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REGENERATION OF INDIGENOUS WOODY SPECIES IN THE UNDERSTOREY OF EXOTIC TREE SPECIES PLANTATIONS IN SOUTHWESTERN ETHIOPIA

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ABSTRACT: Regeneration of native woody species in the understorey of exotic plantations and in the adjacent natural forest of a moist montane forest ecosystem was investigated. The objectives of the study were to assess whether exotic plantations in the moist montane forest ecosystem of Ethiopia foster regeneration of native woody species and the effect of plantation density on their regeneration. Quadrats of 10 m x 10 m size were established for the study of population structure and densities of woody species along parallel transect lines within the different plantation stands at every 100 m distance between them. For seedlings, 2 m x 2 m subplots were established within the larger 100 m^2 quadrats. Plant population structure and regeneration status were assessed in arbitrarily defined height classes based on frequency distribution of individuals in each height class. A total of 40 woody plant species belonging to 23 families were regenerated. The highest number of species was recorded for *Eucalyptus camaldulensis* followed by *Grevillea robusta* plantation stand. Similarly, highest density was recorded for the *Eucalyptus camaldulensis* plantation stand. The *Grevillea robusta* stand showed the highest Shannon diversity followed by the *Eucalyptus camaldulensis* plantation stand. Sorenson similarity index showed highest similarity between *Casuarina equisetifolia* and *Grevillea robusta* stands. The natural forest and the *Eucalyptus camaldulensis* plantation stands showed an inverse J-shape population structure. This implies that the population is composed of numerous individuals at the seedling stage, some individuals at the intermediate height classes and few individuals of mature trees, and hence indicates healthy regeneration. The study revealed that native woody species could successfully become established under the canopies of exotic plantations of moist montane forest ecosystem of Ethiopia, but with considerable variation in abundance and diversity of the regenerating species.

Key words/phrases: Population structure; Restoration; Shannon diversity; Sorensen similarity.

INTRODUCTION

Forest degradation and clearance through human disturbances and the deterioration of land productivity due to inappropriate agricultural practices are among the major problems in the tropics (Parrotta *et al.*, 1997). Large areas of forested lands are being cleared for agricultural land expansion,

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timber production and other development activities. In the past three decades, with the objective of meeting the increasing demand for fuel wood, taking off the pressure from natural forests and revitalizing degraded lands, the area for forest plantation has been increasing around the world (Parrotta, 1995; Keenan *et al.*, 1997; Lugo, 1997). For example, against the gross annual loss of 16.1 million ha of natural forest around the world, there was a gain of 3.1 million ha per year from 1990-2000 (Parrotta, 1995). The majority of successful plantations consist of exotic plants such as *Eucalyptus*, *Cupressus*, *Pinus*, *Grevillea* and *Casuarina*. This is possible due to the readily available information on the propagation techniques, species silvicultural behavior and management practices of the exotic species (Jordan and Farnworth, 1982; Demel Teketay, 1996; Mulugeta Lemenih and Demel Teketay, 2004).

On the other hand, plantation forests of native species have been either difficult or unsuccessful because of lack of adequate knowledge on their propagation techniques, ecology, and silviculture management. Various studies have shown that planting exotic trees on degraded sites can dramatically increase the otherwise slow rate of recovery of natural forests (Lugo, 1992; Parrotta, 1995; Keenan *et al.*, 1997; Loumeto and Huttel, 1997). Plantations can recuperate the productive potential of degraded forest land (Shepherd, 1994; Lugo, 1997; Mulugeta Lemenih and Demel Teketay, 2005), and it has been observed that substantial regeneration of native species occurs under these plantations.

Similarly, studies by Friis *et al.* (1996), Yitebitu Moges (1998), Feyera Senbeta and Demel Teketay (2001), Feyera Senbeta *et al.* (2002) and Eshetu Yirdaw (2001) have revealed the potential regeneration of native species under plantation forests in central Ethiopia. These studies have indicated that exotic tree plantations allow the establishment of high concentrations of native tree species in their understorey. All the previous reports (Friis *et al.*, 1996; Yitebitu Moges, 1998; Feyera Senbeta and Demel Teketay, 2001; Feyera Senbeta *et al.*, 2002) were limited to dry Afromontane forest ecosystems of Ethiopia (CSE, 1987; Friis, 1992; NBSP, 2003). However, information is lacking on potential regeneration of native species under exotic plantations of the moist montane forest ecosystems in Ethiopia (Friis, 1992; Kumilachew Yeshitila, 1998; Mulugeta Lemenih and Demel Teketay, 2004). Such information is extremely valuable in the efforts of restoration of native forest flora in the degraded highlands of western Ethiopia (Mulugeta Lemenih and Demel Teketay, 2004).

