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Exotic *Gmelina arborea* Roxb. plantation supports better understory plant diversity than native *Nauclea orientalis* (L.) plantation 30 years after their establishment in a watershed area in Southern Philippines

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Abstract

Native tree plantations are often preferred as nurse vegetation to facilitate succession as they are assumed to have favorable habitat for native species regeneration than exotic stands.. To ascertain this, we characterized the respective attributes of exotic Gmelina (*Gmelina arborea* Roxb., Lamiaceae) and native Bangkal (*Nauclea orientalis* L., Rubiaceae) plantations in terms of canopy structure, understory biomass and soil attributes; and relate these to the diversity and number of regenerating woody species in each stand. We found that exotic Gmelina plantation had significantly better species diversity(H = 1.06 ± 0.10) and species richness(42 species, 959 individuals)than Bangkal(H= 0.52 ± 0.27, 9 species, 584 indivisials). Majority of the species found in Gmelina are trees (64%), while Bangkal was dominated (90%) by herbaceous plants. Themore dense canopy structure in terms of canopy height (36.79 ± 12.37) in Gmelina in comparison to Bangkal (19.61 ± 0.75) appearedto favor woody species regeneration, thus suppressing the possible invasion by herbaceous plants. In contrast, the better soil CEC in Bangkal plantation (i.e. 51.00 ± 8.23 vs 40.20 ± 3.66 in Gmelina) has favored the growth of herbaceous plants and resulted to arrested succession.Thus, our findings suggest that exotic-based tree plantations in the country can beimportant successional sites and are not at all detrimental to biodiversity conservation as commonly perceived. Moreover, it is possible that without active interventions to accelerate the growth of native woody regeneration, succession in tree planrations can be vulnerable to invasionby herbaceous plants over time.

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Introduction

The use of tree plantations on open degraded lands to facilitate succession is widely recognized as a promising approach to forest restoration because of its potential to support successional processes through its influence on soil and microclimate conditions including suppression of dominant grasses and provision of habitats for seed dispersing animals (Parrotta, 1995; Parrotta *et al.*, 1997).Other studies, however, reported that some degraded systems can be resilient to traditional restoration and failure to recognize existing constraints or feedback forces (such as loss of native sources of propagules, shifts in species dominance, competitive exclusion by invasive species, among others) may lead to restoration failure (Hobbs and Norton, 1996; Suding *et al.*, 2004; Young *et al.*, 2005; Hobbs, 2007; Tambosi *et al.*, 2014). Although, there are few established criteria for measuring restoration success (Hobbs and Norton, 1996), the need to monitor the outcomes is critical to determine whether the strategies of a restoration project are effective or not.

A low-cost restoration strategy in tropical forests for degraded sites is to protect the area from local disturbance and allow natural succession to occur and developed into a second growth forest (Aide *et al.*, 2000). This strategy, however, will involve a long timeframe for successional processes to occur and can be less effective in open degraded sites where seed sources are not available or where vegetation cover for the conservation of soil and water is an immediate concern such as watershed areas. Thus, restoration approach that involves planting of fast-growing trees has been widely used in many restoration programs to facilitate the return of native vegetation. In the Philippines, this approach was carried-out using mostly fast-growing exotic species since most native trees are slow growing and there is an apparent lack of knowledge on their propagation and establishment requirements. The facilitative role of exotic tree plantations in native forest recovery however is widely recognized(e.g. Parrotta, 1992; Lugo *et al.*, 1993; Parrotta, 1995; Geldenhuys, 1997; Otsamo, 2000; Viisteensaari *et al.*, 2000). Previous and recent assessments in the country also indicated potential of some existing exotic tree stands to support or facilitate the establishment of native woody species especially when local remnant forest is available (e.g. Lee *et al.*, 2006a; Lee *et al.*, 2006b; Tulod *et al.*, 2017). However, a synthesis of peer-reviewed articles indicated that plantations are most likely to contribute to biodiversity conservation when established on degraded lands using indigenous tree plantations (single or mixed species) rather than exotic(Bremer and Farley, 2010).

Since past reforestation works in the Philippines were heavily dependent on fast-growing exotic species, this means that there have been limited comparative studies quantifying the long-term restoration benefits between native and exotic tree plantations. With the current shift in the country's forest restoration program in terms of species preference (i.e. from pure exotic species to using mostly native tree species in restoration), it is critical to understand the restoration benefits and feedback forces associated with using native tree plantation in comparison with exotic stands. Hence, this assessment was conducted to determine the success of restoration plantings using the exotic Gmelina and native Bangkal plantations about 30 years after their establishment. To our knowledge, the Bangkal plantation in this study is the only native tree plantation in Southern Philippines and one of the few in the whole country; while Gmelina is one of the most common reforestation species in the country.

The objectives of this survey were threefold:1) characterize the respective attributes of these two plantations in terms of canopy structure, understory biomass, and soils;2) determine how these attributes influence the species composition of natural regeneration in the two plantations; and 3) evaluate whether it matters to use native tree plantation over exotic in forest restoration including the implications of this for future reforestation or restoration programs in the country.

