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Full Length Research Paper

Comparison of post-fire planted and natural dry semi-deciduous forest communities in Ghana

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The planting of mixed indigenous tree species for reforestation has gained attention in conservation biology, because they allow the recruitment of other woody species to a site. This study compared the differences in tree species diversity, structure, and composition between secondary dry semi-deciduous forests on two previously burned sites; one site had been planted ten-years prior with mixed mahogany species, while the other naturally regenerated after the fire. Density, dominance, frequency and importance value index (IVI) as well as family important values index (FIV) were computed to evaluate the floristic composition. A variety of diversity measures were also employed to examine heterogeneity in each forest type. For both sites, the most abundant diameter-class was 5-10 cm and the most abundant height-class was 1- 10 m. The study recorded significant differences between the two sites with respect to nearly all the indices of species diversity (Simpson, *P* = 0.037; Shannon, *P* = 0.003 and species richness, *P* = 0.003) employed, with the exception of Pielou's index of evenness (*P* = 0.06). The planted site recorded highest values for all the measures of species diversity. However, Sorensen's similarity index between planted and natural regeneration sites was 0.703. Seventeen and five species respectively were found to be solely associated with the planted and natural regeneration sites. At both sites the four most dominant and abundant tree species which recorded highest importance value index (IVI) were *Ficus exasperate, Terminalia superba*, *Morida lucida*, and *Antiaris toxicaria*. The greatest family importance values (FVI) for both sites were for Moraceae and Fabaceae, especially its sub-family Mimosaceae. The paper concludes that, use of mixed indigenous tree species in restoration facilitate the recruitment of a diverse group of other native tree species.

Key words: Native species, diversity index, restoration, African mahoganies, stand structure.

INTRODUCTION

The structure of plant communities in tropical deciduous dry forest zones is determined by its past history of natural and anthropogenic disturbances (Dunphy et al., 2000). Fire is an example of exogenous disturbance that has converted the vegetation of substantial areas of the dry semi-deciduous forest zone of Ghana. This dry forest constitutes about 8.98% of the total forest area of Ghana (FAO, 2002). In Ghana, continued forest loss at the present annual rate of 1.7% (FAO, 2000) threatens the existence of indigenous tree species and the associated biodiversity (Awanyo, 2007). Thus, there is increasing concern and a need to conserve these species and with them the value of the natural forests. This has led to attention being focused on restoration of degraded forest reserves in the country.

Rehabilitation or restoration activities have often included the establishment of plantations and enrichment planting. Tree planting is the major means of rehabilitating degraded forests in Ghana. The forest and wildlife policy of Ghana emphasizes the need to use indigenous or native tree species for reforestation and restoration of degraded forests. Restoration or rehabilitation of degraded ecosystem is necessitated in

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those instances when the potential or capacity of the ecosystem to regenerate naturally fails and creates room for invasion of non-native species (Suding et al., 2004; Bakker, 1996). The major setback for natural regeneration in dry semi-deciduous forest ecosystems in Ghana is the invasion of obnoxious weeds such as *Chromolaena odorata* Linn. (Asteraceae), *Imperata cylindrica, Pennisetum purpureum* and *Panicum maximum,* in the event of natural or anthropogenic disturbances (Awanyo et al., 2011; Anning and Yeboah-Gyan, 2007). Disturbances create empty niches or opportunity for colonization of these weeds (Anning and Yeboah-Gyan, 2007). Disturbances can change the successional pattern and subsequent composition, diversity, and structure of the forest (Doyle, 1981; Busing, 1995). Weed invasion following both natural and anthropogenic disturbances in the dry semideciduous forest zone, has converted large section of original forest land into savannah woody land (CSIR, 2002). For instance, *C. odorata* suppresses natural regeneration and recruitment of resident tree species (Awanyo et al., 2011; Honu, 2002). However, the natural regeneration of forests in Ghana is generally poor after major disturbances such as logging and fire outbreak (Swaine et al., 1997). As a result of aforementioned problems the obvious option to restore or rehabilitate degraded forest is through tree planting (Lemenih and Teketay, 2004). Reforestation is an important tool for the restoration of degraded ecosystems throughout the tropics (Koonkhunthod, 2007; Bernhard-Reversat, 2001). Trees planted through reforestation in most cases act as pioneer species and facilitate or enhance the colonization of native species (Carnus et al., 2006; Parrotta, 1995) and promote succession forest through modification of the microenvironment condition (Parrotta et al., 1997). Plantations tend to have a positive impact on biodiversity in those situations when they have been used to restore degraded lands (Carnus et al., 2006, Miller and Nair, 2006; Michon et al., 2007).Moreover, there is an abundance of literature that examines tropical plantations of mixed and pure species, including their effect on regeneration and influence on soil (Parrotta, 1995; Carnevale and Montagnini, 2002; Cusack and Montagnini, 2004).

However, there is limited research on the effects of mixed indigenous forest tree plantations on the resident native species succession and floristic composition. It is also unknown whether mixed plantations are self-sustaining, or if they can develop into more species-rich ecosystems (Vieira and Scariot, 2006). The effects of two regeneration methods for the restoration of fire degraded forest were examined: one reforestation through mixed native species plantation with the goal of ecological restoration whereas the other through natural regeneration. We investigated the differences in the species diversity, structure and composition between mixed African mahogany plantation and natural regenerated secondary forest after 10 years of fire outbreak.

