XV WORLD FORESTRY CONGRESS
Building a Green, Healthy and Resilient Future with Forests
2–6 May 2022 | Coex, Seoul, Republic of Korea

Recovery of Tree communities on degraded Tropical forests after Restoration planting

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Abstract

Increasing rates of deforestation in tropical rain forests have been linked to agricultural encroachment. How well trees recover into a more species rich ecosystem after restoration planting remains unclear. The aim of the study was to evaluate the recovery of communities of tree, assess the influence of understory vegetation like *Acanthus pubescens,* and *Pennisetum purpureum*, on the recovery in Kibale National Park (KNP), Uganda. We studied six restored forests fragments ranging in age from 3 to 16 years and three primary forests. Our results showed that although recovery with natural regeneration was more effective than restoration planting the latter enhanced recruitment of native tree seedling. Tree recovery was generally correlated with age so that species density and diversity increased although at different rates. A reverse pattern was found for dominance but no clear pattern was found for tree density. Understory vegetation like *Acanthus pubescens* and *Pennisetum purpureum* negatively correlated with species density, tree density and diversity but a positive correlation was found for dominance. Although restoration planting can enhance recovery, understory vegetation significantly affects recovery of degraded forests. This can affect the cost of restoration of degraded areas

Keywords: *Acanthus pubescens, P. purpureum,* Recruitment, Restoration planting, Tree recovery

Introduction, scope and main objectives

Tropical rain forests are decreasing at an approximate rate of 12.5 million hectares annually due to deforestation and agricultural encroachment (Kobayashi, 2007). These estimates might be higher because illegal activities often go unnoticed. Restoration of forest ecosystems through planting or deliberate seeding is an important management tool for rehabilitating and hastily restoring forests which have lost vegetation cover (Chazdon et al., 2020). However, how the effectiveness and the influence of planted trees on the recruitment of new tree seedlings is less well understood.

In most countries, degraded and secondary forests now exceed areas of primary forests cover (FAO, 2010). For example, between 2000 and 2010, Uganda was among countries with the largest net loss of forest areas approximately 2.6 % per year (FAO, 2010, p.20). In this study, the success of restoration efforts in recovery of tree species communities was assessed in Kibale National Park, Uganda. After the 1994 evictions, tree planting was necessary because woody herbs, shrubs and grasses such as; *Acanthus pubescens* (Acanthaceae), *Aframomum ssp* (Zingiberaceae), *Lantana camara* (Verbenaceae), *Mimulopsis ssp* (Acanthaceae) and *Pennisetum purpureum* (Poaceae) which colonized large parts of the forest precluded colonization and jeopardized tree regeneration. As a result, a mixture of pioneer, intermediate and climax tree species were planted to restore forest cover in the encroached areas (UWA–FACE Project management plan, 2006).

In this study we aimed to; 1) Compare patterns of species density, density (individual / ha), diversity and dominance, in the differently aged restoration, naturally regenerating and primary forests. 2) Compare the recruitment trends of non-planted tree species seedlings in the differently aged restoration, naturally regenerating and primary forests and 3) Assess the influence of *A. pubescens, P. purpureum* and *L. camara* on the recovery tree in the forest.

Methodology/approach

Study area

This study was conducted at Mainaro area, in the southern section of Kibale National Park (KNP), Western Uganda (0'13'-0'41' N and 30'19'-30'32' E). KNP is located near the foothills of the Ruwenzori Mountains, and covers about 795 km^2 (Wasserman and Chapman, 2003). It is a mid-altitude, moist-evergreen forest receiving an average rainfall of 1697mm annually. Rainfall peaks are in March–May and in September–November. After evictions in 1994, Uganda Wildlife Authority (UWA) and Face the Future (previously Forests Absorbing Carbon Emissions (FACE) Foundation) commenced restoration, under a program established and funded by electricity board of Holland. In 1996, site matching was done, and tree species were reduced from 37 to 22, later to 16 in the subsequent years, and finally 10 fast growing species were maintained; (i.e., *Bridelia micranthus, Cordia africana, Cordia millenii, Croton macrocarpus, Croton macrostachyus, Mimusopsis bagshaweii, Prunus africana, Sapium ellipticum, Spathodea campanulata,* and *Warburgia ugandensis*).

