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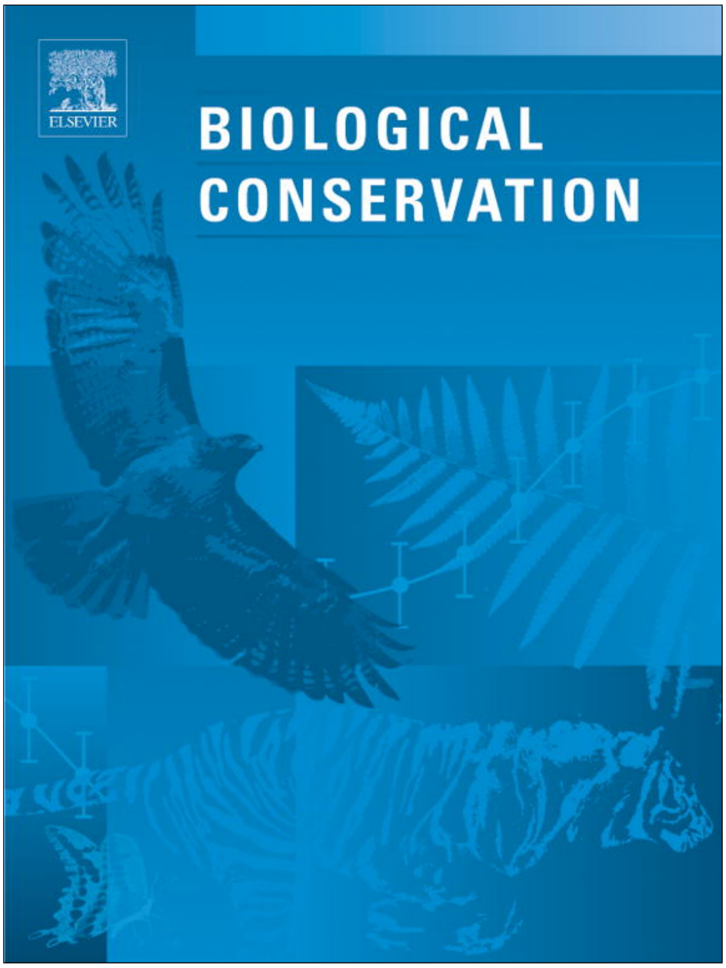

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Complex contexts and dynamic drivers: Understanding four decades of forest loss and recovery in an East African protected area

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ABSTRACT

Protected forests are sometimes encroached by surrounding communities. But patterns of cover change can vary even within one given setting – understanding these complexities can offer insights into the effective maintenance of forest cover. Using satellite image analyses together with historical information, population census data and interviews with local informants, we analysed the drivers of forest cover change in three periods between 1973 and 2009 on Mt Elgon, Uganda. More than 25% of the forest cover of the Mt Elgon Forest Reserve/National Park was lost in 35 years. In periods when law enforcement was weaker, forest clearing was greatest in areas combining a dense population and people who had become relatively wealthy from coffee production. Once stronger law enforcement was re-established forest recovered in most places. Collaborative management agreements between communities and the park authorities were associated with better forest recovery, but deforestation continued in other areas with persistent conflicts about park boundaries. These conflicts were associated with profitability of annual crops and political interference. The interplay of factors originating at larger scales (government policy, market demand, political agendas and community engagement) resulted in a "back-and-forth" of clearing and regrowth. Our study reveals that the *context* (e.g. law enforcement, collaborative management, political interference) under which *drivers* such as population, wealth, market access and commodity prices operate, rather than the drivers *per se*, determines impacts on forest cover. Conservation and development interventions need to recognize and address local factors within the context and conditionalities generated by larger scale external influences.

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1. Introduction

Even though protected areas in the tropics have generally reduced deforestation within their boundaries (Bruner et al., 2001; Naughton-Treves et al., 2005), forest loss still continues in many (DeFries et al., 2005; Nagendra, 2008). This deforestation threatens the provision of forest-derived services and products. These services and products range from climate regulation and biodiversity conservation, to water-catchment protection, to providing local populations with food and timber (Millennium Ecosystem Assessment, 2005). Protected forests in East Africa, for example, often serve as important water catchments supporting high densities of people. They also attract substantial tourism and host rich biodiversity. One of these forests, on Mt Elgon (Kenya, Uganda), provides water for more than 2 million people in the surrounding districts (Fig. 1) and has a rich and remarkable history of both forest loss and forest recovery (KWS et al., 2001; van Heist, 1994).

Across the tropics the underlying drivers and proximate causes of deforestation have been the subject of numerous studies (Geist and Lambin, 2002). Population pressure and rural poverty, leading to agricultural expansion, dominate the global discussion on the causes of forest loss in the tropics (e.g. Allen and Barnes, 1985; Lung and Schaab, 2010; Uusivuori et al., 2002). By contrast, reviews show that these factors are seldom the principal determinants of when and where forest cover is lost (e.g. Angelsen and Kaimowitz, 1999; Rudel and Roper, 1996). Multiple political, institutional, economic and social forces operating at the local, national and global level interact to determine the patterns of tropical deforestation (Angelsen and Kaimowitz, 1999; Carr et al., 2005; Geist and Lambin, 2002; Lambin et al., 2001). The significance of different management arrangements, including the degree of community involvement, remains debated (Hayes, 2006; Southworth et al.,

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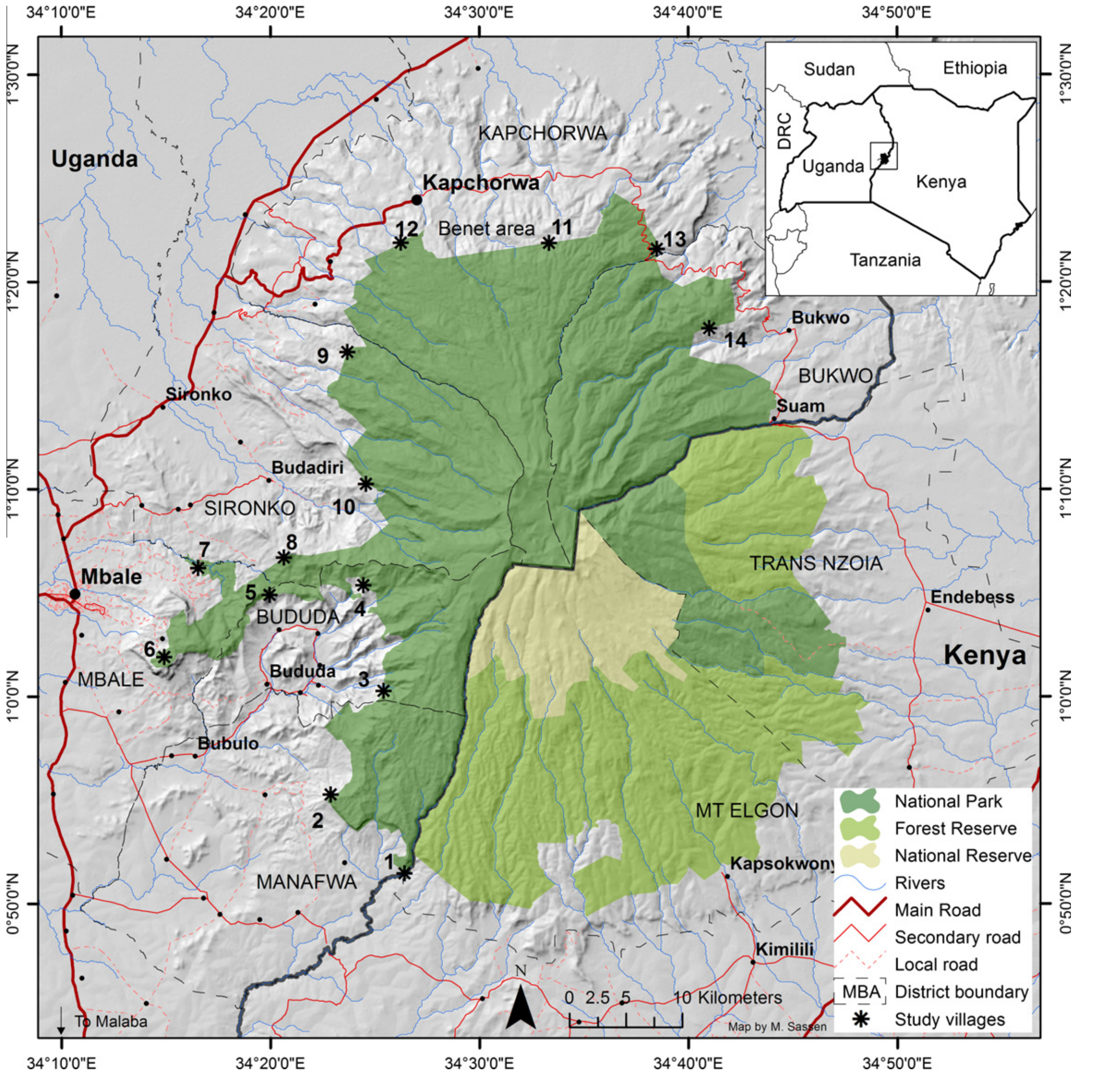

