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SPECIAL FEATURE: ORIGINAL ARTICLE

Biodiversity and Its Ecological Functions in East-Asia and Pacific Region: Status and Challenges

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Plant diversity patterns in remnant forests and exotic tree species-based reforestation in active limestones quarries in the Luzon and Mindanao biogeographic sub-regions in the Philippines

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Abstract The Philippines is both a megadiversity country and a global biodiversity hotspot. The diversity patterns of three major plant groups were assessed: (1) trees (trees and palms), (2) herbs (grasses, shrubs, forbs, ferns), and (3) epiphytes (climbers and epiphytes), by determining the changes in compositional and species richness patterns in two forest conditions, i.e., remnant forests and exotic tree species-based reforested areas, in active forest over limestone quarries in the Luzon and Mindanao biogeographic sub-regions of the Philippines. We identified 458 species comprising 266 tree species, 95 herbaceous species and 97 epiphyte species. Of these, 21 species were categorized as threatened species. Species composition differed between remnant forests and exotic tree species-based reforested areas for tree species and epiphyte species, while composition differences between the Luzon and Mindanao biogeographic sub-regions were limited to tree species only. Differences in species diversity (in terms of richness) were observed between biogeographic sub-regions for all plant groups, while differences between forest conditions were found for tree and epiphyte species only. Interestingly, there were significantly fewer numbers of exotic species in bigger remnant forest sites and in older exotic tree species-based reforested sites, while larger numbers of native species occurred in older than in younger exotic tree species-based reforested sites. The results emphasize the importance of understanding forest recovery in disturbed ecosystems. Conservation attention should focus on protecting remaining forests and planting native species as part of a forest restoration strategy to enhance faster forest recovery and re-connecting remnant forest patches.

Keywords Exotic-species-based reforestation · Forest restoration · Forest over limestone · Remnant forest · Threatened tree species

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Introduction

The Philippines is divided into 16 biogeographic regions, with a number of sub-regions within each region based on the unique species assemblages and ecosystems that arose from a combination of geological, geographic and geomorphological factors (Ong et al. 2002). This gave rise to a high level of endemism, which led to its inclusion as of one of the 17 megadiverse countries in the world (Mittermeier 1997). The country is also considered one of the 36 global biodiversity hotspots (Mittermeier et al. 2011; Noss et al. 2015; CEPF 2017) due to massive deforestation between 1900s to present, endangering many endemic species in the country (Posa et al. 2008; Suarez and Sajise 2010). One of the most affected forest types in the Philippines is the forest over limestone (Restificar et al. 2006); however, very few studies had been conducted on this forest type.

The forest over limestone is one of the 12 forest formations in the Philippines found generally in the lowlands and in karst landscapes (Fernando et al. 2008a). Because of the resources found therein, the forest had been subjected to quarrying to secure products needed in the construction industry (Clements et al.

Table 1 Location of transects established in the two biogeographic sub-regions (three quarry sites each in the Luzon and Mindanao sub-region) and a protected secondary forest over limestone (biodiversity offset site) in the Mindanao sub-region and the forest conditions found therein

Study sites	Transect code	Coordinates		Forest condition	Patchsize/year planted	Sampling year
A. Luzon						
Agno	AG_T1	16°05′27.4″N	119°47′40.0″E	Remnant forest	4.4 ha	November 2013
Agno	AG_T2	16°00′55.4″N	119°48′03.6″E	Remnant forest	2.6 ha	November 2013
Agno	AG_T3	16°02′08.0″N	119°47′02.2″E	Remnant forest	4.3 ha	November 2013
La Union	LN_T1	16°47′16.1″N	120°20′27.1″E	Remnant forest	6.4 ha	October 2013
La Union	LN_T2	16°47′45.8″N	120°20′54.2″E	Remnant forest	3.0 ha	October 2013
La Union	LN_T3	16°49′33.6″N	120°20′28.5″E	Remnant forest	5.7 ha	October 2013
La Union	LN_T4	16°46′16.1″N	120°20′07.6″E	Remnant forest	15.4 ha	October 2013
Bulacan	BL_T1	14°56′08.0″N	121°05′35.4″E	Remnant forest	4.6 ha	November 2013
Bulacan	BL_T2	14°54′26.2″N	121°04′59.6″E	Reforestation site	1996[b]	November 2013
Bulacan	BL_T3	14°54′01.3″N	121°04′47.3″E	Reforestation site	2000[b]	November 2013
B. Mindanao						
Lugait	LG_T1	08°19′19.8″N	124°17′01.2″E	Reforestation site	1995[c]	December 2013
Lugait	LG_T2	08°19′53.9″N	124°16′16.3″E	Reforestation site	1995[b,c]	December 2013
Bunawan	BN_T1	07°12′57.7″N	125°38′25.7″E	Reforestation site	1997[b,c]	January 2014
Bunawan	BN_T2	07°13′06.8″N	125°38′25.4″E	Reforestation site	1993[a]	January 2014
Bunawan	BN_T3	07°14′13.9″N	125°36′59.4″E	Reforestation site	1997[b,c]	January 2014
Mati	MT_T1	06°53′43.1″N	126°08′33.0″E	Reforestation site	1998[b,c]	February 2014
Mati	MT_T2	06°53′19.4″N	126°08′37.1″E	Reforestation site	1993[b]	February 2014
ILPLS	IN_T1	08°32′33.6″N	124°19′00.6″E	Reforestation site	1994[b,c]	November 2014
ILPLS	IN_T2	08°32′40.6″N	124°19′06.9″E	Remnant forest	14 ha	November 2014
ILPLS	IN_T3	08°32′38.2″N	124°19′17.1″E	Remnant forest	36 ha	November 2014

