Fuelwood Resources and Forest Regeneration on Fallow Land in Uganda

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ABSTRACT. East African forests have been largely converted to agriculture. The remaining forests hold many endangered species but are threatened by the heavy local demand for fuelwood. Here we evaluate fallow land in western Uganda as an alternate fuel source to diverse forests. We quantify the regeneration process on fallows, calculate tree biomass increases, and measure grass and woody herb biomass over 44 months. The biomass values we measured were typical or slightly below the average from 11 studies elsewhere in the tropics. Variation in biomass between our neighboring study sites exceeded that between sites on different continents, indicating the sensitivity of vegetation regeneration to local land use. Tree regeneration was extremely slow (0.46 g/m^2/year);

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however, the woody herbs and grasses on a 4 year old fallow of ~0.5 ha can provide much of a family's domestic fuel. Fallow land is generally abundant in western Uganda and can partially alleviate pressure on forests for domestic fuels. Fallows cannot however provide the trees demanded by charcoal, brick, and gin manufacturers. In the future, conserving forests while meeting fuelwood demands will require improving local land tenure security, enhancing the productivity of cultivated and abandoned land, promoting more efficient stoves, stills and kilns, and curtailing illicit, inefficient charcoal manufacture.

KEYWORDS. Biomass fuels, east Africa, fuelwood, fallow, grassland, Kibale National Park, regeneration, succession, Uganda

INTRODUCTION

People have modified east African forests for at least 2,000 years (Hamilton, 1981). Their land use partly created the present spatial heterogeneity of the region's vegetation (Chapman and Chapman, 1996). However, the intensity of contemporary forest use and rate of conversion to agricultural land is unprecedented (FAO, 1999; Lanly et al., 1991; Struhsaker, 1997). Today less than 70,000 km^2 (28%) remains of East Africa's original forests (Martin, 1991).[1] These forests, like most in Africa, are steadily being converted to farmland. Yet during recent years, the net gain in cropland across Africa was considerably less than the net reduction in forests (FAO, 1993; Houghton, 1994). The discrepancy is explained in part by the significant expansion of abandoned and degraded agricultural lands. Every year large areas of forest are converted to cropland, but an even more extensive area of pastures and croplands are left fallow or abandoned (Houghton, 1994). Blaming small scale agriculturalists for deforestation in Africa is inappropriate, considering the fact that forest clearing, land abandonment, and reclamation operate at different temporal and spatial scales, and are often driven by regional or international markets for charcoal or timber (O'Keefe et al., 1984). Nonetheless, abandoned and degraded lands are rapidly expanding, and account for 88% of the net loss of forests in tropical Africa, a level far greater than tropical Asia or America (59% and 34%, respectively) (Houghton, 1994).

Conservationists rarely consider the value of fallow or abandoned agricultural land for slowing deforestation. This oversight ignores the fact that fallow land can potentially provide vital resources to local people (biomass fuels in particular) and thus alleviate pressure on remaining high canopy forests. The conservation importance of *bush fallow* (Norman, 1979) is underscored by the fact that to date, forested African countries have set aside less than 4% of their territory as National Parks or similar protected areas (Chapman et al., 1999; World Resources Institute, 1996). The majority of tropical forests lie outside of parks and have experienced or will soon experience major anthropogenic pressure.

The primary resource extracted from abandoned or fallow agricultural land in east Africa is fuelwood (Barnes et al., 1984; Edmunds, 1997; Wallmo and Jacobson, 1998). Escalating fuelwood demands and forest degradation are commonly reported in arid and semi-arid tropical regions (Leach and Mearns, 1988; Vermeulen et al., 1996). Fuelwood use also has great economic and ecological importance in the humid tropics. For example, during the early 1980s, 90-95% of the total wood consumed in Uganda was used for fuel (Hamilton, 1984). Today wood and charcoal supply > 95% of rural energy requirements in the humid region of western Uganda, one of the highest levels in the world (Bradley, 1991; Government of Uganda, 1992). Current harvest rates are generally considered unsustainable (Howard, 1991). The increased demands for fuelwood and international concern over forest loss have inspired a myriad of programs to reforest land or use fuelwood more efficiently (Howard, 1991; Wallmo and Jacobson, 1998). However, reforestation efforts alone cannot meet the increasing demand for fuelwood (Struhsaker, 1987), and providing fuel-efficient technology may not significantly reduce consumption rates (Wallmo and Jacobson, 1998). These conditions call for detailed studies of biomass fuel sources other than plantations and natural forests.