MATERIALS AND METHODS

Description of study area

The study was carried out in the Pamu-Berekum Forest Reserve (PBFR), Dormaa District, in the Brong Ahafo Region of Ghana.The research site is located at latitude 07°30` N and longitude 03°00´ W (Figure 1). The elevation in the study area is approximately 665 m above sea level and topography is undulating terrain. The area records annual rainfall of approximately 1400 mm which falls primarily from May until November**.** The mean daily temperatures in the warmest month (March) and the coldest month (August) are 30 and 26℃, respectively. Generally the soils in the forest zones in the country are classified as oxysols and ochrosols (Brammer, 1962; Hall and Swaine, 1981). However, based on FAO classification these soils are known as Ferralsols and Acrisols respectively (ISSS/ISRIC/FAO, 1998). The underlain rock at the location consists of granite-gneiss-greenstone rocks, phyllites, schist, and quartzite and strongly deformed metamorphic rocks of Birimian and Tarkwain formations (Key, 1992). This area is subjected to periodic or frequent bush fires due to the fact that it is a buffer between savannah transitional zone in the north and moist semi-deciduous zone in the south. As a result of frequent incidence of bushfires and other anthropogenic disturbances most the forests in the area have been converted to secondary forests of which the majority is degraded. The area is endemic to important timber species such as *Pericopsis elata* (African teak), *Khaya anthotheca, Khaya grandifoliola, Entandrophragma utile, Argomuellera macrophylla, Ceiba pentandra, Talbotiella gentii, Nesogordonia papaverifera, Lecaniodiscus cupanioides* and *Baphia nitida* (Hall and Swaine, 1981, 1976). Natural regeneration to large extent is suppressed and very slow, due to invasion of weeds species such as Imperata *cylindrica, Pennisetum Purpureum and Chromolaena odorata, Panicum maximum, Ageratum* conyzoides and *Adropogon gayanus*. Weed invasion is one factor which has reduced the original size of the forest zone in the country (CSIR, 2002).

Sampling design and data collection

In 2000, we established 8 study plots (100 m × 100 m), 4 for mixed mahogany plantation consisting of *K. anthotheca* (Welw.), *E. utile* (Dawe and Sprague), and *K. grandifoliola* (Welw) C.DC., and 4 for adjacent degraded site undergoing natural regeneration, which is primarily secondary forest, covering a total area of 8 ha. The design was completely randomized design (CRD) with two treatments and four replicates. The mixed plantation stand had not been managed for 10 years after initial establishment to restore fire degraded portions Pamu-Berekum Forest Reserve and to evaluate their impact on native tree species diversity. The mahogany species were planted at spacing of 3 m × 3 m with substitution design (Kelty and Cameron, 1995). The age of natural regeneration site is the same as mixed planted site. Care was taken to prevent or control fire outbreaks at both sites after 10 years of last occurrence. The 100 m × 100 m plots for each treatment were divided in 25 subplots (20 m × 20 m) per plot. The subplots were then divided into 5 m × 5 m grids or arrays, generating 16 grids or arrays per subplot. Total of 10 subplots were randomly selected from 25 subplots per plot (1 ha) and per each treatment. Moving from west to east direction, with aid of handheld GPS every second grid was systematically selected. Within each sampled grid or array, all trees (except Mahogany species) with diameter at breast height (dbh) ≥ 5 cm were identified to the species level. These trees were classified into three dbh sizes-classes: 5-10, 10-20, and >20 cm and three height

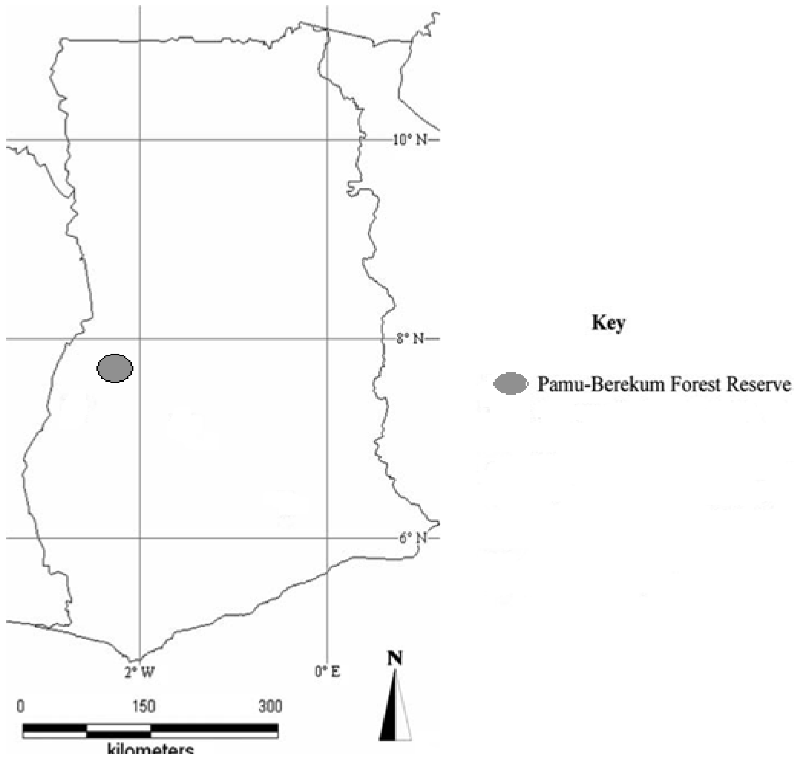

Figure 1. Map of Ghana showing the location of the Pamu-Berekum Forest Reserve.