Holcim Mining Development Corporation (HMDC), an associate member of the LafargeHolcim Group, operates mining concessions in four localities within the country with six active quarry sites. These include the following: In Luzon: La Union concession with quarry sites in the Municipalities of Bacnotan, Province of La Union and Agno, Province of Pangasinan; Bulacan concession with quarry sites covering portions of Municipalities of Norzagaray and Doña Remedios Trinidad in the Province of Bulacan; In Mindanao: Davao concession with quarry sites in the City of Mati, Province of Davao Oriental and in the District of Bunawan, City of Davao; and Lugait concession in the Municipality of Lugait, Province of Misamis Oriental. HMDC have undertaken reforestation activities as part of their quarry rehabilitation plan. HMDC has adopted the Initao-Libertad Protected Landscape and Seascape (ILPLS) as one of its biodiversity offset sites in Misamis Oriental

[a]Planted with auri (*Acacia auriculiformis*), [b] planted with gmelina (*Gmelina* arborea),[c] planted with mahogany (*Swietenia macrophylla*)

2006). Unfortunately, quarrying has detrimental impacts on the existing forest and its environments, jeopardizing biodiversity (Van Beynen and van Beynen 2011; Lad and Samant 2014). In fact, only about 29% or 35,000 km^2 of karst landscape in the Philippines are protected (Day and Urich 2000; Restificar et al. 2006). Furthermore, the impact of quarrying activities to plant diversity in the forest over limestone is not fully understood.

One approach to offset biodiversity loss from mining and quarrying is through reforestation efforts (Khater and Martin 2007; Novák and Prach 2010; Gilardelli et al. 2016). In the past, fast growing exotic tree species had been selected in many reforestation activities. Recent reforestation efforts have increasingly used native tree species to hasten biodiversity recovery (Hall et al. 2011; Anticamara et al. 2012; Middendorp et al. 2016). Some studies revealed that native tree species were found growing in exotic tree species-based reforested areas (e.g. Zhang et al. 2013; Wolfe et al. 2015), an indication that biodiversity recovery is possible even in exotic tree species-based reforestation efforts.

Moreover, remnant forests serve as potential seed sources for reforestation efforts and provide refuges for many forest species (Turner and Corlett 1996; Pither and Kellman 2002; Machado et al. 2016). However, small remnant forest have higher rates of mortality and extinction (Laurance et al. 2011; Pimm et al. 2014; Tomimatsu et al. 2015) and are vulnerable to invasion of exotic species (Raghubanshi and Tripathi 2009; Lôbo et al. 2011; LaPaix et al. 2012; Farmilo et al. 2014). While sufficient studies detected significant biodiversity loss in small forest patches of other tropical forest formations, little is known if this pattern can also be observed in forest over limestone ecosystems.

The current study is part of a long-term ecological research program on the biodiversity of active limestone quarries managed by a private corporation, which has committed itself to the conservation of biodiversity wherever it operates. This is a unique opportunity for the academe and industry to work together and address how to conserve biodiversity in the context of active quarrying (see further details in Table 1).

