable provision of ecosystems goods and services particularly for the natural resources-dependent livelihoods. For example, land cover changes leading to the loss of tree cover with potential soil degradation (Cerdà *et al*., 2010) threatens agricultural productivity, which is the main stay of local people in this area. This is because land use change can affect soil quality (García-Orenes *et al*., 2012), induce spatial variations of soil water (Gao *et al*., 2011) and affect runoff and precipitation infiltration that is of great importance to vegetation restoration and crop production in semi-arid areas (Wang *et al*., 2008; Kashaigili & Majaliwa, 2013).

The high rate of woodland vegetation loss, of about 64% over the 17-year study period, may be attributed to a lack of

Table V. The 24 woody species used for charcoal production in equatorial African savanna woodlands of Nakasongola District, central Uganda

Species	Family	% respondents ($N = 45$)
Combretum molle R. Br. ex G. Don	Combretaceae	67
Combretum collinum Fresen.	Combretaceae	62
Vepris nobilis (Delile) Mziray	Rutaceae	56
Terminalia glaucescens Planch. ex Benth.	Combretaceae	47
Grewia mollis Juss.	Tiliaceae	38
Albizia zygia (DC.) J.F. Macbr.	Mimosaceae	29
Acacia hockii De Wild.	Mimosaceae	24
Gymnosporia senegalensis (Lam.) Loes.	Celastraceae	20
Albizia coriaria Welw. ex Oliv.	Mimosaceae	18
Combretum adenogonium Steud. ex A. Rich.	Combretaceae	18
Piliostigma thonningii (Schumach.) Milne-Redh.	Caesalpiniaceae	18
Acacia polyacantha Willd.	Mimosaceae	11
Hymenocardia acida Tul.	Euphorbiaceae	11
Combretum capituliflorum Fenzl ex Schweinf.	Combretaceae	11
Acacia seyal Delile	Mimosaceae	11
Acacia sieberiana DC.	Mimosaceae	11
Zanthoxylum chalybeum Engl.	Rutaceae	7
Ficus natalensis Hochst.	Moraceae	7
Senna siamea (Lam.) H.S. Irwin & Barneby**	Caesalpiniaceae	7
Trema guineensis (Schumach. & Thonn.) Ficalho	Tiliaceae	7
Dichrostachys cinerea (L.) Wight & Arn.	Mimosaceae	7
Artocarpus heterophyllus Lam*	Moraceae	2
Lannea barteri (Oliv.) Engl.	Anacardiaceae	2
Mangifera indica L*	Anacardiaceae	2

Included are the plant family and the percentage of respondents who used a particular species.
*Fruit trees
**Introduced/invasive species.

sustainable resource management practices in the area, which is common in many African woodland regions and Mediterranean grasslands (Luoga *et al*., 2005; Fisher *et al*., 2012; Biro *et al*., 2013). Uganda's economic recovery since 1986 has driven urban population growth and higher demands for timber, fuel wood, charcoal and food crops, whereas the decentralized system of governance adopted since 1997 has transferred the authority for natural resource management to local governments (i.e. Districts). However, at the local government level, political interests and the need to access resources to alleviate poverty outweigh the need to follow the approved laws and regulations and the desire to manage and conserve natural resources sustainably (Mwavu & Witkowski, 2008). For example, in the study area, the local authorities in their bid to raise income have been licencing charcoal producers without clear guidelines on where, when and how much woody biomass should be harvested seasonally or annually. Various studies (Bazaara, 2003; Banana *et al*., 2007) have shown that in Uganda, local governments' attempts to influence natural resource conservation have not resulted in positive social and environmental outcomes, because of conflicts of interest among the sectors and corruption of local government officials. However, it is possible that with restricted access and controlled use, hence minimal disturbance, some of the woodlands in the area can still be maintained. Moreover, the maintenance of woodland cover in these extensive savannas has a potential to improve their carbon sequestration, thus contributing to the decrease of atmospheric CO_2 emission rates (Muñoz-Rojas *et al*., 2012). Under the current circumstances and given the high dependence of people's livelihoods on land in the study area, sustainable agricultural management is necessary for increased agricultural production and sustainability (García-Orenes *et al*., 2012).

Socio-economic Drivers of Land Cover Changes

The decrease in woodland cover in the study area is attributed to the ever-increasing woody plant harvesting for biomass energy, shifting crop cultivation and establishment of livestock ranches, settlements and other infrastructure. Similarly, several studies in Uganda and elsewhere (Campbell *et al*., 1993; Dale *et al*., 2000; Mwavu & Witkowski, 2008) report that the major anthropogenic causes of land cover change include human population growth and associated livelihood strategies, economic factors, technological capacity, political systems and socio-cultural factors. In their study (Kashaigili & Majaliwa, 2013) report, the principal causes of land use and land cover change include deforestation, expanding agricultural activities characterized by shifting cultivation and population increases.

Charcoal production

In the studied savanna, charcoal production is a widespread and major economic activity for many households, targeting woody plants even on the local and central government-managed forest reserves that are supposedly 'protected' from unplanned harvesting. The unsustainable and lucrative commercial charcoal production is resulting in increased decline/loss of woody cover in the fragile but ecologically important studied equatorial savanna. In Uganda, like in most sub-Saharan African countries, there is a high dependency of the majority of urban households on biomass energy particularly charcoal (Luoga *et al*., 2000a, 2000b; Brouwer & Falcão, 2004), greatly contributing to the deforestation of wooded savannas. This has not been helped by the ever-increasing tariffs on electricity and fossil fuels (e.g. kerosene) in the East African region, making such alternative energy sources unaffordable to many urban households, hence increasing their dependency on the relatively cheaper biomass fuel. Indeed, charcoal has become an increasingly traded commodity, leading to the harvesting of socio-economically valuable savanna tree species such as *Vitellaria paradoxa* C.F. Gaertn, *Tamarindus indica* L., *A. senegal* (L.) Willd. and *Balanites aegyptica* (L.) Delile with a potential for adoption in food systems and pharmaceutical development.