The specific objectives of the present study were to assess 1) the diversity, density and population structure of naturally regenerating woody species under canopies of exotic plantation forests (namely *Grevillea robusta*, *Casuarina equisetifolia*, *Cupressus lusitanica* and *Eucalyptus camaldulensis*) and in the adjacent natural forest of Jirren in southwestern Ethiopia and 2) the effect of plantation density on the regeneration of native species.

MATERIALS AND METHODS

Description of the study site

The study was conducted at Jirren forest situated 350 km southwest of Addis Ababa (near the town of Jimma) in Oromia Regional State, at 8° 40′N, 37° 55′E. The southwestern plateau of Ethiopia contains precambrian rocks and tertiary lava that lie directly on the crystalline basement (Mohr, 1971). The soils are reddish dystric nitisols. Soil acidity tends to become an environmental problem due to high leaching (Zerihun Woldu, 1999). The average annual rainfall ranges between 1600-2552 mm, and the mean annual temperature varies from 15-25°C (NMSA, 2003). The southwestern forests of Ethiopia are characterized as moist montane forest ecosystems (CSE, 1987; Friis, 1992; Kumilachew Yeshitila, 1998; NBSP, 2003). The Jirren forest consists of a secondary forest, which was deforested some 50 to 60 years ago (Michelsen *et al.*, 1996). Plantation of exotic tree species in the area began some thirty years ago for the purpose of supply of fuel wood and construction poles (von Breitenbach, 1961).

Data collection

For the purpose of this study, the terms "seedling" and "mature tree" were defined as plants with heights < 1.5 m and > 5 m, respectively. To investigate the regeneration and population structure under exotic plantations, quadrats of 10 m x 10 m were established at 100 m intervals along line transects following Muller-Dombois and Ellenberg (1974), which were oriented in an east-west direction. Transects were spaced 100 m apart. A 2 m x 2 m subplot was taken within each 100 m^2 quadrat for the purpose of seedling enumeration and measurement. A similar method was used in the adjacent undisturbed natural forest for comparison. A total of 72 quadrats, 48 from plantations (12 quadrats per plantation) and 24 from adjacent natural forests were studied. In each quadrat the frequency, diameter at breast height and heights of all regenerating woody species were measured and recorded. Plant specimens were collected and identified at the

National Herbarium, Addis Ababa University. The nomenclature of plant species in this paper follows Hedberg and Edwards (1989), Friis (1992) and Edwards *et al.* (1995, 1997).

Data analysis

The study on the population structure, which was defined as the frequency distribution of individuals in arbitrarily defined height classes was carried out based on four classes. The height classes were < 1.5 m, 1.5-3 m, 3-5 m and > 5 m, respectively. Height class distribution diagrams were analyzed with Spearman's rank correlation test (Poorter *et al.*, 1996).

The Shannon-Wiener diversity index (H'), and Shannon evenness (E) were computed following Magurran (1988) and Krebs (1999). Similarity in species composition among the plantation stands was computed using Sorensen similarity index. Correlation test was performed to analyze the relationships between the various plantation stands. Analysis of variance (ANOVA) was used to reveal the effect of the different plantation stands on native vegetation regeneration. Tukey's multiple range test was chosen for the comparison of means because the test is very robust for data with unequal sample size (Day and Quinn, 1989).

RESULTS

Stand structure of the plantation species

Variation in mean diameter at breast height (DBH) and height among the plantation stands was relatively low (Table 1). DBH ranged between 9.5 and 15.3 cm in *Cupressus lusitanica* plantation, 3.7 to 18.5 cm in *Eucalyptus camaldulensis* stand, 6.4 to 18.6 cm in *Grevillea robusta* stand and 9.1 to 18.6 in *Casuarina equisetifolia* plantation stand. The density of planted trees showed considerable variation among the plantation stands. Plantation stand density ranged from 400 to 1200 individuals ha^{-1} in *Eucalyptus camaldulensis* plantation, 600 to 800 individuals ha^{-1} in the *Casuarina equisetifolia* stand, 700 to 1000 individuals ha^{-1} in the *Cupressus lusitanica* plantation and 1100 to 1200 individuals ha^{-1} in the *Grevillea robusta* plantation.

