Does Weeding Promote Regeneration of an Indigenous Tree Community in Felled Pine Plantations in Uganda?

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Abstract

The use of plantations to manage extensive tracks of deforested lands in the tropics is a conservation strategy that has recently received considerable attention. Plantation trees can promote seed dispersal by attracting dispersers and creating favorable site conditions, leading to increased germination and establishment of indigenous trees. Subsequently, plantation trees can be harvested for profit or left to senesce, leaving a native tree community. We evaluated the effect of vine, grass, and shrub cutting (weeding) over a 3-year period on regeneration of indigenous trees subsequent to the removal of plantation softwoods in Kibale National Park, Uganda. Counter to what would be expected if weeding released trees from competition, we found no difference in the total number of stems or in the stems greater than 10 cm diameter at breast height between control and weeded plots; there were more stems greater than 1 cm diameter at breast height in the control plots. For species found in both control and weeded plots, the maximum size of individuals did not differ. At the end of the study, 61 species were found in the control plots and 43 species were found in the weeded plots, and in both types of plots the three most abundant species were the same. The number of species and stems classified as early or middle successional species did not differ between weeded and control plots. The fact that weeding did not promote regeneration of indigenous trees after the removal of plantation trees illustrates the importance of evaluating and field-testing potential management options.

Key words: weeding, forest restoration, forest management, tropical forests, plantations, regeneration, competition, degraded areas.

Introduction

During the last century there has been rapid conversion of forests to pasture and agricultural land (Brown & Lugo 1994). The FAO (1999) estimated that 65.1 million ha of forest are converted each year to agricultural/pasture lands in developing countries. Forested lands converted to agriculture and pasture are frequently abandoned after a few years of use because of soil nutrient depletion and/or invasion by weeds and other pests and pathogens (Brown & Lugo 1994; Dobson et al. 1997). As a result, degraded tropical land occupies approximately 2.1 billion ha (Grainger 1988).

Forest cover can return to some degraded areas within a reasonable time frame (i.e., years to a few decades) through natural succession (Reiners et al. 1994). However, forest succession can also occur at a very slow rate (Brown & Lugo 1994; Cohen et al. 1995; Chapman & Chapman 1999). Succession is considered arrested when it does not proceed within a reasonable time frame. Arrested succession resulting from both anthropogenic and natural causes has been reported throughout the tropics, including Brazil (Nepstad et al. 1991), Colombia (Aide & Cavelier 1994), Panama (Brokaw 1983), Sri Lanka (Ashton et al. 1997), Singapore (Corlett 1991), and Uganda (Chapman et al. 1999; Duncan & Chapman 1999). Arrested succession may reflect a lack of tree seeds or resprouts, high seed or seedling mortality (Cohen et al. 1995; Nepstad et al. 1996; Ashton et al. 1997; but see Aide & Cavelier 1994), inhospitable abiotic and biotic site conditions (e.g., a lack of mycorrhizae or limited soil nutrients; Janos 1980; Corlett 1991; Nepstad et al. 1996; Otsamo et al. 1996; Johnson & Wedin 1997), fire (Kellman 1980; Uhl & Kauffman 1990), and/or competitive dominance of invasive herbs and shrubs (Brokaw 1983; Putz & Canham 1992; Duncan & Chapman 1999).

When succession is arrested, human intervention may be required to facilitate reforestation. Plantations have frequently been suggested as an option to rehabilitate de-

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graded lands (Brown & Lugo 1994; Parrotta et al. 1997; Evans 1999). Plantation trees can promote seed dispersal by attracting dispersers and creating favorable site conditions, leading to increased seed germination and seedling establishment (Lugo 1992; Parrotta 1993). Subsequently, plantation trees can be harvested for profit or left to senesce, leaving a native tree community. However, if the plantation trees are harvested, which seems very likely in most developing tropical countries, the area may be invaded by weeds and other pests and pathogens (Brown & Lugo 1994; Dobson et al. 1997).