Fig. 1. Map of Mt Elgon, Uganda and Kenya, with the location of the 14 study villages.

2006). Deforestation by small scale farmers reflects marginal choices about whether and where to clear (Sheil and Wunder, 2002). Such choices depend on the availability of the resources needed for agricultural production, infrastructure, markets, perceived costs and benefits and alternative options outside agriculture (Angelsen et al., 1999; Kaimowitz and Angelsen, 1998; Maeda et al., 2010). These factors are often time and location specific, but local studies using longitudinal data and linking people and place can clarify their role (see e.g. Fox et al., 2003).

We assess how changing contexts in combination with more local drivers can influence forest cover within one protected area (see also Gaveau et al., 2009; Nagendra et al., 2010). We examine cover in Mt Elgon National Park, Uganda between 1973 and 2009. Previous studies emphasized the deforestation during the civil unrest of the 1970s and 1980s (Otte, 1991; van Heist, 1994). Some forest recovered subsequently though clearance has remained a local concern (UWA, 2000). We use a combination of data and methods to investigate the diversity of factors that affected forest clearance and recovery within a single national park (as in Ostrom and Nagendra, 2006). We examine three periods broadly corresponding to weak enforcement, strong enforcement and community engagement periods, and investigated the effects of changing political, economic and social factors.

2. Study area

2.1. Mt Elgon

Mt Elgon is an extinct 4321 m high Miocene volcano, shared between Kenya and Uganda. Its slopes are generally gentle (averaging less than 4°), with characteristic natural terraces cut by sheer cliffs in the north, and steep slopes in the south and south-west. A parasitic vent formed the 20 km long ridge that extends towards the west. The protected area covers approximately 1120 km^2 in Uganda and 1400 km^2 in Kenya (Fig. 1). Dry north-easterly and moist south-westerly winds determine the climate. July–August and December–February are relatively dry, although rain falls in all months (Fig. 2). Annual precipitation in the protected area is between 1500 and 2000 mm. More rain falls on the western and south-western slopes and most falls mid-slope at between 2000 and 3000 m altitude (m.a.s.l.) (Dale, 1940; IUCN, 2005). The mountain is an important water catchment area for the Turkwell and Lake Turkana systems, the Lake Victoria Basin, Lake Kyoga and the Nile Basin (IUCN, 2005). The vegetation is composed of an afromontane forest belt (*Podocarpus* spp., *Cornus volkensii*, *Schefflera* spp., *Hagenia abyssinica*, *Olea* spp., *Prunus africana*) with large areas of bamboo (*Arundinaria alpina*) on average between 2000 and

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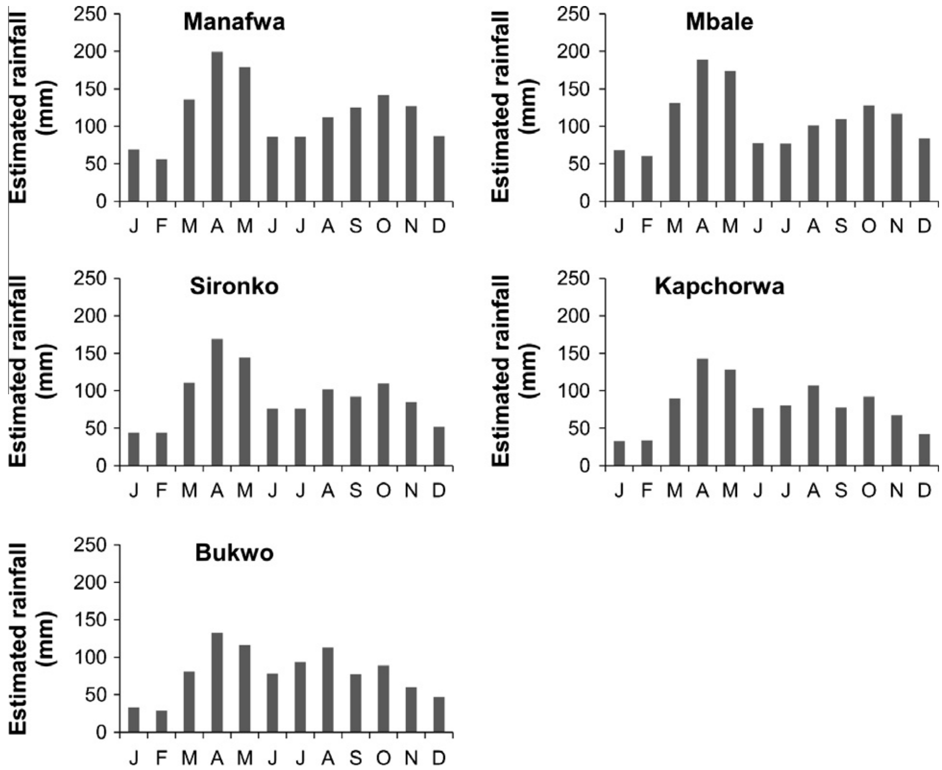

Fig. 2. Estimated average monthly rainfall in five districts around Mt Elgon (2007–2011). See Fig. 1 for district boundaries. Data for Manafwa district includes Bududa. (Data source: FAO/GIEWS, 2012).

3000 m, followed by heathers (*Philippia* spp.), and high altitude moorland (*Senecio* spp., *Lobelia* spp., *Alchemilla* spp.) (Dale, 1940; van Heist, 1994). Fire on the moorlands plays a role in determining the upper forest boundary (Hamilton and Perrott, 1981). Mt Elgon hosts biodiversity of global significance, including 39 endemic species of vascular plants specific to Mt Elgon and many species with limited distributions, such as *Lobelia elgonensis* and *Senecio elgonensis*, *Hypericum afromontanum*, *Juniperus procera* and *Euphorbia obovalifolia* (for details see Davenport et al., 1996; IUCN, 2005).