Materials and methods

Site description

This study was conducted in a watershed area within the landholding of the National Power Corporation (NPC) Pulangi IV Hydroelectric Plant located in Maramag, Bukidnon, in the central part of Mindanao, Southern Philippines. The area is geographically situated between 7°47′11″North and 125°1′25″East at an altitude of about 300meters above sea level. Previous report classified the soils in the area as mainly oxisols (Poudel and West, 1999), a typical soil attribute of tropical rain forest. Based on the data from the closest climatological stations, Bukidnon has mean annual rainfall of 2,800mm, mean annual temperature ranging between 20°C and 34°C, and relative humidity that range from 90.86% to 92.85%. The climate of the province falls under type IV with no dry season or the rainfall is evenly distributed throughout the year based on the modified Coronas classification.

The plantation sites were formerly logged-over forests and was devoid of original vegetation cover for several years prior to the reforestation of the watershed area in 1986using the species of *Gmelina arborea* Roxb. or Gmelina (ca. 16.9 hectares) and *Nauclea orientalis* (L.) or locally named as Bangkal (ca. 3.5 hectares). Since then, the reforestations sites were under the protection of NPC with no records of silvicultural treatments and/or enrichment planting. Because there is no natural forest close to or around these plantations, we assumed that the presence of regeneration in the area indicates the potential of each stand to support plant establishment through seeds that have long been stored in the soils or from dispersed seeds by animals from nearby forest remnants.

Sampling of regenerating plants

The sampling was carried-out using nested sampling plot design described in Hairiah *et al.* (2011), i.e. 5 m x 40 m or 200 m² as main plot and four 1 m x 1m quadrats as subplots randomly located at the center of each main plot. Total sampling area for Gmelina plantation was 1200 m² i.e. 6 main plots with 24 subplots, while for Bangkal plantation was 800 m² (i.e. 4 main plots with 16 subplots). The sampling was limited by the inaccessibility of some locations within the protected watershed, hence, the different number of sample plots. In each plot, all indigenous woody regeneration (i.e. tree species with height >0.3m but≤15cm diameter at breast height, dbh) found were counted, identified to species level, and measured for their diameter and height. The diameter was measured at 5mm above the ground for regeneration with 0.3 to 1.3m in height and at dbh(diameter at breast height) or 1.3m above the ground for those with >1.3m in height. Other plants such as vines, lianas, and grasses including tree species (with height below 0.3m) were sampled (counted and identified) in the four 1m x 1m subplots.

Litter and understory biomass

After recording all the plant species within the 1m x 1m subplots, destructive sampling was employed to estimate the biomass of litter and green plants. The total fresh sample was weighed in the field after which a sub-sample of approximately 300grams was taken for subsequent oven drying. Oven dry weights of sub-samples were determined to compute for the total dry weights. Oven drying was set at 80°C and was observed until the samples reached their constant oven-dried weight. The biomass density was then computed with the following equation:

$$\text{Total dry weight }(\text{kg/m}^2) = \frac{\text{Total fresh weight (kg) x subsample dry weight (g)}}{\text{Subsample fresh weight (g)x sample area }(\text{m}^2)}$$

Soil and canopy structure

Soils in each stand were sampled within the 1 m × 1 m subplots. Two samples with 1 kg soil per sample were obtained from 0-30cm soil depth in each subplot and were brought to the soil laboratory for moisture and chemical/nutrient content analyses. Canopy structure (such as mean height, dbh, basal area, stem density, canopy cover) was also determined by measuring the total height and diameter of trees with dbh> 15 cm within the main plots.

Canopy cover was estimated using the GRS tube densitometer following the procedure described in its manual by Stumpf (2008). We used 15 sampling points inter-distant 10 m in each plot.

Data manipulation and analysis

The diversity estimators used in this study include rarefaction, Shannon-Weiner diversity index (H), evenness (also referred to as Shannon J or the ratio of the observed H' to the H_{max},), and Simpsons diversity (D) index. These were calculated using the BioPro software (McAleece *et al.*, 1997). Rarefaction is a technique which allows for the calculation of the expected number of species for a given number of individuals, thus allowing comparisons of diversity with different size of samples (Brewer and Williamson, 1994). Measurements of the canopy structures and soils of the two stands were compared using the Student's *t*–test for two samples or Welch's t-test for samples with heteroscedasticity issues.

We used ordination methods to test the influence of canopy structure and soil variables on the variability of regenerating species composition in the two stands. Detrended Correspondence Analysis (DCA) was first used to determine the length of the first DCA axis, which is scaled in units of standard deviation (SD). Because the data set was relatively heterogeneous as shown by the length of the first DCA axis (i.e. DCA axis 1 > 5 SD)(Lepš and Šmilauer, 2003), Canonical Correspondence Analysis (CCA) was used instead via a stepwise model from "ordistep" function. Then, Variance Inflation Factors (VIF) were calculated for each of the constraints (variables) in the reduced model to detect collinearity (VIF>10). Since no variable is redundant with each other (all of them have VIF<10), we proceeded to test the significance of the obtained reduced model, the explanatory variable(s) and the CCA axes on the plant species composition using the Monte Carlo permutation test (a test of significance of the variance explained by environmental factors). We used unrestricted permutations because the sample data were randomly collected without obvious spatial arrangement. A total of 999 permutations were performed and results of the analyses were depicted as graph using the ordination "plot" function. Generalized linear model (with poison distribution and log link) was used to verify the influence of significant variables in the CCA reduced models on species composition. All statistical analyses and ordination were performed using R software (R Development Core Team, 2015).

