Research Article

Fire control as a simple means of promoting tropical forest restoration

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Abstract

Tropical deforestation is occurring at an alarming rate. The loss of these forests contributes significantly to total global carbon dioxide emissions and accelerating rates of climate change; moreover, many deforested lands lose fertility and are abandoned. Demands to protect biodiversity and reverse climate change call for efforts to reforest such lands, and one method is through fire control, as fire suppresses tree regeneration. Unfortunately, the success of fire control is often not known for tropical regions because research efforts must span decades. We compared above ground biomass in two plots of regenerating forest that were protected from fire for 12 and 32 years in Kibale National Park, Uganda. Tree biomass of the plots was substantial, and while the biomass of the 12- and 32-year plots did not differ significantly, the 12-year plot had a higher biomass in the small diameter classes in comparison to the 32-year plot. Twenty-four tree species were growing in 12-year plot, while 46 grew in the 32-year plot. We conclude that fire exclusion is a promising approach for tropical forest restoration, and we demonstrate that it is cost-effective relative to programs that plant tree seedlings.

Keywords: reforestation, regeneration, Kibale National Park, Uganda,

Resumen

La deforestación de los bosques tropicales esta ocurriendo a tasas alarmantes y su pérdida contribuye significantemente a las emisiones totales de dióxido de carbono acelerando así el calentamiento global. Sin embargo, muchas áreas deforestadas pierden su fertilidad y son rápidamente abandonadas, por lo tanto ante la urgente necesidad de proteger la biodiversidad y detener el calentamiento global es necesario reforestar dichas áreas. Aquí comparamos la biomasa vegetal de dos parcelas con bosque en regeneración que fueron protegidas del fuego hace 12 y 32 años en el Parque Nacional Kibale, Uganda. La biomasa de arboles encontrada en las parcelas fue substancial y aunque no difiere significativamente entre parcelas la parcela de 12 años tiene una biomasa más grande en las clases de menor diámetro en comparación con la parcela de 32 años. Se encontraron 24 especies de árboles en la parcela de 12 años mientras que 46 especies fueron encontradas en la parcela de 32 años. Concluimos que la protección contra el fuego es un manejo promisorio en la restauración de bosques tropicales y también demostramos que es efectivo en términos de costos en relación con programas que incluyen plantar árboles.

Palabras clave: reforestación, regeneración, Parque Nacional Kibale, Uganda.

Received: 23 May 2011; Accepted: 11 July 2011; Published: 26 September 2011.

Cite this paper as: Omeja, P.A., Lwanga, J.S., Obua, J. and Chapman, C. A. Fire control as a simple means of promoting tropical forest restoration. *Tropical Conservation Science* Vol. 4(3):287-299. Available online: www.tropicalconservationscience.org

Introduction

Estimates suggest that forests of the world are being destroyed at a rate of approximately 200 km^2 a day [1]. This deforestation and other land use changes are estimated to have released 150 billion metric tons of carbon into the atmosphere since 1850, approximately one fifth of the total carbon in the atmosphere [2]. The third largest source of emissions [3, 4], deforestation currently accounts for approximately 18% of global carbon emissions. This has contributed to the warming of the earth's climate by approximately 0.6 °C over the past 100 years; some estimates suggest that the climate will warm up by 5.8°C this century [5, 6]. Many formerly forested lands rapidly lose soil fertility and are subsequently abandoned [7, 8]. As a result, it is estimated that globally there are 350 million ha deforested and another 500 million ha degraded tropical forests; many of these areas have since been abandoned [9, 10].

If reforestation occurred within a reasonable time frame (i.e., years to a few decades) [11], the carbon originally released into the atmosphere at the time of deforestation could be re-captured and sequestered in tree biomass, negating the effect of the carbon emissions on global warming. However, unlike treefall gaps and other naturally disturbed areas, the regeneration of secondary forests on anthropogenically disturbed lands does not always follow predictable pathways [12, 13], and regeneration is often arrested [7, 14, 15]. Such arrested succession has been attributed to a number of factors, including degraded soils, competition from undesirable species such as grasses, and the action of animals [16-18]. Lands on which succession is arrested are typically biologically impoverished. Demands to protect biodiversity and reverse climate change call for habitat restoration [19, 20]. However, in many areas of the tropics restoring lands represents a particularly challenging problem because of the size of the areas and the number of species involved, making artificial restoration logistically very difficult and costly. For example, forest restoration is estimated to cost $250,000 US per km^2 on bauxite mined land in the Amazon [21] and $120,000 US per km^2 in Kibale National Park, Uganda on abandoned agricultural lands that were replanted with tree seedlings [22].