size-class 5-10cm, 10-20cm, and >20cm and three height size-class 1-10m, 10-15m, and >15m. Data were collected from total of forty subplots and 320 grids or arrays for each treatment.

Calculation and statistical analysis

The species diversity and richness for each plot was quantified using the number of species per unit area and three widely accepted indices: the Shannon-Wiener diversity index (H) (Shannon, 1949; Magurran, 2004), Pielou's evenness index (J) (Pielou, 1966; Magurran, 2004), and Simpson's index (D) (Simpson, 1949; Magurran, 2004). The H, J, and D values were calculated for each species per subplot (that is, 1 to 40 mixed mahogany plantations or 1 to 40 natural regeneration) using the following formulae:

$$\mathrm{H} = -\sum_{i=1}^{S} p_i \ln p_i \qquad (1)$$

$$J = \frac{\mathrm{H}}{\ln S} \qquad (2)$$

$$D = \sum \left[n_i(n_i - 1) / N(N-1) \right] \qquad (3)$$

Simpson's index of diversity (Magurran, 2004) is expressed as 1 - D

Where: p_i = frequency of occurrence of each species relative to frequency of occurrence of all species in each plot; S = number of species in each plot (species richness); n_i = the number of individuals in the ith species (*i*); and N = total number of all the species in a unit area.

Simpson's Index of diversity (1 - D) ranges between 0 and 1, where values near 1 correspond to highly diverse or heterogeneous ecosystems and values near zero correspond to more homogeneous ecosystems. The greater the value of 1 - D, the greater the sample diversity. As D increases, diversity decreases. The mean values of H, S, J and 1 - D as well as stand structure variables for each site were compared with t-test. The t-test was conducted after testing for normality and equality or homogeneity of variance. The test indicated that the data did not follow a normal distribution. Thus, a natural logarithm transformation was applied to the data. Independent t-tests were conducted to compare differences between planted site and natural regeneration site. The importance value index (*IVI*) and family importance value index (FIV) (Kreb, 1989; Romero-Dugue et al., 2007) were used to analyze the relative importance of each species in each survey:

$$IVI = \lambda + \Phi + \Omega \qquad (4)$$

Where λ = number of individuals of a species /total number of individuals (relative density); Φ = frequency of a species/ total of frequencies of all species (relative frequency), and Ω = total basal area for species /total basal area for all species (relative dominance).

The frequency of a species is defined as the number of plots in which it is present. The theoretical range for Ω, λ, and Φ is 0 to 100, thus the IVI of any species may vary from 0 to 300. The FIV was computed in a similar way as the IVI, with the exception that the relative density was replaced by the relative family density, computed as the number of species in a family/total number of species (Gonzalez-Iturb et al., 2002). The similarity of the composition of species for the two sites was evaluated with the Sorensen similarity index (C_s) (Magurran, 2004) defined as:

$$C_s = \frac{2a}{2a+b+c} \tag{5}$$

Where: a = number of species common to both sites; b = number of species within site B; c = number of species found within site C

Sorensen's index (C_s) is regarded as one of the most effective presence/absence similarity measures (Magurran, 2004; Southwood and Henderson, 2000). C_s value close to 1 indicates sites with most of their species in common and for dissimilar sites the value is close to 0. All statistical analyses were done using Addinsoft XLSTAT-Pro 2009, a data analysis and statistical application software package for Microsoft's Excel 2007 spreadsheet software.

RESULTS

Species diversity and composition

A total of 49 woody species of economic importance were recorded at both sites (Table 1). The mixed mahogany plantation site had a greater species richness (10.10 ± 0.566) than the natural regeneration site (7.926 ± 0.370), and the difference was significant (*P* = 0.003) according to t-test (Table 2). Other measures of diversity indices of the two sites were significantly different according to the Shannon-Weiner (*P* = 0.003) and Simpson´s indices (*P* = 0.037). In all these cases, the planted site recorded highest mean values of species diversity indices as compared to the natural regeneration site. However, there was no significant difference between the sites based on Pielou's evenness index (P > 0.05) (Table 2).The natural regeneration site supported 30 species from 24 genera and 15 families (Table 1); the most common families were Moraceae (5 species), Fabaceae (4), and Euphorbiaceae (3). The planted site supported 45 species from 38 genera and 22 families, with Moraceae (6 species), Fabaceae (6), Euphorbiaceae (4), Mimosaceae (3), and Apocynaceae (3) being the predominant families (Table 1). 17 species were found exclusively on the planted site whereas 5 were found only on the natural regeneration site (Table 3). The Sorensen's index of similarity between mixed mahogany plantation site and the adjacent natural regeneration site was 0.703. On the planted site, the top three species by abundance and dominance (based on basal area) were *Ficus exasperata*, *Terminalia superb*, and *Morinda lucida*; these species had the three greatest recorded *IVI* values: 37.69, 36.14, and 23.82 respectively. However, on the natural regeneration site the most relatively dominant three species with the greatest IVI values were *Antiaris toxicaria* (53.15), *F. exasperta* (37.99), and *M. lucida* (33.47) (Table 4).