If plantations are to be used as a mechanism to encourage regrowth of indigenous trees, we need to understand the effects of weeds on regenerating indigenous trees. It has been well documented that when plantations are first established, the most common cause of mortality and growth suppression is weed competition, particularly by grasses (Zobel et al. 1987). Plantation survival is increased by as much as 90% and volume growth by more than 50% with early competition control, typically by manually cutting grass and shrub competitors (Lowery et al. 1993). However, weeding may also increase mortality because it is difficult to avoid killing some newly establishing seedlings hidden in dense clumps of grasses, or it may cause unfavorable changes in microclimate. Manual weeding is extensively used in the tropics when plantations are established (Lowery et al. 1993) and is a financially viable management option to encourage indigenous tree establishment and growth.

The objective of this study was to evaluate a management scheme that would involve cutting vines, grasses, and shrubs on regeneration of indigenous trees subsequent to removal of plantation softwoods in Kibale National Park, Uganda. To meet this objective, areas that had recently been logged by pitsawyers were either left alone (control) or were subjected to a treatment involving the periodic cutting of non-trees (weeded). Regeneration in these areas was evaluated over 3 years.

Methods

This study was conducted in Kibale National Park (766 km^2; 0°13′ to 0°41′N and 30°19′ to 30°32′E), located in western Uganda approximately 24 km east of the Rwenzori Mountains. Kibale consists of mature, mid-altitude, moist, semi-deciduous and evergreen forest (57%), grassland (15%), woodland (4%), swamp (4%), colonizing forest (19%), and plantations of exotic trees (1%; primarily *Cupressus lusitanica* [Mexican cypress], *Pinus patula* [Mexican weeping pine], *Pinus caribaea* [Caribbean pine], and *Eucalyptus* spp. [primarily *E. grandis*]; Chapman & Lambert 2000). Our work was conducted near the Makerere University Biological Field Station in the northern portion of the park (1,500-m elevation) at the Kanyawara plantation. This region has annual average daily minimum and maximum temperatures of 15.5 and 23.7°C, respectively, and an annual average of 1,778 mm of rainfall (1990–1998). Rainfall is bimodal, with two rainy seasons occurring from March to May and September to November.

Kibale forest received National Park status in 1993. Before 1993 it was a forest reserve, gazetted in 1932, with the stated goal of providing a sustained production of hardwood timber through selective logging and softwoods from plantations established on anthropogenic grasslands. The grasslands were sites of human settlement; however, the villages were abandoned during the early 1900s (Osmaston 1959; Kingston 1967). Pines (especially *P. patula* and *P. caribaea*) and cypress (*C. lusitanica*) were planted on 393 ha of grassland hilltops between 1953 and 1977 (Kaumi 1989). Plantations were partially to completely weeded to decrease competition between plantation trees and grasses; also some pruning and thinning of plantation trees were initially done (Osmaston 1959; Kingston 1967). During Uganda's political upheaval in the 1970s and 1980s, the plantations were not managed (Kaumi 1989). However, since 1993 the planted exotics in Kibale have been extracted (via manual pit saws and portable sawmills) with the ultimate goal of facilitating forest regeneration with indigenous species.

The Kanyawara plantation was harvested by pitsawers in March and April 1996. Many of the crowns of taller indigenous trees were damaged by the felling, and much of the undergrowth was damaged when logs were rolled to the pitsawing platforms. There was an average of six trees per hectare greater than 10 cm diameter at breast height (DBH) left standing after the harvest. A large number of pitsawing platforms were established in the plantation; thus, logs were typically not rolled more than 20 m. To facilitate rolling, much of the regrowth over 1 cm DBH along the route of log travel was cut at ground level. In the area of study, the nature of the damage was relatively homogenous.

When evaluating the use of plantations as a management tool to facilitate regeneration of indigenous trees, it is important to consider the nature of the extraction, damage to the indigenous trees, and alteration of the physical environment (e.g., soil compaction). In comparison with the use of portable sawmills, which have been used in other areas of Kibale, the damage to the indigenous trees established in the Kanyawara plantation was minimal. This is because logs are typically rolled much greater distances to portable sawmills and saplings along the route are cut at ground level.

In July 1996, after the pitsawyers had completed their work, twenty 10 × 10-m plots were established off a 1-m wide transect cut up the slope of the hill. Plots were randomly assigned to control or treatment (weeded). To mimic a project aiming to reforest a large area, we hired local laborers to cut all non-tree growth from those plots assigned to that treatment. Vines were also cut off trees, typically near the base of the tree. The laborers were given careful instructions not to cut tree seedlings. The plots were cut on average once every 7 months, with the interval depending on the speed of weed growth. Cutting was done with a slasher, a 1-m long wooden-handled metal blade with the last 15-cm bent at a 30-degree angle and sharpened. One of the investigators or a student working for the project supervised the weeding.

