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Fuelwood collection and its impacts on a protected tropical mountain forest in Uganda

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ABSTRACT

Local communities who live close to protected tropical forests often depend on them for woodfuel, their main source of energy. The impacts of fuelwood extraction in humid forests are rarely studied, yet the extraction of wood for fuel can impact forest structure, function and biodiversity. We assessed the effects of fuelwood collection on the forest of Mt Elgon National Park (Uganda). We interviewed 192 households about fuelwood use and surveyed dead wood in 81 plots inside the park. Forest was the most important source of fuelwood. People collected on average between 1.1 and 2.0 m^3 of fuelwood per capita per year. Other activities involving wood fuel extraction from the forest included illegal commercial fuelwood harvesting and charcoal making. Quantities of dead wood were affected by fuelwood collection up to at least 1000 m inside the boundary of the park. Depletion of dead wood inside the park was greater in the sites where the population was most dense. Nevertheless, people who planted more trees on their own land perceived land outside the park to be important and valued old growth forest less as a source of fuelwood. Highly-preferred tree species were most depleted, particularly when they were also valued timber trees, such as *Prunus africana*, *Popocarpus milianjianus*, *Allophylus abyssinicus* and *Olea* spp. Locally dominant species were less affected. Impacts varied among sites depending on the history of agricultural encroachment and locally-specific forest uses, e.g. harvesting of trees for poles or use of the forest land for grazing. Allowing the collection of dead wood in forests is double-edged as it creates opportunities for other activities that are more damaging. Demand for wood fuel from tropical forests is still likely to grow in the foreseeable future. Our results indicate that the forest may become more degraded as a result, with negative consequences for the people who depend on the forest and for conservation. Research into local ecological and cultural contexts and perceptions concerning costs and benefits can help devise more sustainable management options, including alternative sources of fuel.

1. Introduction

Fuelwood is the main source of energy for cooking and heating in large parts of the world (FAO, 2010). Sub-Saharan Africa is the region with the world's highest average per capita wood fuel consumption (0.69 m^3/year) (Iiyama et al., 2014) and more than 80% of the population rely on wood fuels – firewood and charcoal – for energy. While this percentage is expected to decline, total consumption will likely increase due to population growth (OECD/IEA, 2010). Most fuelwood comes from bush and fallow lands, but forests provide a locally important source where people lack alternatives (Arnold et al., 2003). Small land-holdings and high population densities in many humid tropical areas increase people's dependence on protected areas for wood (Naughton-Treves et al., 2007; Hartter et al., 2011). The extraction of wood for fuel by collecting dead wood or by harvesting trees or their branches, can impact forest structure, function and biodiversity (Ndangalasi et al., 2007). Woody debris plays an important role in forest ecosystems, in nutrient cycling processes and as habitat for a diversity of fauna, plants and other organisms (Duplessis, 1995). Intensive harvesting may lead to forest degradation and loss (Geist and Lambin, 2002).

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New attitudes to tropical forest management call for more devolved approaches to conservation compared with older 'fortress conservation' approaches (Wells and McShane, 2004; Lele et al., 2010). They allow access and use of forest resources by local communities living in the vicinity of protected areas, in exchange for improved forest protection (Vermeulen and Sheil, 2007). There is evidence from sub-Saharan Africa and elsewhere that where local communities participate in forest management this leads to improved environmental outcomes (Persha et al., 2011; MacKenzie et al., 2012). The management of tropical forested protected areas needs to consider both the needs of the surrounding population and the impacts of any forest use (Kaimowitz and Sheil, 2007). Yet, the implications of growing demands for food and energy on tropical forest resources are poorly characterised at local scales where outcomes can vary considerably even under a similar management regime (Sassen et al., 2013). The management of protected areas must balance conservation and human needs making it crucial to understand how various activities impact forests.

This study investigates the patterns, effects and potential management implications of fuelwood extraction on the edges of Mt Elgon National Park a mountain forest in eastern Uganda. In Uganda, more than 85% of households use fuelwood as the main cooking fuel, 98% if charcoal is included (UBOS, 2006). As in other sub-Saharan African countries, pressure on protected forests in Uganda increases due to a combination of population growth, demands for land and expanding industrial and domestic consumption of wood fuels, including charcoal. Remnant natural forests outside reserves or national parks are rapidly decreasing (Naughton-Treves et al., 2007). In this regard, Mt Elgon permits examination of the impacts of fuelwood collection in a protected area with a history of conflict between surrounding populations and conservation actors. No other forest remains in its direct vicinity and conservation outcomes vary considerably around the park boundary (Sassen et al., 2013; Sassen and Sheil, 2013).

In this paper we examine the effects of fuelwood collection and other activities on the availability and distribution of dead wood in Mt Elgon's forest. We consider their relation to historical agricultural encroachment, distance from the park boundary, forest structure and local preferences for fuelwood species. We also investigate the role of alternatives sources of fuel as we expected that many people would depend on the park for fuelwood, but people with alternative fuel sources less so. We hypothesized that preferred species would be most depleted and at greater distances inside the park and that this would impact fuelwood use.

This study is the third in a series of linked studies that examine these forests and their relationship with local people. In a first paper we described the contexts and drivers that led to local variation in forest loss and recovery over recent decades (Sassen et al., 2013). A second paper examined the nature of the resulting forests under different patterns of local use (Sassen and Sheil, 2013).

2. Study area

Mt Elgon is located on the border between Uganda and Kenya. It is a large extinct volcano (4321 m) with generally gentle slopes until 2800–3000 m down from the 8 km wide crater-rim. Below this, slopes are steeper to the south-west while characteristic sheer cliffs drop down to the plains in the north (Fig. 1). Annual precipitation between 1500 and 2000 mm falls year round but peaks in April–May and September–November. Rainfall is higher on the southern and western slopes than on the northern and eastern slopes (Dale, 1940; IUCN, 2005). Mt Elgon is an important water catchment area for several million people in the surrounding districts and for important areas such as the Nile and Victoria Basins (IUCN, 2005). The mountain is covered with a belt of bamboo and afromontane forest at on average between 2000 and 3000 m, followed by heathers and high altitude moorland (Dale, 1940; van Heist, 1994). The forests above 2000 m and the higher altitude vegetation host biodiversity characteristic of the Afromontane Region, with a number of species endemic to Mt Elgon (for details see Davenport et al., 1996; IUCN, 2005).

Mt Elgon's volcanic soils are fertile and in the south and south-west they support an intensive mixed coffee and banana based agriculture (Kayiso, 1993; ILRI, 2007). Coffee (*Coffea arabica*) is the main cash crop and is traditionally grown in combination with bananas and multi-purpose shade-trees, both indigenous and exotic species. *Eucalyptus* woodlots are often planted in stream valleys. People have been settled and cultivating the slopes since around 1500 AD. In the north and northeast, agriculture is practiced on larger plots of maize, potatoes, wheat and pasture (ILRI, 2007). In this area, people started practicing agriculture from the 1980s, when they were resettled down from the higher slopes of the mountain and from the insecure lower plains to the North.