F. exasperta and *A. toxicaria* are prominent at both sites in terms of their basal area, relative dominance, relative frequency, and IVI (Table 3). On the planted site, the most specious families with the greatest IFV values were Moraceae and the Fabaceae sub-family Mimosaceae (Table 5). Similarly, the families Moraceae, Fabaceae, and Euphorbiaceae recorded the greatest IFV values for the natural regeneration site. The larger basal areas were recorded on both sites for more fast growing species: *F. exasperta, A. toxicaria*, *M. lucida* and *T. superba*. Also note worthy by their basal areas on both sites were *Trema occidentalis*, *Ceiba pentandra*, *Albizia adianthifolia* and *Sterculia tragacantha*.

Vegetation structure

For both sites, the most abundant diameter-size class was that of the 5-10 cm class whereas trees greater than 20 cm in diameter were the least abundant (Table 1 and Figure 2). Comparison of the means with a paired t-test within each diameter-class indicated a significant difference between the sites (5-10 cm, *P* < 0.001; 10-20 cm, *P* < 0.003; > 20 cm, *P* < 0.001; Figure 2). Overall, trees in the 10-20 cm diameter-class comprised the greatest proportion of the basal area (Figure 2). The mean diameter for the planted site was 16.28 cm and for the natural regeneration site 13.04 cm; these means are significantly different (*P* < 0.0001).

For both sites, the height-class with the most trees was the 1-10 m class, the least number of trees were in the ≥ 15 m class (Table 1 and Figure 3). Moreover, between the two sites there were significant differences in the number of trees in the 1-10 m (*P* < 0.001) and the ≥ 15 m (*P* < 0.009) height-classes (Figure 3). Although the number of trees within 10-15 m class for both sites were relatively higher than for ≥ 15 m class, there was no significant difference between the sites for this class. The mean height of the trees varied significantly (*P* < 0.0001) between the two sites (Table 1 and Figure 3).

The number of species in each height-class was skewed toward the lower classes, with a large proportion falling within the 1-10 m class. However, for the diameter-classes, species richness had a nearly even distribution across the classes. Yet, the greatest species richness was concentrated within the 10-20 cm diameter-class. The observed species richness for both sites decreased as diameter increased. For both sites, the height-class with the most trees was the1-10 m class, the least number of trees were in the ≥ 15 m class (Table 2 and Figure 3). The number of species in each height-class was skewed toward the lower classes, with a large proportion falling within the 1-10 m class. However, for the diameter-classes, species richness had a nearly even distribution across the classes. Yet, the greatest species richness was concentrated within the 10-20 cm diameter-class. The observed species richness for both sites decreased as diameter increased.

Table 1. Native woody species found on one or two contrasting sites of dry semi-deciduous secondary forest in the Pamu-Berekum Forest Reserve of Brong Region of Ghana. The results represent two methods for restoring fire degraded forest Pamu-Berekum Forest Reserve: Mixed mahogany plantation and Natural Regeneration.

Family	Species	Planted sites	Natural regeneration sites
Anacardiaceae	*Lannea kerstingii*	X	
Apocynaceae	*Alstonia boonei*	X	X
	Rauvolfia vomitoria	X	
	Holarrhena floribunda	X	X
Asteraceae	*Vernonia amygdalina*	X	
Bignoniaceae	*Spathodea campanulata*	X	
	Newbouldia lavis	X	
Bombaceae	*Ceiba pentandra*	X	X
	Bombax buonopozense	X	X
Boraginaceae	*Nesogordonia papaverifera*	X	X
	Cordia millenia	X	
	Cordia senegalensis	X	
Caesalpinioideae	*Dialium dinklagei*	X	
Caricaceae	*Carica papaye*	X	
Celastraceae	*Hippocratea africana*	X	
Combretaceae	*Terminalia superba*	X	X
	Terminalia ivorensis		X
Euphorbiaceae	*Alchornea cordifolia*	X	X
	Mareya micrantha	X	X
	Magaritaria discoidea	X	X
Fabaceae	*Pericopsis elata*	X	X
	Amphimas pterocarpoides		X
	Afzelia africana	X	
	Tetrapleura tetraptera		X
	Senna siamea	X	
	Pentaclethra macrophylla	X	
	Berlinia spp	X	
Meliaceae	*Trichilia monodelpha*	X	
Mimosaceae	*Albizia adianthifolia*	X	X
	Albizia ferruginea	X	X
	Albizia glaberrima	X	
	Xylia evensii	X	
	Albizia zygia	X	X
Moraceae	*Ficus exasperata*	X	X
	Antiaris toxicaria	X	X
	Ficus sur	X	X
	Ficus capensis	X	X
	Morus mesozygia	X	X
	Milicia excelsa	X	

Table 1. Contd.