Results

Canopy structure, understory biomass and soil attributes of the two plantations

A relatively similar set of canopy structure, understory biomass, and soil attributes (Table1) characterized the two stands except for the mean height of canopy trees, soil CEC, and extractable P. Gmelina stand has significantly taller canopy trees, higher soil extractable P but lower in soil CEC as compared to Bangkal stand. Generally, canopy trees in the Gmelina stand have greater stem density, basal area, and canopy cover than the Bangkal stand, although both plantations have limited or poor soil resources.

Species composition and importance of value

A total of 48 species of plants (i.e. a mix of trees, shrubs, herbs, ferns, vines and grasses) from 28 families and 1,543 individuals were identified in the two plantations (Tables 2 & 3). Forty-two (42) of these species with 959 individuals were tallied in the Gmelina stand with the fewer number species (only 9 species from 584 individuals) was recorded in the Bangkal plantation. Although majority of the species found in the plantation of Gmelina are trees (64%), the most dominant based on relative densities are the species of *Gmelina arborea* (21.58%), *Ficus* spp. (9.59%), *Lygodium circinnatum* (8.24%), *Centrosema pubescens* (6.67%), and *Paspalum conjugatum* (5.11%). These are the first five species plotted on the left side of rank density curve in Fig. 1. Similar species had the highest importance value (SIV) in the Gmelina stand (i.e. ranked from 24.46 to 9.99, respectively), but the species of *P. conjugatum, Ficus septica,* *Melanolepis multiglandulosa* along with *G. arborea* were the most frequent or widely distributed in the site based on their relative frequency value of 4.88%. In the Bangkal plantation, a different set of species of mostly herbs and grasses was tallied in the area. Based on the ranking of species importance value (Table 3) and as shown in the species density curve (first five species plotted on the left side of Fig. 1), the species of *Desmodium* spp. (41.34), *Leptchloa chinensis* (38.09), *Nauclea orientalis* (37.88), *Acrysanthes aspera* (28.84) and *P. conjugatum* (19.80) were the most dominant and widely distributed in the area.

Table 1. Soil and vegetative characteristics (mean ± SD) of the two reforestation stands.

Characteristics	Bangkal	Gmelina	*P* -value
Upper layer			
Basal area (Bao, m^2/ha)	49.17 ± 27.34	55.77 ± 38.68	0.7378
Mean DBH (DBHo, cm)	24.40 ± 3.16	36.79 ± 12.37	0.0584
Mean height (Hto, m)	19.61 ± 0.75	24.52 ± 3.69	0.0214*
Number of stem (DENo per ha)	525.0 ± 272.34	391.67 ± 321.58	0.5161
Canopy cover (Crown, %)	73.35 ± 18.05	80.0 ± 12.63	0.5087
Understory layer			
Litter biomass (Lb, ton/ha)	5.43 ± 1.12	5.65 ± 1.02	0.7512
Understory vegetation biomass (GCb, ton/ha)	2.33 ± 1.08	2.25 ± 0.83	0.9040
Soil			
C/N	12.63 ± 1.32	14.11 ± 2.30	0.2841
Total N (%)	0.13 ± 0.05	0.12 ± 0.04	0.8232
Extractable P (ppm)	3.47 ± 3.53	33.53 ± 19.97	0.0133*
Exchangeable K (ppm)	269.25 ± 121.72	343.75 ± 201.12	0.5295
Organic carbon (OC, %)	1.60 ± 0.47	1.69 ± 0.48	0.7842
CEC (meq/100 g)	51.00 ± 8.23	40.20 ± 3.66	0.0206*
pH	6.43 ± 0.10	6.32 ± 0.20	0.3553
Soil Moisture (MC, %)	7.06 ± 1.41	6.03 ± 0.64	0.1469

Asterisk (*) in the P value column indicates significant difference of the measured variable in the two stands.

Species diversity and rarefaction

Table 4 presents the plant species diversity values of the area using the Shannon, Evenness, and Simpson diversity estimators. Shannon diversity index (H') ranges are typically from 1.5 to 3.5 and rarely reach 4.5 with a higher index value means a higher species diversity. In the study, the Shannon indices were very low but the two sites differ significantly with Gmelina plantation supporting higher number of species diversity as compared to Bangkal plantation. The Evenness was not statistically different between the two plantations similar to the Simpson diversity index. Numerically, however, higher Evenness index was observed in Gmelina indicative that more species are widely distributed in the area than in the Bangkal stand.

The Simpson diversity index, which allows comparison of trend of dominance with the bigger the value of D the lower the diversity, was greater in the Bangkal plantation suggesting that a few number of species were dominating the area than in Gmelina plantation.

The rarefaction curve for the expected number of species for a given number of individuals shows that the number of sample plots in the study already approximates the total number of species that can be observed in each site thus allowing comparison of diversity for the different sample size of the two stands (Fig. 2). The relatively steeper curve slopefora more diverse Gmelina plantation indicates that a small fraction of the species in the area were still unaccounted. This means that additional sample plots in Gmelina plantation can still yield a few more species. In Bangkal plantation, although with fewer number of species and sample plots, the curve slopes are flatter to the right suggesting that a reasonable number of species have been accounted thus additional sampling plots are likely to yield similar species.