We studied communities of trees in six restoration sites hereby classified as Age Class (AC) which are medians of the different years of restoration planting; (AC 3, AC 5, AC 8, AC 11, AC 14 and AC16), and compared them to the Naturally Regenerating Forest (NREG) and three primary forests: Mainaro Primary Forests; MIF 1, MIF 2 and MIF 3. Plots ranging between 20-41 (sample replicates) were randomly established in each of the six reforested sites (a total of 124 plots), 41 in naturally regenerating forest and 63 plots in the three primary forest compartments using a grid system (Table 1).

Table 1. Description of the different aged restoration, naturally regenerating and the primary forests in Kibale National Park (KNP), Uganda.

Restored, regenerating & primary forests	Median years since restoration	Years of replanting	Number of plots
AC3	3	2010-2011	20
AC5	5	2006-2008	20
AC8	8	2003-2005	20
AC11	11	2000-2002	21

AC14	14	1999	22
AC16	16	1994-1996	21
NREG	N/A	Regenerating	41
MIF1	N/A	Primary forest	20
MIF2	N/A	Primary forest	23
MIF3	N/A	Primary forest	20

Data for: Age Class (ACs) and Naturally Regenerating (NREG) obtained from the replanted area compartments of different years (UWA– Face Project management plan, 2006). Age data for ACs are median of years of restoration planting.

Measuring tree communities

For each plot, we measured the trees and diameter of those at least 1.3 m tall (diameter at breast height, dbh). Four nested plots were used; for large / mature trees (dbh > 20 cm), small trees / poles (dbh 10–20), saplings (diameter 5–10 cm) and seedlings (diameter < 5 cm) measured at the root cap. Large trees, small trees, poles and seedlings were measured in plot sizes of 40 m x 20 m, 20 m x 20 m, 20 m x 10 m, and 10 m x 10 m respectively. For each plot, the cover of *Acanthus pubescens, Lantana camara* and *Pennisetum purpureum* were separately and visually estimated in percentages: 0, <1% = <0.5, <10% = <1, <20% = <2, <30% = <3, <40% = <4 etc.

Data analysis

For each study plot, we evaluated overall and tree seedling data separately for, (1) Species density, (2) Tree density (individuals / ha), (3) Simpson diversity index (Simpson's D = $1 - \Sigma((N_i*(N_i - 1)) / (N*(N - 1)))$; where N_i = number of individuals in species *i* and *N* = total number of individuals) and (4) Berger-Parker dominance index (proportion of all individuals represented by the most abundant species, P_{max}; Magurran and McGill, 2011). We tested each of the univariate variables separately with one-way ANOVA, including pair-wise post-hoc tests (Tukey). To test for the influence of *A. pubescens, P. purpureum* and *L. camara* cover on species density, tree density, basal area, diversity, and dominance, Spearman Rank order correlation and regression analysis were fitted, cover of any of the herbs, shrubs and grasses were the explanatory factor. The distributions of *A. pubescens, P. purpureum* and *L. camara* covers were compared with Kruskal-wallis test.

Results

An overall total of 19 517 trees representing 118 taxa were sampled from 228 study plots across the differently aged restoration, naturally regenerating and primary forests. The primary forests had the highest tree species. The naturally regenerating forest had more tree species compared to the differently aged restoration forests. But among the restoration, the highest number of species was recorded in AC 16 (49) and the least in AC 3 (19).