There are reasons to be optimistic for some areas. Rates of forest recovery can be accelerated if prior land-use intensity was low, if recovering areas are relatively small, if soils are fertile, if areas are not colonized by herbaceous growth or grasses that suppress tree establishment or growth, and if there are remnant forest areas nearby to act as seed sources [18, 23, 24]. In such situations, isolated residual trees often become focal points for further seed recruitment [25, 26]. This may be because they act as perch trees for frugivorous birds or because these trees partially shade out competitive open-field herbs and grasses [27]. However, the situation is not always so positive. Where woody species do not quickly establish, invasions by grasses often take their place. These grasses increase the likelihood of fire, which inhibits the establishment of woody vegetation and arrests forest regeneration [23] (Fig. 1).

Although fire is a natural component of many forest ecosystems, it is not a natural component of a number of moist or wet tropical ecosystems. In many locations fire frequency is elevated as the result of burning to improve pastureland, to clear land for agriculture, or to flush wildlife to facilitate hunting. Today most forest fires in tropical regions are anthropogenically set for a number of reasons including: deliberate deforestation (e.g., forest conversion to establish cattle grazing lands), slash and burn cultivation; rangeland regeneration for grazing; driving animals to facilitate hunting; accidental expansion of fires from agricultural lands to protected areas; traditional use (e.g., religious and tribal ceremonies); and political and socio-economic conflicts over land use and ownership rights (e.g., land use conflicts) [28].

In this paper we measure the size and amount of above-ground biomass in two plots in Kibale National Park, Uganda that have been protected from fire for 12 and 32 years; hereafter called the 12-year and 32-year plots. Some tropical rainforests, like that of Kibale, are thought to be fire resistant environments because of high atmospheric and soil moisture levels, two rainy seasons, and the fact that major wild fires have historically been very rare events [29]. However, Kibale`s landscape was degraded by cultivators and abandoned shortly after 1900 [30-32], and fire-maintained grasslands, resulting from uncontrolled fires, have remained serious impediments to restoration [33]. To determine whether fire exclusion might allow grasslands to regenerate to forest in a timeframe suitable for many restoration efforts, we compared tree species richness, Diameter at Breast Height (DBH), Diameter at Ground Height (DGH), and total woody biomass accumulation at each plot. We predicted (1) that each of these parameters would be greater in the plot protected for a longer time and (2) that the nature of the regeneration would suggest that successful fire control is a useful tool in the restoration of this type of forest.

Methods

Study Area

The study was conducted between February and April 2007 in the Ngogo research compartment of Kibale National Park, Uganda (Fig. 1). The park covers 795km^2 and is located in western Uganda (0 13' - 0 41' N and 30 19' - 30 32' E), near the foothills of the Ruwenzori Mountains [34]. Kibale is a mid-altitude, moist-evergreen forest receiving 1707 mm of rain annually (1990-2010), with more rain falling in the north than the south.