2.2. Land use

In the period covered by this study, nearly all land within 20 km from the protected area was grazed or under cultivation (IUCN, 2005; van Heist, 1994) (see images in Appendix A). The region's volcanic soils are fertile and support intensive mixed agriculture in the south and west, known as the "coffee–banana farming system" (ILRI, 2007; Kayiso, 1993). Coffee (*Coffea arabica*) is commonly grown in combination with multipurpose shade trees, while stream valleys are often planted with *Eucalyptus* woodlots. On the north and north-eastern slopes extensive maize, potatoes, wheat and pasture dominate (ILRI, 2007), while trees are scarce, especially nearer the park boundary. The western and southwestern slopes of Mt Elgon in Uganda have been among the most densely populated and cultivated in the country since before 1960 (McMaster, 1962). In 2002, human population densities in the surrounding parishes ranged from 150 p/km^2 in the north and northeast to more than 1000 p/km^2 in the west. Average annual population growth rates ranged between 2.5% and 4.3% (UBOS, 2002a,b,c). Two ethnic groups predominate around Mt Elgon in Uganda: The Bagisu, of Bantu origin, in the south and south-west and the Sabiny, of Nilo-Cushtic origin in the north and north-east. Coffee was introduced in 1912 on the north-western slopes of Mt Elgon. The crop helped the agriculturalist Bagisu gain substantial economic and political power and according to Bunker (1987), the region had the second highest per capita income in Uganda in the 1950s. Much of this power was lost during and after the political upheaval of the 1970s and 1980s and many coffee farmers diversified into additional subsistence or cash crops (Bunker, 1987). The Sabiny were originally pastoralists dwelling in both the semi-natural forest grasslands and high altitude moorlands and in the lower northern plains. Since the 1980s, they turned to agriculture for cash, often under the influence of Bagisu or immigrants from the plains. Cattle remain very important (Scott, 1998). Maize was introduced to Uganda before colonial times and it became an important food crop on the northern flanks of Mt Elgon (McMaster, 1962). From 2003, a new murram road from Mbale to Kapchorwa has improved their access to markets, but historically the Sabiny have lagged behind in terms of education, transport, access to agricultural support and credit (Kasfir, 1976). Major local markets for agricultural produce exist in the west, northwest and on the borders with Kenya (see towns in Fig. 1). Transport costs are high as many roads are unusable during heavy rains. Land degradation is a concern and landslides occur regularly on the relatively steep slopes on the Ugandan side of Mt Elgon (Knapen et al., 2006).

2.3. Management history

Uganda's forests were brought under government control from 1929, as colonial powers were concerned that expanding agricultural activities would cause forest loss and damage water catchments (Turyahabwe and Banana, 2008). The management objectives of the forest reserve on Mt Elgon were protection and timber extraction. From 1955, forest clearing started on the north-eastern side of the mountain to establish pine and cypress plantations (Synnott, 1968). A system of resident cultivation attracted neighboring people who settled inside the reserve by the

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northernmost plantation (Government of Uganda, 1996; Luzinda, 2008; Médard, 2006; Scott, 1998). In 1968, forest management in Uganda was centralized and reserve boundaries were officially demarcated (Table 1).

During the years of Idi Amin (1971) and Milton Obote (1978), who took power through successive military coups, there was a general breakdown in national and local forest management institutions. In 1975, in a drive to increase national agricultural production, Idi Amin declared all land public and open for settlement (Hamilton, 1985; Turyahabwe and Banana, 2008). In the plains north of Mt Elgon, cattle raiding activities intensified due to the increased availability of firearms (Otte, 1991; Scott, 1998). This phase of instability lasted until 1986 when peace was restored under President Yoweri Museveni. From 1987 onwards, a conservation and development project and forest restoration projects were implemented on Mt Elgon (Table 1) (UWA, 2000). In 1993 the forest was re-gazetted as a National Park and brought under the management of Uganda National Parks (UNP, now Uganda Wildlife Authority, UWA), except for a small protuberance north of the western arm (Fig. 1). Increasing restrictions on local people led to the disintegration of existing indigenous forest resource management systems and sparked conflict (Scott, 1998). In the early 1990s, UWA policy shifted to include more collaborative and participatory approaches to park management (Hinchley, 2000). From 1999 onwards, agreements between local people and park management in the form of resource use agreements, boundary management agreements and beekeeping agreements were initiated in a number of parishes surrounding the park (Scott, 1998; UWA, 2000). In other places, recurrent evictions created strong tensions between local people and park management (Table 1). In 1983 the Forest Department allocated land to be excised for the resettlement of forest dwelling Sabiny. This area in the north of the reserve is now called the "Benet resettlement area" (Luzinda, 2008; Scott, 1998) (Fig. 1). Lowland Sabiny who had settled on the forest edge to escape cattle raiding from neighboring tribes were also included (Banana and Gombya-Ssebajjwe, 2000; Government of Uganda, 1996). The process suffered from a number of problems. Land was illicitly acquired by members of the land allocation committees, some intended beneficiaries received little or no land while others preferred to stay in the forest (Government of Uganda, 1996; IUCN, 2005; UWA, 2000). The 1993 boundary survey found that 1500 ha more land than planned had been given out. The eviction of settlers from these 1500 ha led to court cases and conflicts between local communities and park management that remain unresolved (Himmelfarb, 2006; Scott, 1998). In the meantime, people live in temporary settlements both inside and outside the contested area (Table 1). Conflicts also occur when politicians promise people land inside the park to gain support. This was exacerbated after multi-party politics were re-established in Uganda in 2005 and competition among candidates increased (Banana et al., 2010).

3. Materials and methods

3.1. Forest cover change

We used Landsat images for February 1973 (MSS), 1988, 2001 (TM) and January 2009 (ETM) (Table B.1). Image dates correspond to the second half of the dry season, when differences between

Table 1
Historical timeline of larger and local scale contexts for forest conservation and management on Mt Elgon in Uganda (sources: Bunker, 1987; Government of Uganda, 1996; Luzinda, 2008; Scott, 1998; Synnott, 1968; Turyahabwe and Banana, 2008).

Dates	National/regional context	Local events
±1910	Coffee introduced as a cash crop by colonial power	Start of Arabica coffee cultivation by the Bagisu on Elgon (northwest)
1929–1951	First national forest policy	Establishment of Mt Elgon Forest Reserve, subsequently: Mt Elgon Crown forest, Central Forest Reserve and Demarcated Protection Reserve
	Afforestation programs for fuelwood outside existing forests Management by the Forest Department	
1955		Forest clearing for plantations in northeast. Resident cultivation system ("Taungya")
1962	Independence from Britain	
1968	Centralization of forest management	Forest Reserve boundary marked Loss of local forest management institutions
1971–1986	Idi Amin–Obote coups, political instability. Withdrawal of foreign funding. Breakdown in forest management institutions	Encroachment into the Forest Reserve Peak in coffee prices
	Dysfunctional coffee buying cooperative All land declared public	Bagisu–Sabiny conflicts Start diversification of cash-crops Intensified cattle raiding from the north
1983		Benet resettlement (> 1000 people)
1986	Museveni president	
1986–1988	Coffee production improvement program.	Raises in coffee prices to producers to reflect world market prices
From 1987	Rehabilitation of the forestry sector. Support for protected area management by international donors	Mt Elgon Conservation and Development Project (MECDP) supported by IUCN
1988	New Uganda forest policy	Start forest rehabilitation, re-establishment of boundaries
1989	Collapse International Coffee Organization (ICO) agreement	Low coffee prices Eviction of settlers near plantations
1992–1995	Liberalization of the Uganda coffee market Coffee price boom on world markets	Eviction of encroachers High local coffee prices
1993	Policy decision to increase the protection status of 5 forest reserves, under (UWA)	Forest Reserve converted to National Park. Boundary survey
1994–2002		Forest restoration project (UWA-FACE) funded through carbon emissions mitigation
1996		Collaborative management pilot projects
2001–2009	New forest policy, decentralization including collaborative forest management	Evictions and temporary resettlement inside the boundary in Benet (± $9km^{2)}$
2004–2005	Rise in coffee-prices	Boundary tracing and conflicts in southwest and south
2006	Multi-party elections and campaigns	Conflicts and encroachment
2008–2009	Increase demand for maize in Kenya and Sudan: prices doubled	Evictions in the north and northeast leading to conflicts. Temporary resettlement inside the boundary in Benet

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Table 2
Forest cover, proportion of forest cover and forest cover change for the study villages.