Palmae	*Elaeis guineensis*	X	X
Papilionaceae	*Baphia nitida*	X	X
	Milletia zechiana	X	X
Rubiaceae	*Morinda lucida*	X	X
Sapindaceae	*Blighia unijugata*	X	X
	Blighia sapida	X	X
Sterculiaceae	*Sterculia tragacantha*	X	X
Tiliaceae	*Christiana africana*	X	
Ulmaceae	*Trema occidentalis*	X	X
Myristicaceae	*Pycnanthus angolense*		X

NB: Planted species are not presented. *Khaya species* and *Entandrophragma utile.*

Table 2. Summary statistics from two-tailed t-test, plant community structural characteristics and measures of diversity for two regenerated sites (planted: mixed mahogany and natural regeneration) of dry semi-deciduous secondary Pamu-Berekum Forest Reserve in Ghana.

Measure	**Planted site (n= 40)**		**Natural regeneration site (n=40)**		**t-test (2-tailed)**
***Diversity indices**	**Mean ± se**	**Min-Max**	**Mean ± se**	**Min-Max**	***P*-values**
Simpson's index of diversity (D - 1)	0,835 ± 0.021	0.949-0.552	0.768 ± 0.016	0.866-0.506	0.0370
Shannon -Wiener diversity Index(H)	1.906 ± 0.074	0.988-2.619	1.596 ± 0.062	0.887-2.181	0.0030
Species richness(S)	10.10 ± 0.566	4-17	7.926 ± 0.370	3-14	0.0030
Pielou's evenness index(J)	0.821 ± 0.017	0.495-0.944	0.776 ± 0.017	0.617-0.949	0.0600
Sorensen similarity index(C_s)$^{\mathrm{e}}$	0.703	-	0.703	-	-
****Stand structure characteristics**					
DBH (5-10 cm)	12.90 ± 0.731	5-21	9.04 ± 0.670	1-17	0.0001
DBH (10-20 cm)	12.63 ± 0.705	5-23	9.78 ± 0.553	3-14	0.0030
DBH (≥20 cm)	9.63 ± 0.834	3-24	4.82 ± 0.527	0-4	0.0001
Mean DBH (cm)	16.28 ± 0.456	12.08-23.67	13.04 ± 0.325	9.79-16.23	0.0001
Height (1-10 m)	18.70 ± 0.795	11-28	13.33 ± 0.986	3-23	0.0001
Height (10-15 m)	11.63 ± 0.925	6-27	9.78 ± 0.701	2-16	0.1220
Height (≥15 m)	3.93 ± 0.669	0-13	1.85 ± 0.313	0-5	0.0090
Mean height (m)	11.17 ± 0.244	8.63-13.48	9.82 ± 0.195	12.01-23.66	0.0001

*Calculation was done according to the 20 m × 20 m subplots. **Numbers of individual species were observed for the specified interval (of diameter or height) per hectare. $^{\mathrm{e}}$Sorensen similarity index was computed for the entire study plots (8 ha).

DISCUSSION

Species diversity

The site with the mixed mahogany species supported a greater diversity of species than the natural regeneration site; it performed better with respect to nearly all indicators and measures of diversity. However, species evenness was similar for both sites. Other comparative studies of the species diversity of degraded sites have also shown that plantations tend to have greater species diversity (Nagaike et al., 2006, Koonkhunthod et al., 2007). Greater species richness in the planted site is in line with results of Parrotta (1992). Mixed plantations have a larger variety of environments for seed dispersers and a greater variety of ecological niches, thus allowing for more diverse regeneration (Parrotta, 1992; Parrotta, et al., 1997). Plantations on degraded lands in the tropics

Table 3. Families and their corresponding woody species that are unique to one regeneration site (that is either planted or natural regeneration) of dry semi-deciduous secondary forest in the Pamu-Berekum Forest Reserve of Ghana.

Planted site		Natural regeneration site	
Family	**Species**	**Family**	**Species**
Anacardiaceae	*Lannea kerstingii*	Celastraceae	*Hippocratea africana*
Apocynaceae	*Rauvolfia vomitoria*	Combretaceae	*Terminalia ivorensis*
Asteraceae	*Vernonia amygdalina*	Fabaceae	*Amphimas pterocarpoides*
Bignoniaceae	*Spathodea campanulata*		*Tetrapleura tetraptera*
	Newbouldia lavis	Tiliaceae	*Christiana africana*
Boraginaceae	*Cordia millenia*		
	Cordia senegalensis		
Caesalpinioideae	*Dialium dinklagei*		
Euphorbiaceae	*Mareya micrantha*		
Fabaceae	*Afzelia africana*		
	Senna siamea		
	Pentaclethra macrophylla		
	Berlinia spp		
Meliaceae	*Trichilia monodelpha*		
Mimosaceae	*Albizia glaberrima*		
	Xylia evensii		
Moraceae	*Milicia excelsa*		

Table 4. Ten most abundant woody species on two regenerated sites (planted and natural regeneration) of dry semi-deciduous secondary forest in the Pamu-Berekum Forest Reserve of Ghana, listed according to descending importance value index (IVI).