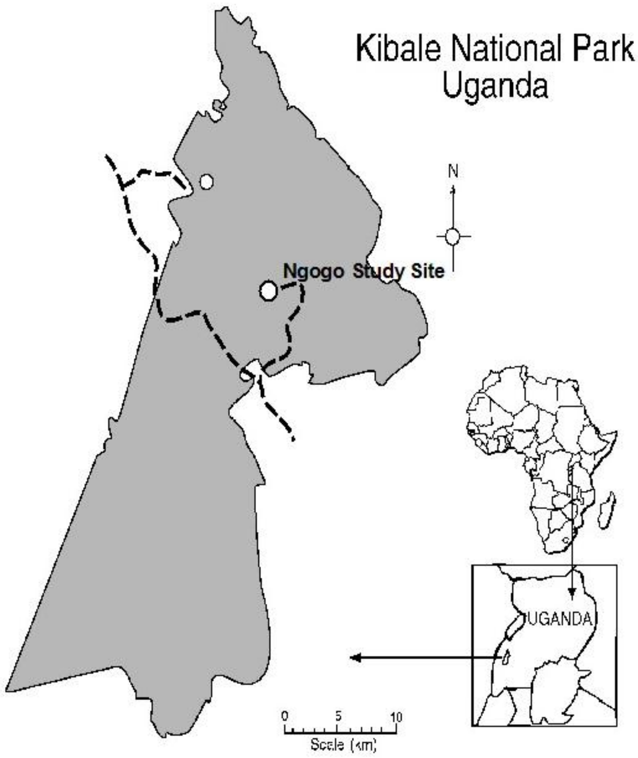

Fig 1: A map showing the location of the Ngogo study site within Kibale National Park, Uganda (the second circle is the site of the Makerere University Biological Field Station where the majority of the research from Kibale originates).

Early records by Osmaston [30] and Kingston [32] indicate that there are two grassland areas in the northern section of Kibale and suggest that most of the grasslands in this region result from repeated cultivation, grazing, and burning. These grasslands were dominated by tall elephant grass (*Pennisetum purpureum* Schumach). Forest has begun to re-establish in some grasslands; however, fire maintains the grassland in most areas [35]. Fire regimes vary depending on location. Fire occurs more frequently, often almost annually, on the edge of the park as fires set to burn agricultural lands or pasture easily spread into the park. In areas remote from outposts of rangers of the Uganda Wildlife Authority and researchers, fires are set by poachers to drive wildlife, and fire frequency is less predictable (i.e., from annually to once approximately every 5 years). The Ngogo grassland is in the center of the park and has been partially protected from fires since the 1970s by the activity of the researchers and the presence of park rangers [35].

When Ngogo research camp was established 35 years ago, the grassland around the camp and within the trail system started receiving fire protection [35]. The effectiveness of this protection was not uniform throughout the area, as some areas burnt at different times. The plots have been monitored since 1975, and times of fire incidences are known [35]. The 12-year plot (0.5 ha) is bordered by a motorable track on the western side and firebreak on either side. It burnt in 1996. In contrast, the 32-year plot (0.5 ha) was open grassland and has not burned since monitoring began in 1975.

Plot layout and biomass estimation

Plots were 0.5 ha. (100 m x 50 m) and within each plot 21 subplots of 0.02 ha (20 m x 10 m) were established. Plants in these subplots were enumerated according to their size: all trees >10cm DBH and/or >2m high were measured. To assess seedlings, saplings, and ground vegetation, we randomly established ten small sampling areas (1 m x 1 m) per subplot. For each of the seedlings, saplings, and mature trees we identified the species, and measurements were made of stems if DBH was above 1.3 m, and DGH 0.3 m above the ground. Species identification was based on a number of recognized plant keys [36-39]. Ideally, when fire control was initiated, control plots would have been established; however, this was not done because initially this was simply an effort to promote regeneration. However, areas adjacent to the control plots where fire control was not done are to this day grasslands with a few acacia trees that are resistant to fire (Fig. 2a,b).

To estimate the biomass accumulation of trees in each plot, we selected sample trees of varying sizes for harvest and determined their dry weight [40]. Trees in forest lands adjacent to the park were identified, DBH and DGH measured, the trees were felled, and their total stem lengths measured. Trees were selected that were similar in size to those regenerating in the plots (i.e., DBH 1.1 – 10.0 cm and DGH 1.6 – 11.0 cm; within the weights of 0.25 – 10 kg; n = 200). Choice of tree species for biomass estimation was based on a survey of the vegetation in the regenerating study area. In total, 200 stems (20 stems per species) were harvested. The species included *Albizia grandibracteata* Taub., *Bridelia micrantha* Baill., *Celtis africana* Burm. f., *Celtis durandii* Engl., *Clausena* spp, *Maesa lanceolata* Forssk., *Funtumia latifolia* Stapt, *Milletia dura* Dunn., and *Trema orientalis* Blume. First, stems and leaves were removed and air dried until constant dry mass was attained. Second, the tree stems were cut into small sections and air dried. Once all components had reached a constant dry weight, the total weight of the tree was quantified. These results provided above ground woody tree species dry biomass estimates used to calculate overall biomass in the plots.