In this study, plant diversity was assessed in quarry sites to understand species composition and richness patterns in two forest conditions (remnant forest and exotic tree species-based reforested area) around active limestone quarries in the two biogeographic sub-regions of the Philippines (Luzon and Mindanao). Answers to the following questions were sought: (1) Are diversity patterns different between forest conditions and between

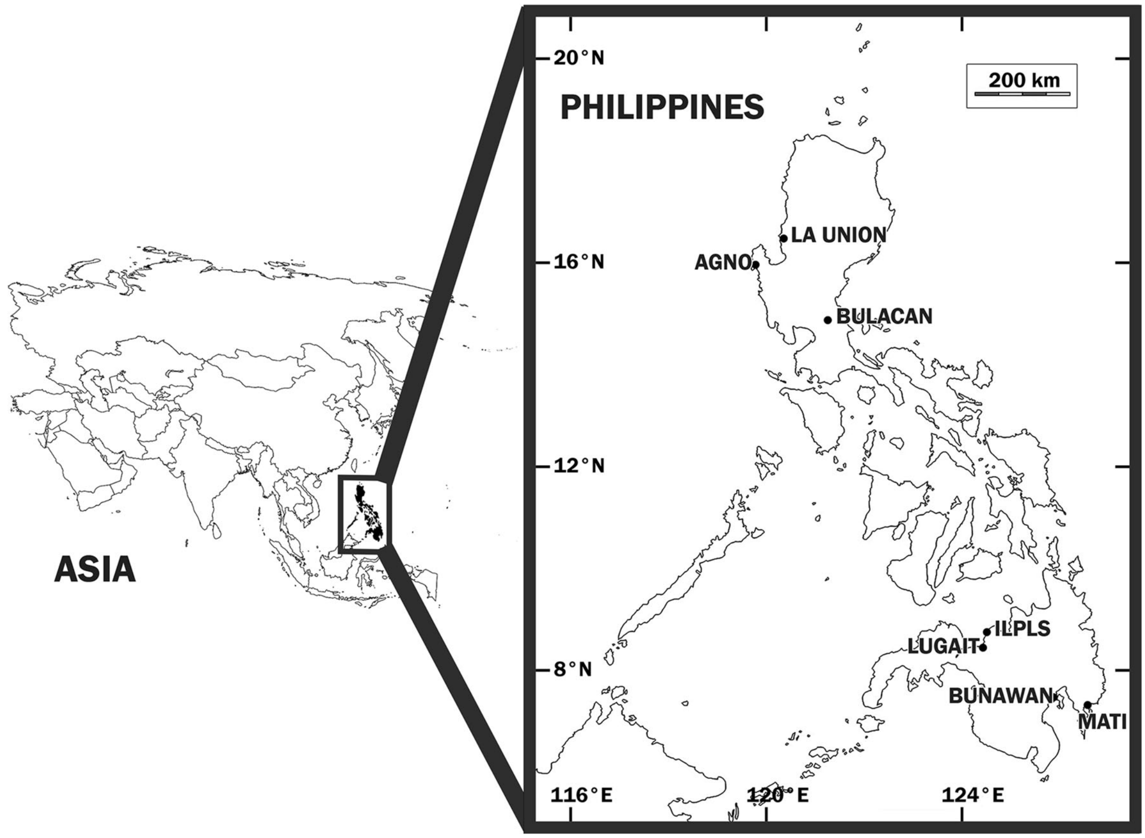

Fig. 1 Location of the study sites across the Philippine archipelago: Luzon biogeographic sub-regions in the north and Mindanao biogeographic sub-region in the south. Plot points are main locations where transects were established

biogeographic sub-regions? (2) Within each forest condition, is exotic tree species richness higher in small forest patches? (3) Similarly, is indigenous species richness higher in older reforested sites? Based on a review of available literature, this is the first study of its kind that looks into biodiversity changes in two contrasting forest conditions—remnant forests that were the consequence of continuous deforestation and forests that aim to offset impacts of deforestation.

Methods

Study sites

In 2013 and 2014, an extensive biodiversity study was conducted in active limestone quarries operated by a private corporation in the Philippines (Fig. 1; see site description in Table 1). A total of 20 transects were established in six active quarry sites and one biodiversity offset site in two major biogeographic sub-regions in the Philippines: the Luzon transects in northern part of the Philippines and the Mindanao transects in the southern part of the Philippines. Transects were established in two forest habitat conditions: remnant forest fragments and exotic tree species-based reforested areas maintained by the company.

All quarry sites in this study are located at slopes of low gradients extend to near the coast, except for some transects in the Bulacan quarry site in Luzon. The exotic tree species-based reforestation sites, which started between 1990s and 2000s, were planted with fast growing exotic species of auri (*Acacia auriculiformis*), gmelina (*Gmelina arborea*) and mahogany (*Swietenia macrophylla*) in the middle of agricultural and built-up areas near the active quarries. The remnant forest sites are highly degraded, and the original forests had long been transformed into human settlements with agriculture as the dominant land use. Thus, very few patches of remnant forests are left, and those big enough for sampling (> 2 hectares), were found only along limestone gullies and creeks, and rarely in limestone hills (see description in Table 1).