Table 2. Relative density, relative frequency, and importance value (SIV) of regenerating species in Gmelina plantation. Classification symbols: T = tree, S = shrub, H = herb, G = grass, F = fern, V = vine.

Species	Family	RD %	RF %	SIV	Classification
Gmelina arborea Roxb.	Lamiaceae	21.5	4.88	26.46	T*
Ficus spp.	Moraceae	9.59	3.25	12.85	T
Lygodium circinnatum (Burm.) Sw.	Lygodiaceae	8.24	4.07	12.30	F
Centrosema pubescens (Turp.) Benth.	Fabaceae	6.67	4.07	10.74	V
Paspalum conjugatum Berg.	Poaceae	5.11	4.88	9.99	G
Ficus septica Burn.f	Moraceae	4.48	4.88	9.36	T
Melanolepis multiglandulosa (Reinw. ex Blume) Reich.f.	Euphorbiaceae	2.61	4.88	7.48	T
Commelina benghalensis L.	Commelinaceae	3.96	3.25	7.21	H
Swietenia macrophylla King	Meliaceae	3.86	3.25	7.11	T*
Litsea perrottetii (Blume) Fern.	Lauraceae	3.02	4.07	7.09	T
Acrostichum danaeifolium Langsd. & Fisch.	Pteridaceae	3.55	3.25	6.80	F
Glochidion album (Blanco) Boerl.	Phyllanthaceae	2.09	4.07	6.15	S
Leucaena leucocephala (Lam.) de Wit	Fabaceae	2.09	3.25	5.34	T**
Semecarpus philippinensis Engl.	Anacardiaceae	1.15	4.07	5.21	F
Polyscias nodosa (Blume) Seem.	Araliaceae	0.73	4.07	4.79	T
Mimosa pudica L.	Fabaceae	2.09	2.44	4.52	H
Pneumatopteris nitidula (C. Presl) Holtt.	Thelypteridaceae	1.77	2.44	4.21	F
Shorea contorta Vid.	Dipterocarpaceae	0.83	3.25	4.09	T
Ipomoea triloba L.	Convolvulaceae	1.56	2.44	4.00	V*
Rottboellia cochinchinensis (Lour.) Clayton	Poaceae	2.29	1.63	3.92	G
Kleinhovia hospita L.	Malvaceae	1.46	2.44	3.90	T
Selaginella cupressina (Willd.) Spring	Selaginellaceae	2.92	0.81	3.73	F
Drypetes longifolia (Blume) Pax & K.Hoffm.	Putranjivaceae	0.63	2.44	3.06	T
Acacia mangium Willd.	Fabaceae	1.25	1.63	2.88	T*
Annona muricata L.	Annonaceae	0.42	2.44	2.86	T
Litsea philippinensis Merr.	Lauraceae	0.42	2.44	2.86	T
Dysoxylum gaudichaudianum (A. Juss.) Miq.	Meliaceae	1.15	1.63	2.77	T
Chromolaena odorata (L.) King & H.E. Robins.	Asteraceae	1.36	0.81	2.17	S
Digitaria ciliaris (Retz) Koel.	Poaceae	1.04	0.81	1.86	G
Psidium guajava L.	Myrtaceae	0.21	1.63	1.83	T
Terminalia catappa L.	Combretaceae	0.21	1.63	1.83	T
Pterocarpus indicus Willd.	Fabaceae	0.31	0.81	1.13	T
Artocarpus odoratissimus Blanco	Moraceae	0.21	0.81	1.02	T
Premna cumingiana Schauer in DC	Lamiaceae	0.21	0.81	1.02	T

Spathodea campanulata P. Beauv.	Bignoniaceae	0.21	0.81	1.02	T
Acacia auriculiformis A.Cunn. Ex Benth.	Fabaceae	0.10	0.81	0.92	T*
Buchanania arborescens (Blume) Blume	Anacardiaceae	0.10	0.81	0.92	T
Ceiba pentandra (L.) Gaertn	Bombacaceae	0.10	0.81	0.92	T
Litsea glutinosa (Lour.) C Robinson	Lauraceae	0.10	0.81	0.92	T
Litsea philippinensis Merr.	Lauraceae	0.10	0.81	0.92	T
Piper arborescens Roxb.	Piperaceae	0.10	0.81	0.92	S
Vitex glabrata R.Br.	Lamiaceae	0.10	0.81	0.92	T
Total species			42		
Total individuals			959		

*Exotic, **exotic but naturalized.

The two plantations, despite their proximity and similarity in vegetation structure and soil attributes, exhibited uniqueness in terms of species composition with percent similarity index of only 10.24% (Fig. 3). This similarity was largely due to the presence of *C. benghalensis* and *P. conjugatum*in the two stands, a perennial herb and grass native in the Philippines.

Table 3. Relative density, relative frequency, and importance value (SIV) of regenerating species in Bangkal plantation. Classification symbols: T = tree, S = shrub, H = herb, G = grass, V = vine.