From this dry mass data, allometric relationships were developed between stem diameter (DGH) and above-ground biomass. We developed our own predictive equations because published allometric equations are typically site-specific, reflecting the original objective for which they were developed [41, 42]. Where general allometric relationships have been developed, they typically have been reliant on the combination of regression equations to produce either species-specific allometry or allometry for groups of species [43, 44].

Data Analysis

We developed regression equations to predict above-ground dry tree biomass from DGH with log transformed data. The DBH and biomass were compared between the plots using a Mann-Whitney test where subplots were considered the independent unit. Non-parametric analyses were appropriate because as expected the dataset contained many small individuals and thus was skewed to smaller sizes.

We computed two non-parametric estimators of species richness (Abundance-based Coverage Estimator (ACE) and Chao1) using the software EstimateS version 7.5 [45]. Chao1 is based on the number of singletons (species with one individual) and doubletons (species with two individuals), whereas ACE is based on the number of species found with ten or fewer individuals [46]. The sample order was randomized 50 times without replacement, and the mean and standard deviation were computed for each value of N, where N is the number of subplots within each site [45].

Fig. 2 a) An area of Kibale National Park, Uganda where forest was cleared for agricultural use and then has not regenerated to forest since it is frequently burnt. b) A typical area of young regenerating forest that has been protected from fire.

Results

Using DGH the dry biomass of trees was predicted by the equation y=2.053x + 2.056 (R^2 = 0.653, n =200, where y is dry biomass in kg and x is log10 DGH (cm) measured at 0.3 m from the base). Biomass of the tree species in the 12-year plot was 34,297 kg /ha (n = 1331 measurable stems), while the biomass in the 32-year plot was 29,860 kg/ha (n = 1256 measurable stems). Counter to what might be expected there was no difference in the biomass between the plots (Mann-Whitney U=190, P=0.443), nor did total DGH differ between the plots (U=177, P=0.274; Fig. 3). The 12-year plot had a higher biomass in the small diameter classes (0.8 – 10 and 10 – 19.9 cm DBH) than in the 32-year plot, which had a greater proportion of its tree biomass in the larger DBH classes (Fig. 3. Appendix 1).

Fifty tree species were identified, in both plots: 24 in the 12-year plot, and 46 in the 32-year plot. The 12-year plot accounted for 49% (n = 3,014 all stems – includes species in the small 1 x 1 m sampling areas) and the 32-year plot for 51% (n = 3,194) of the total number of stems (n = 6,294 all stems; Table 1). There was a high degree of species overlap between the two plots (Table 1, 2); however, the number of stems of particular species could be markedly different between the two plots (Fig. 3). Non-parametric estimators of species richness suggest that the plots are more similar than indicated by species richness (Table 2).

Table 1 Density of trees (#/ha) of 23 most abundant tree species within the 12-year and the 32-year old plots at the Ngogo study site in Kibale National Park Uganda.

Species	Family	Type	12-year plot	32-year plot
Acacia sp.	Leguminosae	Grassland	180	0
Albizia grandibracteata	Leguminosae	Young Forest	386	442
Bridelia micrantha	Euphorbiaceae	Young Forest	38	2
Cassia spp.	Fabaceae	Young Forest	7	0
Celtis durandii	Ulmaceae	Young Forest	29	96
Clausena anistata	Rutaceae	Young Forest	2	41
Dichrostachys glomerata	Mimosaceae	Young Forest	252	5
Diospyros abyssinica	Ebenaceae	Old Forest	50	463
Dombeya mukole	Sterculiaceae	Young Forest	17	5
Erythrina abyssinica	Papilionaceae	Grassland	77	0
Fagarospsis angolensis	Rutaceae	Young Forest	17	106
Ficus vallis	Moraceae	Young Forest	7	0
Harrisonia abyssinica	Simaroubaceae	Young Forest	130	173
Maesa lanceolata	Myrsinaceae	Young Forest	1,738	180
Markhamia platycalyx	Bignoniaceae	Young Forest	2	12
Mimusops bagshawei	Sapotaceae	Old Forest	5	7
Morus lacteal	Moraceae	Old Forest	2	5
Olea welwitschii	Oleaceae	Old Forest	5	34
Pterygota mildbraedii	Sterculiaceae	Old Forest	2	10
Tabernaemontana holstii	Apocynaceae	Young Forest	41	118
Teclea nobilis	Rutaceae	Young Forest	12	456
Uvariopsis congensis	Annonaceae	Old Forest	5	386
Warbugia ugandensis	Conellaceae	Young Forest	22	149