During each sampling period, tree species from seedlings to adult trees were identified to species; only 1.4% of the individuals could not be identified. The diameter of all stems more than 1.2 m tall were measured at that height (DBH). The diameter of relatively small plants was measured with calipers or a ruler, whereas larger tree diameter was measured with a DBH tape. In the weeded plots the measurements were made after the area was cleared. For control sites, we carefully searched through the often dense vegetation for tree seedlings and saplings. The weed vegetation in the control plots established within a few months after the harvest and formed a continuous dense layer that reached up to 3 m in height. To our knowledge, there were no introduced weeds in the plots. Species were assigned a priori to one of three successional stages (early, middle, or late) based on statements made in the literature (Polhill 1952; Hamilton 1991; Katende et al. 1995) or on personal observations. Tree species nomenclature follows the most recent citation for a given species in Hamilton (1991), Katende et al. (1995), or Polhill (2000).

Results

At the end of the monitoring, 36 months after the harvest, there was no difference in the total number of stems of tree species between the control and weeded plots (mean number control = 68, weeded = 48, $t = -1.13$, $p = 0.272$) (Fig. 1). However, the number of stems that had reached a size of 1 cm DBH or greater

Figure 1. Tree regeneration in a weeded plot in the foreground and an unweeded plot to the side just after the initiation of the experiment in Kibale National Park, Uganda. The unweeded plot illustrates the height and density of the shrub and vine layer that was typical throughout the study.

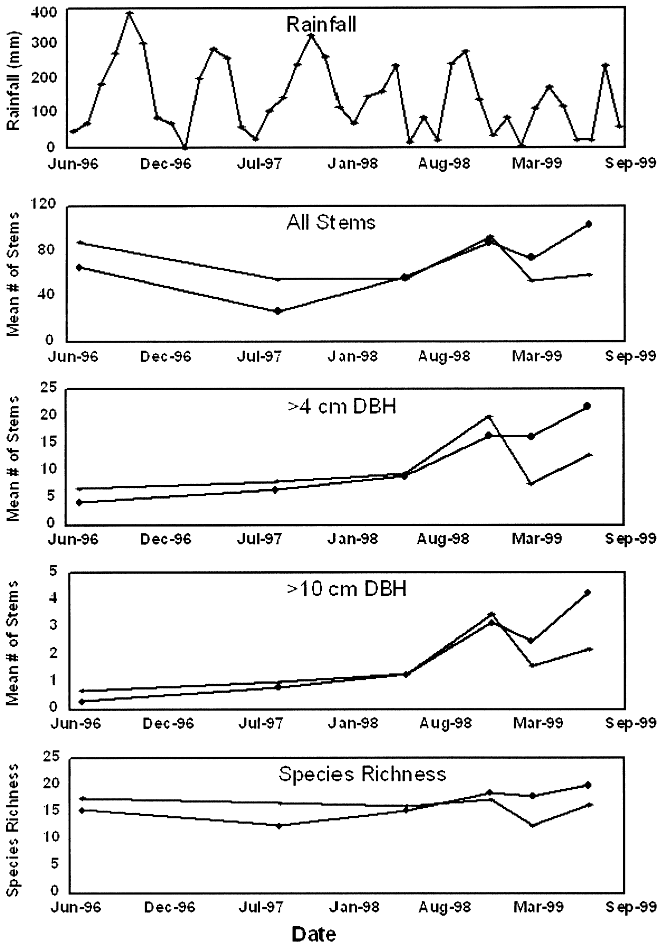

Figure 2. Monthly rainfall over the period of study and changes in the mean number of tree stems of different sizes in 10 × 10-m control and treated (weeded) plots and tree species richness in all 10 plots of each treatment after the removal of the plantation trees in Kibale National Park, Uganda. —◆—, weeded plot; —●—, control plot. Standard error bars are presented.