Species density, tree density, diversity and dominance patterns

We found significant differences in species density and Simpson's D values between the six restoration forests, naturally regenerating and primary forests (Species density, ANOVA, $F_{9,218} = 122.64$, $P < 0.001$; Simpson's D values, Kruskal-Wallis test, $\chi^2 = 128.79$, df = 9, $P < 0.001$; Fig. 1d). In addition, the naturally regenerating forest had substantially higher species density and diversity compared to the restoration forests. Species density and diversity were lower among recently planted areas (AC 3-8) compared to

source

the oldest reforestation (AC 11-16). There was a significant difference in tree density (individuals / ha), among the restoration, regenerating and primary forests ($F_{9,218}$ = 28.13, P < 0.001). Tree density increased with age among the recently planted areas (AC 3-8). However, for the subsequent years, there was a slight decrease in tree density amongst the oldest restoration areas (AC 11-16), so that there density (individuals / ha) were similar (P > 0.05) to recently planted 5 years ago (AC 5). In addition, the primary forests (MIF 1-3) had substantially higher tree density compared to the regenerating and restoration forests (Fig. 1b). Berger-Parker dominance index values differed between differently aged restoration sites and primary forests (Kruskal-Wallis test, χ^2 = 104.14, df = 9, P < 0.001). Dominance declined along the restoration gradient, so that the recently planted areas AC 3-8 had significantly higher dominance compared to the older restoration sites AC 11-16 (Fig. 1e).