Discussion

Our results indicate that fire protection of grassland in Kibale National Park has resulted in rapid establishment of trees, suggesting that fire protection is an important tool in restoring tropical forests. Protection from fire allowed tree species to establish, grow, and compete with herbaceous plants and grasses. In terms of tree species richness and biomass accumulation in the two plots, the rate of forest recovery appears to be following a successful trend and is in line with the findings of previous studies demonstrating that restoration can be achieved when fire is excluded from a formerly disturbed forested area [47, 48].

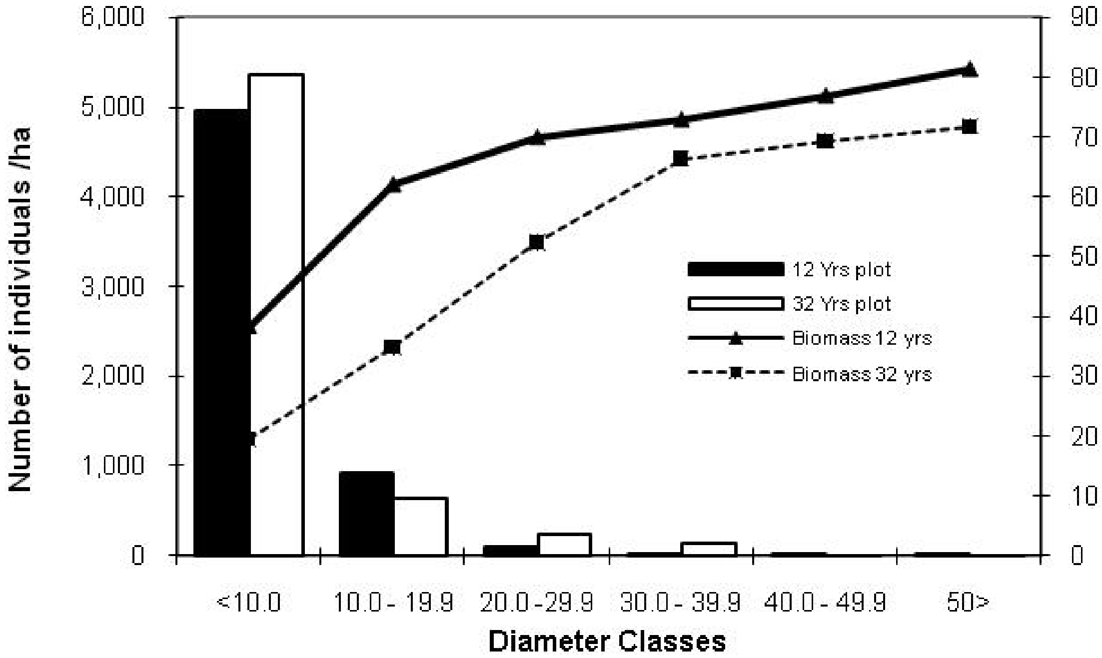

Fig. 3 Comparison of the number of individuals / ha and the total biomass in the different size classes for tree species in two plots in Ngogo in Kibale National Park Uganda.