Vegetation sampling

An extensive vegetation survey was undertaken using a variable belt-transect method (VTM). The VTM is a modified standardized belt-transect method with its length determined by the number of individual plants to be counted (Foster et al. 1998). In this study, a transect was laid with a predetermined width according to vegetation type, and the length of the transect was determined when 50 trees [≥ 30 cm diameter at breast height (DBH)] had been measured. Except for one site which had few such trees; hence, a 20-cm DBH limit was set as a cut-off. In forest patches and other complex communities like the existing vegetation within the study sites, canopy trees were used as a class that defined the ultimate dimensions of the transect.

In each transect, six nested sub-transects (classes) at pre-determined width were measured according to vegetation type. The classes were: Class I—larger trees with ≥ 30 cm DBH (transect width 20 m), Class II—medium-sized trees with 10–29.9 cm DBH (transect width 10 m), Class III—small trees and saplings with 1–9.9 cm DBH (transect width 2 m), Class IV—palms (transect width 5 m), Class V—herbaceous understory, grasses, ferns (transect width 5 m), and Class VI—plants attached to trees in Classes I and II (proto-terrestrial herbs, vines, epiphytes, hemi-epiphytes). Diameter at breast height (DBH) was measured for the Class I–IV vegetation types. The Braun-Blanquet method was used to determine the cover-abundance scale (Braun-Blanquet 1932) of the Class V vegetation type.

Preliminary identification of species was determined on-site and verified using taxonomic keys (Rojo 1999; Pancho and Gruezo 2006). Voucher specimens were collected and deposited at the University of the Philippines Herbarium (PUH).

Biodiversity assessment

Vegetation types were categorized into three main plant groups: (1) Tree species included vegetation types from Class I to IV, which were erect woody trees (> 1 cm DBH) and palms; (2) herbaceous species were vegetation types included in Class V, which are understory species with succulent stems; and (3) epiphytes were vegetation type included in Class VI, which are species that used trees (in Class I and II) as structural support. There were no overlapping species between plant groups.

To undertake the assessment, all plants encountered were identified up to the morpho-species level. Plants were further classified as either native (indigenous and endemic) or exotic species. Identified species were further classified based on threatened status, based on the categories of the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2017) as well as the categories in the Philippine Red List of Threatened Plant Species (Fernando et al. 2008b).

Statistical analyses

All statistical analyses were performed using R version 3.3.0 (Team 2016). Two main response variables were used: species composition and species richness. These are commonly used measures in ecological studies. Species composition includes all species found within the scale of the study (transect scale, forest condition, biogeographic sub-regions) while species richness (alpha diversity) refers to the number of species within the scale of the study.

Species composition and richness patterns were compared between forest conditions and between biogeographic sub-regions. For species composition, the R package vegan (Oksanen et al. 2007) was used to construct a non-metric multidimensional scaling (NMDS) ordination biplot and fitted forest conditions and biogeographic sub-regions to the distance matrix output from the NMDS ordination. For species richness, one-way ANOVA was used to test the differences in species richness between forest conditions and between biogeographic sub-regions.

How each forest condition responds to quarrying was determined by identifying the number of native species and exotic species growing in the exotic tree species-based reforested sites and in the remnant forest sites. Using species richness of native and exotic species as response variable, regression analysis was performed using general regression model (GLM) with Poisson error structure to model the relationship of species number to remnant forest size and reforestation age.

Results

Species occurrence

A total of 458 plant morpho-species from 89 known families, including nine unidentified species, were collected. Thirteen plant families had at least 10 species constituting to at most 50% of the total number of species found across the study sites. The most notable plant groups encountered were legumes (Fabaceae, 35 species, 7.66%), figs (Moraceae, 27 species, 5.91%), members of the coffee family (Rubiaceae, 21 species, 4.60%), grasses (Poaceae, 20 species, 4.38%), and palms (Arecaceae, 19 species, 4.16%). Across the landscape, 266 tree species (trees and palms), 95 herbaceous species, and 97 epiphytes (climbers and epiphytes), were found. Of these, 228 species were identified up to the species level, of which 183 species were native (45 species were Philippine endemics and 138 species were indigenous to the Philippines), and 45 species were exotics.

The remnant forest sites were dominated by native tree species like *Vitex parviflora*, *Wrightia pubescens*, *Pterocymbium tinctorium*, *Pterospermum diversifolium*, *Pterocarpus indicus*, *Afzelia rhomboidea*, *Terminalia foetidissima*, *Ziziphus talanai*, *Celtis philippensis* and *Buchanania arborescens*. However, exotic species were also growing in the remnant forest such as *Albizia saman*, *Chromolaena odorata*, *Leucaena leucocephala*, *Artocapus heterophyllus*, and *Gliricidia sepium*.