Species	Planted site				
	Basal area (m^2/ha)	Relative dominance (%)	Relative density (%)	Relative frequency (%)	IVI
Ficus exasperata	53.05	12.99	15.78	8.92	37.69
Terminalia superba	81.83	20.04	11.01	5.09	36.14
Morinda lucida	42.80	10.48	6.97	6.37	23.82
Vernonia amygdalina	18.92	4.63	10.27	5.09	20.00
Antiaris toxicaria	21.41	5.24	5.32	7.64	18.21
Trema occidentalis	31.09	7.61	8.07	1.91	17.60
Sterculia tragacantha	18.69	4.57	6.97	3.82	15.37
Albizia adianthifolia	16.93	4.15	2.93	7.00	14.09
Ceiba pentandra	29.43	7.21	1.10	2.55	10.85
Blighia unijugata	5.96	1.46	2.20	4.46	8.12
	Natural regeneration site				
Antiaris toxicaria	58.51	20.50	19.18	13.46	53.15
Ficus exasperata	34.04	11.92	18.37	7.69	37.99
Morinda lucida	38.62	13.54	12.24	7.69	33.47
Albizia adianthifolia	11.88	6.17	5.61	7.69	17.16
Terminalia superba	24.66	8.64	4.08	3.84	16.57
Sterculia tragacantha	13.92	4.88	4.89	5.77	15.55

Table 4. Contd.

Ficus capensis	4.51	1.58	3.67	5.77	11.02
Ceiba pentandra	22.37	7.84	1.22	1.92	10.99
Bombax buonopozense	10.22	3.58	2.86	3.84	10.28
Amphimas pterocarpoides	5.62	1.97	3.26	4.80	10.04

Table 5. The ten most important plant families on two regenerated sites (planted and natural regeneration) of dry semi-deciduous secondary forest in the in the Pamu-Berekum Forest Reserve of Ghana, listed according to descending family importance value (FIV).

Planted site					Natural regeneration site				
Family	**Genus**	**Species**	**N/ha***	**IFV**	**Family**	**Genus**	**Species**	**N/ha***	**IFV**
Moraceae	4	6	229	121.89	Moraceae	3	5	139	167.31
Fabaceae	6	6	23	91.45	Fabaceae	4	4	19	77.57
Mimosaceae	3	5	113	65.06	Euphorbiaceae	3	3	11	36.35
Euphorbiaceae	4	4	19	38.68	Bombaceae	2	2	13	29.79
Combretaceae	1	1	21	33.22	Rubiaceae	1	1	54	29.35
Apocynaceae	3	3	13	25.30	Combretaceae	2	2	12	28.10
Sterculiaceae	2	2	27	21.64	Mimosaceae	1	2	27	24.82
Rubiaceae	1	1	48	19.63	Apocynaceae	2	2	7	17.86
Bombaceae	2	2	10	18.73	Papilionaceae	2	2	10	17.54
Ulmaceae	1	1	20	17.86	Ulmaceae	1	1	16	14.13

*Total number of species within each family per hectare (N/ha).