Uganda's protected forests were widely encroached during a period of political instability that lasted from 1971 until 1986 (Hamilton, 1985; Turyahabwe and Banana, 2008). Since 1987, forest restoration activities were started in the worst affected areas on the western slopes (UWA, 2000), with mixed success. In later years new forest clearing took place in different areas of the park (Sassen et al., 2013). When Mt Elgon was gazetted a national park in 1993, local communities lost all legal access rights (Scott, 1998). Since the late 1990s park management has initiated resource use agreements with local communities living next to the park (at parish level) that allow regulated collection of a limited number of non-timber products, fallen dead wood and stems from certain shrub species (e.g. *Vernonia* spp.) to support crops like bananas and climbing beans (UWA, 2000). Cattle grazing, tree-cutting, charcoal burning and hunting are illegal but widespread (Norgrove, 2002; Sassen and Sheil, 2013). Whether or not a community living next to the park has entered into such an agreement depends strongly on the level of conflict with the park management about park boundaries and access for cattle grazing (Sassen et al., 2013). In areas without agreements some uses, including dead wood collection, are sometimes tolerated on an *ad-hoc* basis in an effort by local rangers to minimize conflicts. Dependence on forest products remains important (Katto, 2004). This is unlikely to decrease in the near future as population densities continue to grow and increase local demands for wood. No natural forests remain within 20 km around the protected area (Sassen et al., 2013). In 2002, human population densities in the parishes surrounding Mt Elgon ranged from 150 p/km^2 in the north 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).

3. Methods

3.1. Field data

We collected data in four contrasting sites situated along the northern and western boundaries of Mt Elgon National Park, to represent different elevations, forest types and forest cover change histories (Sites 2, 9, 11 and 14, Fig. 1, Table 1). Forest cover change on Mt Elgon is strongly related to its history of recurrent agricultural encroachment (Sassen et al., 2013). Sites 2 and 9 have a long history of clearing for agriculture inside the park, with more (Site 9) or less (Site 2) successful forest restoration efforts. In Sites 11 and 14 most forest clearing for agriculture started after the establishment of the park. Each site corresponded to a sample village (Sassen and Sheil, 2013) (Table 1).

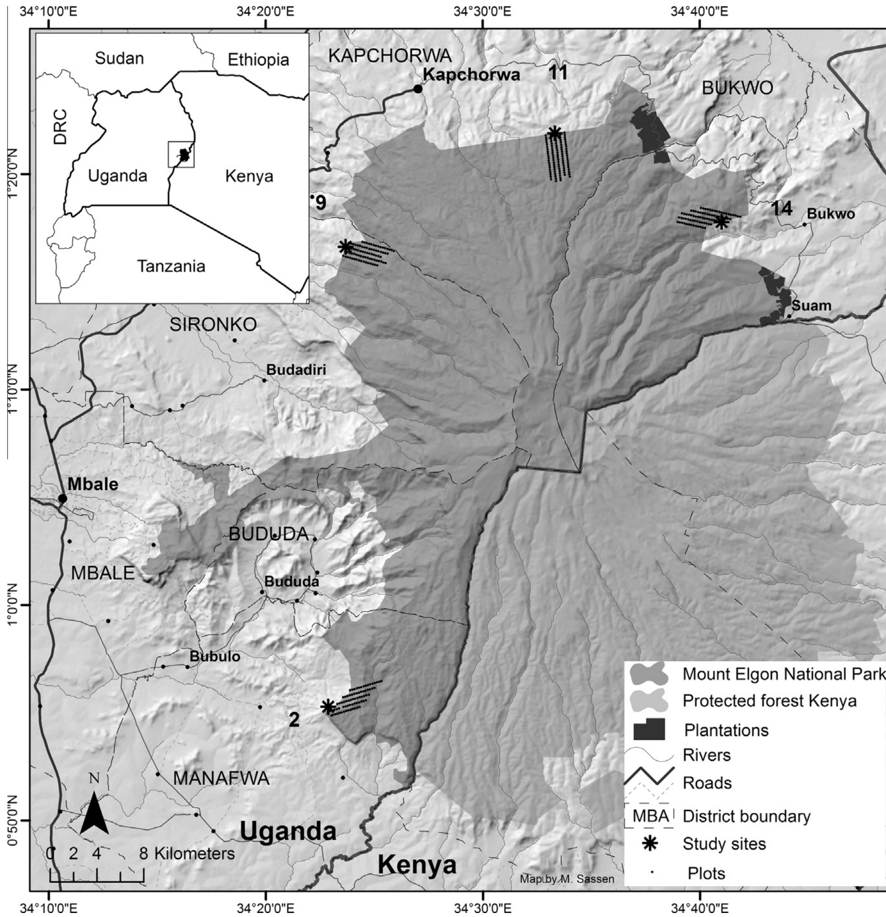

Fig. 1. Map of Mt Elgon with the study sites (administrative division boundaries valid in 2010).

Table 1
Characteristics of the study sites.

	Site 2	Site 9	Site 11	Site 14
Village (2011)	Bukuwa	Kinyofu/ Gibuzale	Korto/ Kamatelon	Sindet/ Kapsata
Sub-county (2011)	Bupoto	Masira	Kwosir	Kortek
Population density 2002[a]	631 p km^{-1}	712 p km^{-1}	448 p km^{-1}	374 p km^{-1}
Dominant ethnic group	Bagisu	Bagisu	Sabiny	Sabiny
HH interviewed (% of total)	53 (77%)	45 (45%)	51 (63%)	43 (66%)
Mean household size	4.7	5.2	5.6	5.8
Mean land holding (acre)[b]	1.5	0.9	0.9	0.8
Mean number of trees (/HH)	33.3	27.3	3	8.2
Livestock system	Zero-grazing	Zero-grazing	Pasture	Pasture
Resource use agreement	No	Yes	No	No
Forest restoration 1990s	++	+	–	–
Field plots	17	20	25	19
Elevation plots in masl	1911–2318	2152–2606	2478–2877	2238–2699

[a] UBOS (2002a,b,c).
[b] Including rented land.

In each site, we first laid out one transect perpendicular to the general orientation of the boundary, and then two parallel transects 400 m apart on each side (Fig. 1). We measured dead wood volumes on plots 50 m, 850 m, 1850 m, 2850 m and when possible 3850 m along the transects. Due to irregular shape of the boundary, this translated to different actual distances from the boundary. Actual distance to the boundary for each plot was calculated using a GIS. We used a handheld GPS (Garmin 60CSx) to determine plot position and orientation along the transect line. On each transect line we measured between 3 and 4 plots (15–21 per site, 81 in total), depending on travel time between plots which was influenced by terrain (e.g. obstacles) and vegetation.

We adapted methods for assessing woody debris from Harmon and Sexton (1996). We established three 16 m sampling lines from the centre of each plot to record dead wood using a line intercept method (diameter at intercept, decay class for larger pieces, count for smaller ones). The first line was oriented East and the other two at 135° and 225° anticlockwise. We recorded woody debris lying or hanging <2 m from the ground. For each coarse woody debris (⩾5.1 cm diam.) crossing the sampling lines we measured the diameter at line intercept and recorded the decay class as follows: class 1: solid wood, recently fallen, with bark still intact, cannot push a nail into the wood by hand; class 2: solid wood with >50% bark still intact, can push a nail into the wood by hand to a maximum of 0.5 cm; class 3: less-solid wood, especially the outer layer, but with deeper layers still hard, bark <50% intact, a nail can be pushed into the wood by hand more than 0.5 cm; rotten: soft, rotten wood, no bark, a metal nail can be pushed into the wood easily or it collapses when stepped on. We tallied smaller pieces (1–5 cm) on sampling line segments of 5 m long (starting from the centre). Only non-rotten pieces of wood were counted.