Village	Forest cover (km^2)				Forest cover (%)				Rate of forest cover change (%/y)		
	1973	1988	2001	2009	1973	1988	2001	2009	1973–1988	1988–2001	2001–2009
1	7.9	5.3	6.2	3.0	79	53	62	30	−1.7	0.7	−3.9
2	21.8	12.4	17.8	7.8	95	54	78	34	−2.7	1.8	−5.5
3	15.3	8.0	11.9	10.3	95	50	74	64	−3.0	1.9	−1.2
4	20.2	10.2	13.0	9.6	97	49	62	46	−3.2	1.0	−2.0
5	17.8	8.2	10.9	12.0	87	40	53	59	−3.2	1.0	0.7
6	16.7	2.7	5.1	5.1	94	15	29	29	−5.3	1.0	0.0
7	8.9	0.6	0.5	1.5	93	6	5	16	−5.8	0.0	1.3
8	7.9	3.6	4.6	4.1	96	44	56	49	−3.5	0.9	−0.8
9	27.9	7.1	17.8	23.6	96	24	61	81	−4.8	2.8	2.5
10	24.7	13.0	11.1	14.8	92	49	41	55	−2.9	−0.6	1.7
11[a]	22.9	20.9	5.4	3.5	96	87	23	14	−0.6	−5.0	−1.0
12[a]	21.8	14.5	14.1	17.7	84	56	54	68	−1.9	−0.1	1.7
13[a]	9.1	0.7	2.5	1.6	52	4	14	9	−3.2	0.8	−0.6
14[a]	27.9	17.0	17.8	19.3	75	46	48	52	−1.9	0.1	0.5

[a] Sabiny dominated villages, the others are Bagisu dominated.

evergreen and seasonal vegetation are greatest. Recurrent cloud cover on Mt Elgon limited the number of useful images and prevented a more frequent time-series. We also used forest boundaries for 1967 (Department of Lands and Surveys, 1967), a vegetation map with data from approximately 1990 (van Heist, 1994), a 90 m digital elevation model (Jarvis et al., 2008) and conducted detailed field surveys in 2009 and 2010.

Image processing was done using the ENVI 4.0 (RSI) software. Each image was co-registered to the 2001 image using Nearest Neighbor resampling with a root mean square error (RMSE) of less than 0.4 pixels (Schowengerdt, 1997). The analysis focused on the Afromontane and the Afromontane Rain Forest Zones inside the protected area boundaries, as defined by van Heist (1994). We will further refer to this area of approximately 860 km^2 as "the forest zone". Clouds and their shadows partly obscured the higher altitudes in the 1988 and 2001 images and were masked out using visual interpretation and classification (e.g. Martinuzzi et al., 2007) (see Appendix B for details). Softwood plantations (near Village 13) were also masked-out and labeled "non-forest". An unsupervised classification on the remainder of each image (Schowengerdt, 1997) helped to identify natural spectral clusters. We then selected training areas using visual interpretation of natural clusters from the unsupervised classification, false color composites of the images and the maps (Foody and Hill, 1996). Finally a supervised classification was run using a Maximum Likelihood Classification algorithm (Schowengerdt, 1997). This resulted in 4–7 classes per image that were combined into two: "forest" (minimum canopy cover of 30%, based on van Heist (1994)) and "non-forest" (see Appendix B for details). Where possible, gaps from clouds and their shadows were filled manually using the 1990 map (1988 image) and Google Earth (2001 image) as references.

We used the 1967 and 1990 forest cover maps, high resolution imagery from Google Earth (2003, 0.5–2.5 m resolution) and field observations as references to validate the accuracies of the four classification maps. We then generated four confusion matrices by allocating either forest or non-forest classes to additional randomly selected sample points on each classification map and its reference (see Appendix B for details). Overall accuracies ranged between 91% and 95%, with kappa coefficients between 0.79 and 0.88 (Table B.2) (Congalton and Green, 1999). Quantity and allocation disagreements following Pontius and Millones (2011) gave values of 5%, 8%, 4% and 1% quantity disagreement for 1973, 1988, 2001 and 2009 respectively, while allocation disagreement was 0%, 1%, 6% and 5%.

3.2. Population data

Using administrative boundaries and population numbers from databases at the International Livestock Research Institute (ILRI, 2007) and Uganda Bureau of Statistics (UBOS, 2002a,b,c), we established GIS layers of administrative boundaries for 1991 and 2002, population data at parish level for 1969, 1991 and 2002, and data on immigrants for 2002. The finest scale for which population data was available was the parish, which usually consists of one to four villages. Between 1969 and 1991 and then 2002, some parishes became sub-counties that were then subdivided into new parishes. For 1969, visual inspection of topographic maps of the 1960s helped match administrative unit names and boundaries between 1969 and 1991. After 1991, subdivisions were more frequent and involved more boundary shifting. Sometimes pieces of former parishes were divided among different new sub-counties or (groups of) parishes. Therefore we calculated population density for 2002 using the area corresponding to the parish boundaries of 1991. In all cases where boundaries had changed, we assumed that the relative population in a parish, within the larger sub-county or a group of parishes, remained constant over time. We then used the 1991 proportions as a basis to estimate population numbers over a corresponding area in other years. This method is also used by the Uganda Bureau of statistics in their population projections. Population density for a parish p in the census year of interest y was then estimated as:

$$P_{p,y} = (P_{p,1991}/P_{s,1991}) \times P_{s,y}$$

With $P_{p,y}$, the unknown population of the parish of interest in year y, $P_{p,\ 1991}$ and $P_{s,\ 1991}$ the known population of the parish and its sub-county in 1991 and $P_{s,\ y}$ the known population of that sub-county in census year y. When possible we used a group of parishes instead of the larger sub-county as a reference.

3.3. Local livelihoods' survey

We collected livelihood-related information from 14 villages around the boundary of the protected area. The sites were spread evenly around the boundary to represent as much variation as possible. Fifteen points were originally located on the boundary line, using a GIS (ArcGIS 10). These were later located in the field using a GPS (Garmin 60CSx). As all villages are settled up to the park boundary each point was always located in a village. That village was identified in the field. The village at point 15 was excluded as the local leader was uncooperative and demanded payment. In

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each village, we applied a range of survey techniques including village meetings with semi-structured discussions collecting basic data on ethnicity, education, wealth, infrastructure, distance to markets, cropping and livestock feeding systems, boundary conflicts, historical changes in land use and collaborative management agreements (McCracken et al., 1988). Scoring exercises were used to gauge and understand people's perceptions on the relative importance of agricultural land and forest (see Sheil and Liswanti, 2006 for a review and discussion of these methods). We conducted the exercise separately with groups of men and women volunteers in each village. Villages identified different land and forest types. For comparison among villages, we aggregated the scores into two classes: agricultural land and forest. Informal conversations with villagers during our stay in each village (3 days) allowed us to cross-reference information gathered during the more formal meetings. We also conducted semi-structured interviews with UWA personnel based at Mt Elgon.