Scientific name	Family	RD %	RF %	SIV	Classification
Desmodium spp.	Fabaceae	27.05	14.29	41.34	S
Leptchloa chinensis (L.) Nees	Poaceae	23.80	14.29	38.09	G
Nauclea orientalis (L.)	Rubiaceae	18.84	19.05	37.88	T
Acrysanthes aspera L.	Amaranthaceae	14.55	14.29	28.84	S
Paspalum conjugatum Berg.	Poaceae	10.27	9.52	19.80	G
Commelina benghalensis L.	Commelinaceae	4.11	9.52	13.63	H
Ipomoea triloba L.	Convolvulaceae	0.86	9.52	10.38	H
Urena lobata L.	Malvaceae	0.34	4.76	5.10	S
Centrosema pubescens (Turp.)	Fabaceae	0.17	4.76	4.93	V
Total species	9				
Total individuals	584				

Influence of canopy structure, understory biomass, and soil attributes on species composition

Ordination showed significant influence of vegetation structure (i.e. the combination of tree DBH, height, density, crown cover, and litter biomass) and soil CEC and explained 48.96% and 66.26%, respectively, of the difference in species composition between the two plantations (Table 5, Fig. 4).

However, only the canopy trees DBH, height, and crown cover were found to significantly ($P < 0.05$) explain the understory species composition in the Gmelina stand in the reduced CCA model. Conversely, the higher CEC content of the soils in the Bangkal plantation mostly explained the dominance of herbs and grass species among sample plots especially *Desmodium* sp., *A. aspera, L. chinensis,* and *P. conjugatum.*

Table 4. Mean diversity indices of regeneration in Bangkal and Gmelina plantations.

Diversity indices	Shannon (H')	Evenness	Simpson (D)
Bangkal	0.52 ± 0.27a	0.78 ± 0.06a	0.39 ± 0.24a
Gmelina	1.06 ± 0.10b	0.81 ± 0.04a	0.12 ± 0.03a

Values in the same column with different letters indicate significant difference (P-value ≤ 0.05).

Table 5. Variance partitioning of the reduced canonical correspondence analysis (CCA) model.

Reduced model	Total inertia	% Variance explained (axis 2)	F-ratio (axis 2)	P-value (axis 2)
Effects of soil (~ CEC)	2.2289	48.86	2.2461	0.014
Effects of canopy structure and understory biomass (~ DBHo + Hto + DENo + Lb + Crown)	2.2289	66.26 (31.31)	3.7927 (1.7921)	0.033 (0.145)
Significance of each term:				
DBHo			2.0150	0.024
Hto			1.8575	0.031
DENo			1.6020	0.090
Lb			1.3875	0.150
Crown			1.8964	0.041

% Variance explained – variance of species distribution explained by CCA constrained axis 1 (axis 2), F-ratio - F statistics for axis 1 (axis 2), P-value - corresponding probability value obtained using the Monte Carlo permutation test for axis 1 (axis 2) with 999 permutations. Abbreviations: CEC, BAo, DBHo, Hto, DENo, Lb, Crown - soil and vegetation structure attributes according to Table 1.

In the Gmelina stand, all species responded favorably towards greater canopy height, diameter and crown density despite the presence of some herb and grass species in the area.

Discussion

Species composition and diversity as influenced by microsite conditions in the two plantations

Exotic based plantations are not necessarily always “green deserts” as some can support succession comparative to native forest (Brockerhoff *et al.*, 2008; Bremer and Farley, 2010). In this study, we found thatexotic Gmelina plantation had significantly betterspecies diversity and almost five times species rich thanthe native Bangkal plantation.

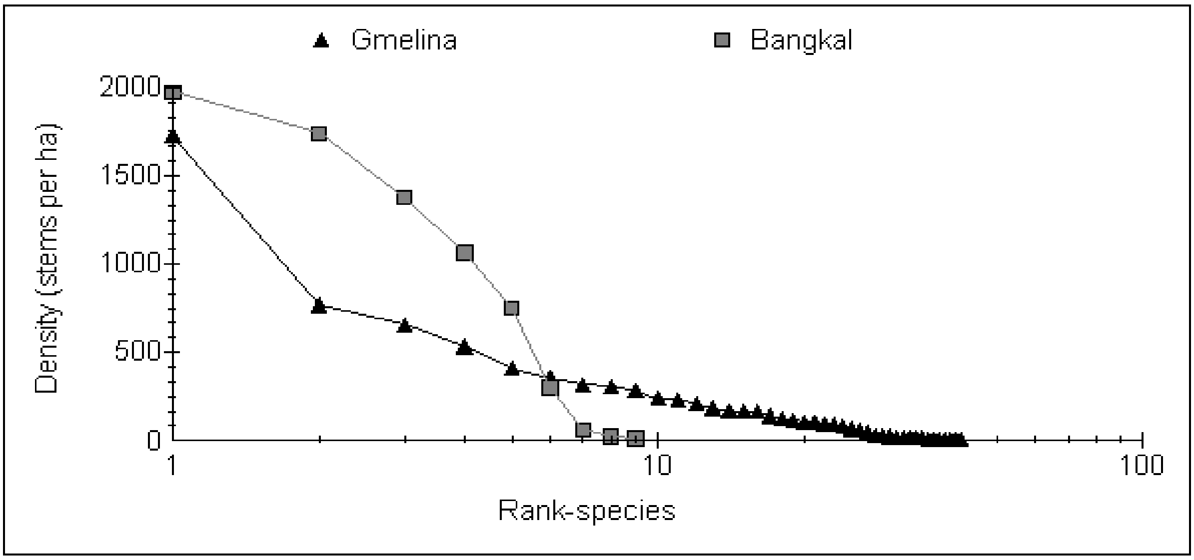

Fig. 1. Species rank-density curve in the Gmelina and Bangkal plantations. Species are plotted in rank order based on density (stems per hectare).