In an assessment of forest structure we recorded the basal area of standing live and dead trees (taller than 1.30 m at dbh) in 343 plots using angle count sampling, and measured stem density in 81 plots (Sassen and Sheil, 2013). The same plot-centres were used for the assessment of standing trees and dead wood. In each plot we recorded terrain, vegetation cover, signs of disturbance and history of encroachment. With the help of local informants, we classified each plot into one of the following categories: c1 = not cultivated within living memory (also called 'old-growth forest'), c2 = cleared in the 1970s and 1980s but now recovering, c3 = cleared in the 1990s and 2000s but now recovering, c4 = currently cleared and cultivated or grazed (2011).

Species were identified by local informants and two knowledgeable rangers (one of each local ethnic background). We cross-referenced the names of standing trees with available references (Hamilton, 1991; Katende et al., 2000). Photographs of unknown species were taken to the Institute for Tropical Forest Conservation (ITFC), Uganda, for identification. Surrounding trees aided identification of woody debris that were harder to recognize, but decay hindered identification.

3.2. Data on firewood collection and use

In each site, we conducted semi-structured interviews within the sample village and the neighbouring village that most corresponded to the boundary section intersected by the five transects. We aimed to interview half of the households in each study site. Final numbers depended on time available in the field (Table 1). The interviewed households were selected by randomly drawing names from a list established with the help of village leaders. Respondents provided information on land ownership, frequency, quantities and location of fuelwood collection, preferred and used species, perceived changes in the availability of fuelwood and numbers and species of trees and large shrubs on their own land.

We considered different sources of fuelwood: "Old forest" was defined as forest that was never cleared for cultivation within living memory but still accessed for other uses such as fuelwood, crop stakes, herbs and vegetables and to reach bamboo or grazing areas deeper into the forest. "Formerly encroached forest" included areas that had been cleared at some point in the past (from the 1970s onwards) and that were in various stages of recovery at the time of this study. "Own land" was defined as land owned, rented or otherwise occupied by people. In sites with on-going encroachment, this sometimes included land inside the official boundary of the park. Fuelwood from the market was usually purchased within the parish or neighbouring parishes, collected from either the forest or from planted trees (*Eucalyptus* sp.).

The Uganda Wildlife Authority defines a back- or headload as a bundle that people can carry on their backs or heads in one haul. We use headload as a standard term from here-on. We asked people to estimate the number of headloads they collected per week and per source area. All members of households collect firewood, but women do the majority. Headload size varies somewhat among men, women and children. We use an average here. We measured 22 loads of fuelwood carried by people coming out of the forest in Site 9 on resource collection days. In the other sites this was more difficult because people did not have a resource use agreement with UWA and therefore fuelwood collection was formally prohibited.

3.3. Data analysis

We used a conservative approach to estimate the volumes of fuelwood collected per household per year. We did not include fuelwood reportedly collected from people's own land because we observed that people tended to collect pieces or bundles on a more *ad hoc* basis from there. Reported loads of fuelwood from the forest and from markets were more likely to be consistent in size with the headloads we measured. We also did not include fuelwood bought from markets to avoid double counting with wood that people collected from the forest and then sold. It was not possible to get figures for quantities sold. People were more willing to say that they bought fuelwood than that they collected fuelwood for sale, as this was illegal. For the conversion of the volume of a bundle of fuelwood to a solid volume measure, we used a conservative average conversion measure of 0.37 (FAO, 1983).

The relative score for preferred or used species consisted of the sum of the scores (inverse of rank) that a species received from each respondent divided by the total score for all species in that site. We compared the lists of the five most preferred and the five most used species in each site, hypothesizing that discrepancies between the lists indicate depletion due to overharvesting or difficulties of access.

We calculated the volumes of dead wood following Harmon and Sexton (1996), and the volume of standing dead trees using dbh and height and a form factor of 0.5. We explored the correlations between volumes of dead wood and encroachment, distance into the park and measures of forest structure. We assessed differences in the impacts of harvesting (for fuelwood but also other uses) on preferred species and on the species people reportedly actually used by comparing their relative basal area. Data analysis was carried-out using SPSS version 18.0 (SPSS Inc., Chicago IL).

4. Results

4.1. Fuelwood collection and use

The park – old growth forest and regenerating areas combined – supplied the largest quantities of fuelwood, followed by markets (Table 2). The average volume of a measured headload of fuelwood was 0.14 m^3 ($N = 25$), which translated into an average solid volume of 0.05 m^3 (±0.003, 96% confidence interval) per headload. Taking household sizes into consideration implies that people collected on average between 1.1 and 2.0 m^3 of solid fuelwood per capita per year (Table 2). The number of bundles that people reportedly collected per week was not significantly correlated with the size of the household (Kendall's tau-b = −0.12, $p = 0.825$, $n = 192$) or the area of land owned (Kendall's tau-b = 0.19, $p = 0.754$, $n = 177$). Larger households tended to own more land and households in the Sabiny-dominated sites (Sites 11 and 14) were larger than those in the Bagisu-dominated sites (Sites 2 and 9), but the area of land owned did not differ between ethnic groups (data not presented). In all households the primary use of fuelwood was cooking (Table 2). Some sale of fuelwood was reported in all sites.

4.2. Sources of fuelwood

In all four sites local respondents considered forest – in particular old growth forest –the most important source of fuelwood (Table 3). In Site 2, 85% of the respondents also reported buying fuelwood, at least occasionally. In Site 9, 69% and in Site 11, 43% of people sometimes bought fuelwood, whereas all fuelwood in Site 14 reportedly came from the forest; although two people in this site also listed regenerating areas as a primary source (Table 2). In Site 2 and 9, respectively 60% and 51% of the respondents collected fuelwood from their own land (Table 3).

The 192 households we interviewed reported a total 51 (39 native) species of trees and shrubs on their own land. The mean number of stems per household was lowest in Site 11 (less than 3 stems/HH) and highest in Site 2 (more than 33 stems/HH or 31 stems/HH when not counting tree-like shrubs such as *Ricinus communis* and *Vernonia* spp.). Households in Site 2 and 9 reported a

Table 2
Average estimated number of head-loads of fuelwood used per household per week from different sources, volume and reported use.

Site	Source (headloads per HH)					Volume		Use (% HH)			
	Old forest	Form. encr[a]	Own land	Market	Total	Per HH $m^3\ y^{-1}$	Per capita $m^3\ y^{-1}$	Cook	Heat	Brew	Sale
2	2.2	1.4	0.9	1.6	6.1	9.5 (±9.5)	2.0	100	0	4	13
9	1.8	1.4	0.6	1.0	4.8	8.4 (±3.7)	1.6	100	0	11	7
11	2.4	0.0	0.1	1.6	4.1	6.3 (±4.4)	1.1	100	2	6	6
14	3.2	0.0	0.0	0.0	3.2	8.3 (±4.9)	1.4	100	0	0	5

[a] Formerly encroached land inside the park.

Table 3
Ranks given to different sources of fuelwood per site (% households).

Site	Old forest		Form. encr.[a]		Own land			Market			
	1st	2nd	1st	2nd	1st	2nd	3rd	1st	2nd	3rd	4th
2	74	2	4	45	13	21	26	9	13	38	25
9	80	16	18	51	2	16	33	2	11	29	22
11	98	0	0	0	2	8	0	0	43	8	0
14	93	0	5	0	0	0	0	0	0	0	0

[a] Formerly encroached land inside the park.

greater variety of species and more trees on average than in Sites 11 and 14. Exotic species were the most common species at all sites, but were especially dominant at Sites 11 and 14 (Table 4).