At this site, there are other drivers and processes acting favorably alongside fire prevention to promote recovery of these degraded sites. For example, the proximity of the plots to a mature forest with a high density of animal dispersers and a diversity of mature trees [49] likely facilitated tree regeneration [50-53]. Also, there are a number of seed-dispersing large mammals such as baboons (*Papio anubis* Lesson) and elephants (*Loxodonta africana* Blumenbach) that forage in both forest and grasslands and move seeds between the two habitats [54]. As has been noted elsewhere, the exclusion of fire appeared to facilitate the establishment of early successional tree species that subsequently provided ground cover and facilitated the accumulation of soil organic matter [55].

Table 2 Descriptors and nonparametric abundance-based estimators of species richness by plots in Ngogo site, Kibale National Park, Uganda

Indices	12-year plot	32-year plot
Number of 0.02 ha plots	21	21
Number of species observed	24	46
Number of individuals	1256	1331
Non-parametric estimators		
Abundance-based Coverage Estimator (ACE)	26.3	24.2
Chao1	24.5	22.0
Chao 1 S/D	2.2	2.2

It is worth considering the potential of these sites to facilitate the development of advanced stages of succession. In the 32-year plot, there were more trees that were mid-successional or old-growth species than in the younger plot [as defined by 56, Peter Grubb personel communications 57]. The young forest tree species in the 32-year plot were senescing and were being gradually replaced by slower growing, mid-successional or old forest species (as indicated by the density of *Albizia grandibractata* and *Maesa* *lanceolata* in the two plots, Table 1). This process explains the higher species richness found in the older plot. However, because of advanced age, there is a considerable amount of crown die-back of young forest species coupled with a high volume of dead biomass litter visible on the forest floor in the 32-year plot.

In the absence of fire to reduce the amount of litter accumulation on the forest floor, there may be a steady increase of litter. This will likely have opposing effects. First, establishment of a dense cover of woody debris could lead to the reduction of the grass cover and a facilitation of further tree seedling establishment. Second, this would contribute to the combustible fuel layer. Studies conducted in Tanzania [58] and in the Amazonia in Brazil and Venezuela [48, 59] have shown that one of the most alarming features of the latter scenario is that accidental fires in areas with a very heavy deadwood accumulation can trigger a negative feedback system, potentially leading to the progressive impoverishment and degradation of the forest. High post-burn tree mortality could significantly reduce canopy cover and therefore create a hotter and drier microclimate as more solar radiation passes through to the understory, which could increase the rate of fuel drying [60, 61]. Firebreaks and fire reduction programs must therefore be maintained for a considerable duration until the canopy closes, the microhabitat under the canopy becomes moist, and the biomass of deadwood accumulation is reduced.

Implications for Conservation

Given trends in land use, restoration of tropical forest will be a powerful tool for future conservation. We make the following suggestions that should generally apply to forest regeneration in moist-evergreen forests. First, in many tropical landscapes fire is an important determinant of grassland ecosystems, and the mosaic of forest and grassland habitats is to a large extent the result of the synergistic interactions between past human disturbance and current fire regimes. Second, fire exclusion is a promising method to promote forest restoration for degraded moist-evergreen forests that have been converted to grassland. However, observations suggests that fire prevention must be maintained for decades until both the grass is suppressed by the regenerating trees and the accumulation of deadwood resulting from the senescing of the earliest-established trees is no longer present. Third, while a detailed breakdown of the costs of fire breaks is not available for this study, given the fiscal constraints of re-planting forests in a developing country, we believe the process of natural restoration through fire exclusion is a very practical approach. As a result, this restoration project is a good model for restoration of similar habitats in many developing nations [20].

Acknowledgement

This research was supported by Canada Research Chairs Program, Wildlife Conservation Society, Natural Science and Engineering Research Council of Canada, the Committee on Scientific and Technological Cooperation of the Organization of Islamic Conference, Islamabad, Pakistan, and the International Foundation for Science, Stockholm, Sweden. We would also like to thank the Uganda Wildlife Authority, Uganda National Council for Science and Technology, and Makerere University Biological Field Station for granting permission to conduct this research. The field assistants of Kibale Fish and Monkeys Projects provided very valuable help. We thank Aerin Jacob, Lauren Chapman, and Raja Sengupta for helpful comments on the manuscript.