Using 44 months of field data on biomass accumulation, we evaluate fallow agricultural land in western Uganda as a source of fuel. We provide a detailed quantification of the regeneration process following abandonment, calculate the annual increment of tree biomass, and measure the biomass of woody grasses and herbs after 44 months of regeneration. We then compare our results to other studies in the tropics, which describe biomass accumulations after different types of human modifications. Finally, we evaluate the capacity of fallow land to meet the growing fuelwood demands of both commercial and domestic consumers.

MATERIALS AND METHODS

Study Site and Local Land Use

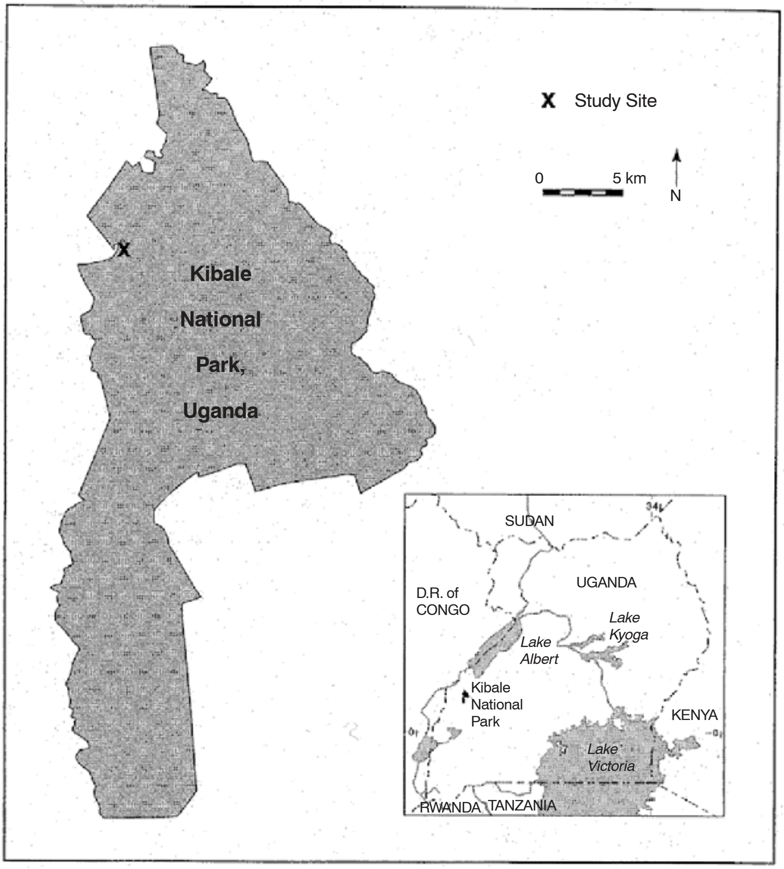
The study was conducted within Kibale National Park, Uganda (Figure 1). Kibale (766 km^2) is found just east of the Ruwenzori Mountains (0° 13′-0 41′ N and 30° 19′-30 32′ E), at an elevation of 1500 m and receives 1700 mm rainfall per year (1984-1996). Around Kibale, people use land primarily for semi-intensive rainfed cropping (54% of the area, Naughton-Treves, 1998). Farms near Kibale average 1.4 ha, of which on average 40% is under fallow (Naughton-Treves, 1998). Fallows vary considerably in age, from a single season to > 20 years. Classifying fallow vegetation is difficult due to the innumerable possible sequences in land use (grazing, slashing, burning, interplanting, etc.), which lead to variable patterns of succession. For the purposes of this study, we define "abandoned" land as arable land free of cultivation or grazing for over four years. This definition encompasses vegetation under a variety of socioeconomic and tenurial categories. Rarely is land in western Uganda "abandoned" in the sociopolitical sense, rather, most bushy fallows are claimed and/or valued by local user groups, women in particular (Croll and Parkin, 1992; Edmunds, 1997).

Treatment of Regeneration Plots

At our first study site (Site 1), we measured annual fuelwood accumulation for 44 months after cultivation was abandoned. At Site 2 we made a single assessment of fuelwood biomass on land fallowed for 6 years after several years of grazing and cultivation. These two sites were within the park, were separated by 200 m, and lay adjacent to 300-ha of natural forest.