Overall, the importance – in rank, frequency and for quantities – that households gave their own land as a source of fuelwood was positively correlated with the number of trees they had on their own land and the amount of land they owned. The correlation results for the number of trees were respectively for rank, frequency and quantities: Kendall's tau-b = 0.465, 0.415 and 0.444, $n = 192$, $p < 0.001$. The correlations for the area of land were respectively for rank, frequency and quantities: Kendall's tau-b = 0.289, 0.247 and 0.248 $n = 177$, $p < 0.001$. The correlations between the density of trees on people's land and the importance of various sources of fuelwood were similar although there were variations within sites which are reported in Appendix A.

Combining all sites, the importance – in terms of frequency and for quantity – of old growth forest was significantly negatively correlated with the number of trees people had on their own land, although the correlation was weak. The correlation results were respectively for rank, frequency and quantities: Kendall's tau-b = −0.095 with $p = 0.120$, -0.125 with $p = 0.035$ and −0.135 with $p = 0.017$, $n = 192$ (details per site in Appendix A). The importance of formerly encroached forest was also positively correlated with the number of trees that households report they had on their own land although the correlation was less strong than for "own land" (respectively for rank, frequency and quantities: Kendall's tau-b = 0.240, 0.295 and 0.286, $n = 192$, $p < 0.001$ for all). Households with more land had more trees on that land (Kendall's tau-b = 0.233, $n = 177$, $p < 0.001$), but not always a higher tree density (Kendall's tau-b = −0.050, $n = 169$, $p = 0.400$).

4.3. Woody debris

4.3.1. Quantities of woody debris

Mean volumes of dead wood per hectare were smallest in Site 11. The largest volumes of dead wood occurred in old-growth forest, followed by long-recovered areas and the smallest volumes in the most recently-encroached lands (Fig. 2).

Table 4
Mean number of tree species reported per site, percentage of households (HH) with trees on their land (minimum 1 stem), mean number of trees per household (bold in table) and maximum number of stems listed by one household. For the five most frequently reported species per household: percentage of households listing the species, mean number of stems and range. All can be used for fuelwood.

	Species	Proportion of households (%)	Mean number stems per HH	Maximum number of stems
Site 2	**All (3.98 ± 2.54 species)**	**87**	**33.25**	**178**
$n = 53$	*Eucalyptus* sp.	51	16.98	100
	Markhamia platycalyx	16	5.21	50
	Cordia africana	6	1.83	12
	Persea americana	5	1.74	18
	Vernonia auriculifera	4	1.21	40
Site 9	**All (4.51 ± 2.46 species)**	**93**	**27.29**	**155**
$n = 45$	*Eucalyptus* sp.	47	13.11	100
	Persea americana	15	4.07	20
	Markhamia platycalyx	8	2.22	30
	Eriobotrya japonica	6	1.78	10
	Ehretia cymosa	4	1.13	20
Site 11	**All (0.65 ± 0.90 species)**	**43**	**2.96**	**40**
$n = 51$	*Eucalyptus* sp.	53	1.57	40
	Allophylus abyssinicus	17	0.49	10
	Cornus volkensii	10	0.29	10
	Grevillea robusta	6	0.18	6
	Dombeya goetzenii	4	0.12	4
Site 14[a]	**All (0.56 ± 0.63 species)**	**49**	**8.16**	**70**
$n = 46$	*Eucalyptus* sp.	95	7.79	70
	Grevillea robusta	3	0.21	5
	Ekebergia capensis	1	0.09	4
	Persea americana	1	0.07	3

[a] In Site 14 only four species were reported.

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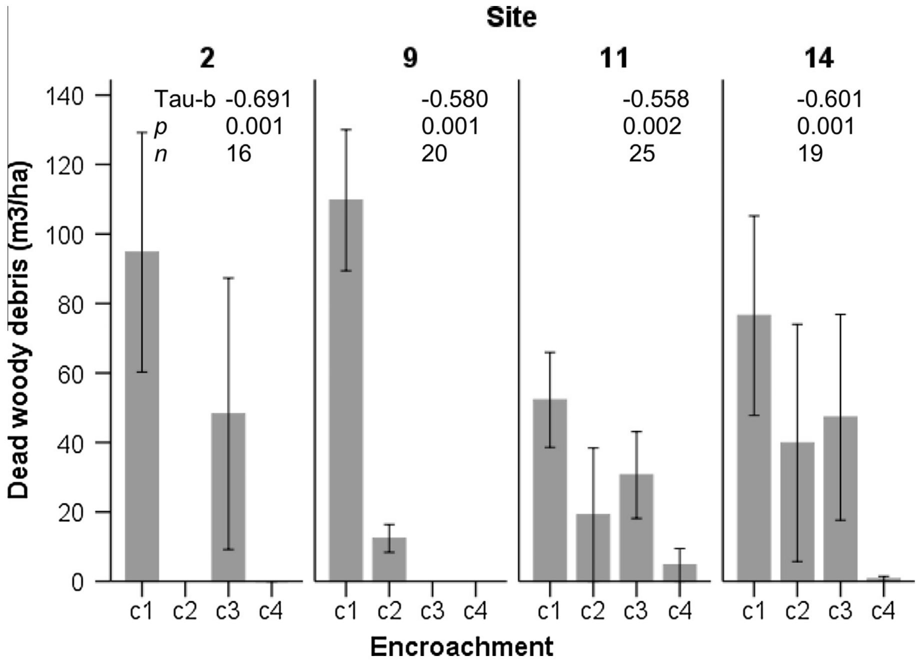

Fig. 2. Mean total dead wood volume (±1 standard error) per site and per encroachment category: c1 = never cultivated, c2 = cleared in the 1970s and 1980s now recovering, c3 = cleared in the 1990s and 2000s now recovering, c4 = currently cleared and cultivated (2011). Kendall's tau-b correlation results are given for each site.