was higher in the control plots than in the weeded plots (mean number control = 52, weeded = 32, $t = -2.57$, $p = 0.019$). Similarly, the number of stems that were more than 4 cm DBH was marginally higher in the control plots (mean number control = 14, weeded = 11, $t = -1.90$, $p = 0.074$). In contrast, there was no difference in the number of trees that were more than 10 cm DBH between control and treatment plots (mean number control = 2.7, weeded = 1.9, $t = -1.51$, $p = 0.149$). Average tree size did not differ among the plots that were weeded and those that were not (>4 cm $t = 0.21$, $p = 0.839$, >10 cm $t = 0.019$, $p = 0.985$) nor did the maximum size of individuals (paired t test $t = 0.616$, $p = 0.543$, paired by species). At the end of the study, 61 species were found in the control plots and 43 species were found in the weeded plots, and on average species richness was marginally higher in the control plots (control plots = 19.5, weeded plots = 16.7, $t = -2.04$, $p = 0.056$).

These general patterns were not consistent over the duration of the study, and the pattern of change differed depending on which size class was considered (Fig. 2). For all size classes combined, abundance declined in both the control and weeded plots between the first and second sampling periods. This reflects mortality of the small size classes, particularly seedlings, likely associated with opening of the canopy. The second dry season of the year occurred between the first and second sampling periods. This decline was not observed in larger size classes. In the initial sampling periods when dense grasses had to be cut, the density of stems was slightly higher in the weeded plots compared with the control (Fig. 2). This suggests that in the process of weeding plots the local laborers did not kill many seedlings. After this initial period there was a gradual increase in abundance in all size classes until February 1999, when there was a die-off in all size classes. This die-off was more severe in the weeded plots than in the control plots and produced the differences seen at the end of the study. This die-off occurred during the first dry season of the year, and February 1999 was the driest month of the study (Fig. 2). For all size classes, the slope of the increase in abundance in the weeded plots after this die-off was similar to or less than the slope in the control plots, suggesting that tree abundance in the control plot will remain higher than in the treatment plots for some time.

Species richness did not change dramatically over the study (Fig. 2). There was a decline in richness after the first dry season of 1999 (particularly in the weeded plots), but species richness had increased (weeded) or surpassed (control) its previous level by the next sampling period. In general, species richness was high in the plantation area; 42 species were found in the 2 ha sampled (control and weeded plots combined), as compared with 78 species in a 5.4-ha area of adjacent intact forest (Chapman & Chapman 1996).

The control and weeded plots were very similar with respect to the species they contained and their rank order of abundance (Table 1). Seventy-two percent of the species were found in both the control and weeded plots. For both types of plots, *Diospyros abyssinica*, *Celtis africana*, and *Celtis durandii* were the three most abundant species. For those species found in control and weeded plots, their abundance ($r = 0.985$, $p < 0.001$) and their rank order of abundance ($r_{sp} = 0.847$, $p < 0.001$) were highly correlated.

At the end of the study, the number of species that were classed as early (8 species) or middle successional stage (11 species) was identical for weeded and control plots. The number of stems of early (weeded = 74, control = 69) or middle successional stage species (weeded =

Table 1. A description of tree regeneration in weeded and unweeded plots (all stems considered).