Site 1 was located within the National Park where corn (*Zea mays*) and yams (*Dioscorea* sp.) had been cultivated for three consecutive years, then abandoned. As per local farming tradition, most trees, logs, and stumps had been removed, the area burnt, and the soil hoed by hand. Each year, before planting, the area was burnt and hoed to remove colonizing grasses (e.g., *Pennesetum purpureum*). Two seasonal plantings were made during each year of cultivation. The land was subsequently abandoned in 1987. At the onset of the study in August 1993, the land was again hoed by hand as if it were to be planted, but was then abandoned. A 30 m by 50 m plot was selected and subdivided into 10 m by 10 m subplots (n = 15). The location, size, and identity of any trees in

FIGURE 1. Map of study site, Kibale National Park, Uganda.



the plot were recorded. Fire was suppressed and no extraction occurred during the entire study period.

Site 2 (7097 m^2) had a longer and more intense history of use. This area is also within the park's boundaries, but it had been cleared prior to 1970 for grazing. Thereafter, vegetation was cut and burned repeatedly so as to maintain a pasture for over two decades. Bananas were once planted in the area, but soon abandoned. At times the area was also used as a soccer field (T.T. Struhsaker, pers. comm.), but it was primarily used for grazing. In 1991 the area was abandoned and no longer cut or burned. In June of 1997, the vegetation growing at this site was assessed.

The fuel sources present at Sites 1 and 2 included: trees, elephant grass (*Pennesetum purpureum*), and a fast growing woody herb, *Acanthus pubescens*. Each source was evaluated separately. The establishment, growth, and mortality of natural tree seedlings were monitored at Site 1 approximately every 3 months for 44 months (September 1993 to April 1997). Each 10 m by 10 m subplot (n = 15) was searched for seedlings and every tree seedling encountered was identified by species and marked. Local residents generally only harvest trees > 50 cm height, using small saplings as kindling and larger poles for cooking. Accordingly, only trees > 50 cm were included in fuelwood biomass calculations. To estimate annual above-ground living tree biomass, regression equations were calculated between tree height and dry weight for a sample of similar trees harvested from forest patches outside of the park (n = 28, trees > 50 cm to 2 m in height, no tree had exceeded 2 m by the end of the study; methods follow Whittaker and Marks, 1975 and Uhl, 1987). The species selected from forest patches were those commonly found in the study plots, and approximated the relative abundance of the species in the study area. For each tree, its height and diameter at ground level were measured after the tree was harvested by cutting it at ground level. Then leaves were separated from stems and trunk and all components were returned to our field camp where wet weight was determined. The material considered locally as fuel (stems and trunk) were then air dried by hanging them under a tin roof that protected them from the rain, but permitted airflow. Samples were allowed to dry until they reached a constant weight. Regression equations between tree height and dry weight were established from this sample (Log dry weight = 0.00452 (height) + 1.476; $r^2 = 0.791$, $P < 0.0001$, n = 28). Subsequently, the expected dry weight of every tree > 50 cm tall was calculated for the Site 1 plot.

We measured vegetation changes in Site 1 every 3 months. Four quadrats (65 cm × 65 cm) were placed in each of the 25 subplots, 2 m from the center of the subplot at each cardinal point. This sampling revealed that, unlike other studies conducted in South America, grasses (particularly elephant grass–*Pennesetum purpureum*) and the woody herb, *Acanthus pubescens,* constituted a significant component of the biomass. Thus, in the final sampling period (April 1997), the height of all *A. pubescens* stems were measured (n = 161, density = 1.07 stems/m^2) and dry weight was estimated for all stems in the plot using regression equations for height to dry weight derived from forest patches outside of the National Park (dry weight = 0.7165(height) − 885.243; r^2 = 0.584, $P < 0.004$, n = 12).

Elephant grass grows in dense clusters over extensive areas and typically reaches a height of 2 m. The proportion of each 10 m by 10 m subplot dominated by elephant grass was visually estimated. At the end of the study, twelve 1 m^2 areas (locations randomly selected) were harvested by cutting all stems at ground level. These grass bundles were transported back to camp and weighed. Subsequently, local residents were asked to separate those components of the grass that they would use as a fuel source from those they would discard. The fuel component of the grass they identified was then dried.

In the second area (Site 2), all *A. pubescens* stems were measured and the proportion of the area under elephant grass was measured in June 1997 (roughly 6 years after this heavily modified area was abandoned). No attempt was made to locate tree seedlings because (a) the *A. pubescens* and elephant grasses were often very difficult to penetrate, and (b) the detailed study of Site 1 suggested that trees rarely grew high and thus were contributing little to the overall biomass of the area. The biomass of usable *A. pubescens* and elephant grass was determined as in Site 1.