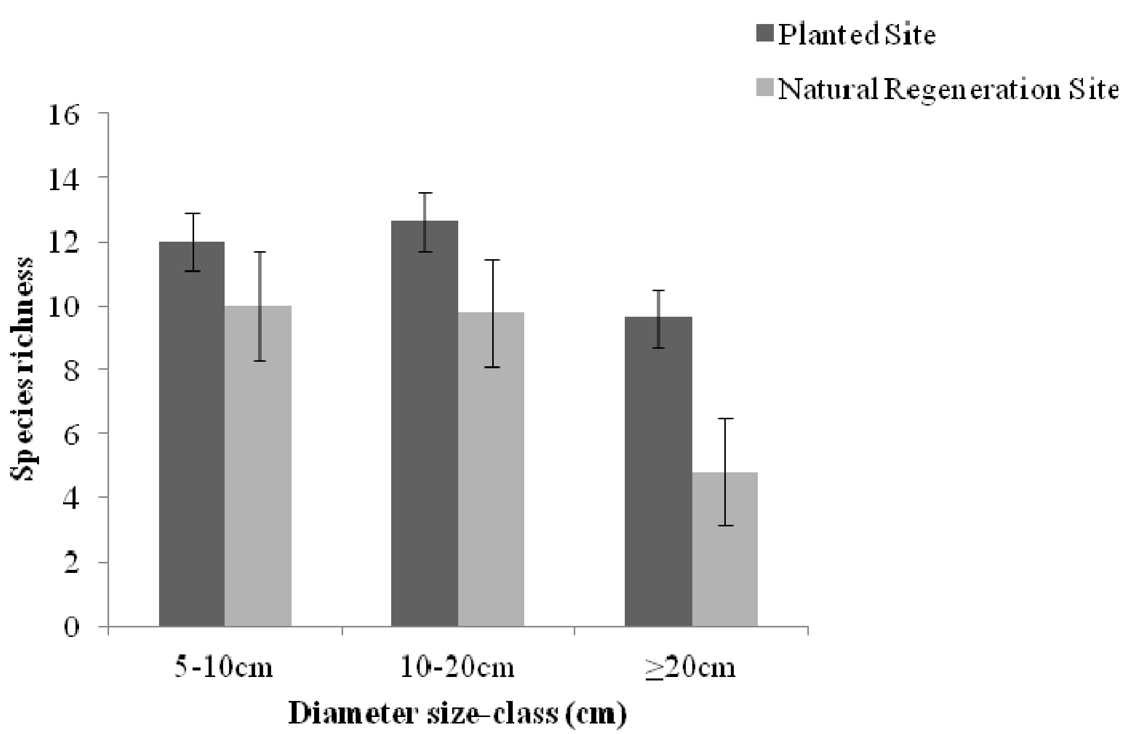

Figure 2. Relationship between species richness (mean with standard error bar; n = 40 for both planted and natural regeneration sites) and diameter class of the tree species found on either of two regenerated sites (planted and natural regeneration) of dry semi-deciduous secondary forest in the in the Pamu-Berekum Forest Reserve of Ghana.

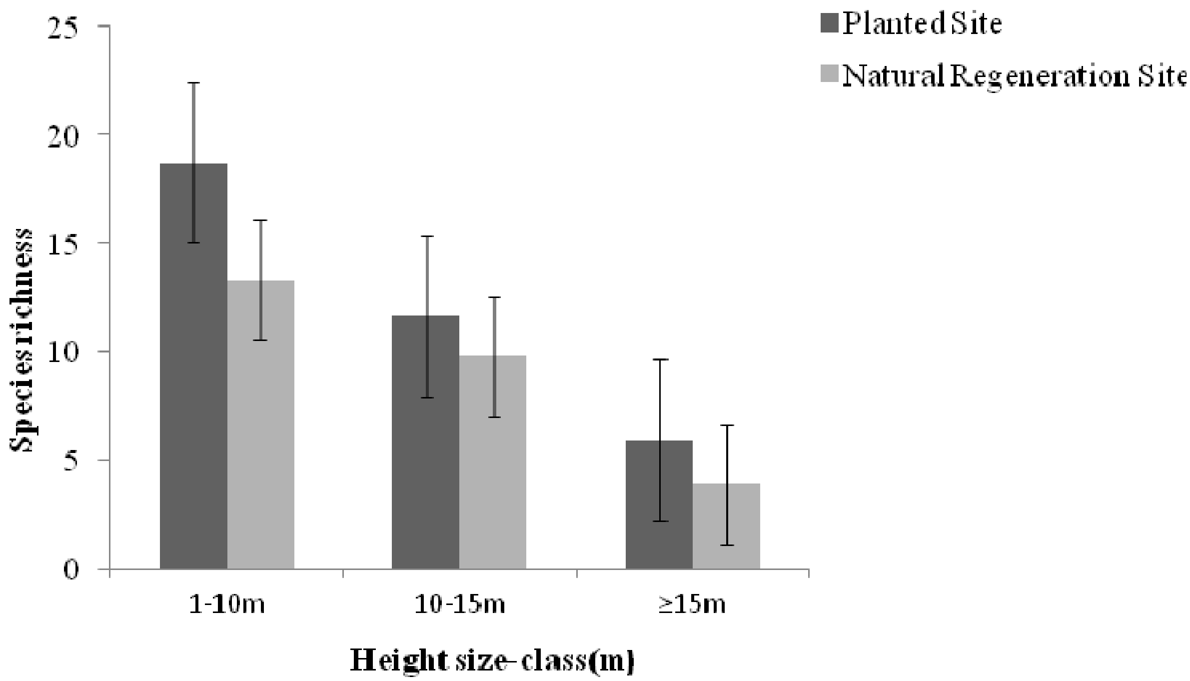

Figure 3. Relationship between species richness (mean with standard error bar; n=40 for both planted and natural regeneration sites) and height-class of the tree species found on either of two regenerated sites (planted and natural regeneration) of dry semi-deciduous secondary forest in the in the Pamu-Berekum Forest Reserve of Ghana.

have been shown to increase the recovery of pre-disturbance biodiversity levels and promote the regeneration of other woody species by accelerating forest succession processes, increasing soil fertility, and improving other site conditions (Cusack and Montagnini, 2004). The presence of large numbers of native tree species diversity at the mixed mahogany plantation site is a measure of successful restoration and suitability of mahogany species in recruiting other native species (Ruiz-Jaen and Aide, 2005). African mahoganies can enhance the recovery of the native species forest tree species in degraded dry semi-deciduous forest eco-systems. In this study, 45 native species were recorded at the planted site. However, Haggar et al. (1997) reported 69 native woody species upon reforestation of degraded pasture with mixed tree species. Thus, the results show that mixed native tree plantations facilitate regeneration and recruitment of resident species.