3.4. Data analysis

To analyze changes in forest cover against local population and livelihoods data, their area of influence had to be determined. We drew a 2 km wide zone parallel to the boundary (after excision) inside the protected area. This captured the area where the initial wave of encroachment for agriculture took place in the 1970s and 1980s (Hamilton, 1985 and this study), while at the same time avoiding much of the upslope cloud cover and bamboo areas, which experienced natural death and regrowth during the study periods. All villages around the park boundary are adjacent, and the areas they use in the forest overlap (Scott, 1994). Traditional clan boundaries, corresponding to historical use zones in the forest, did not apply during the land rush that took place during the 1970s and 1980s (villagers, personal communication). As it was not feasible to exactly delimit their area of influence, we assigned each study village an area using the Euclidean allocation tool in ArcGIS 10, which allocated each cell in the buffer zone to the nearest sample point (Fig. 1). Forest cover change is expressed as a net % change between end and base year (positive = net gain, and negative = net loss). The three periods are: 1973–1988, 1988–2001 and 2001–2009. The % change is then converted to an annual rate of change (assuming a simple linear rate). Rate of change (%) in region a:

$$R_a = (100 \times (F_a2 - F_a1)/S_a)/(t_2 - t_1)$$

where F_a1 is the area of forest in region a at time t_1, F_a2, the area of forest in region a at time t_2, S_a the area of region a, t_1 the base year and t_2 the end year of the period. Remaining areas of cloud cover that could not be filled with other images were removed from all dates.

We used inter-battery factor analysis (Tucker, 1958), also known as principal component-based coinertia analysis (Dray et al., 2003) to investigate the relationships between two groups of variables. The first group included the livelihood variables, population density in 1969, population density change between 1969, 1991 and 2002 and scores for forest or agricultural land types. The second group consisted of the forest cover and forest cover change rates. Inter-battery factor analysis was chosen instead of canonical correlation analysis, because of the small number of villages (14) compared with the number of variables (31 + 7). Inter-battery factor analysis searches for normalized linear combinations of the variables in each set, such that their covariance is maximized. The statistical significance of the relationship was tested using Monte Carlo permutation (999 permutations). The results are presented in a biplot with arrows and points for variables and villages (Gabriel, 1982). We focus on the correlations between the two sets of variables – livelihoods and forest cover – and also show the variation of livelihood variables among villages. All variables were standardized to zero mean and unit variance. The analysis and statistical test were carried out using the R-package ade4 (Dray and Dufour, 2007) and the graph was made with Canoco for Windows (ter Braak and Šmilauer, 2002). We tested for differences in forest cover change between villages with and without collaborative management agreements separately using non-parametric Mann–Whitney U tests in the SPSS software package (IBM SPSS 18).

4. Results

4.1. Forest cover change on Mt Elgon, Uganda

In the north and northeast of Mt Elgon around 50 km^2 of forest had already been cleared before 1973, around the plantations and on the northern edge of the reserve (NF–NF in Fig. 3). Between 1973 and 2009, patterns of forest loss and recovery in the protected area varied considerably among locations (Fig. 3). The annual average forest loss and recovery rates for each period are summarized in Fig. 4. During the 1970s and 1980s, more than a quarter of the remaining forest cover in the forest zone was lost, at a rate of almost 12% per year (F–NF in Figs. 3 and 4). Between 1988 and 2001, many formerly-encroached areas on the western side started recovering (NF–F in Fig. 3). Overall annual rates of forest recovery (6%) compensated new losses (4.5%) past the officially mapped 1993-boundary in the Benet resettlement in the north (Figs. 3 and 4). Recovery continued in many places of the northwest and west between 2001 and 2009, but the trend was reversed to the southwest of the mountain. The changes seen on the higher slopes reflected natural bamboo dying and its regeneration (Fig. 3).

4.2. Population, local livelihoods and forest cover

The area cleared under the resettlement exercise is not included in the following results as it is formally outside the protected area (Fig. 1). From here we focus on the 2 km study zone as described in the methods.

Livelihood variables (Appendix C), including population (Table 3) and forest cover and cover change were significantly correlated (permutation test based on inter-battery factor analysis, $p = 0.017$). A biplot (Fig. 5) summarizes the correlations between the livelihood variables and forest cover and cover change, as well as the variation in the livelihood variables among the villages (see also Table 4). The first (horizontal) component represents 57% of the sum of squared correlations and the second (vertical) component 23%, together 80%. The third component is not shown as it adds only 13%. The first component largely characterizes the two main land use systems (Fig. 5): on the left hand side, maize-based villages, for both cash and staple, with pastures and high scores for forest and, on the right hand side, older coffee-based villages, with banana or maize as a main staple and high scores for agricultural land and high population density. Maize-based villages were poorer with a larger proportion of thatched roofs, using mainly pasture and the forest as a source of fodder (Table 4). Villages with coffee as the main cash crop had access to formal credit and were generally wealthier with more metal roofs and planted grass to feed their mainly stall-fed livestock (Table 4). Component two is associated with accessibility expressed by distance to roads and markets, better education and the estimated number of tree species planted in the village (Fig. 5).

In 1973 forest cover was still high even in the densely populated areas on the western and south-western slopes (Table 2, Fig. 5). However, between 1973 and 1988 most forest was cleared near these densely populated, older, wealthier and coffee–(banana)-based villages (Fig. 5). Population increased a great deal in maize-based

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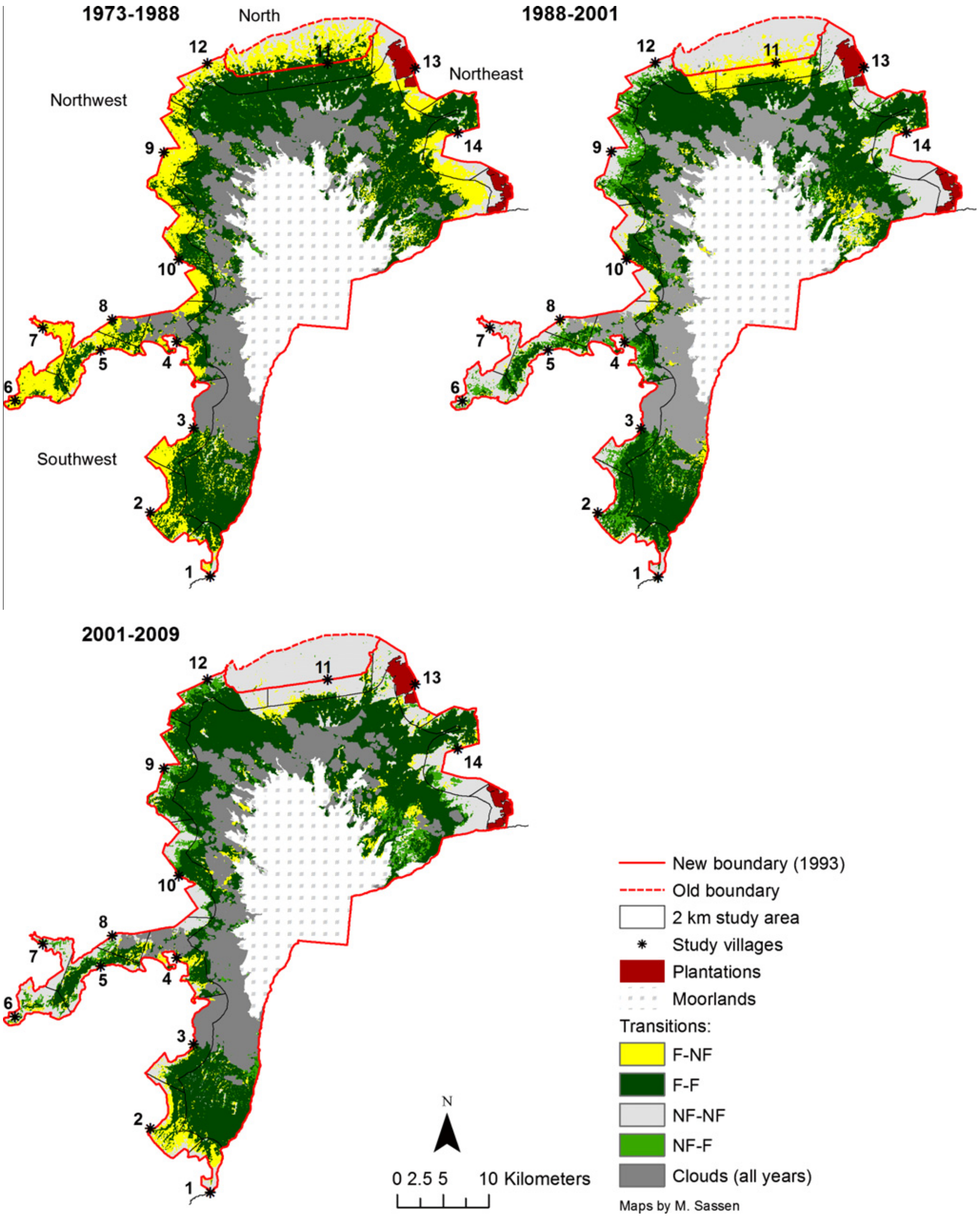