Comparing Regeneration Rates with Other Tropical Sites

To assess the generality of patterns observed at Kibale, we reviewed similar studies conducted elsewhere in the humid tropics. Here we only report results from those studies that approximate the four year period used in this study. Long-term regeneration records (e.g., the 60-80 year period reported by Saldarriaga et al., 1988) provide critical benchmark data, but far exceed the practical constraints and planning horizon of individuals managing fallows around Kibale. Caution should be used when comparing the results of these studies to ours because they all report total biomass, not the amount of biomass suitable for local fuel use. In our study, local residents identified only 62% of the total biomass as a potential fuel source. Therefore in addition to reporting data from other studies on total biomass, we use a conversion factor of 62% to estimate fuel biomass accumulated at each site. By so doing, we assume that elsewhere a similar proportion of the total biomass is available for fuel as what we documented at our Ugandan site. This assumption is likely violated in locations where biomass is accumulated in plants that are unsuitable for burning (e.g., short grasses; Richards, 1996; Uhl, 1987).

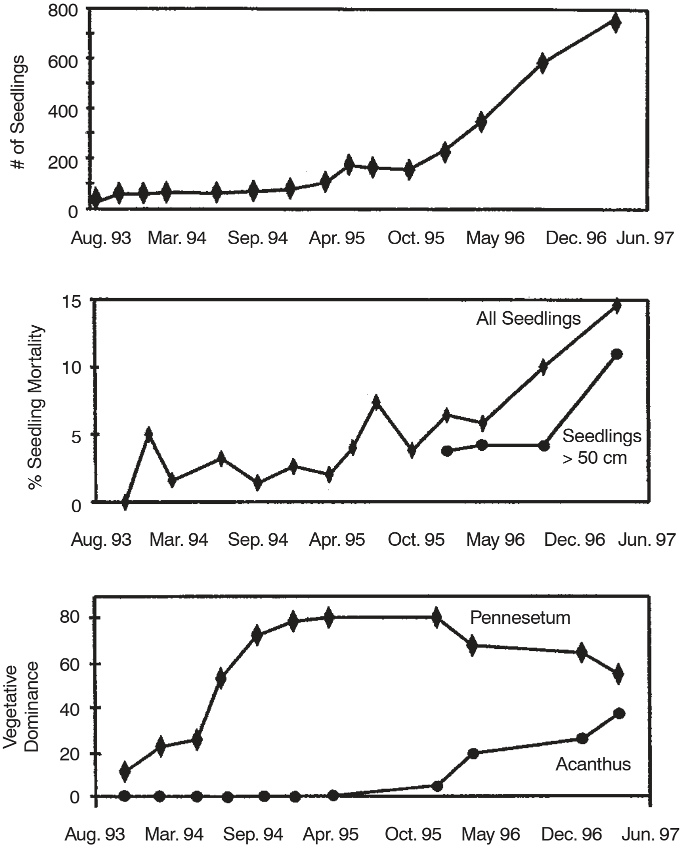
RESULTS

The rate of tree seedling establishment was slow during the first 2 years following abandonment, but increased rapidly during years 3 and 4 (Figure 2a). Mortality of seedlings followed a similar pattern (Figure 2b). After 44 months, only 3 trees had reached > 1 m in height (*Acrocapus fraxinifolius*, *Persea americana*-Avocado, and *Maesa lanceolata*) and only 20 trees exceeded 50 cm. No tree at Site 1 exceeded 2 m by the end of the study. *A. fraxinifolius* was introduced to East Africa from Southeast Asia and is planted as a source of fuelwood. Avocado is an exotic introduced for its edible fruits. The seed was likely introduced when the area was cleared. *M. lanceolata* is a fast growing native tree that coppices readily. Tree biomass was extremely low throughout the study. It increased steadily over the first three years (year 1 = 0.64 g/m^2, year 2 = 1.01 g/m^2, year 3 = 1.07 g/m^2), but declined in the fourth year (-0.89 g/m^2). The decline followed increased mortality of trees between 50 cm to 1 m tall and slow recruitment into this size class. This increased mortality corresponded to the time when elephant grass dominated the plot and *A. pubescens* was increasingly common (Figure 2c). In general, trees made up a very small component of the potential fuel sources that grew on the plot in the 44 months following abandonment.