In the reforested sites, exotics other than the planted species were also found, such as *Chromolaena odorata,*

Table 2 List of threatened species assessed based on national (Department of Environment and Natural Resources Administrative Order 2007-01 (Fernando et al 2008b) and global criteria (IUCN 2017)

Family	Species	IUCN assessment (IUCN 2017)	DAO 2007-01 (Fernando et al. 2008b)
Arecaceae	*Adonidia merrillii* (Becc.) Becc.	Near threatened	Endangered
Fabaceae	*Afzelia rhomboidea* (Blanco) Vidal	Vulnerable	Endangered
Meliaceae	*Aglaia cumingiana* Turcz.	Vulnerable	Vulnerable
Polypdiaceae	*Aglaomorpha meyeniana* (Hook.) Schott	Not evaluated	Vulnerable
Meliaceae	*Aphanamixis polystachya* (Wall.) R.Parker	Least concern	Vulnerable
Moraceae	*Artocarpus blancoi* (Elmer) Merr.	Vulnerable	Not evaluated
Ebenaceae	*Diospyros discolor* A DC *as Diospyros philippinensis (Desr.) Gürke*	Endangered	Critically endangered
Ebenaceae	*Diospyros cauliflora* Blume	Not evaluated	Critically endangered
Malvaceae	*Diplodiscus paniculatus* Turcz.	Vulnerable	Not evaluated
Moraceae	*Ficus ulmifolia* Lam.	Vulnerable	Not evaluated
Sapindaceae	*Guioa discolor* Radlk.	Endangered	Endangered
Euphorbiaceae	*Macaranga bicolor* Müll.Arg.	Vulnerable	Not evaluated
Euphorbiaceae	*Macaranga grandifolia* (Blanco) Merr.	Vulnerable	Least concern
Sapotaceae	*Palaquium philippinense* (Perr.) C Robinson	Not evaluated	Vulnerable
Fabaceae	*Pterocarpus indicus* Merr.	Vulnerable	Critically endangered
Euphorbiaceae	*Reutealis trisperma* (Blanco) Airy Shaw	Vulnerable	Critically endangered
Fabaceae	*Securinega flexuosa* (Müll.Arg.) Müll.Arg.	Vulnerable	Vulnerable
Meliaceae	*Swietenia macrophylla* King	Vulnerable	Not evaluated (Exotic)
Lamiaceae	*Vitex parviflora* A.Juss.	Vulnerable	Endangered
Rhamnaceae	*Ziziphus* cf. *hutchinsonii* Merr	Vulnerable	Not evaluated
Rhamnaceae	*Ziziphus talanai* (Blanco) Merr	Vulnerable	Not evaluated

Lantana camara, and *Leucaena leucocephala*. Early successional native tree species were also encountered such as *Melanolepis multiglandulosa, Brossounetia luzonica*, *Ficus ampelas*, *Pometia pinnata*, *Pterospermum diversifolium*, *Radermachera pinnata, Streblus asper*, *Livistona rotundifolia, Tabernaemontana pandacaqui,* and *Macaranga tanarius* in the midst of several reforested sites, along with native herbaceous species like *Cyrtococcum patens* and *Desmodium laxifolium,* and epiphytes like *Tinosmiscium petiolare* and *Epipremnum pinnatum*.

In the plant assemblage encountered, there were 21 threatened species (i.e. vulnerable, endangered, critically endangered) based on IUCN Red List of Threatened Species categories and the Philippine Red List of Threatened Plant Species (Table 2).

Species composition and species richness patterns

Differences in species composition and species richness between biogeographic sub-regions and between forest conditions were not consistent between plant groups (Figs. 2, 3). The fitted environmental variable in the NMDS ordination biplot (Fig. 2) indicated significant differences in species composition in both biogeographic sub-region and in forest condition related to tree species composition (Fig. 2a), forest condition only related to herbaceous species composition (Fig. 2b), and none for epiphyte species composition (Fig. 2c). Consequently, one way ANOVA *t* test showed that the species richness between Luzon and Mindanao sub-regions differed only for epiphyte species (Fig. 3e), while the species richness between remnant forest and reforested sites differed for both tree and epiphyte species (Fig. 3b, f).

Native and exotic patterns along remnant forest size and reforestation age

Interestingly, the number of native species in the reforested sites did not increase with forest size (Fig. 4a), but did so with reforestation age (Fig. 4b). Moreover, significantly fewer numbers of exotic species were encountered in bigger remnant forest and older reforested sites (Fig. 4c–d).

