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Towards Forest Landscape Restoration Programs in the Philippines: Evidence from Logged Forests and Mixed-Species Plantations

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Abstract: With only 7.01 million hectares of remaining forested areas in the Philippines, there is an urgency to protect these areas, while also implementing restoration strategies to increase forest cover and improve forest functionality. In this study, we assess how the so called "rainforestation" approach, attempts to implement close-to-nature restoration strategies in humid tropic areas. One of the main objectives of the "rainforestation" approach as a form of a mixed-species plantation is the rehabilitation of structural and floristic integrity similar to natural conditions. We compared study areas located in the provinces of Leyte and Southern Leyte composed of logged forests (temporary plots), with logged forests on a permanent research plot and with mixed-species plantations. Basal area, carbon stocks, volume and biological diversity between study areas were calculated and compared, both for static and dynamic data. Results from the static data indicate that carbon stocks (89.30 t ha^{-1}) and volume (262.56 m^3 ha^{-1}) of the mixed-species plantations ("rainforestation" approach) is significantly lower than that of the logged forests. However, when it comes to the capacity of the study areas for potential increments, the mixed-species plantations are not significantly different on basal area increment (0.99 m^2 ha^{-1} yr^{-1}), carbon stock increment (3.67 t ha^{-1} yr^{-1}) and total volume increment (10.47 m^3 ha^{-1} yr^{-1}) as compared to the logged forests' capacity (basal area—1.08 m^2 ha^{-1} yr^{-1}, carbon—4.06 t ha^{-1} yr^{-1} and total volume—11.98 m^3 ha^{-1} yr^{-1}). The species composition was only partly comparable to logged forests of the region, but overall tree species richness is high in comparison to classical plantation approaches. Previously logged forests are able to recover fast reaching surprisingly high values of carbon stocks and potential commercial timber volume. Our study indicates that "rainforestation" cannot fully replace the functionality of natural forests, but can provide a surprisingly multifunctional tool for landscape restoration, providing both timber and non-timber ecosystem services.

Keywords: restoration; natural forests; biodiversity conservation; mixed-species plantations; multi-purpose forestry

1. Introduction

Tropical rainforests are vital to the global carbon cycle, the conservation of biodiversity and the provision of services to the local population [1,2]. It is estimated that these ecosystems store 228.7 Pg of carbon in vegetation and soil [3,4]. Much of this stored carbon, though, is lost through deforestation and degradation that account for 18–20% of the total global carbon emissions [5]. Tropical forests in Southeast Asia exhibited an annual increase in deforestation from 0.83% between 1990–2000 to 0.98% for the period of 2000–2005 [6–9]. Despite the prevailing deforestation rates, Southeast Asia experienced a net forest cover change of 0.67 million ha (1990–2000) and 0.59 million ha (2000–2010) [10]. Studies of repeated measurements of permanent plots in tropical forests showed an increase in biomass and growth [11–13].

The underlying framework used for the study is the forest transition theory (FTT). The term was coined by Alexander Mather (1990) and described as the shift from a prolonged decline to a partial recovery in the extent of the forest [14]. Studies suggest that a forest transition from net reduction to net expansion has been observed in many tropical countries [15,16]. Other environmental services (e.g., accumulation of aboveground biomass, soil infiltration and recovery of species richness) associated with forests have been documented to be affected positively by net forest cover expansion [15,17,18]. The Philippines have been experiencing the prolonged decline phase of the forest transition theory as evidenced in increasing deforestation rates in the country [8,19,20]. However, various reforestation initiatives have been implemented in the country since the early 1990s to prevent further deforestation and transition into the other branches of FTT, which reflects partial net forest gain [21]. With the current forest transition trend, the Philippines is experiencing alongside its international commitments related to halting emissions [22,23], preserving the remaining biodiversity [24], and addressing sustainable development goals, the country provides a good example of how to achieve increased net forest cover without neglecting forest and biodiversity conservation.