Vegetative cover at the Site 1 plot was assessed 11 times between November 1993 and April 1997 (41 months) at approximately 3 month intervals. Short grasses and non-woody herbs dominated the first year of growth (particularly *Cynodon dactylon* and *Bidens pilosa*). Elephant grass soon succeeded short grass and gradually dominated the area (Figure 2c). Near the end of the study, *A. pubescens* began replacing elephant grass (Figure 2c). By year 4, the biomass of elephant grass fuel averaged 1492 g/m^2, while *A. pubescens* fuel biomass averaged 1810 g/m^2. At the second site, the biomass of elephant grass after 6 years was 1684 g/m^2, while *A. pubescens* biomass was 172 g/m^2. Total biomass accumulated at Sites 1 and 2 was 5,361 and 2,994 g/m^2, respectively.

We located data on above-ground dry biomass for 25 sites, from 11 studies (Table 1). The biomass ranged from 77 g/m^2 on a Venezuelan site which had been cut and cleared by a bulldozer and then abandoned for 3 years, to 8890 g/m^2 on an 8 year old abandoned pasture in Brazil. This variation is not surprising considering the diversity of land use practices and physical conditions. The biomass values we measured at Kibale appear to be typical or slightly lower than the average from the 11 studies.

FIGURE 2. Description of the restoration process that occurred on a section (30 m by 50 m) of fallow agricultural land that was converted from moist-tropical forest in Kibale National Park, Uganda: (a) the number of seedlings found in the restoration plot, (b) % of seedlings dying between sampling periods, (c) the % of quadrats dominated by *Pennesetum purpureum* (elephant grass) and *Acanthus pubescens*.



MANAGEMENT IMPLICATIONS

Substantial biomass fuel was found on Ugandan agricultural land that had been abandoned for 4-6 years. The majority of this biomass was elephant grass and a woody herb (*A. pubescens*). Tree regeneration was slow and did not contribute a substantial proportion to the biomass.

TABLE 1. Standing dry vegetation biomass (g/m^2) at Kibale National Park, Uganda and 25 other tropical sites following different periods since abandonment and different types of land use practices.

Years	Land Use	Dry Biomass	Fuel	Source/Site
4	Slash and Burn	5361	3308	This Study, Uganda
6	Pasture, Heavy Use	2994	1856	This Study, Uganda
9	Slash and Burn	5130	3181	Saldarriaga et al. 1988, Columbia/Venezuela
4	Mixed Species Fallow	2771	1718	Tergas 1965, Guatemala
4	Slash and Burn	2888	1791	Uhl and Jordon 1984, Venezuela
4	Slash and Burn	3796	2354	Ewel 1971, Panama
4	Slash and Burn	4839	3000	Gamble et al. 1969 (in 1), Colombia
5	Slash and Burn	7669	4755	Bartholomew et al. 1953, DR Congo
6	Slash and Burn	4609	2858	Nye & Greenland 1960 (in 1), Nigeria
3	Cut Forest	1291	800	Uhl et al. 1982, Venezuela
3	Cut and Burned	870	539	Uhl et al. 1982, Venezuela
3	Cut and Bulldozed	77	48	Uhl et al. 1982, Venezuela
4	Slash and Burn	2861	1774	Uhl 1987, Venezuela
3.5	Pasture, Light Use	2940	1823	Buschbacher et al. 1992, Brazil
4.5	Pasture, Light Use	5340	3311	Buschbacher et al. 1992, Brazil
8	Pasture, Light Use	8610	5338	Buschbacher et al. 1992, Brazil
8	Pasture, Light Use	8890	5512	Buschbacher et al. 1992, Brazil
3.5	Pasture, Moderate Use	830	515	Buschbacher et al. 1992, Brazil
3.5	Pasture, Moderate Use	1680	1041	Buschbacher et al. 1992, Brazil
4	Pasture, Moderate Use	1700	1054	Buschbacher et al. 1992, Brazil
7.5	Pasture, Moderate Use	3700	2294	Buschbacher et al. 1992, Brazil
8	Pasture, Moderate Use	3280	2034	Buschbacher et al. 1992, Brazil
2.5	Pasture, Heavy Use	760	456	Buschbacher et al. 1992, Brazil
2.5	Pasture, Heavy Use	1550	961	Buschbacher et al. 1992, Brazil
8	Pasture, Heavy Use	470	291	Buschbacher et al. 1992, Brazil

1 = Uhl and Jordon 1984

Note: For the 11 other sites we estimate the amount of the total biomass that could be used as a fuel source assuming a similar ratio of total biomass to fuel biomass as was calculated in this study (62%). The relationship between above-ground dry biomass and the year since abandonment for 25 sites (biomass = 664.54 (year)-12.531, r = 0.552, P = 0.004). Years = Years since abandonment, Dry Biomass and Fuel is expressed as g/m^2.