The result is comparative to diversity ofsuccession observed in a natural second growth forest and other tree plantations in the Philippines and elsewhere (e.g. Otsamo, 2000; Viisteensaari *et al.*, 2000; Lee *et al.*, 2006a; Lee *et al.*, 2006b; Tulod *et al.*, 2017). For instance, Tulod *et al.* (2017) tallied 20 tree species in a natural forest and about 15 and 11 species, respectively, in exotic tree plantations of Teak (*Tectona grandis*) and Mangium (*Acacia mangium*). These are almost similar or even lower to the number of tree species observed in the Gmelina plantation in this study.Variations in site characteristics (e.g. soil attributes, herbaceous plant cover, etc.)may explain the variations in the amount of regenerating species even among similar vegetation typesat the same sites (Zanne and Chapman, 2001).

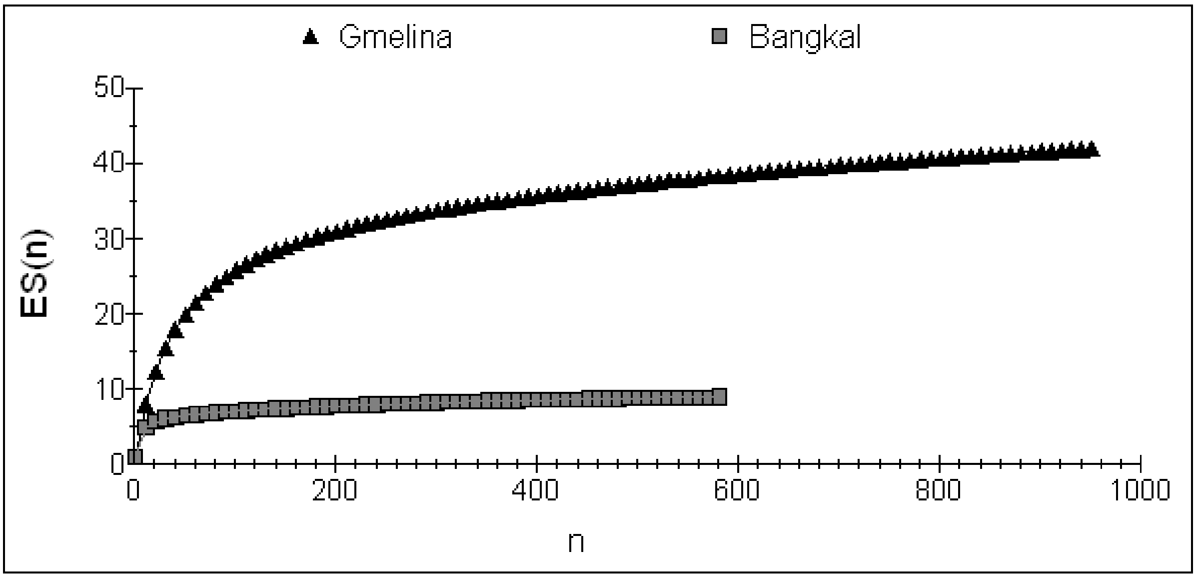

Fig. 2. Rarefaction curve of species per number of individuals observed.

The apparent separation of the two stands along the ordinal axis and the observed low similarity index suggest that Gmelina and Bangkal plantations are heading towards a different succession trajectory despite of their proximity. The improvement in understory regeneration in Gmelina that involved more than 60% woody species of mostly native appeared to occur along the gradientswith greater mean height, diameter, and crown cover structure of canopy trees, which may have supressed the invasion of grassess and herbaceous plants in the area. In contrast, the recruitment or establishment ofwoody species regeneration in the Bangkal plantation is seemed to be constraint by the dominance of herbaceous vegetations such as*A. aspera*, *Desmodium* sp., *L. chinensis,* and *P. conjugatum*, which developed favorably due mainly to better soil CEC content of the area. This may represent a competitive exclusion by herbaceous plants resulting to a delayed or arrested succession, and may last indefinitely unless managed accordinglyor if tree species are able to compete and outgrow these herbaceous vegetation.Arrested succession usually occurs in sites whereperennial shrubs or herbaceous species are the most dominant understory layer(e.g. Putz and Canham, 1992; Sarmiento, 1997; Royo and Carson, 2006; Acácio *et al.*, 2007) as their growth form (i.e. large densely-branched rhizome or expanded tussock structure) allow them to exploit the resources above and belowground intensively and extensively (Grime, 1973) and can be more severe on sites where soil resources are limited (Putz and Canham, 1992).