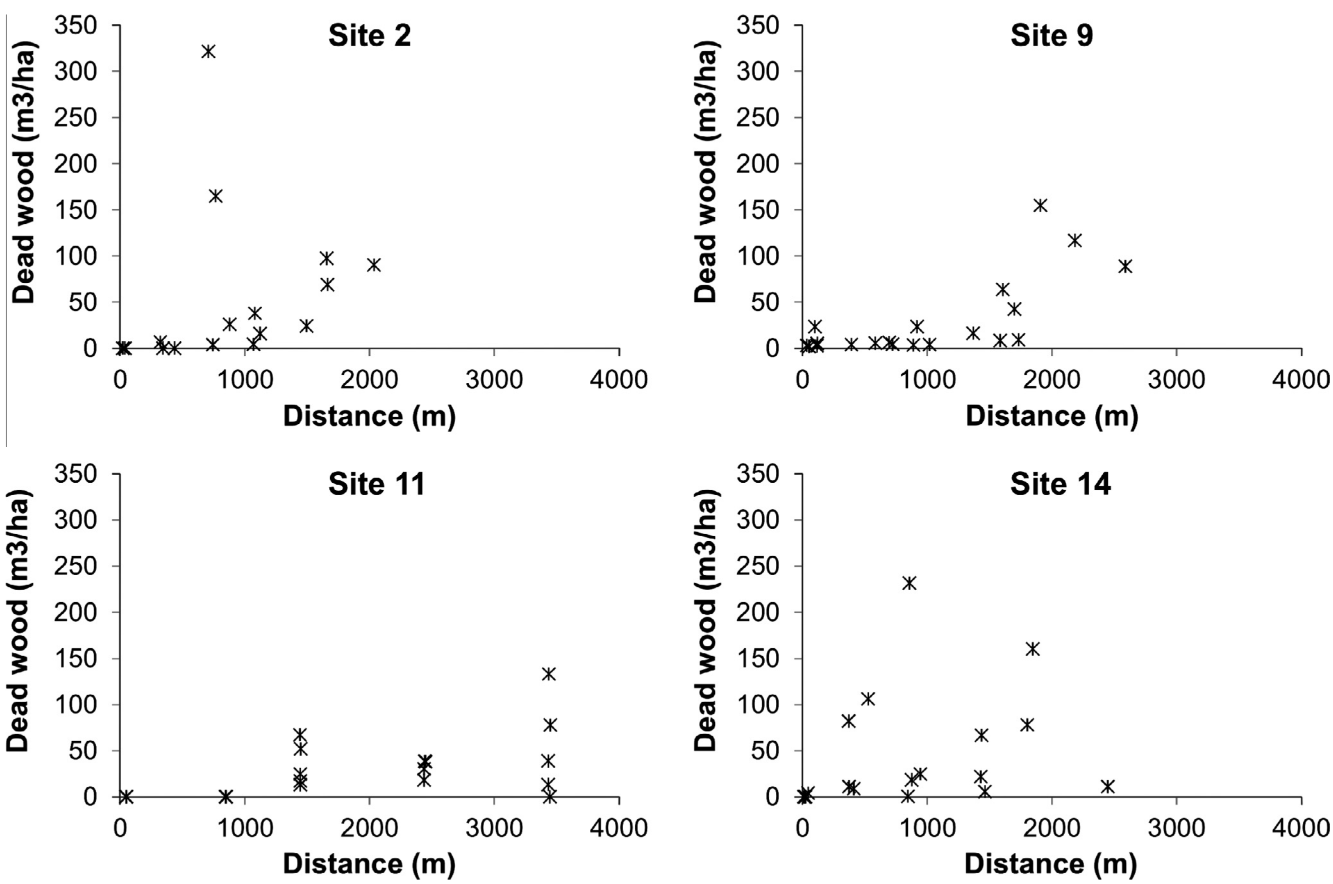

Fig. 3. Volume of dead wood per ha with distance from the boundary in the four study sites. Note: In Site 3 two large fallen *Aningeria* spp. in resulted in high values in two plots at around 800 m from the boundary.

Volumes of dead wood per plot generally increased with greater distance into the park (Fig. 3). Total dead wood volume per plot was positively correlated with distance inside the park boundary, live tree basal area and tree density in all sites (Kendall's tau-b = 0.449, 0.520 and 0.425 respectively for distance, BA and stem density, $n = 81$, $p < 0.001$ for all sites combined). Overall, the volume of woody debris was neither correlated with slope (Kendall's tau-b = 0.009, $p = 0.913$, $n = 80$) nor elevation (Kendall's

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tau-b = 0.103, $p = 0.184$, $n = 81$) although there were variations among sites (details in Appendix B).

Woody debris that originated from human activities varied between 1% and 18% of all recorded LWD. The highest proportion of debris that showed signs of manual cutting was found in Site 9 (Table 5).

4.3.2. Suitability of woody debris for fuel

Around 25% of woody debris in Sites 9 and 11 showed no signs of decay. In Sites 2 and 14 this was 40% or more (Table 5). The proportion of dead wood suitable to use as fuelwood according to local informants varied between 54% and 87%, with the rest being too rotten. We found the smallest proportion of rotten wood in Sites 9 and 14, where people were also the least selective in terms of fuelwood quality: almost all pieces of wood in decay class 3 were still considered usable as fuelwood (Table 5). In Site 11 only one third of wood in decay class 3 was considered suitable as fuelwood.

4.4. Impacts of fuelwood collection on preferred species

4.4.1. Preferred and used species

The number of different species listed in the 'top 5 preferred species' by the different households ranged from 39 in Site 2 ($N = 53$) to 15 in Site 14 ($N = 43$). Sites 9 (26 species; $N = 45$) and 11 (17 species; $N = 51$) were intermediate.

Certain species were consistently given high ranks by most households in a site, such as *Prunus africana* (listed by 64%, 89%, 84% and 79% of all households in Sites 2, 9, 11 and 14 respectively), *Cornus volkensii* and *Olea chrysophylla* (both listed by 76% of the households in Site 11) and *Allophylus abyssinicus* (listed by 69% and 93% of households in Sites 11 and 14 respectively). In Sites 2 and 9, respectively, at least 57% and 67% of the households listed each of the top two preferred species while the other three were listed by between 32% and 44% of the households. In Sites 11 and 14 the species in the top five preferred species were listed by at least 55% and the top 3 by at least 76% of the households. Not all listed species were forest species (Table 6). For example in Site 2, *Eucalyptus* sp. was listed among the top five of preferred species by 36% of the households (detail in Appendix C). In Sites 11 and 14 the list of the five most preferred and the five most used species had more names in common than in Sites 2 and 9 (Table 6).

4.4.2. Basal area and dead wood of preferred and used species

The basal area of the five most highly preferred and used forest species decreased with distance from inside the park towards the boundary (Fig. 4). Certain species were almost completely depleted within the distance range of our study, e.g. *P. africana* and *Croton* spp. in Site 2. Many highly preferred forest species that had small actual (Fig. 4) and relative (Table 6) basal area were not in the top five of most used species in that site, except for example *O. chrysophylla* and *A. abyssinicus* in Site 11. The basal area of locally dominant species that were also highly preferred or used – such as *Hagenia abyssinica*, *Neoboutonia macrocalyx* (Site 9), *C. volkensii* (Site 11) and *A. abyssinicus* (Site 14) – was generally relatively high, although they were all depleted near the boundary (Fig. 4). Less dominant species had relatively low basal areas, including some preferred species such as *A. abyssinicus* and *O. chrysophylla* in Site 11 and *Croton* spp. in Site 14, but also others such as *Markhamia platycalyx* in Site 2 and *Olea welwitschii* in Site 9 (Table 6, Fig. 4a).

Woody debris remained unidentified in 5%, 8%, 9% and 4% of the cases in Sites 2, 9, 11 and 14 respectively (see volume equivalents under Table 5). The tree species for which we found the largest quantities of dead wood and those for which we found the highest relative basal areas were similar in most sites. Dead wood was most abundant for the dominant species in their respective sites (Table 5) and completely absent for others, such as for the preferred forest species *P. africana* and *Croton* spp. in Site 2. For others, such as *O. chrysophylla* in Site 11, we found only stumps (volumes of dead wood per species with distance into the park in Appendix D).

5. Discussion

First, we discuss the intensity of fuelwood collection on Mt Elgon and then the importance of the forest as a source of fuelwood. We then reflect on how fuelwood collection has affected the availability of woody debris and the tree species composition in the four study sites. In our analyses, we considered availability, location and preferences. Finally, we consider the likely implications of future demands for fuel and discuss options to address these impacts as well as needs for further research.