Fig. 3. Forest cover on Mt Elgon, Uganda in 1973, 1988, 2001 and 2009 derived from classification of Landsat satellite images (see text for details and accuracy of the methods employed). Transitions at higher altitudes are related to die-off and regrowth of bamboo areas.

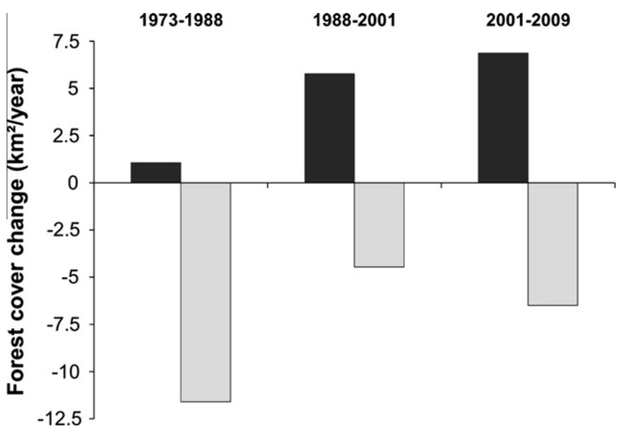

Fig. 4. Annual average rates of forest loss (negative rates) and recovery (positive rates) on Mt Elgon, Uganda during three time periods between 1973 and 2009.

villages during this period (Fig. 5), as immigrants were attracted to the resettlement and plantation areas (Villages 11 and 13) (Table 3). This did not significantly affect forest cover near the still forested resettlement area as loss inside the new boundary was limited (Fig. 5). Between 1988 and 2001 however, population continued to increase in the resettlement area and forest was cleared beyond the intended boundary (Figs. 3 and 5). While in 2001 forest cover had somewhat recovered in coffee- based villages, it was cleared again in the south (Villages 1 till 4) between 2001 and 2009 (Fig. 5). During this period, recovery continued in coffee–banana villages, especially those with more educated people (Fig. 5).

4.3. Collaborative management

Of the 14 study villages, five had a resource use agreement in 2009–2010 (Villages 6 and 9–12). Informants in four of the villages

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Table 3
Population, population density and proportion of immigrants in the parishes where the study villages are located.

Parish	Population numbers			Population density (/km^2)			Immigrants (%)
	1969	1991	2002	1969	1991	2002	2002
1	5415	11420	17126	242	511	766	0.53
2	5167	7317	10127	322	456	631	0.36
3	1922	3293	4444	314	539	727	0.20
4	3058	4398	7967	259	372	673	0.26
5	5165	8093	16145	374	587	1170	0.52
6	2967	5564	8651	247	464	721	0.34
7	4418	9966	18244	316	714	1307	0.87
8	7279	9723	13581	335	448	625	0.61
9	5837	8633	11245	369	546	712	0.77
10	2101	2393	2758	314	358	413	0.26
11	284	5268	16682[a]	10	188	448	2.11
12	1809	2935	4336	211	342	506	0.74
13	781	1998	3082	62	158	244	3.54
14	1194	2277	3575	125	238	374	0.56

[a] The enumeration area for this parish in 2002 is larger than in previous years as it included a new area of temporary resettlement inside the official boundary and data on the split of population between old and new parish boundaries was unavailable. Adding this area and assuming no-one lived there in 1969 and 1991 would reduce population densities in those years by 25% but is not realistic. People were living inside the forest at low densities but not necessarily "counted".

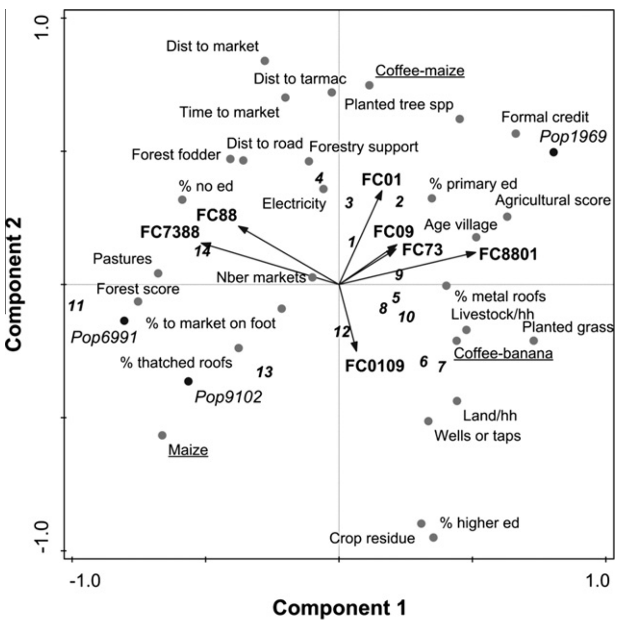

Fig. 5. Results of the co-inertia analysis of livelihoods variables, population and forest cover and cover change with villages (numbers). Forest cover and forest cover change variables are indicated with the abbreviation FC, followed by a shortened year or period indication (e.g. FC73 or FC7388). Population density is indicated with "pop" followed by the year (e.g. pop1969) or the period (e.g. pop0109). In the plot the forest cover arrows point – from their average value – in the direction of their steepest increase and their lengths express the displayed variance in forest cover. Less than average values, in particular negative change (loss) in forest cover between dates can be obtained by extending the arrows beyond the plot origin. The approximate correlation between the variables and forest cover or cover change can be read by projecting the variables onto the line overlaying the FC arrows. The absolute value of the inferred correlation is proportional to the distance of the projection point from the plot origin. The correlation is positive if the projection point is on the same side of the origin as the arrow-head and negative otherwise. The approximate ranking of the values of variables in villages can be read by projecting the villages onto the imaginary line running through the variable point and the origin of the plot. Villages 1–10 are Bagisu and villages 11–14 are Sabiny dominated.

with no agreement said that having an agreement would enable them to access resources without conflict with UWA (village meeting). The main reason cited for not renewing past agreements (Villages 2 and 4) or refusing any form of agreement (Villages 1 and 13) were the villager's own feelings of entitlement to access and their resentment with the park authorities concerning boundary conflicts. Forest recovery near villages with an agreement, tended to be higher (+1%/y on average) than in those without (−1.6%/y on average) ($U = 34$, $n = 13$, $P = 0.045$). We found no significant ($p < 0.05$) relation between the presence of a resource use agreement and the first two components of the inter-battery factor analysis.

Table 4
Values for livelihoods variables per group of villages.