Family	*Species*	*Number*	*Abundance Rank*	*Largest DBH*	*Successional Status*
Weeded plots					
Alangiaceae	*Alangium chinense*	3	15	5.2	E
Anacardiaceae	*Pseudospondias microcarpa*	1	17	6.2	L
Annonaceae	*Monodora myristica*	4	14	3.2	L
Apocynaceae	*Funtumia latifolia*	10	10	11.5	E/M/L
Araliaceae	*Polyscias fulva*	8	12	19	E
Bignoniaceae	*Markhamia platycalyx*	5	13	9.3	M
Bignoniaceae	*Spathodea campanulata*	3	15	12.4	E/M
Ebenaceae	*Diospyros abyssinica*	206	1	7	E/M/L
Euphorbiaceae	*Bridelia micrantha*	19	6	8.5	E
Euphorbiaceae	*Sapium ellipticum*	4	14	9.7	E
Flacourtiaceae	*Casearia engleri*	3	15	5.7	?
Flacourtiaceae	*Oncoba routledgei*	2	16	3	E/M
Lauraceae	*Persea americana*	1	17	7.8	I
Leguminosae	*Albizia grandibracteae*	4	14	6.7	E/M
Melianthaceae	*Bersama abyssinica*	23	5	5.8	E
Moraceae	*Ficus brachylepis*	1	17	3.5	L
Moraceae	*Ficus exasperata*	10	10	16	E/M
Myrsinaceae	*Maesa lanceolata*	8	12	14.1	E
Myrtaceae	*Psidium guajava*	1	17	5.1	I
Oleaceae	*Linociera johnsonii*	1	17	2.5	E/M
Oleaceae	*Olea welwitschii*	16	7	6.2	E/M
Rosaceae	*Prunus africana*	15	8	15	E/M
Rubiaceae	*Oxyanthus speciosus*	2	16	9.6	L
Rutaceae	*Clausena anisata*	7	12	3.3	E
Rutaceae	*Fagaropsis angolensis*	34	4	3.2	M
Rutaceae	*Teclea nobilis*	9	11	11	M
Sapindaceae	*Blighia welwitschii*	13	9	6.4	M/L
Sapotaceae	*Mimusops bagshawei*	10	10	7.3	L
Sterculiaceae	*Leptonychia mildbraedii*	2	16	5.4	M/L
Ulmaceae	*Celtis africana*	47	2	23.5	E/M
Ulmaceae	*Celtis durandii*	44	3	9.1	E/M
Ulmaceae	*Celtis zenkeri*	4	14	8.5	E/M
Ulmaceae	*Trema orientalis*	2	16	19.5	E
Verbenaceae	*Premna angolensis*	9	11	5.9	E/M
Control plots					
Alangiaceae	*Alangium chinense*	3	17	6.2	E
Anacardiaceae	*Pseudospondias microcarpa*	4	16	5	L
Annonaceae	*Monodora myristica*	1	19	1.8	L
Apocynaceae	*Funtumia latifolia*	34	6	20	E/M/L
Araliaceae	*Polyscias fulva*	12	12	17	E
Bignoniaceae	*Markhamia platycalyx*	4	16	9.3	M
Bignoniaceae	*Spathodea campanulata*	3	17	10	E/M
Ebenaceae	*Diospyros abyssinica*	249	1	9.2	E/M/L
Euphorbiaceae	*Bridelia micrantha*	11	13	8.3	E
Flacourtiaceae	*Casearia engleri*	1	19	1	?
Flacourtiaceae	*Dovyalis macrocalyx*	1	19	0.7	E/M
Leguminosae	*Albizia grandibracteae*	11	13	7.6	E/M
Leguminosae	*Newtonia buchananii*	1	19	1.2	M/L
Melianthaceae	*Bersama abyssinica*	23	8	4.2	E
Moraceae	*Ficus exasperata*	9	15	27	E/M
Myrsinaceae	*Maesa lanceolata*	16	10	10.4	E
Myrtaceae	*Psidium guajava*	1	19	3.7	I
Olacaceae	*Strombosia scheffleri*	2	18	2.5	L
Oleaceae	*Linociera johnsonii*	10	14	7.1	E/M
Oleaceae	*Olea welwitschii*	32	7	18.2	E/M
Rhisophoraceae	*Cassipourea ruwensorensis*	1	19	1	M
Rosaceae	*Prunus africana*	15	11	9.5	E/M

continued

Table 1. Continued.

Family	*Species*	*Number*	*Abundance Rank*	*Largest DBH*	*Succesional Status*
Rutaceae	*Clausena anisata*	2	18	3.5	E
Rutaceae	*Fagara angolensis*	35	5	6	M
Rutaceae	*Fagaropsis angolensis*	35	5	4.2	M
Rutaceae	*Teclea nobilis*	11	13	3.6	M
Sapindaceae	*Blighia welwitschii*	40	4	3	M/L
Sapotaceae	*Mimusops bagshawei*	18	9	4.8	L
Sterculiaceae	*Dombeya mukole*	1	19	11.2	E
Ulmaceae	*Celtis africana*	55	2	16.1	E/M
Ulmaceae	*Celtis durandii*	48	3	8.5	E/M
Ulmaceae	*Celtis zenkeri*	3	17	1	E/M
Ulmaceae	*Chaetaeme aristata*	1	19	1	M
Ulmaceae	*Trema orientalis*	1	19	6.5	E
Verbenaceae	*Premna angolensis*	10	14	3.5	E/M

E, early; M, middle; L, late; ?, unknown; I, introduced.