Table 1 Characteristics of plantation stands sampled at Jirren forest.

	Area (ha)	Age (yrs)	Mean basal area ($m^2 ha^{-1}$)	Mean DBH (cm^2)	Canopy height (m)	Density (individuals ha^{-1})
Cupressus lusitanica	150	25-30	13.3	13	22-26	900
Eucalyptus camaldulensis	150	25-30	6.4	9	19-29	900
Grevillea robusta	30	25-30	17.7	15	14-16	1200
Casuarina equisetifolia	20	25-30	8.5	10	19-22	700

The plot size was 100 m^2 in each plantation stand.

Floristic composition and number of regenerating species

A total of 40 woody plant species belonging to 23 families were recorded regenerating both under the plantation and the adjacent natural forest at the study site (Table 2). Under the plantation stands alone, a total of 30 native woody species and 2 exotic species, representing 19 plant families, were recorded.

Table 2 Density (no. of individuals ha^{-1}) of woody plants regenerated under the canopies of the different plantation stands at Jirren forest.

Species name	Family	CL	EC	GR	CE	NF
Acacia negrii	Fabaceae	-	24	-	-	-
Albizia schimperiana	Fabaceae	-	-	-	-	152
Allophyllus abyssinicus	Sapindaceae	-	-	-	-	24
Allophylus rubifolius	Sapindaceae	-	124	432	104	624
Bersama abyssinica	Melianthiaceae	52	424	501	48	600
Calpurnia aurea	Fabaceae	-	1252	2602	48	124
Capparis tomentosa	Caparidaceae	24	-	-	104	-
Carissa edulis	Apocynaceae	576	124	32	-	124
Clausena anisata	Rutaceae	-	776	235	-	424
Coffea arabica	Rubiaceae	-	-	32	104	952
Combretum collinum	Combretaceae	-	52	-	-	-
Cordia africana	Boraginaceae	-	24	-	48	-
Croton macrostachyus	Euphorbiaceae	176	100	32	400	152
Cupressus lusitanica	Cupressaceae	752	24	-	-	-
Dracaena steudneri	Dracaenaceae	-	-	-	-	52
Ehretia cymosa	Boraginaceaea	-	-	32	-	-
Euphorbia ampliphylla	Euphorbiaceae	-	-	-	-	200
Ficus vallis-choudae	Moraceae	-	-	32	48	-
Grevillea robusta	Proteaceae	-	24	-	-	-
Grewia ferruginea	Tiliaceae	-	-	-	-	24
Macaranga capensis	Euphorbiaceae	52	24	-	-	200
Maesa lanceolata	Myrsinaceae	-	124	368	248	252
Maytenus gracilipes	Celastraceae	-	-	-	-	-
Maytenus arbutifolia	Celastraceae	276	624	832	552	1652
Maytenus senegalensis	Celastraceae	-	-	-	48	-
Maytenus undata	Celastraceae	300	24	-	-	-
Millettia ferruginea	Fabaceae	-	-	-	-	300
Myrica salicifolia	Myricaceae	-	-	-	-	24
Ocimum lamiifolium	Lamiaceae	-	4852	-	-	552
Phoenix reclinata	Arecaceae	-	-	-	-	52
Phyllanthus ovalifolius	Euphorbiaceae	-	52	-	-	-
Afrocarpus falcatus	Podocarpaceae	-	-	-	-	324
Pterollobium stellatum	Fabaceae	-	-	-	152	224

Table 2 contd.

Species name	Family	CL	EC	GR	CE	NF
Rhamnus prinoides	Rhamnaceae	-	-	-	-	124
Rubus steudneri	Rosaceae	-	76	69	1000	76
Rytigynia neglecta	Rubiaceae	-	-	133	-	124
Sapium ellipticum	Euphorbiaceae	-	-	-	-	52
Syzygium guineense	Myrtaceae	-	24	32	-	52
Teclea nobilis	Rutaceae	24	100	32	200	-
Vernonia auriculifera	Asteraceae	2100	376	267	3448	-

Forest type: CL= *Cupressus lusitanica*, EC= *Eucalyptus camaldulensis*, GR= *Grevillea robusta*, CE= *Casuarina equisetifolia*, and NF= Natural forest.

The most common regenerating woody species included *Bersama abyssinica, Calpurnia aurea, Clausena anisata, Croton macrostachyus* and *Maesa lanceolata* (Table 2). Among the native woody species regenerated in the plantation stands, three were represented in the upper canopy of the adjacent natural forest, while 27 species were found to be understorey trees, shrubs and climbers.