Only a very small proportion of the biomass was exotic species (e.g., *Lantana* sp.). People readily use both elephant grass and *A. pubescens* for cooking, particularly for small meals or warming foods. These two plants are not suitable for tasks which require high heats or long cooking times (e.g., cooking beans), nor for commercial uses (e.g., firing bricks in kilns or distilling banana gin; Vermeuln et al., 1996).

Estimates of domestic fuel use by people around Kibale indicate that a typical family (5.1 people) uses 8.4 kg of fuelwood each day for cooking (Wallmo, 1996). Thus, in one year a local family would use 3,066 kg, and in 4 years, 12,264 kg (this value is slightly lower than average for non-Liquid Propane Gas users in East Africa, Kammen, 1995). In our 4 year study, the amount of cooking fuel accumulating at Site 1 was 3.3 kg/m^2. Given these values, an average family would require an area of 3,716 m^2 (0.37 ha) to meet many of their domestic fuel needs; an area less than the average farm fallow size near Kibale (0.55 ha). A similar set of calculations from Site 2 indicates that a family would need to leave an area of 6,813 m^2 (0.68 ha) fallow to meet their fuel needs, a value exceeding the average fallow size. The variability between Site 1 and 2 reflects the great sensitivity of vegetative regeneration to local land use. The data from these sites also suggest that many farmers are able to rely heavily on private fallows for domestic fuel supply, however, those residing on degraded or small farms cannot.

The regression equation derived from the data in Table 1 allows us to predict biomass regeneration over 4 years in a variety of tropical countries after various types of human modification. Based on this equation, 4 years after abandonment, tropical lands at 25 sites on average accumulated 2.6 kg/m^2. If, as in Kibale, 62% of this biomass is suitable for fuel, then the land would yield 1.68 kg/m^2 of fuel. If a family used similar amounts of fuelwood as they do around Kibale, they would need a 7300 m^2 area of fallow land to provide them with fuel (approximately 85 m by 85 m).

These analyses are simplistic in a number of ways. For one, not all material has the same combustion properties (e.g., elephant grass will burn much faster than a tropical hardwood). People demand different types of fuelwood according to their economic activity and local availability (Reddy, 1997). Where wood is scarce, people will cook with leaves, short grasses or even crop residue, whereas women around Kibale can afford to reject these materials as fuel. The relative abundance of woody plants at Kibale may also partly explain why private landowners commonly share *A. pubescens* and other fast growing species with other non-commercial users. On the other hand, there are growing conflicts among community members at Kibale regarding access to hardwoods. Commercial user groups, such as charcoal, brick, and gin manufacturers, prefer to fuel their kilns and stills with hardwood logs (Naughton-Treves, unpub. data). Our study indicates that regeneration of hardwoods is slow, even at sites adjacent to intact natural forest. After 4 years of fallow at Site 1, only 3 trees were > 1 m tall. After 6 years of fallow at Site 2, seedlings were all but absent. The recently abandoned land around Kibale therefore is unlikely to satisfy commercial fuel consumers who will likely continue to draw on the dwindling riparian and lacustrine forests, or the National Park.

The predominant form of tropical forest in the future will be secondary and regenerating forest (Brown and Lugo, 1990; Corlett, 1995). If managed properly, the secondary forests and fallows in western Uganda can provide an important source for domestic fuel and thereby alleviate pressure on the few remaining high-canopy forests. Promising initiatives for practical community-based forest management outside of parks and reserves are already underway in Uganda (Banana and Pereza, 1996). The slow rate of tree regeneration measured in this study suggests, however, that expanding urban markets for charcoal, gin, and bricks will continue to threaten old-growth forests. Before promoting large-scale softwood plantations, further research is warranted to learn how to enhance regeneration of forest on fallow lands for both social and ecological long-term benefit.

NOTE

1. Estimates of original forest area and deforestation rates vary widely. The figures presented come from pollen analysis and remote sensing (Martin, 1991) and lie roughly in the middle range of estimates.

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