Discussions

Plant diversity of active limestone quarries

The plant diversity status of active limestone quarries in two biogeographic sub-regions in the Philippines was extensively studied. The number of species encountered in this study reflects the rich plant diversity of forests over limestone. In this study, a cumulative total of 222 species of trees were found in all transects, of which 97 species were found only in the Luzon transects, 95 species were found in the Mindanao transects, and 37 species were found in both sub-regions. For comparison, in a 16-ha tropical lowland forest in Luzon Island still unaffected by anthropogenic activities but subjected to natural catastrophic disturbances, at least 320 tree species were recorded (see the Palanan Permanent Forest Dynamics Plot in Co et al. 2006).

The forests over limestone have been home for many endemic species because of their unique environmental conditions, e.g., the saline soil properties, dry environment, and shallow soil parent materials, which allowed for the evolution of limestone-adapted species (Quere-

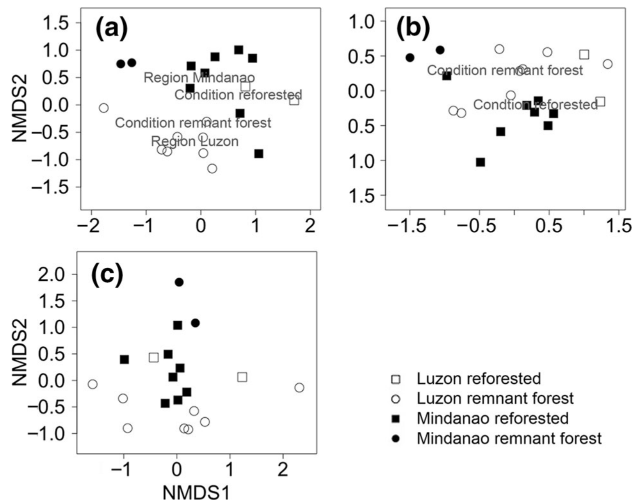

Fig. 2 Non-metric multidimensional scaling (NMDS) ordination plots based on presence-absence matrix composition of **a** tree species, **b** herbaceous species, and **c** epiphyte species. Text inside the NMDS plot indicates significant species compositional differences between biogeographic sub-regions and between forest conditions

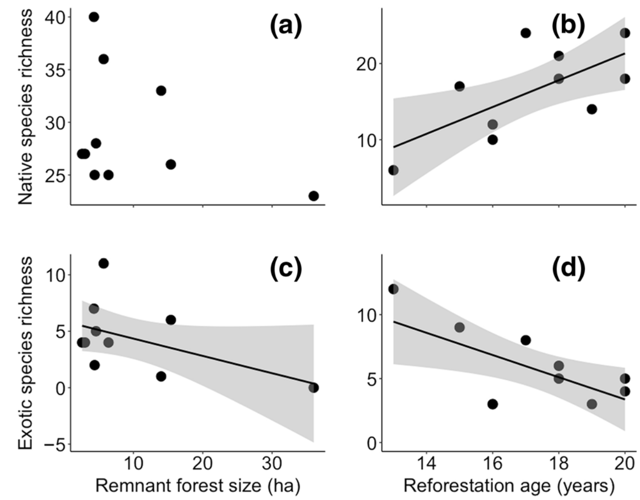

Fig. 4 Regression relationships for native and exotic tree species richness with remnant forest size (**a** native, **c** exotic) and reforestation age (**b** native, **d** exotic). The regression model was based from general linear model (GLM) with poisson error distribution. Plots with 95% confidence intervals are from models with significant relationships ($P < 0.05$)

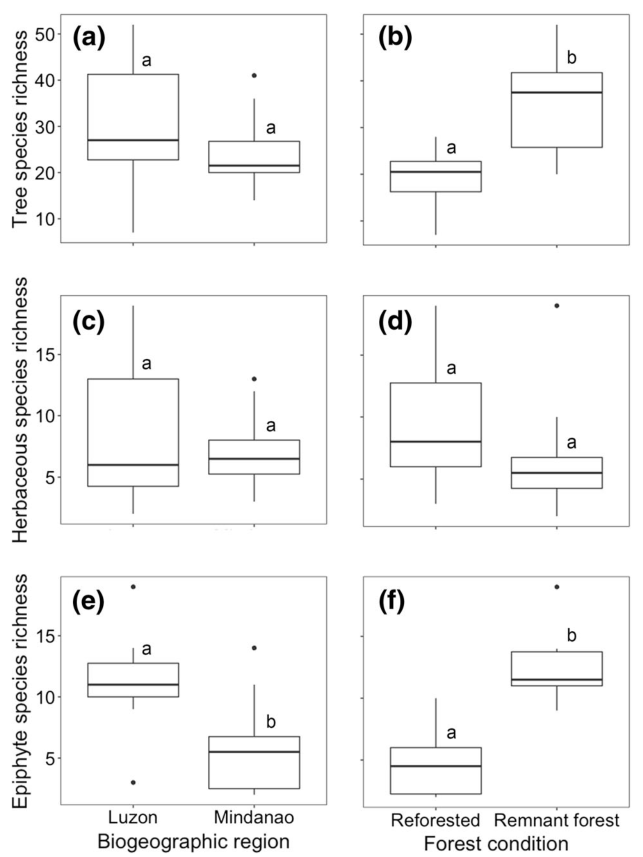

Fig. 3 Box-and-whiskers plot comparing differences in species richness between biogeographic sub-region and between forest conditions for tree species (**a**, **b**), herbaceous species (**c**, **d**), and epiphyte species (**e**, **f**) (Legend: *a* and *b* indicates significant differences). An outlier is denoted by a filled point