The different plantation stands showed marked variation in the number of regenerating plant species under their canopies (Table 3). The highest number of species was recorded for *Eucalyptus camaldulensis* plantation stand followed by that of *Grevillea robusta* and *Casuarina equisetifolia* (Table 3). The *Eucalyptus camaldulensis* plantation stand showed a relatively comparable number of regenerating woody species with the natural forest (Table 3). Species richness was significantly different ($p < 0.001$) between the *Cupressus lusitanica* plantation stand and the adjacent natural forest.

Table 3 Species diversity, evenness and number of regenerated individuals recorded in each plantation types at Jirren forest.

Forest type	R	R'	N	H'	ED	N'
C. lusitanica	6*	12*	83	0.90*	0.21*	8584
E. camaldulensis	11	24	71	1.77	0.43	14228
G. robusta	11	17	69	1.78	0.45	11097
C. equisetifolia	12	16	69	1.69	0.40	6856
Natural forest	18*	31*	103	2.3	0.51	9836
p in ANOVA	0.000	-	0.566	0.000	0.007	-

NOTE: R= mean richness/plot, R'= richness/forest type, N= mean number of individuals/plot, N'= total number of individuals, H'= Shannon-Wiener diversity index, ED= evenness.
*Means are significantly different at p= 0.05.

Variation in density of regeneration among the plantation stands

The density of regenerated plants in the plantation stands varied considerably (Table 3). The highest density of regeneration (number of regenerated individuals per hectare) was recorded for *Eucalyptus camaldulensis* plantation followed by *Grevillea robusta* plantation (Table 3). The density of regenerated species ranged from 24 to 576, 24 to

4852, 32 to 2602 and 48 to 1000 individuals ha^{-1} under the canopies of *Cupressus lusitanica*, *Eucalyptus camaldulensis*, *Grevillea robusta* and *Casuarina equisetifolia*, respectively. Similarly, the density of regenerated species ranged from 24 to 1652 individuals ha^{-1} in the natural forest.

Diversity and similarity of regeneration under plantation stands

Shannon diversity index and evenness showed considerable variation among the plantation stands (Table 3). *Grevillea robusta* plantation stand exhibited the highest values of Shannon diversity and evenness followed by *Eucalyptus camaldulensis*. The natural forest, on the other hand, showed higher Shannon diversity and evenness than any of the plantation stands (Table 3).

Highest similarity index was observed between the plantation stands of *Casuarina equisetifolia* and *Grevillea robusta* and also between *Eucalyptus camaldulensis* and *Grevillea robusta* stands. On the other hand, the *Cupressus lusitanica* and *Grevillea robusta* plantation stands showed relatively weak similarity. *Eucalyptus camaldulensis* and *Grevillea robusta* plantations had relatively higher similarity to the natural forest (Table 4).

Table 4 Sorenson similarity index among the plantation stands at Jirren forest.

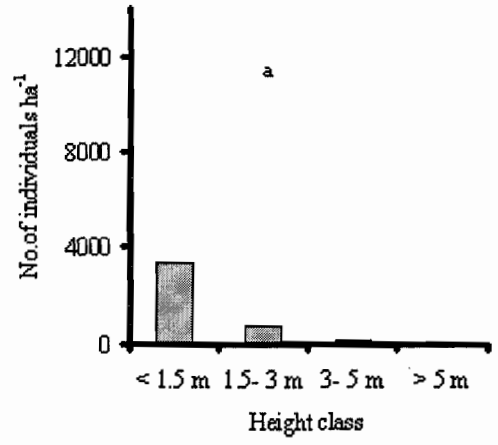
	CL	EC	GR	CE
EC	0.55			
GR	0.41	0.58		
CE	0.42	0.50	0.66	
NF	0.27	0.50	0.5	0.38

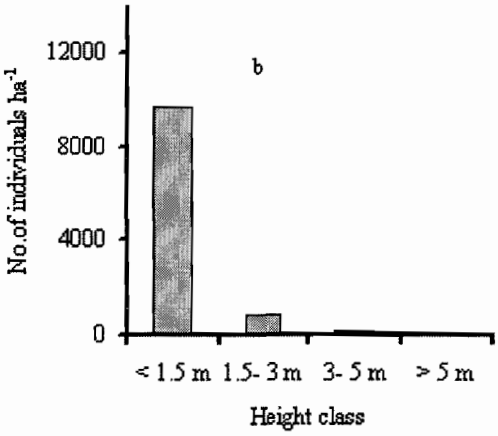
Plantation type: CL= *Cupressus lusitanica*, EC= *Eucalyptus camaldulensis*, GR= *Grevillea robusta*, CE= *Casuarina equisetifolia* and NF= Natural forest.