Implications to future forest restoration in the Philippines using exotic and/or native tree plantations

Whether plantations with native species are effective or not in initiating the recovery of plant biodiversity, they are often the first choice over exotic species in restoration programs as they are assumed to preclude the risk associated to exotic species (e.g. invasive potential, vulnerability to pest and disease outbreak, among others), are more favorable habitat and food source for vast number of fauna and microorganisms, including a number of other ecological benefits(Bremer and Farley, 2010). However, the list of attributes to assess the success of a restoration project developed by the Society for Ecological Restoration (SER, 2004)does not in anyway directly advocate the use of native species in restoration,although appropriate species selection at the start of planting remain essential to facilitate early successional processes(Hobbs and Norton, 1996). In the absence of a reference site to assess the sites being restored, the measures of restorationsuccess such as species diversity, vegetation structure, and ecological processes (Ruiz-Jaén and Aide, 2005)can be used to determine if the species selected for restoration is affective or not in facilitating succession.

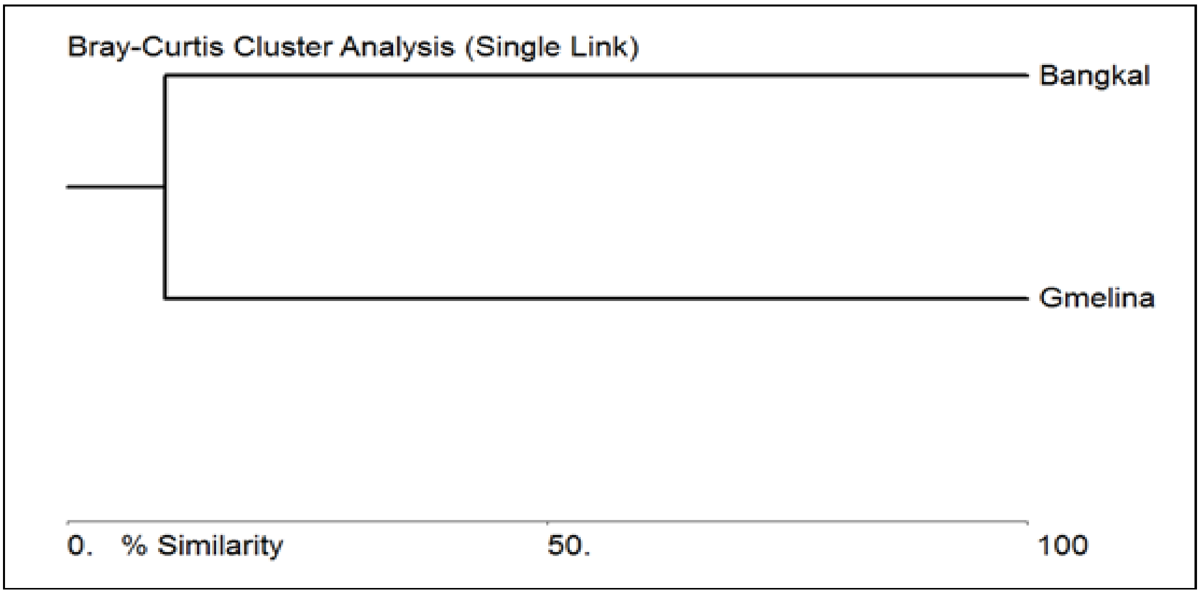

Fig. 3. Percent similarity of regeneration in Gmelina and Bangkal plantations.

In this study, the results showed thatthe existing exotic plantation of Gmelinafrom previous reforestation project was more effective than the native Bangkal plantation in initiating recolonization of native woody species. These number of regenerating tree species are expected to colonize the Gmelina plantation given the higher density and richness of woody seedlingsin the area as compared to Bangkal stand(cf. Ruiz-Jaén and Aide, 2005). This result supports previous findings about the potential of exotic stands in the country to initiate recolonization of native species similar to natural forest (cf. Lee *et al.*, 2006a; Lee *et al.*, 2006b; Tulod *et al.*, 2017), suggesting that exotic plantations are not totally detrimental to biodiversity conservation in the country as often perceived and can be even more effective than native plantations such as the Bangkal stand in this study.However, this may entail actual field experimentation and long-term monitoring to guide the selection of species in future forest restoration as some species, local and native,can be invasive or favorable to invasive herbaceous vegetation leading to arrested succession.

Nonetheless, following the list of key attributes of a succesful restoration developed by SER (2004) such as whether all functional groups necessary for ecosystems' stability are represented and whether the restored ecosystem is self-sustaining, the two reforestation stands appear to be not succesful yet. Even the more diverse Gmelina stand still needs to develop appropriate canopy composition and structure similar to natural forest, although this is possible given the diversity and number of regenerating native woody species under its canopy that are expected to colonize the area. Nonetheless, once all the native woody species are able to growinto the canopy layer, functional processes such as dispersal will not be a constraint as they can be a possible source of food and shelter for birds and other animals, which can also benefit the Bangkal stand given their proximity.