jeta et al. 2007; Fernando et al. 2008a; Liu et al. 2014). Since time immemorial, the original natural vegetation in forests over limestone had long been exploited for their trees, a most valuable resource in the country (Whitford 1911; Goode 1912; Clements et al. 2006). Due to its accessibility, it is considered as one of the most threatened forest formations in the Philippines (Fernando et al. 2008a).

The tree species assemblage recorded across the study was similar to the typical species composition of the molave-type forest described by Whitford (1911) or the forest over limestone formation identified by Fernando et al. (2008a). The typical forest over limestone forest occupies topography similar to that on which tropical semi-evergreen and tropical moist deciduous forest can be found (Fernando et al. 2008a).

Legumes or species from the bean family (Fabaceae) were the most speciose among plant families encountered across the study, followed by coffee family (Rubiaceae), fig family (Moraceae), grass family (Poaceae) and palms (Arecaceae). Legumes have been identified to play critical roles in forest restoration processes due to their nitrogen-fixing capability (Wang et al. 2010; Chaer et al. 2011). Rubiaceae and fig species are known food sources of bats and birds, which in turn can lead to high rates of seed dispersal and recolonization success (Shanahan et al. 2001; Bremer and Farley 2010; Lomáscolo et al. 2010). Grasses are one of the most widely-distributed species in open sites due to their anemophily and anemochory traits, that is, their lightweight grains make wind an efficient agent of distribution (Gafta et al. 2016). Proliferation of these four families in the remnant forests indicates that these sites are still in the early stages of vegetation succession. Palms exhibit an amazing geographic variation in species richness and composition, which make them species-rich across biogeographic regions and across environmental axes (Eiserhardt et al. 2011).

Of the plant species encountered in this study, 21 species were categorized as threatened by the IUCN (2017) and the Philippine Red List of Threatened Plants (Fernando et al. 2008b). The presence of these threatened species should be used as a reminder against prematurely writing off even small remnant forests just because of size, as they are still packed with high levels of biodiversity. Hence, their conservation value cannot be overemphasized.

Compositional and species richness patterns between biogeographic sub-region, and between forest conditions

The results of this study showed that differences in species composition and diversity are more apparent between forest conditions than between biogeographic sub-regions. A high altitude reforestation site in the Mindanao biogeographic sub-region showed species composition and diversity differed from old growth forest fragments (Anticamara et al. 2012). In this study, tree and herbaceous species clustered based on composition in exotic species-based reforested sites (rather than in forest fragment plots), regardless of biogeographic sub-region (Fig. 2). The weak patterns observed between biogeographic sub-regions might be due to within-site environmental variability (i.e. topography, soil, climate) (Valencia et al. 2004; Davidar et al. 2007). However, these environmental variables were not assessed in the current study.

Negative effect of deforestation

Small remnant forests are, in general, vulnerable to exotic species invasion because of increased edge-mediated effects (Yates et al. 2004; Ohlemüller et al. 2006; Vila and Ibáñez 2011). Competitive exclusion by exotic species can be due to increased competition of limiting resources where exotic species, especially invasive ones, often appear to be more competitive than native species in disturbed sites (Mack et al. 2000; Vila and Weiner 2004). Van Kleunen et al. (2010), in their meta-analysis review of trait differences between an invasive and non-invasive species, found that invasive species had higher performance and competitive trait ability compared to non-invasive species.

Several exotic species were found growing in several smaller remnant forests. Among these are leguminous species *Albizia saman*, *Leucaena leucocephala*, and *Gliricidia sepium* that are commonly used as firewood in the Philippines (Yao and Bae 2008; Lasco et al. 2010). These species might have been either planted or had escaped from backyard cultivation because legumes are easily germinating species and can be dispersed by frugivores (Paynter et al. 2003; Sánchez-Blanco et al. 2012; Padmanaba and Corlett 2014). There was also a dominance of the invasive herb-shrub species *Chromolaena odorata*, which is one of the most problematic terrestrial invasive alien species (Zachariades et al. 2009; Li et al. 2012) that has also been found in many parts of Philippines and the Asian region affecting biodiversity and favoring disturbed habitats (Muniappan et al. 2005; Codilla and Metillo 2011).