Variables	Coffee		
	Banana ($n = 7$)	Maize ($n = 4$)	Maize ($n = 3$)
Age of the village (years)	148	107	44
% people with a metal roof	0.7	0.9	0.3
Distance to the nearest road (km)	6.2	2.9	6.4
% of people with no education	13.1	19.7	24.3
% of people with secondary or higher education	0.2	0.3	0.1
Average area of land (acres)	1.7	1.3	0.9
Average number of livestock (equivalents)	1.2	1.5	1
Fodder: planted grass	++	+	–
Fodder: forest	+	–	++
Access to formal credit	+	+	–
Number of tree species planted in the village	5.4	4.0	2.0
Forest scores	36.4	36.6	59.5

5. Discussion

In the following discussion we first review the quality of the cover data and analyses. Then we examine how the contexts that characterized each study period influenced how drivers such as population, wealth, market-access and commodity prices impacted on forest cover. Finally, we summarize our findings and their implications for improving conservation effectiveness.

5.1. Forest cover change mapping on Mt Elgon, Uganda

We achieved high overall classification accuracies (91–95%), which was aided by using broad aggregated cover classes (Appendix B). The kappa coefficient has been widely criticized (Foody, 1992; Pontius, 2000). We therefore calculated an alternative classification error measure that combines pixel quantity and quality errors, as proposed by Pontius and Millones (2011). Because we compared net forest cover over time, errors in the location of forested pixels were less important than errors in total quantity of forest at our four image dates. Quantity disagreement between our images and the reference data was small (1–8%). The 1973 and 1988 maps combined the highest quantity disagreement (5% and 8% respectively) and the least allocation disagreement (0% and 1%), which consisted mainly of forest pixels being classified as non-forest. This is because the reference maps for those years had lower resolution (were more "generalized") than the image classification. For the same reason, the user accuracy was lower for non-forest than for forest in 1973 (69%) and 1988 (77%). Any study such as ours, based on widely spaced images from distinct sources, has a limited ability to examine the finer details of landscape change. The study of change dynamics on Mt Elgon would benefit from the use of a more regular time-series, fuzzy sets and continuous mapping instead of discrete classes as used in this study (see e.g. Hartter et al., 2011; Southworth and Gibbes, 2010; Southworth et al., 2004; Woodcock and Gopal, 2000). The extended time intervals between our images likely obscures a more fluctuating and dynamic pattern of forest loss and recovery than we can

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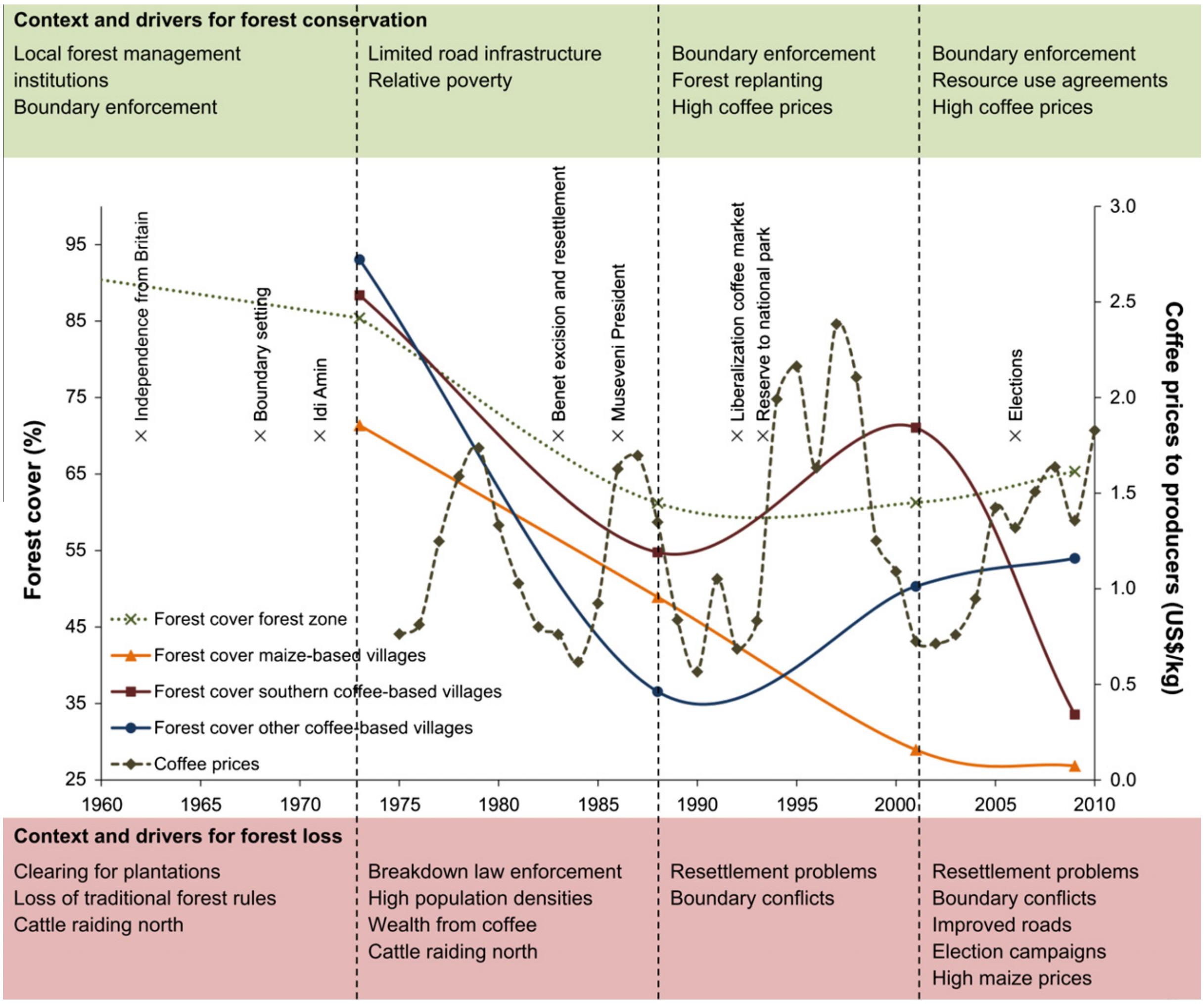

Fig. 6. Forest cover over time in the entire forest zone of the park and in the coffee-based and maize-based study villages (2 km zone) and coffee prices. We separated forest cover for villages in the south to illustrate the difference with other coffee-based villages in the latest period. In the top rectangle are contexts and drivers that contributed to forest conservation in each period, while the lower rectangle lists contexts and incentives for forest clearance. Forest cover prior to 1973 was estimated based on 1967 topographic maps. Coffee prices to growers were corrected for inflation.

observe from our data. Recurrent cloud cover prevented a more frequent time-series. Study areas 3, 4 and 8 were most affected by cloud and cloud shadow cover on deforested areas (Fig. 3), and cloud cover was most important in the 1988 image. This may have caused an underestimation of forest loss in these areas, but it did not affect overall patterns (see Table 2). In all other areas, clouds were concentrated at the upper forest boundary (see e.g. Foody and Hill, 1996 on using ancilliary information to aid classification interpretation). Moreover, the deforestation results (30%) for the first period (1973–1988) of our study are comparable with those found by van Heist (1994), who reported that 28% of the forest on Mt Elgon, Uganda had been encroached by 1989/1990, and Otte (1991), who found that by 1985 30% of the forest on the western slopes had been cleared for agriculture. An overview of the main contexts and factors that affected forest cover during the study periods in the different areas of Mt Elgon is provided in Fig. 6 and discussed below.