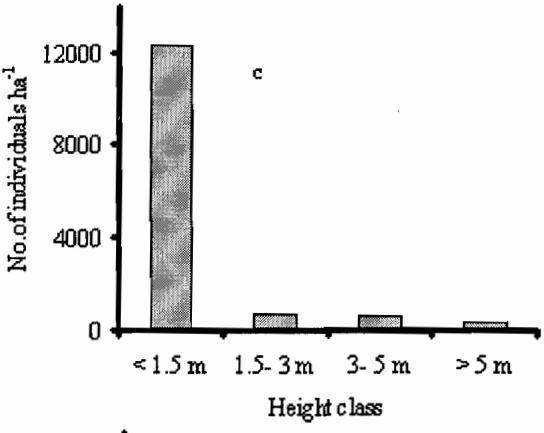
Population structure

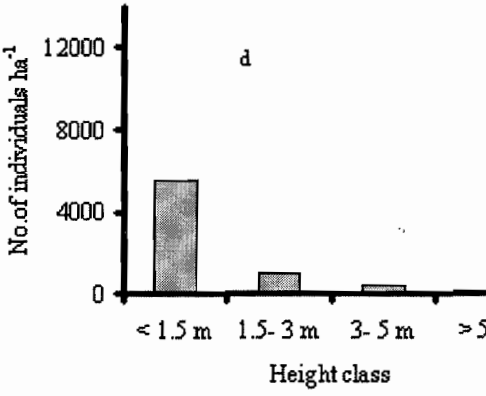
Two major patterns of height class distribution were observed among the plantation stands and natural forest of Jirren (Figs. 1a-e). The first group showed high number of individuals at the lowest height classes, mainly at the seedling stage (< 1.5 m height individuals) and a gradual decline towards the middle and upper height classes. It was to this group that the natural forest, the *Eucalyptus camaldulensis*, the *Grevillea robusta* and the *Casuarina equisetifolia* plantation stands belonged to.

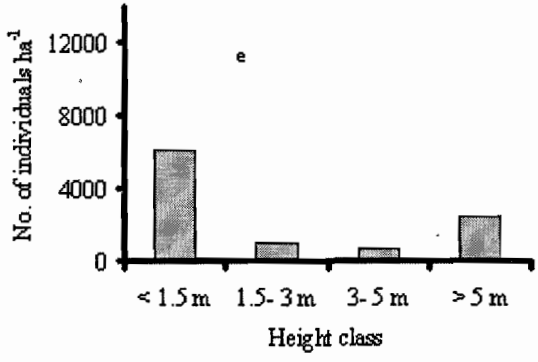
The second pattern showed high number of individuals at the lowest height class but followed by absence of individuals at the upper height class. For instance, individuals in the fourth class were absent in the *Cupressus lusitanica* plantation stand (Figs. 1a-d).











Figs. 1a-e. Frequency distribution of individuals in height classes in the plantation stands and the natural forest at Jirren. a: *Casuarina equisetifolia*, b: *Grevillea robusta*, c: *Eucalyptus camaldulensis*, d: *Cupressus lusitanica*, e: natural forest.

Results of Spearman's rank correlation test for the abundance and height classes of regeneration under each plantation stand showed negative correlation (r_s= -1) for all stands. On the other hand, the adjacent natural forest showed negative correlation coefficient (r_s = - 0.6).

DISCUSSION

The total number of regenerated species at the present study site (40 species) is very close to previous reports from Menagesha forest (37 species) (Feyera Senbeta and Demel Teketay, 2001), but lower than in the Munessa-Shashemene (55 species) (Feyera Senbeta *et al.*, 2002). Of the plant species regenerated under the plantation stand, *Cordia africana*, *Croton macrostachyus* and *Syzygium guineense* species were found to be canopy tree species that also occurred in the natural forest. The most common timber species, such as *Aningeria adolfi-friedericii*, *Afrocarpus falcatus* and *Prunus africana*, were absent under the canopies of the exotic plantation stands.