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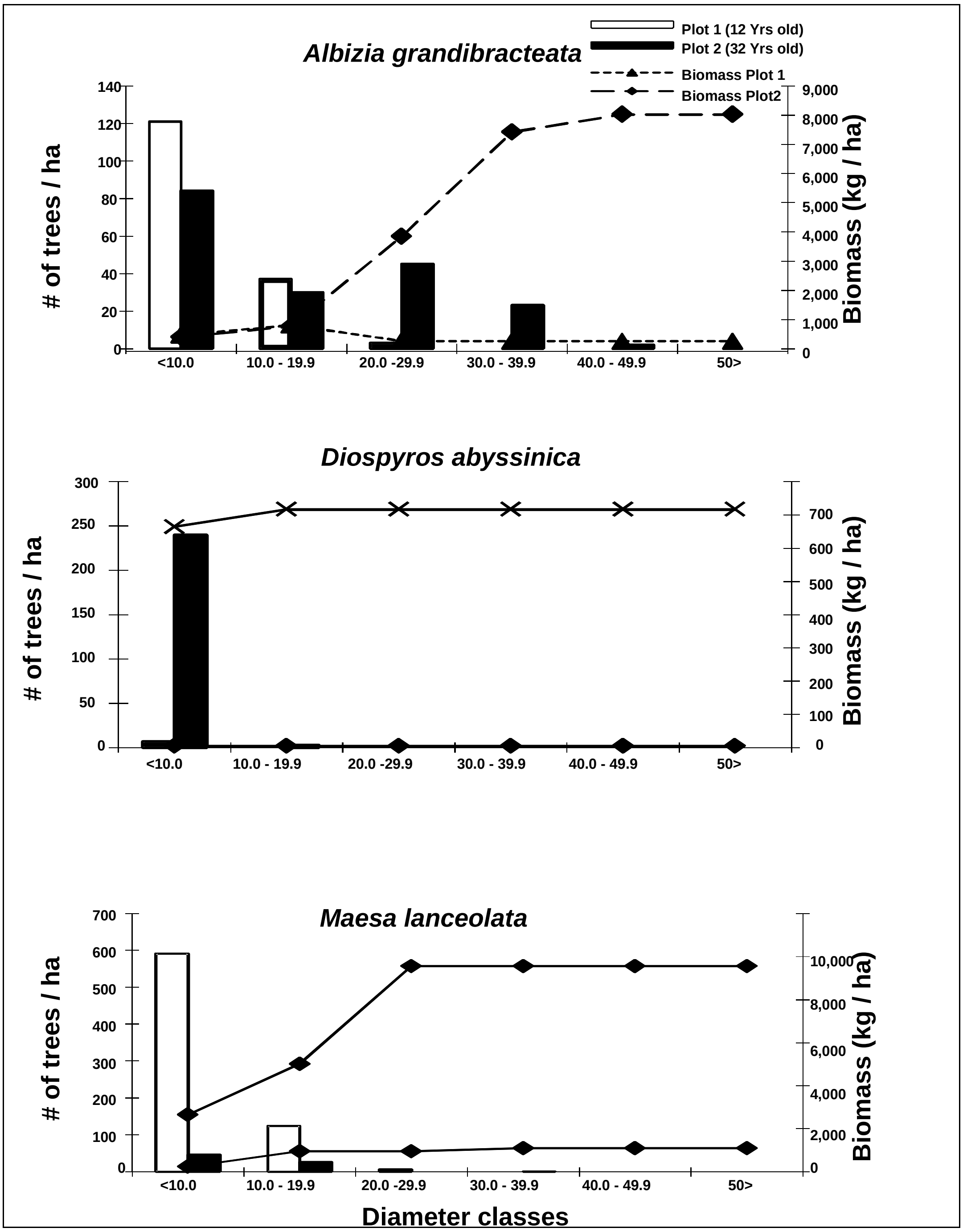
Appendix 1. To to bottom (a) – c) Biomass relationships in the different size classes for six selected trees in the 12 and 32 year plots at the Ngogo site in Kibale National Park Uganda.



Appendix 1 continued. Top to bottom (d) – (f) Biomass relationships in the different size classes for six selected trees in the 12 and 32 year plots at the Ngogo site in Kibale National Park Uganda.