155, control = 197) did not differ between weeded and control plots ($t = 0.415$, $p = 0.681$).

It took two laborers approximately 3 days to carefully weed the 10 plots (1 ha). The typical wage for a laborer in Uganda is approximately 3 dollars a day. Thus, every time one wanted to remove the non-tree growth that might be competing with the regenerating trees, it would cost approximately $18/ha.

Discussion

In severely degraded areas where forest succession is slower than desired by forest managers, plantations of fast-growing trees have been shown to facilitate the establishment and growth of indigenous tree species (Lugo 1992; Parrotta 1993; Parrotta et al. 1997; Harrington 1999; Zanne and Chapman 2001). For example, Zanne & Chapman (2001) found that five plantations in Kibale had higher tree species richness and stem density than nearby anthropogenic grasslands from which they were derived. Because competition control through weeding has been shown to increase the survival and growth of plantation trees (Lowery et al. 1993; Zobel et al. 1987), it seemed logical to suggest that this management scheme would increase regeneration of indigenous trees after removal of the plantation crop. This seemed particularly suitable for Kibale because areas where pine trees had been removed are quickly overgrown with vines, grasses, and shrubs. However, we found no difference in the total number of stems in plots where competing weeds were removed and control plots. Furthermore, the number of stems that had reached a size of 1 cm DBH or higher was greater in the control plot than in the weeded plots, as was species richness. Differences among control and treatment plots varied over time, but at no point did weeded plots show greater regeneration than control plots. After a severe dry season in 1999, there was a die-off in both control and treatment plots, but the intensity of the die-off was more severe in weeded plots. Plants in weeded plots may have experienced more severe water stress, because the canopy was open above them and airflow was not severely impeded by neighboring plants.

These results illustrate the importance of evaluating potential management schemes at the site where they are to be used or a similar site, before implementation. Despite the fact that the literature provided reason to believe that weeding might increase the rate of regeneration of indigenous trees after the plantation crop was removed, it did not. The outcome of these trials might have been different under different conditions. For example, Kibale is in a region with low rainfall for a tropical forest (approximately 1,800 mm annually). If this management scheme was evaluated in a wetter area, the regenerating indigenous trees might not have experienced water stress in the weeded areas, and their survival and growth might have been improved. In addition, if only the area immediately around the regenerating tree was cut, the probability of desiccation might have been less, and the outcome might have been different. However, modification of this management approach in these two ways would only improve the survival of the seedlings. The data we presented suggest that the density in the weeded area would not surpass the density in unweeded areas. Finally, the area in which we evaluated this management scheme was one where the regenerating trees were damaged relatively little during harvest. In areas where portable sawmills are used, logs are rolled much greater distances and there are very few stems left undamaged (R. S. Duncan, personal communication, 2000). If the logs were removed by tractor or caterpillar, the damage and soil compaction would have been even more severe. The weeding of competitors in situations where the existing tree community has been more severely damaged remains untested.

This study was conducted over a 3-year period starting just after the logging of the pines was completed.

Although it is always desirable to have a long time frame to look at regeneration issues, we suspect that the initial period before canopy closure is most critical in determining the species composition of the regenerating forest. In our study at the end of the 3-year study period, the regenerating forest had formed a closed canopy well above the grasses and shrubs, and grasses appeared to be in the process of being shaded out. Although the trees will still be competing with the grass/shrub layer for belowground nutrients, the intensity of the interaction is likely less than that experienced when the trees were seedlings. We suspect that after 3 years the most intense interactions are those among trees competing for access to canopy.

The use of plantations as a means of reforesting degraded areas is a management strategy that has recently received considerable attention and appears to be growing in popularity (Lugo 1992; Parrotta 1992). Given the large national debt, low gross domestic product, and the demand for fuelwood and timber of many tropical countries (FAO 1999), it seems almost inevitable that these plantations will be harvested. Thus, understanding post-harvest regeneration is critical. This study illustrates the importance of evaluating and field testing potential management options. Before the use of plantations is adopted as a conservation tool, we must carefully consider the long-term likelihood of success.

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