No significant relationship was found between native species richness and patch size. The most plausible explanation for this is that the number of native species in small remnant forests may still be the same when it was still a big contiguous forest. This result is consistent with a previous study in tropical fragmented rainforest of southwest China, where weak fragmentation effects were observed between fragmentation parameters explaining tree composition, richness and rarity (Liu and Slik 2014). This result may also be explained by "extension debt" where species response following forest fragmentation, especially in smaller forest patches, are still experiencing its "relaxation" stage, but later on becomes locally extinct, paying for the extinction extension it had during the relaxation period (Vellend et al. 2006).

Positive effect of reforestation

Reforestation in the quarry sites was designed to return the vegetation cover of the mined-out areas and its surrounding areas. Survival and growth rates of species planted in a reforested site were the widely-used measure of success in many reforestation activities. In this study, the increase in the number of native species in reforestation sites could be used as a proxy for reforestation success, in addition to looking at how many individuals survived or how much growth and height the planted species increased. Native plants in different forms other than trees could also be used as indicators of positive gains in reforestation activities (Le et al. 2012).

In this study, an increasing number of native species and decreasing number of exotic species in older exotic tree-species reforested sites was observed (Fig. 4). Although the reforested sites studied were based on exotic tree species, there was a positive increase in the number of native species and a significant decline in the number of exotic tree species. Similarly, a study from an exotic tree species-based reforestation in limestone quarries in Hong Kong conducted by Zhang et al. (2013) showed that native forest tree species were becoming more abundant after 10-years or older since reforestation planting. Moreover, a comparison of understory vegetation structure in Panama showed no differences in compositional and richness patterns between an exotic and native species plantation (Wolfe et al. 2015). Some studies have criticized exotic tree species-based reforestation as having more negative than positive impacts to plant diversity and they are more commonly used as production forests (Carnus et al. 2006; Bremer and Farley 2010). Moreover, planting exotic tree species for reforestation can potentially cause invasion of the same exotic tree species into adjacent natural communities (Engelmark et al. 2001) or can alter ecosystem processes (i.e. soil quality and water levels) due to the abilities of exotic species for more efficient water extraction and the requirements of exotic species in plantations (McLaren 1996). More studies are needed to understand how native species can recover from exotic tree species-based reforestation in comparison to native tree species-based reforestation programs. As of now, native tree species-based reforestation in many countries such as the Philippines remain limited, probably due to the preference by those who designed the reforestation which consequently resulted to problems associated with availability of seed source, nursery management, and undeveloped silvicultural practices for native tree species (Tolentino 2008; Garen et al. 2009).

In this study, in reforestation activities, whether exotic tree species-based or native trees species-based, the levels of plant diversity seem to increase as the reforestation sites grow older. Understanding germination and silvicultural treatment of native species found in this study can increase forest recovery. It might take a long time for a reforested site to reach levels equivalent to the nearby natural remnant forest, but gradual recovery can be attained through alternative approaches in reforestation and restoration efforts (Choi 2004; Chazdon 2008; Anticamara et al. 2012).

Implications for conservation

Conservation attention should be given to protecting the remaining forests and planting native species as part of a forest restoration strategy to enhance faster forest recovery and re-connect remnant forests. The extent of limestone forests continues to decline and many are still unprotected (Day and Urich 2000; Restificar et al. 2006). Based on this study, the remnant forests over limestone contain a high number of native species. Good forest management practices for the conservation and maintenance of plant diversity levels are needed in these remnant forests and reforestation sites, as they accelerate restoration process of the forest ecosystems (Burke et al. 2008). Forest restoration and reforestation efforts within and adjacent to quarry sites should also take into account the original forest formation that once covered the land prior to their degradation. Augmenting native tree species-based reforestation near the remnant fragments can increase the buffer areas in forests and reconnecting these remnant forests can be made easier. Reforestation near forest fragments can hasten the recovery and growth of the reforested sites due to the increase in colonization coming from nearby forest fragments. Furthermore, most of the reforestation efforts in the country are focused on the number of trees planted and do not account for the long-term survival of the species. It is therefore imperative that forest restoration efforts should invest more in the long-term maintenance of reforested areas to provide time for native plants to recolonize the plantation area hastening its recovery.

The findings in this long term ecological research study were made possible because chrono-sequenced data were kept by the company on when their reforestation sites commenced and what species were planted. By keeping these records, the long term ecological impacts of using exotic tree species-based reforestation, on plant diversity, both positive and negative, could be compared across bio-geographic sub-region, size and age.

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