5.2. Population, wealth and agricultural expansion

The forest inside the reserve boundary was largely intact on the southern and western sides of the mountain until the mid-1970s, (Otte, 1991; Scott, 1998) (see also Fig. 3). The breakdown in law enforcement of the 1970s and 1980s led to a *de facto* free access to most forests in Uganda and widespread encroachment into forest reserves (Turyahabwe and Banana, 2008). Our data indicates that relatively wealthy people with strong agricultural traditions and high population density were more likely to clear forest for agriculture compared with their neighbors who were poorer and less densely settled (Fig. 5). In an older study, Scott (1994) also found that wealthier, more educated households on Mt Elgon consumed more forest products than poorer households. Moreover, a recent study of 8000 households in 40 sites across the tropics, relating poverty and the environment, suggests that wealth rather than poverty drove faster deforestation (CIFOR, 2011). A combination of other factors added to the drive for agricultural expansion on the western slopes during this period. In 1979, Bagisu who had been progressively migrating into Sabiny areas were violently evicted and on returning to their home areas exacerbated pressure on land (Scott, 1998). Also, despite a rise in prices (Fig 6.), returns from coffee in the early 1980s were poor because of the collapse of the main cooperative (Table 1), which led to a diversification of cropping systems and additional demands for land (Bunker, 1987). Only seasonal crops were planted inside the reserve due to the risk of eviction and crop slashing by UWA (local villagers, 2009, personal communication).

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5.3. Law enforcement and coffee prices

Otte (1991) predicted that Mt Elgon's forests would be entirely cleared by 1990. However, between 1988 and 2001 the forest near densely populated coffee growing areas showed signs of recovery (Fig. 3). Increased law enforcement and the change in status to national park coincided with the coffee-price boom in 1994–1995. Under a liberalized market (Table 1 and Fig. 6), Bussolo et al. (2007) found that in other coffee producing districts in Uganda, gains from the coffee boom helped farmers diversify their agriculture and start other activities that helped them cope with later price drops. In Village 9, local informants said that after eviction, they decided to concentrate on their existing land outside the park, which was made easier because of good returns from coffee (local villagers, 2010, personal communication). Contrary to the previous period, this time high returns from coffee, followed by diversification during a subsequent time of low prices, did not lead to expansion into the protected area. Conversely, law enforcement did not have the same effect in the Benet resettlement scheme where conflicts about the boundary were associated with continued forest loss.

5.4. Commodity markets, collaborative management and elections

From the early 2000s, stiff competition among coffee buyers drove local prices upwards again (Fig. 6). During the same period (2001–2009) coffee growing areas in the southwest (Villages 1 and 2) where forest had previously recovered, now showed important new losses (Table 2). According to local informants in these villages, government-promoted vanilla and chilies replaced coffee when prices went down around 2000 (Fig. 6). They also felt that their coffee bushes were old and unproductive and the proximity of the Kenyan border provided ready markets for seasonal cash crops such as onions and maize (villagers, 2009, personal communication). Increased demand from Sudan and Kenya caused maize prices in Uganda to double between 2008 and 2009 (IFPRI, 2009). In Kenya maize is the main staple but crop failures and political turmoil caused shortages. Although the area near Village 10 has also known long standing boundary conflicts that have precluded any forest recovery (Fig. 3), conflicts between local communities and park management over boundaries were more marked in the south (R. Matanda, Community Conservation Warden Mt Elgon National Park, 2009, personal communication). These conflicts were mainly fueled by political interference during parliamentary election campaigns in 2001 and 2006 (Norgrove and Hulme, 2006 and villagers, 2009, personal communication). The protected area is large – 1120 km^2 and 288 km of boundary – with limited staff (187 armed personnel in 2010, A. Bintoora, Conservation Area Manager, 2010, personal communication) and law enforcement alone cannot stop people encroaching into the park (Norgrove and Hulme, 2006). Interactions between local people and park rangers were often negative, but seemed less so in villages with collaborative management agreements. This was observed by Sletten (2004), local rangers, villagers (2009–2010, personal communication) and M. Sassen (2009–2011, personal observation). We found that study villages with agreements tended to have better forest recovery. Nevertheless, cause and effect are hard to determine as agreements can only be implemented effectively with willing communities. In non-coffee growing areas of the north, people gave high scores to the forest compared with agricultural land, yet forest clearing remained important (Fig. 6). Government decisions to remove people from the forest led to a sense of alienation and to the disappearance of local forest management institutions (Scott, 1998; Turyahabwe and Banana, 2008 and local informants Village 14, 2009, personal communication). Cutting down or burning trees also maintains accessible pasture on the edges of the park (M. Sassen, 2009–2011, personal observation), as people lost access to traditional grazing areas inside the forest when the national park was created. Most villages in the north remain dependent on the forest for wood products because of a lack of alternatives and demand is likely to grow as population is increasing at an average rate of 4.3% per year (Kapchorwa District, 2007). During the most recent study period however, clearing seemed to have slowed (Fig. 6).

5.5. Lessons for conservation and development

Studies in Indonesia have shown negative impacts of rising coffee prices on forest conservation (as in this study's first period) and that effective law enforcement can reduce these impacts (Gaveau et al., 2009; O'Brien and Kinnaird, 2003). With our study we add to the evidence that as long as law enforcement is effective and conflicts with park management are minimized high prices for coffee alone do not lead to forest encroachment. The intensity of conflicts between communities and authorities seems strongly dependent on politics as a process. Banana et al. (2010) identified political interference as a major obstacle to forest conservation in East-Africa. The choice of cash crop by local farmers is strongly dependent on history, national policy incentives and regional market factors. In their study of factors driving Tanzanian farmers to expand into the forest, Angelsen et al. (1999) found that apart from population growth, agricultural product prices explained most of the deforestation in their model. This was particularly the case for non-permanent crops. In southern villages on Elgon, the returns from illegal cultivation of seasonal crops inside the park seemingly outweigh the risk of eviction for some farmers. In these places, people are especially sensitive to (and encouraging for) campaigning politicians, fueling rule defiance and conflicts in their search for local votes. In the traditionally less densely populated areas, changes in agricultural lifestyles and increasing populations lead to new demands for land (Scott, 1998). Efforts to mitigate these effects should come from both from policy and park management (see also Struhsaker et al., 2005). As in our study, a number of recent meta-analyses support the view that collaborative management can benefit local people and improve conservation outcomes (Persha et al., 2011; Porter-Bolland et al., 2011). But conflicts need to be resolved. Attempts by park management to include local politicians in public discussions about conservation with local communities may help to strengthen governance of forest use (A. Bintoora, Conservation Area Manager, 2011, personal communication). A carefully selected combination of incentives for conservation as well as disincentives for encroachment is likely to be most effective. These must be tailored and kept updated to address local contexts and can include measures for the promotion of agroforestry or conservation-related certification or fair trade schemes. The Mount Elgon Regional Conservation and Development Project (MERECP), has recently supported payments to local communities to avoid deforestation and restore forest inside the park (LVBC, 2009). This adds another potential lever with which those concerned with conservation outcomes might seek to improve effectiveness. In the longer term local interventions may be inadequate if wider regional pressures and contexts do not provide sufficient support. In any case conservation outcomes require us to consider a wide range of factors operating at different scales but determining local choices.

6. Conclusions

The role of protected forests as providers of ecosystem services and products is threatened by deforestation and forest degradation. Mt Elgon presents an opportunity to unravel the effects of

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changing political, institutional and socio-economic factors on forest loss and recovery in a protected area over an extended period of time. Protected areas are spatially and socially heterogeneous (see also Nagendra et al., 2010) and population or poverty alone did not explain the patterns we observed. The motivation for people to encroach into a park is dependent on the balance of factors that originate at larger scales, such as policy, commodity prices, law enforcement and political interests. It is the *context* under which underlying *drivers* such as population, wealth and market access operate and influence local drivers, rather than these drivers *per se*, that influences the way they impact forest cover. Even when actively policed, boundaries are easily encroached when other factors allow and even encourage it. Understanding the changing contexts and multiple influences that determine which drivers impact local choices and subsequent forest cover changes in any given time and place will help identify interventions that yield better forest protection, while also supporting local needs and development.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2012.12.003.

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