5.1. Fuelwood collection and use

Fuelwood collection on Mt Elgon appears more intense than in other forests in the region. The volume of 0.05 m^3 per headload we estimated was greater than the standard 0.03 m^3 used elsewhere in Uganda (Banana and Turiho-habwe, 1999). We calculated yearly quantities that were almost double the 4.5 m^3 per household or the 0.6–0.7 m^3 per capita found near Budongo forest in Uganda (see Table 2). In Rwanda, Ndayambaje and Mohren (2011) report a per capita consumption of 0.91 $m^3\,y^{-1}$, while in a moist semi-deciduous forest in Ghana Osei (1993) reports a per capita use of between 1 and 1.2 m^3 per year. If we used the standard size of 0.03 m^3, then fuelwood collection (3.8–5.7 $m^3\,y^{-1}$ per household) would be more consistent with the averages reported in Budongo (Banana and Turiho-habwe, 1999). The official allowance per household under resource use agreements was one headload twice per week but reported collection was 50% higher in most sites (Table 2).

Other studies examined fuelwood *consumed* by households whereas we investigated the fuelwood *collected*. It is common for people, women mostly, to sell fuelwood when cash is needed, which likely contributes to the relatively high collection values. Other contributing factors may include the strong reliance on beans and bananas, which are a staple in Sites 2 and 9, and require

Table 5
Percentages of rotten wood and large woody debris (LWD) that was considered suitable for fuelwood per decay class and proportion cut by people.

Site	Mean volume per decay class ($m^3\,ha^{-1}$) and %				LWD suitable as fuelwood per decay class (% of volume found)			LWD cut by people (% of pieces found)
	1	2	3	Rotten	All	1 and 2	3	
2	22 (48%)	4 (8%)	10 (21%)	10 (22%)	64[a]	96	48	1
9	6 (25%)	7 (30%)	9 (34%)	3 (11%)	87	98	98	18
11	4 (23%)	4 (24%)	6 (33%)	3 (20%)	54	91	33	12
14	15 (40%)	10 (26%)	8 (22%)	4 (11%)	87	99	96	5

[a] In Site 14 class 2 included some burnt LWD.

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Table 6
Relative scores of preferred and used species from household interviews and relative volumes of dead wood for the species found in the forest survey (unidentified species omitted, see notes).

Site	Preferred species	Score (%)	% of total BA	Used species	Score (%)	% of total BA	Dead wood found	% Vol/ha	% of total BA	Trees found	% of total BA
2	*Prunus africana*	16.6	1.5	*Eucalyptus* sp.	20.2		*Aningeria* spp.	60	2.9	*Neoboutonia macrocalyx*	27.53
	Aningeria spp.	13.3	6.1	*Vernonia auriculifera*	11.2		*Neoboutonia macrocalyx*	16	27.5	*Macaranga kilimandscharica*	17.37
	Eucalyptus sp.	9.5	0.0	*Markhamia platycalyx*	10.6	0.2	*Syzygium guineense*	8	4.1	*Tabernaemontana holstii*	12.80
	Croton spp.	8.1	0.2	*Cordia africana*	9.3	0.0	*Macaranga kilimandscharica*	6	17.4	*Syzygium guineense*	4.11
	Vernonia auriculifera	7.3		Maize stems/cobs	6.3		*Mimulopsis arborea*	5[a]		*Strombosia scheffleri*	3.31
9	*Prunus africana*	21.5	1.5	*Vernonia auriculifera*	27.9		*Syzygium guineense*[b]	27	6.6	*Neoboutonia macrocalyx*	26.85
	Podocarpus milianjianus	16.7	1.4	*Hagenia abyssinica*	12.6	20.5	*Prunus africana*	18	1.5	*Hagenia abyssinica*	20.31
	Allophylus abyssinicus	9.3	4.0	*Neoboutonia macrocalyx*	12.3	27.1	*Podocarpus milianjianus*	17	1.4	*Macaranga kilimandscharica*	8.92
	Hagenia abyssinica	8.3	20.5	*Maesa lanceolata*	11.6	4.8	*Neoboutonia macrocalyx*	15	26.9	*Syzygium guineense*	6.64
	Olea welwitschii	6.8	0.5	*Mimulopsis arborea*	10.6		*Hagenia abyssinica*	10	20.3	*Schefflera volkensii*	5.24
11	*Cornus volkensii*	18.2	59.7	*Cornus volkensii*	17.7	59.7	*Cornus volkensii*	44	59.7	*Cornus volkensii*	59.69
	Olea chrysophylla	16.8	0.9	*Olea chrysophylla*	15.3	0.9	*Allophylus abyssinicus*	14[c]	0.9	*Podocarpus milianjianus*	10.12
	Prunus africana	16.0	5.2	*Allophylus abyssinicus*	15.0	0.9	*Prunus africana*	13	5.2	*Schefflera volkensii*	7.61
	Allophylus abyssinicus	15.4	0.9	*Prunus africana*	15.0	5.2	*Dombeya goetzenii*	10	1.6	*Hagenia abyssinica*	6.01
	Podocarpus milianjianus	11.4	10.1	*Podocarpus milianjianus*	10.5	10.1	*Rapanea melanophloeos*	7	3.2	*Prunus africana*	5.16
14	*Prunus africana*	18.5	2.8	*Vernonia* spp.	28.3		*Allophylus abyssinicus*	37	26.1	*Allophylus abyssinicus*	26.05
	Allophylus abyssinicus	17.8	26.1	*Solanum* sp.	22.7		*Olea welwitschii*	25	0.8	*Neoboutonia macrocalyx*	19.45
	Vernonia sp.	13.3		*Prunus africana*	10.9	2.8	*Neoboutonia macrocalyx*	16	19.4	*Hagenia abyssinica*	7.45
	Croton spp.	12.9	2.7	*Allophylus abyssinicus*	9.5	26.1	*Croton* spp.	9[d]	2.8	*Ekebergia capensis*	6.94
	Ekebergia capensis	11.4	6.9	*Croton* spp.	6.5	2.7	*Rapanea melanophloeos*	4	2.0	*Schefflera volkensii*	6.46

[a] Unidentified species made up 5% of the volume/ha.
[b] Unidentified species made up 43% of the volume/ha, but 85% of that was one unidentified log.
[c] Unidentified species made up 19% of the volume/ha.
[d] Unidentified species made up 6% of the volume/ha.