In the present study, species richness was higher in the *Eucalyptus camaldulensis* plantation stand whereas *Eucalyptus globulus* and *Juniperus procera*, each with 27 species, had higher number of species at Menagesha forest (Feyera Senbeta and Demel Teketay, 2001). In contrast, *Cupressus lusitanica* was represented with higher species richness (30 species) at Munessa-Shashemene forest. Unlike the Munessa-Shashemene forest where *Cupressus lusitanica* had the highest species richness, it was found to be low in terms of species richness in the present study.

The density of regenerated plants in the plantation stands ranged from 6,856 to 14,228 individuals ha^{-1}. The results are within the ranges that have been reported from Munessa-Shashemene forest (Feyera Senbeta *et al.*, 2002) and relatively higher than what was reported from Menagesha forest (Feyera Senbeta and Demel Teketay, 2001). The variation in density of regenerated species could be attributed to the site-specific differences, differences due to species composition or management history of the forests. For example, species of *Calpurnia aurea*, *Ocimum lamiifolium*, *Vernonia auriculifera* and *Maytenus arbutifolia* have pronounced contributions (all having > 1000 seedlings ha^{-1}) to the total density or regeneration of the forests in the present study. The density of regeneration under the *Eucalyptus camaldulensis* was 14,228 individuals ha^{-1}, and similar results were reported from Munessa-Shashemene under *E. globulus* and *E. saligna* plantation

stands. Similarly, *Cupressus lusitanica* plantations showed comparable density of regeneration both at Munessa-Shashemene and in the present study.

The Shannon diversity index was higher for *Eucalyptus camaldulensis* and *Grevillea robusta* plantation stands. A similar result was reported for *Eucalyptus globulus* stand from Menagesha (Feyera Senbeta and Demel Teketay, 2001). This implies that *Eucalyptus* and *Grevillea* plantation stands could be more preferred to other exotic species for the purposes of ecosystem restoration through exotic plantations and maintenance of biodiversity on degraded fields.

The Sorensen similarity indices showed relatively close similarity between the *Casuarina equisetifolia* and *Grevillea robusta* plantation stands, because the two stands share higher number of species in common and also their close proximity to each other. On the other hand, *Eucalyptus camaldulensis* and *Grevillea robusta* plantation stands have greater similarities to the natural forest than to the other plantation stands. The similarity between these plantation stands and the natural forest could be attributed to the position and closeness of the distance between them. The closeness of the distance would help sufficient amount of fruits or seeds to reach plantation stands through dispersal which also enhances the chances of seed germination as well as regeneration.

Patterns of population structure in the natural forest and all the plantation stands showed a good representation of individuals at all size classes implying that a healthy regeneration is taking place. They had high number of individuals at the seedling stage and a gradual decrease towards sapling and mature trees indicating continuous or good regeneration. Such patterns, commonly referred to as reverse "J" distribution, represent stable population structures (Silvertown 1982; Getachew Tesfaye *et al.*, 2002).

On the other hand, the number of larger-sized individuals in the upper height class was relatively higher in the natural forest implying the presence of good number of mature tree population for seed/fruit production for future regeneration (Getachew Tesfaye *et al.*, 2002). A similar population structure or healthy plant regeneration status has also been reported from the plantation stands and the natural forest of Munessa-Shashemene (Feyera Senbeta *et al.*, 2002).

IMPLICATION FOR RESTORATION

Our results indicate that native forest species can successfully be established under the storey of exotic plantation stands in moist montane forest ecosystem of Ethiopia, but with marked differences in number of species and density of regeneration between different species. This considerable variation, both in abundance and diversity, could be attributed to the presence of seed sources (mother trees) within the vicinity of the plantation stands and their seed/fruit dispersal. The two plantation stands namely, *Eucalyptus camaldulensis* and *Grevillea robusta* supported relatively higher density of regeneration, implying their significance to foster regeneration of native flora on degraded sites.

Unlike previous studies from Munessa-Shashemene and Menagesha forests, the present study showed absence of regeneration of the most dominant as well as important timber species, for example, *Aningeria adolfi-friedericii*, *Afrocarpus falcatus* and *Prunus africana* under the canopies of the plantation stands. This could be attributed to scarcity of seed sources or the ecological requirements for seed germination and seedling growth of the species. An understanding of the ecological factors such as the availability of seed sources, seed dispersal and other environmental requirements for seed germination and seedling growth of the species under the canopies of exotic plantations is crucial in the restoration of degraded areas with native flora including the most common timber species. The fact that numerous native woody species were recorded under the different plantation stands suggests that restoration of these systems to native forest vegetation is a potential management alternative for degraded mountain areas in southwestern Ethiopia.

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