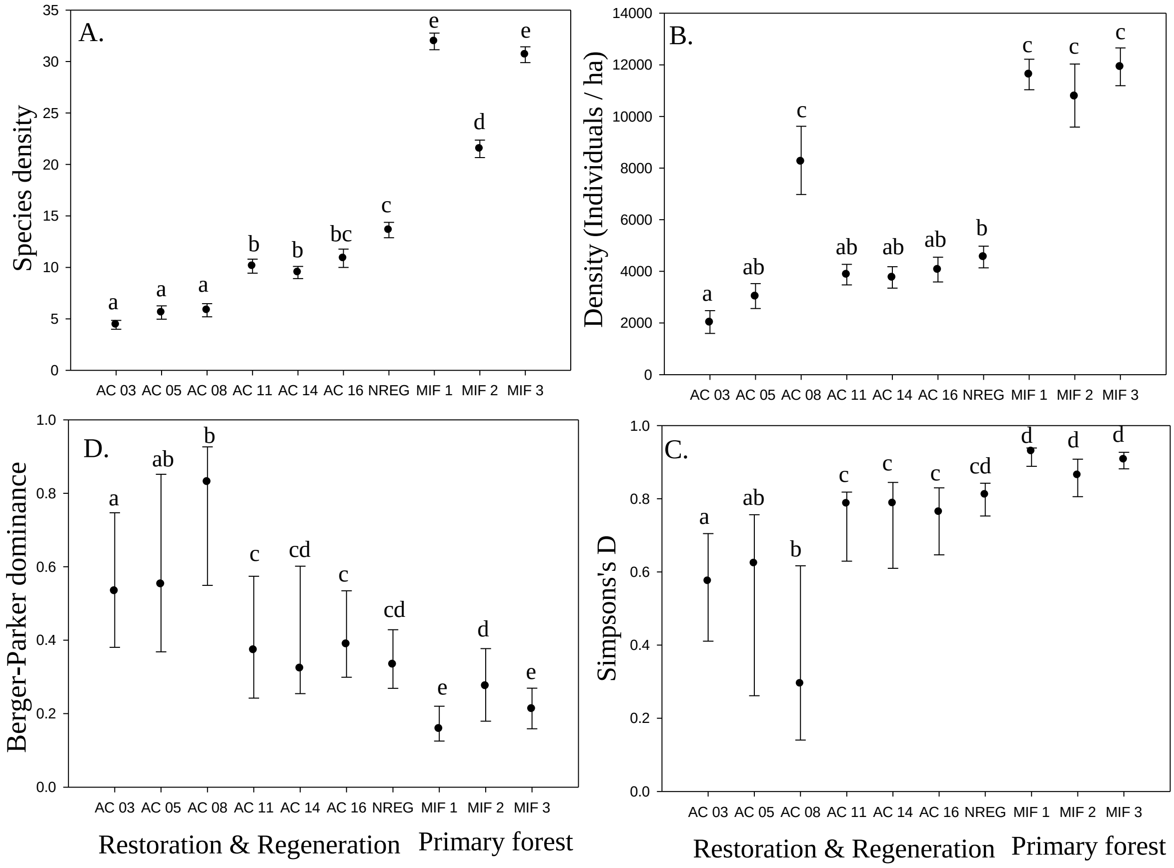

Fig 1. The averages (± SE) of A) Species density, B) Tree density (individuals ha^{-1}), C) Simpson's diversity and D) Berger-Parker dominance in the restoration, naturally regenerating and primary forest in KNP, Uganda. Species density and Tree density values represent back-transformed values. Bars are SE and different letters represent significant differences (Tukey's HSD, *P* < 0.05).

Tree seedling communities

We recorded a total of 13 335 tree seedlings in the study. The highest numbers were in the primary, followed by the naturally regenerating forest. Meanwhile, among the restoration forests the highest were in AC 8 and the least were in AC 3 (Fig 2). We also found that 60 tree seedlings recruited in the naturally regenerating forest compared to 59 non-planted tree seedlings species in the restoration forests. The highest recruitment of seedlings species were 40 species in AC 16, followed by 38 species in AC 14, 33 species in AC 11, 21 species in AC 8, 29 species in AC 5 and the least were 16 species in AC 3. There were significant differences in seedling density (individuals / ha), among the restoration, regenerating and primary forests ($F_{9,218}$ = 23.60, P < 0.001). There were significant differences in diversity of tree seedlings among the restoration, regenerating and primary forest (Kruskal-Wallis test, χ^2= 123.75, df = 9, P < 0.001). Although we found variations among the restoration forests, seedling diversity was lower in the recently planted sites (AC 3-8) compared to the oldest sites (AC 11-16) and regenerating forests. Berger-Parker dominance index values also differed between the seedling communities in the different forests ($F_{9,218}$ = 20.15, P < 0.001).

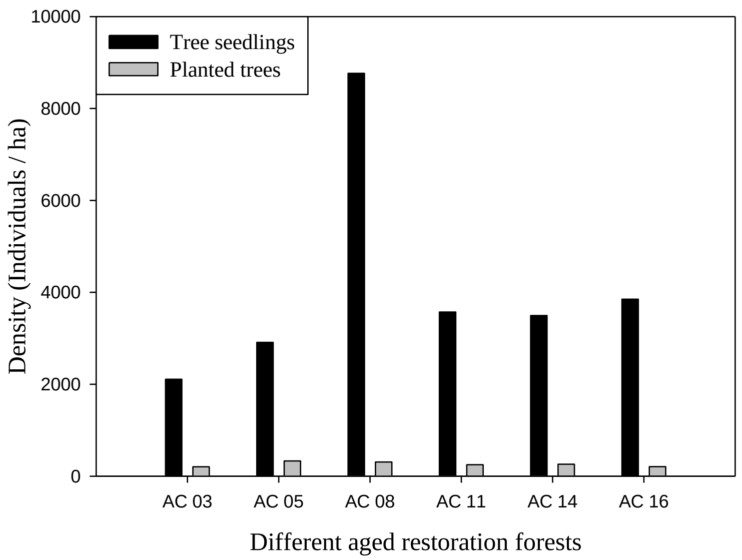

Fig 2. Average tree density (Individuals ha^{-1}) and population structure of non-planted naturally recruiting tree seedlings as influenced by planted trees in the differently aged restoration forests

Influence of Acanthus pubescens, Pennisetum purpureum and Lantana camara on tree communities