Species composition

The poor performance of the natural regeneration site is not uncommon, especially in the tropical dry semi-deciduous ecological zones of Ghana (Awanyo et al., 2011). In general, dry semi-deciduous forest zone is one of the fragile ecosystems in the country. The area is prone to colonization by weed species following distur-bances. The competitive advantage of weeds species combined with degraded soils, lack of nutrients, and a poor seed bank, act to suppress or prevent germination and initiation of tree seedlings (Chapman and Chapman, 1996). Thus, natural regeneration and recruitment are inhibited. In the forest zone of the Ivory Coast, De foresta and Schwartz (1991) noted that areas dominated with *C. odorata* tend to have a delayed or slow natural succession. It is often advised that during the establishment of a plantation, a treatment that eliminates or moderates invasion by weeds is necessary to ameliorate the conditions for tree growth (Ashton, 1997; Fimbel and Fimbel, 1996; Otsamo et al., 1999). It is not a surprising result in mind of some or all of the aforementioned factors that the natural regeneration site had a relatively low tree species diversity compared to the planted site. The similar species evenness values for both sites, however, revealed a similarity in the pattern of tree species distribution common to the region where both sites are located. Yet, the two contrasting sites had a shared species composition of approximately 0.703 according to Sorensen’s index of similarity, suggesting there are factors limiting the establishment of more tree species on the natural regeneration site. Other researchers have shown that substrate conditions and mechanisms that severely stunt on-site regeneration can create opportunities for species invasion (Aide et al., 1995; Gonzalez-Iturbe, 2002; Molina and Lugo, 2006); this may be the case for the studied natural regeneration site. Additional, this may alter succession pathway leading to variation in tree species diversity, composition and structure (Doyle, 1981; Busing, 1995). The high proportion or dominance of *Albizia adianthifolia* and *F. exasperata* on both sites is indicative of areas with histories of disturbances (Henri, 2008). According to Schnell (1997), variation in the structure and the composition of vegetation in the forest zone of West Africa particularly in the disturbed ecosystem can be related to the presence of some species such as *T. occidentalis, A. toxcaria*, *M. lucida*, *F. exasperata*, and *T. superb*. However, Swaine and Hall (1983) reported high growth rate and tree species diversity on previously cleared forest site in early successional stage, and attributed this to the pioneering role of *T. occidentalis*. *T. occidentalis* invades gaps and disturbed areas as a pioneer species, and then persists to maturity. As result of its rapid growth rate, *T. occidentalis* is able to overcome competition from weeds. Amongst the dominant species, Ficus species have fleshy or arillate fruits thus are often dispersed by bats and birds. However, the high proportion of Albizia species found on the sites may be due to the fact they are wind-dispersed immigrants (Swaine and Hall, 1983). Albizia species have been reported to suppress the invasive weed *C. odorata* (Henri et al., 2008). In addition, Albizia species have the ability to fix nitrogen and are tolerant to low nutrient levels (Swaine et al., 2007; Swaine et al., 2005). In fact, Camargo-Ricalde (2002) demonstrated importance of many species belonging to the Fabaceae family due to their abilities to influence soil chemical and biological properties, as well as micro-environmental factors, which could allow the establishment and growth of other species. Moreover, the top two families with the greatest family importance values (FIV) in the study area were Moraceae (which include species like: *F. exasperata, A. toxicaria, Morus mesozygia* and *Milicia excelsa*) and Fabaceae, especially the subfamily Mimosoideae.

Vegetation structure

Structurally the two sites had relatively large numbers of species in the 10-20 cm diameter-class, tapering off notably for the greater than 20 cm class, this structure seems to be a characteristic feature of a recovering dry secondary forest and reflects the degree of disturbance (Romero-Duque et al. 2007).There are high proportions of individuals or species within the 10-20 cm diameter-class for both sites in this study, which is similar to the results reported by Romero-Duque et al. (2007). However, there is a significant difference between the planted and the natural regeneration sites in terms of the number of species. The structure of the height distribution for both sites is such that more species fall within the height-class 1-10 m. The high species numbers within this height-class may be due to the fact that both sites are at an early stage of succession. As the canopy closes over time, most species will grow into taller height-classes, and there will be a reduction in number of species in this lower height-class. It is expected that some individuals will come to dominate while others will become suppressed, due to normal competitive processes (Westoby, 1982; Weiner and Thomas, 1986; Weiner, 1990). However, Vandermeera and Granzow de la Cerda (2004) reported high species diversity in 5 to 15 m height-class after 14 years of regeneration from hurricane damage and attributed it to dynamic competition.

Conclusions

It is obvious that climax species regenerate differentially within secondary forest of the dry semi-deciduous zone, a process occurring at a time scale and related to the past history of the area. This has important implications when considering options for forest restoration, which could include the deliberate introduction of climax forest tree species with African mahoganies. The most important concept from this work is that according to nearly all diversity indices an area planted with African mahoganies performs better than a similar area with only natural regeneration, attesting to that fact that the use of indigenous tree species for the plantation will enhance the recruitment of other native forest tree species. Thus, for rehabilitation or restoration of degraded forest reserves in dry semi-deciduous forest zone the most appropriate option or pathway to recovery is through reforestation with mixed native species. Nevertheless, comprehensive study is required to cover large area to serve as bases for implementation. This is preliminary study; hence, within its confinement the data are limited. However, caution must be taken, since the successful implementation of any restoration project will rely on fire prevention measures in order not to disrupt successional pathway to climax. Further studies should be conducted to indentify native tree species that could be used as firebreaks at the fringes of dry semi-deciduous forest zone. The benefit of educating local communities on fire prevention should also not be overlooked.

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