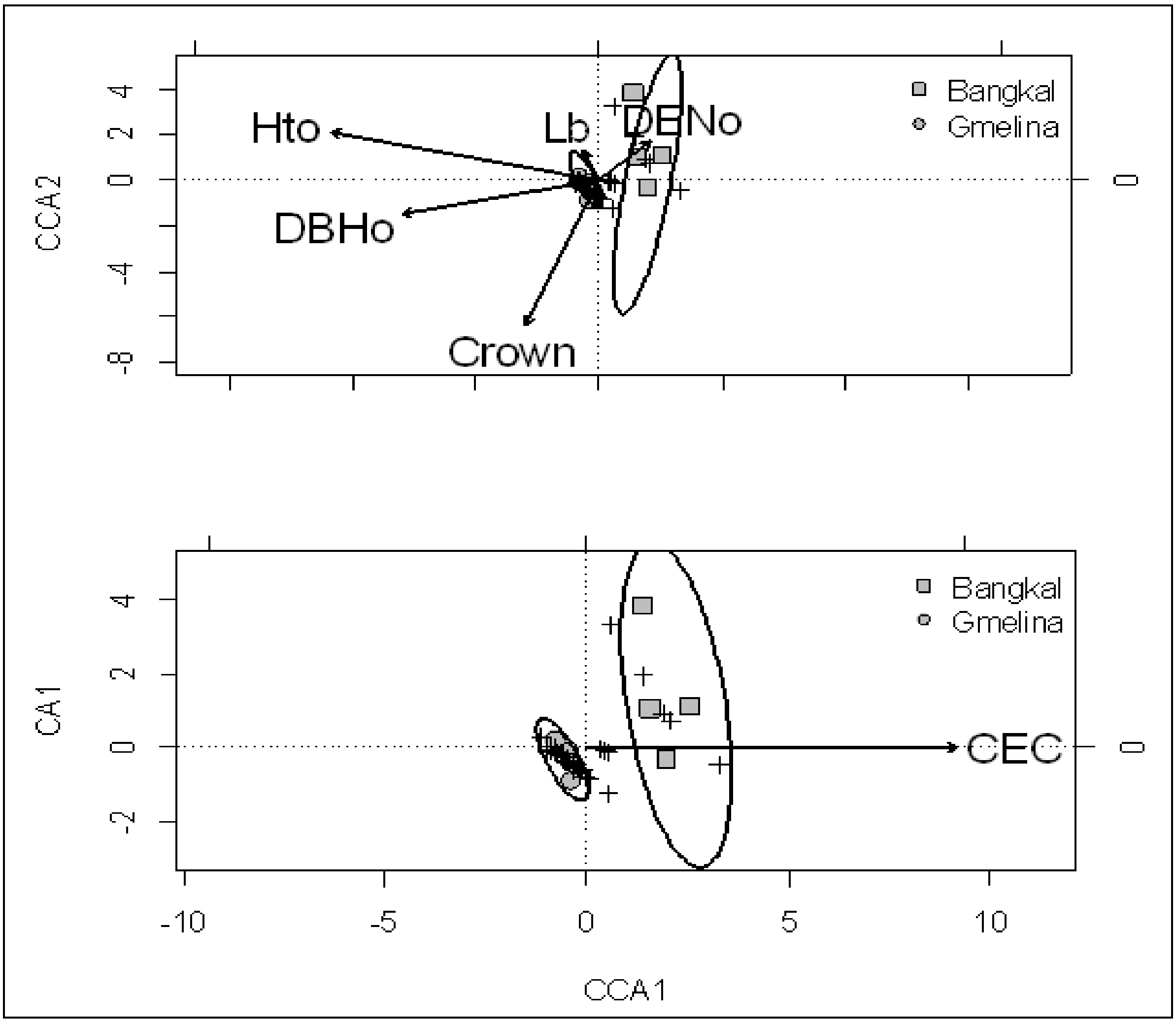

Fig. 4. Ordination diagram showing the reduced CCA model. Upper diagram shows the explanatory variables using the measured canopy structure and understory biomass variables, while the diagram below is the reduced model using the soil variables. The plus symbol denotes species distribution while the filled circle and square symbols indicate, respectively, the sample plots in Gmelina and Bangkal plantations.

Some management interventions may be necessary, however, for Bangkal plantation to control the spread of herbaceous vegetation and to allow native woody species to establish and colonize. Moreover, the Gmelina stand appear to be self-sustaining as the identity and number of its regenerating species have the potential to persist indefinitely under its existing environmental condition.

Conclusion

Despite the proximity of Gmelina and Bangkal plantations in this study, the two plantations appeared to be heading towards a different succession trajectory with Gmelina plantation being more self-sustaining given the higher diversity and number of its regenerating tree species than the Bangkal stand.

Thus, the results suggest that exotic-based tree plantations in the country can be important successional sites for secondary natural forest and are not at all detrimental to biodiversity conservation as commonly perceived. However, while the exotic Gmelina stand facilitated higher number of native woody regeneration than the native Bangkal stand, it is important that the existing number of native woody regeneration are able to grow into the canopy and create appropriate canopy structure similar to natural forest to be more stable. Controlling the density of the canopy trees in the Gmelina stand is therefore necessary to create enough canopy gaps and facilitate the rapid development of woody seedlings into the upper canopy layer while allowing species composition and environmental attributes to evolve further similar to natural forest.

The study also provided evidence of competitive exclusion by herbaceous vegetation that restricted the recruitment or establishment of native woody species in the Bangkal plantation resulting to the failure of the regeneration. A more favorable condition in native Bangkal plantation has favored the growth of aggressive herbaceous plants that restricted the growth of woody species. This outcome requires a more deliberate intervention to control the spread of herbaceous plants and to allow re-establishment and colonization of native woody species in the Bangkal stand. Overall, this study shows that without active interventions following plantation establishment, the restoration of native forest either through native or exotic plantation species can be very slow and even vulnerable to competition with invasive herbaceous plants that may result to arrested succession.

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