The percentage cover of *A. pubescens* (Kruskal-Wallis test, χ^2 = 83.22, df = 9, P < 0.001)*, P. purpureum* (χ^2 = 165.11, df = 9, P < 0.001) and *L. camara* (χ^2 = 102.16, df = 9, P < 0.001) significantly differed among the different restoration forests, naturally regenerating and one plot of the primary forest (MIF 2). At plot level, *A. pubescens*, *P. purpureum* and *L. camara* cover correlated negatively with species density, tree density and Simpson's D, but a positive correlation was found for dominance. We also found that species density, tree density and diversity declined in nearly all plots especially where *A. pubescens, P. purpureum* and *L. camara* cover was mostly found (Fig 3). When considered separately, *P. purpureum* had the strongest influence on the recovery compared to *A. pubescens* and *L. camara.* But the effect of *P. purpureum* was stronger on tree dominance (R^2 = 0.58) when compared to *A. pubescens* (R^2 = 0.23) and *L. camara* cover (R^2 = 0.06). Also, *L. camara* had the least negative influence on the recovery of trees.

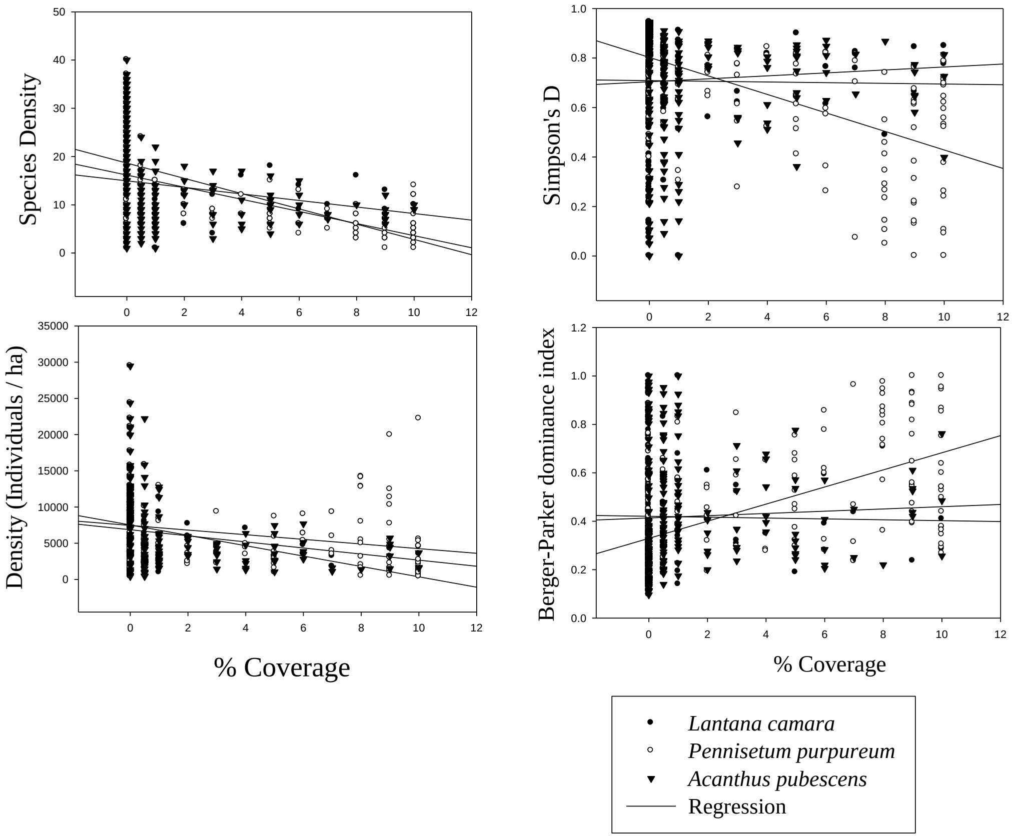

Fig 3. Scatterplots of tree communities in 228 study plots, showing influence of *Acanthus pubescens, Pennisetum purpureum* and *Lantana camara* cover on Species density, Tree density (individuals / ha^{-1}), Simpson's D, and Dominance using Regression and Spearman Rank order correlation (R^2). Plots represent the six restoration, naturally regenerating and three primary forests.