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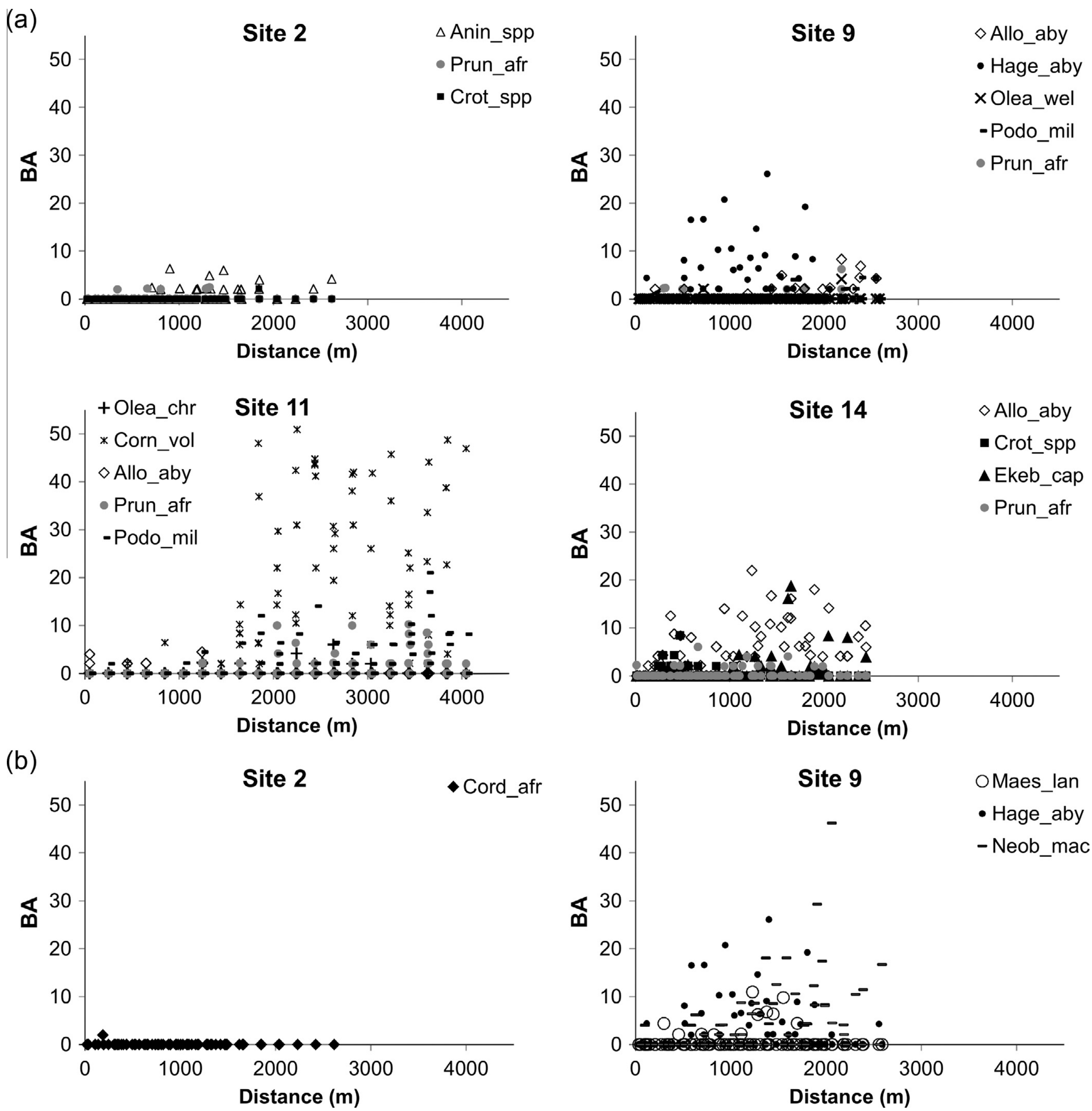

Fig. 4. Basal area (BA) of (a) preferred and (b) used species for fuelwood with distance from the boundary. Preferred and used species are the same in Site 11 and 14, except *Ekebergia capensis* in Site 14 but no dead wood was found for that species. Key to species abbreviations: Anin_spp: *Aningeria* spp., Prun_afr: *Prunus africana*, Crot_spp: *Croton* spp., Allo_aby: *Allophylus abyssinicus*, Hage_aby: *Hagenia abyssinica*, Olea_wel: *Olea welwitschii*, Podo_mil: *Podocarpus milianjianus*, Olea_chr: *Olea chrysophylla*, Corn_vol: *Cornus volkensii*, Ekeb_cap: *Ekebergia capensis*, Maes_lan: *Maesa lanceolata*, Neob_mac: *Neoboutonia macrocalyx*.

more fuel than maize and potatoes. Furthermore as water boils at a lower temperature at higher elevations cooking times are extended. People also heated water for bathing because it was often cold (<10 °C at night, Sites 11 and 14). Despite past attempts to introduce fuel-saving stoves none of the households that we stayed in used one (14 in total).

Other uses of wood for fuel that contribute to high wood consumption were unlikely to be included in the quantities reported by our respondents, e.g. commercial harvesting and charcoal making. Because commercial collection is illegal, selling was likely under-reported (see Table 2). Commercial brick- and charcoal-making contribute to high wood consumption in other Ugandan forests (Naughton-Treves et al., 2007). In our study neither activity was mentioned. We did not observe brick-making in our sites, but found charcoal pits and evidence of commercial fuelwood harvesting in Sites 2 and 9 inside the park. Charcoal making was noted near Site 2 in the 1990s (Scott, 1994) and has impacted forest structure in this area (Sassen and Sheil, 2013).

While more than half of our respondents also used fuelwood from elsewhere, the forest – which on Mt Elgon means the national park – was the most important source of fuelwood in terms of both its perceived importance and the quantities reported. Areas with the highest density of trees outside the park (on people's land) also had the densest human populations, explaining why the park remains important to meet their fuelwood needs. The density of trees on people's land reflects local history. In densely-populated areas, such as Sites 2 and 9, that have been settled and cultivated since around 1500 AD, households had native trees as part of the intensive coffee-banana system that was introduced in the early 1900s. Households with sufficient land also had woodlots of exotic species (*Eucalyptus* sp.). In the less-densely populated areas such as Sites 11 and 14 that were settled only during the 20th century, there were few trees except for scattered forest individuals left after clearing land (Table 4). We observed that these relics were progressively being felled. Here, the people were formerly pastoralists with no culture of tree planting (Scott, 1998). Also, tenure insecurity related to conflicts about the boundary of the area excised for resettlement and the allocation of land, likely dampened people's motivation to plant trees (Himmelfarb, 2006).

Households with more trees on their own land tended to value this land as a source of fuelwood more and used old-growth forest less than those with fewer trees. For example, in Site 9 people with more trees on their own land ranked old-growth forest as a less important source of firewood (Tables 2 and 3). In Site 2, people highly valued old growth forest for fuelwood, but then reported using mainly trees from their own land (Tables 3 and 6). In Sites 11 and 14, there were few trees outside the park but still many close to the boundary and as a consequence forest was the main source of fuelwood regardless of the number of trees on people's own land (Appendix A and Tables 2–4). Our results suggest that people forage less far for fuel when there are alternatives closer-by.

5.2. The quantity of fuelwood in the park

Fuelwood collection reduced the amount of dead wood in the forest, in particular in accessible areas close to the boundary. In addition, site-specific encroachment histories and other forest uses impacted local forest structure (Sassen and Sheil, 2013), which in turn influenced dead wood availability at varying distances into the park. For example, in Sites 11 and 14 previous encroachment into the park had been less intense, and encroached areas had more dead wood compared to Sites 2 and 9 (Sassen et al., 2013). In total however, the largest volumes of dead wood were found in Sites 2 and 14. In site 2 because of relatively high rates of tree fall, and in Site 14 because of frequent forest fires that do not always consume large debris. The elevation range of our plots (1911–2877 masl) was too narrow to influence rates of decomposition markedly, suggesting that removal was the main reason that volumes of dead wood increased further into the park.

The selectivity of fuelwood collectors was influenced by the quantity and quality of dead wood available in combination with species preference. For example, in Site 9 people were less selective because of a shortage of fuelwood, especially in the formerly-encroached areas near the boundary (Fig. 3). In Site 14, on the other hand, preferred species were still available and people collected these before others even when seemingly more decayed, as they were often hardwood species.

5.3. Impacts of fuelwood collection on preferred woody species

The interviews as well as the field survey provided evidence that certain tree species in the forest were overexploited for fuelwood and other uses. Highly-preferred species were not necessarily the ones people actually used the most. When queried, our informants always said this was because they were depleted in accessible areas. According to them this was because they were also valued and harvested for timber (data not presented).