Establishment and development of livestock ranches, livestock grazing and seasonal fires

Livestock grazing is also a very common and one of the major land uses and income-generating activities in the studied savanna, with the rehabilitation of old ranches and establishment of new ones in the area. In the process, woody plant cover is cleared to allow grasses to flourish, consequently reducing woodland cover. Large areas (about 23,624 ha) are reported to have been fenced between 1985 and 2004, reducing open-access grazing land leading to vegetation degradation in common access grazing areas (District Livestock Officer, pers. comm.).

The increased loss of woodland vegetation cover in the study area may also be attributed to the interaction between fires and animal grazing that is common in the studied savanna. Fires in combination with livestock grazing may arrest the vegetation transition from savanna grassland to woodland. In semi-arid areas such as the savannas, wildfire temporarily removes vegetation and alters soil properties, increases the susceptibility of soil to erosion processes thereby contributing to the increased vulnerability of soils to land degradation (Cerdà, 1998; Lasanta & Cerdà, 2005; Pérez-Cabello *et al*., 2012). On the other hand, the combined use of goats with support from burning, clearing and trimming has been reported to control the spread of shrubs in the degraded pastures in the semi-arid Cantabrian Mountains of northern Spain (Álvarez-Martínez *et al*., 2013). Therefore, in some savannas, the protection against fire and herbivores may result in higher densities of trees (Bond *et al*., 2005), while complete cessation of burning may promote the development of woody vegetation (Everett *et al*., 2000; Uys *et al*., 2004). Protecting a vegetated landscape from anthropogenic disturbances has the potential to improve most of the soil properties particularly saturation capacity, permeability, total porosity and organic matter (Özcan *et al*., 2013), thereby increasing its ability to provide ecosystem goods and services. Although this secondary succession in vegetation has some positive effects, it also has drawbacks that include an increase in fire risk, loss of diversity in land use, constraints on livestock farming (which is one of the major livelihood activities in this savanna), a reduced number of local species and loss of biodiversity (Álvarez-Martínez *et al*., 2013) that may negatively impact local livelihoods in this savanna. In this case, sustainable management of the vegetation may be required if we are to maintain the landscape for provision of ecosystem goods and services to the majorly land-dependent households.

Increasing human population and expanding shifting crop cultivation

The over 80% increase in land area under crop cultivation and settlements in the study area over the period 1984–2001 may be attributed to the increase in the human population that is majorly dependent on land resources for its livelihood strategies. Local households practise subsistence shifting crop cultivation that is associated with the slashing and burning of woody vegetation, thereby contributing to the loss of woodland cover. In these fragile and low soil fertility savannas, wooded areas are usually targeted for agricultural expansion on the assumption that they are more fertile and could give higher crop yields. Shifting cultivation has been cited for the modification and transformation of the landscape and deforestation in the sub-Saharan African savanna woodlands (Luoga *et al*., 2000b; Kamusoko & Aniya, 2007; Kashaigili & Majaliwa, 2013). Increasing human population and ongoing demand for land for crop cultivation in the studied savanna is also leading to shorter fallow periods of less than 2 years, which is insufficient to allow recovery of woody vegetation. Indeed, agricultural expansion has been by far the leading cause of land use/cover change associated with deforestation in Asia, Africa and Latin America (Reid *et al*., 2000; Geist & Lambin, 2002).

Land tenure systems

In Uganda, restricted use of woodlands, and therefore less woodland loss, would be expected under the mailo land tenure system, in which the registered owner holds land in perpetuity, but is subject to customary and statutory rights of lawful and *bona fide* occupants (GOU, 2001). However, woodland loss in the study area continues to occur mostly in areas under mailo and customary land tenure systems and also on privately owned lands, particularly those with absentee landlords. In fact, these savanna woodlands seem to be *de facto* open-access regimes, with no effective institutions and mechanisms to enforce the regulations to ensure that they are sustainably managed. There is no consistent and secure land tenure system in the studied savanna, thereby undermining the sustainable utilization of woody plant resources. Land ownership may play an important role in the spatial distribution and magnitude of change in vegetation patterns (Kennedy & Spies, 2004), with common property regimes being responsible for overexploitation and destruction of natural resources (Hanna *et al*., 1995).

CONCLUSIONS

Analysis of Landsat imagery and socio-economic interviews facilitated a better understanding of the dynamics of land cover change and woodland loss in the studied equatorial savanna. A combination of socio-economic factors including increased demand for biomass energy and establishment of land-dependent agricultural enterprises as livelihood strategies for the majority of households are leading to increased loss of woody plant cover threatening the sustainability of this savanna. It is possible that charcoal commercial producers, whose decisions are driven by short-term profits, will continue harvesting woody plants for as long as there are woodlands left to clear. The continued loss of woodland cover has implications for plant diversity and consequently the provision of ecosystem goods and services essential for human well-being. If landscape cover changes continue to follow woodland loss and land degradation trends, the savanna's ability to continue providing ecosystem services will be highly compromised particularly in the face of climate change where such landscapes with their natural vegetation are crucial in climate change mitigation. Indeed, the continued losses of woodland cover in these fragile and climate change vulnerable savannas threaten local community livelihoods that are already vulnerable to the impacts of climate change and variability. Therefore, sustainable land management approaches are required for these socio-economically and ecologically important but fragile landscapes. Hence, the baseline land cover change maps produced in this study may provide a valuable tool to aid the planning and implementation of sustainable development programmes within Uganda's equatorial savannas and similar landscapes in sub-Saharan Africa.

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