Discussion

We have demonstrated that natural regeneration is more effective than restoration planting in enhancing tree community recovery. Notably, restoration planting can reestablish forests with high species density, tree density and diversity, but these dependents on the age and the extent of any of the understorey vegetation such as herbs, grasses and shrubs cover.

We found that restoration planting facilitated the recruitment of non-planted tree seedlings among the different aged forests. Again, seedling recruitment generally correlated with age after planting, so that newer seedling species were recruited in each age class along the gradient. Our findings concur with Omeja et al., (2011), that many tree species naturally established under planted trees of KNP. This is possibly because, restoration planting might have provided artificial perching structures and food resources for seed dispersing birds and mammals which subsequently accelerated seed deposition Guariguata and Ostertag, (2001) in the different forests. In an earlier study, Omeja et al., (2011) recorded 39 new tree species, but here we found that 59 tree species had established. In other words 20 new tree species established in the KNP restoration area. One significant contribution of the UWA-FACE restoration program has been facilitation of recruitment of new indigenous trees species in the former extensively degraded forest. Accordingly, we illustrated that recruitment of new species was accompanied by gradual increases in species density and diversity along the restoration gradient creating a more reasonably rich tree species assemblage. Like (Farwig et al., 2009), we conclude that plantations enhance forest recovery possibly by influencing conditions that support natural recruitment of more new trees species.

We further showed that woody herbs, shrubs and grasses affected tree recovery to various extents. The decrease in species density, tree density and diversity shows how increase in cover of the sub canopy vegetation influences tree growths. However, the variation in cover of *A. pubescens, L. camara* and *P. purpureum* within plots, could have spread out the compounding impact of the sub canopy vegetation, so that even if tree establishment were suppressed, the forest as a whole gradually recovered. Our findings accords well with (Lawes and Chapman, 2006) that sub canopy herbs, shrubs, and grasses inhibits tree recruitment in tropical forests. Further, we showed that *P. purpureum* had the strongest direct effect in suppressing tree recovery. We attributed this to the dispersal and space limitation which arises in cases where *P. purpureum* intensively colonizes an area. The restoration program has been successful, because of the reduction in *P. purpureum* cover, along the gradient, suggestive that *P. purpureum* is sensitive to tree canopy closure. But, unexpectedly trees were more likely to reestablish in areas with *L. camara* than areas dominated by *A. pubescens.* Furthermore *L. camara* had direct negative influence on, species density, tree density, basal area and diversity, a finding consistent with the assertions by Omeja et al., (2011). We attributed this pattern to the growth architecture of lantana, were light infiltration to the ground is restricted resulting in a decline of tree seedlings and changes in species composition and even soil properties (Sharma and Raghubanshi, 2011). We also illustrated that *A. pubescens* cover negatively affected trees in the restoration forests. This might be due to recruitment limitation characteristic of *A. pubescens* dominated areas (Lawes and Chapman, 2006), consequently causing 'arrested succession' Chapman and Chapman (2004). Our findings accord well with Paul et al., (2004) who found that tree seedlings were least in *A. pubescens* dominated areas compared to areas without it.

Conclusions/ wider implications of findings

We conclude that forest recovery is more effective with natural regeneration compared to restoration planting especially if the regenerating forests were not extensively deforested to a threshold below which it cannot recover unaided. restoration planting enhanced recruitment of non-planted tree seedling species. However, *P. purpureum*, *A. pubescens* and *L. camara* growth affected tree recovery, possibly slowing it. We recommend a study on the impact of restoration on costs of managing recovery of degraded forests

Acknowledgements

Permission to conduct this study was granted by the Uganda Wildlife Authority. I thank Sabiiti Richard and Erimosi Agaba, for helping during fieldwork.

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