Results from the field survey confirmed that preferred, but also highly used species were depleted. The volumes of dead wood and the basal area of the most highly-preferred and used species were all smaller near the park boundary. Some species were particularly preferred and affected, especially slow growing hardwood species that are also valued for timber, e.g. *P. africana*, *Podocarpus milianjianus*, *Aningeria* spp., *O. chrysophylla* and *O. welwitschii* (Scott, 1994; Hitimana et al., 2010). Often they still occurred further inside the park (>2000 m inside the boundary), but they had become difficult to access. For example in Site 9, *P. africana* was highly preferred but not highly used. Even though its woody debris represented 18% of all dead wood recorded in this site, stems and dead wood were found mostly further from the boundary (Fig. 4).

The degree of depletion of highly-preferred or used species was affected by site specific species composition. Stems of much preferred or used, but locally dominant, species such as *C. volkensii*, *A. abyssinicus*, *N. macrocalyx* and *H. abyssinica* (Table 6) were more abundant closer to the boundary than less dominant species. Some of these, such as pioneer species *H. abyssinica* and *N. macrocalyx* that dominate the older regenerating areas of Site 9, are also much used as crop supports and poles. Other pioneers include *Vernonia* spp., a fast growing tree-like seasonal shrub that grows in degraded areas just inside the park boundary.

In places with less dense population and less historical degradation, but with a lack of alternatives outside the park, pressure is likely to increase in the future. Such as in Site 11 and 14 where most preferred species were still heavily used, but where certain species that were both highly preferred and used – such as *O. chrysophylla* and *A. abyssinicus* in Site 11 and *Ekebergia capensis* in Site 14 – had small relative (Table 6) and absolute (Fig. 4) basal area, suggesting they may become depleted if current use continues.

Tree species composition varied with elevation independently of human impacts, and care is required not to confuse natural distribution effects with human influence. For example the upper altitudinal range of *A. abyssinicus* is likely close to the boundary of the park in Site 11 (2478 masl). *P. milianjianus* in Site 9 seemed depleted close to the boundary but is likely restricted to higher elevations within this site.

5.4. Future developments

Fuelwood collection is important for local people on Mt Elgon. They lack sufficient alternatives and this dependence affects the forest. Fuelwood collection and other forest uses impact forest structure (Sassen and Sheil, 2013), species composition and the availability of woody debris (this study). This in turn affects forest functioning and its ability to provide important resources for local populations in the long run.

As population increases, demand for fuelwood is likely to grow. Our study indicates that this may lead to further forest degradation, both in intensity and extent. On Mt Elgon new roads are constructed and access is improved (Sassen et al., 2013). On each of our visits between 2009 and 2011, we observed new buildings being constructed in the small trading centres along the roads or paths leading to the park. The main town of Mbale (Fig. 1) is expanding (Mbale District, 2007) which will certainly lead to an increase in commercial fuelwood harvesting and an increasing demand for charcoal in the foreseeable future (Girard, 2002; Bensel, 2008; Zulu and Richardson, 2013). Commercial fuelwood extraction and charcoal production can lead to much more severe impacts on the forest than dead wood collection because entire trees are removed (Mwampamba, 2007; Sassen and Sheil, 2013).

Allowing people access to the forest inside the park is double-edged. Currently some communities near the park boundary are given legal access to the park to collect dead wood and

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non-timber resources. UWA patrols the forest. They report that they arrest and fine people found breaking rules. Local people report more violent confrontations. In areas without formal agreements (e.g. Sites 2, 11 and 14) local rangers sometimes tolerate the collection of dead wood to avoid conflicts (Community conservation ranger, personal communication). On the one hand, granting people formal or informal access aids relations between the park and local people, and may help curb agricultural encroachment (Sassen et al., 2013). But the park management lacks the means to enforce the rules of the agreements and local forest user committees are unable or unwilling to impose them. Thus, illegal activities abound, including cutting of whole trees. In previous assessments there were indications that human uses had less impact on forest cover and structure in sites with a collaborative management agreement compared with sites where there was no agreement (Sassen and Sheil, 2013; Sassen et al., 2013). But we also found most intense commercial fuelwood harvesting in a site where an agreement with park authorities gave people access twice a week (Sassen and Sheil, 2013). We also observed that people from neighbouring parishes entered the forest on each other's allocated resource collection days. Completely banning fuelwood collection is unrealistic. Even if off-take was better monitored and found to be unsustainable, it would be impossible to stop people from entering the park. But dead wood collection and tree cutting should be viewed differently and there is a need for a system that regulates or controls the cutting of whole trees which at the same time allows the collection of dead wood.

No one wins by losing the forest. The poorest and most vulnerable rural households especially rely on forest resources for energy, food and medicine (McSweeney, 2004; Powell et al., 2011). There is therefore a need to investigate ways in which local people can be empowered to have more ownership and control over the forest and how this can lead to more effective forest management. An important insight is that forest degradation is more likely where people view forests as an open-access resource rather than a common-pool resource (Ostrom, 1999). The resource use agreements on Mt Elgon are an attempt to give people more ownership over resources in exchange for forest protection, but the degree of human impacts indicates that they are inadequate (Sassen and Sheil, 2013). There is evidence from elsewhere suggesting that local participation in forest management leads to more sustainable forest use, but that this depends on effective supporting institutions (Persha et al., 2011).

In sites with the highest pressure (Sites 2 and 9), people realized the impacts of firewood collection and other uses such as timber harvesting on the provision of these resources. And research has shown that such realization is an important condition for the development of sustainable local rules (Ostrom, 1999). Ostrom and others have found that congruence of local ecological and cultural contexts with perceived benefits and costs affect the success and sustainability of common-pool management arrangements (Ostrom and Hess, 2010). Ostrom's (1999) design principles for sustainable common-pool resource management regimes could guide successful forest management on Mt Elgon. As an example, it may be possible to determine different rules with local communities regarding the use of slow-growing old growth forest species that are also valued for timber, trees with multiple uses and fast-growing pioneer species, if the local communities had a clear stake in the outcomes.

Access to alternatives can make a difference in the importance people attribute to the park as a source of fuelwood. Even when trees are not planted for this purpose, they are often highly valued as sources of fuel (Arnold et al., 2006; Ndayambaje and Mohren, 2011). For instance, in Site 2, *M. platycalyx* and *Cordia africana*, which are commonly planted as shade trees for coffee, were also amongst the most used species for fuelwood. Although people with little or no land may have fewer options to plant trees, the most densely populated areas on Mt Elgon were also the ones with the highest tree density on people's land. Identifying the right incentives may therefore help increase the availability of alternative wood resources outside the park, in particular in areas where few trees are planted traditionally. Forest use for fuelwood or other uses varies among local communities which leads to different impacts within one protected area. There is clearly a need to look for locally appropriate options, incentives and alternatives that balance the needs of local livelihoods and forest conservation.

6. Conclusions

Fuelwood demand around Mt Elgon has intense but varying impacts over a large area of the park. All tree species used as fuelwood were negatively impacted on the edges of the park – key old growth forest species more so than pioneer and locally dominant species. Similar impacts are likely in other forests surrounded by dense human populations where access to alternative sources of fuel is limited. Our results demonstrate the strong impacts of fuelwood extraction, in combination with other uses. These impacts have future consequences for both people who depend on the forest and for conservation, yet are understudied. As the pressure on forests for fuel increases, incentives for sustainable forest use that build on local people's perceptions of costs and benefits are urgently required.

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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.foreco.2015.06.037.

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