Historically, the Philippines once possessed vast forested areas that accounted for 90% of the entire land cover of the archipelago [25]. Introduction of modern logging systems in the 1920s have contributed to the degradation and deforestation in the country and caused a decrease in forest cover to 22% (6.46 million ha) [19,26]. The latest national statistics indicated that the remaining forest cover in the country is 7.01 million ha [27]. Southern Leyte is considered as one of the most deforested provinces in the country and has been under a logging ban since the Administrative Order No. 31 (1992), and Republic Act No. 9772 (2009) [28] were enacted [29]. Studies by Lasco et al. [20,30] highlighted the importance of addressing the continuous deforestation through the REDD+ mechanism and restoration of biomass and associated biodiversity found in these remaining forested areas.

Additionally, the country also enacted Executive Order No. 23 ("National Logging Ban"), to address deforestation in natural and residual forests [31]. More recently through the Executive Order No. 26 enacted in 2011, the Philippine government started a nationwide reforestation program that does not only aim to increase forested areas in the country, but simultaneously addresses poverty, food security, biodiversity conservation and climate change. This is further enhanced by the issuance of the Executive Order No. 193, series of 2015 titled "Expanding the Coverage of the National Greening Program" (ENGP) [31] that aims to continue the program's efforts to address forest cover loss, poverty and other related national issues.

A unique restoration program in the Philippines is the "rainforestation" approach as a form of a mixed-species plantation. The "rainforestation" approach comprises the planting of native tree species together with fruit trees in a system that mimics previous natural conditions. The approach was based on the hypothesis that "a farming system in the humid tropics is increasingly more sustainable the closer it is in its species composition to the original local rainforest" [32]. Rainforestation was designed in 1992 involving 28 small-scale plantation owners in Leyte Island, Eastern Visayas [33]. One of the more recognizable features of this approach is the use of native species to resemble that of the previous natural conditions. The practice of "rainforestation" focuses on biodiversity by specifically planting native tree species found in nearby forests. The approach was

predicated on this rationale to achieve not only economic restoration, but also to address ecological restoration in the long-term.

Since the inception of the "rainforestation" approach for restoration in the country, various studies have assessed its potential to address the economic [34], and ecological needs of the sites [35,36], and the communities [32,33,37–40]. However, these studies have focused solely on the "rainforestation" sites. Still lacking is knowledge about the capability of the "rainforestation" approach to mimic the previous conditions of the natural forests. Bearing this in mind, we investigated the impacts of the "rainforestation" approach by addressing one of its core attributes, which is to resemble the previously existing natural forests in the areas where it is being implemented.

This paper examines how the "rainforestation" approach in the form of a mixed-species plantation resembles that of natural forests by addressing these questions: To what extent are "rainforestation"-derived use potential (i.e., carbon sequestration, tree diversity and volume) comparable to those of natural forests? What are the implications of continuously implementing the "rainforestation" approach and continuing the logging ban in natural forests for addressing conservation, sustainable forest management and restoration efforts in this region of the Philippines?

2. Methodology

2.1. Study Sites

Three sites were used for this study (Table 1). The first site was established by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). GIZ established the plots as part of the baseline information on the demonstration site for a project on Reducing Emissions from Deforestation and Forest Degradation (REDD+) in Leyte and Southern Leyte provinces. In this study, the inventory plots established by GIZ are referred to as "logged forests (temporary plots)". The second site is the 1-ha Silago Forest Dynamics Plot located in Mt. Nacolod, Silago, Southern Leyte, referred to as "logged forests (permanent research plot)". The third site is composed of the oldest "rainforestation" areas in the Philippines, located on Leyte Island and administered by the Visayas State University. We refer to these "rainforestation" sites as "mixed-species plantations".

Table 1. Summary information of the three study sites used in the study.

Site Information	Study Sites		
	Logged Forests (Temporary Plots)	Logged Forests (Permanent Research Plot)	Mixed-Species Plantations
Plot size	Nested 6 and 12 m circular plots	20 × 20 m	5 m circular plots
Total number of plots used for the study	100	25	51
Sampling design	Stratified systematic grid	Systematic grid	Random design
Date of data collection/inventory	2011–2012	2012 and 2016	2016
Soil type [1]	Ultisols and Inceptisols	Ultisols and Inceptisols	Entisols and Vertisols
Köppen climate classification [2]	Tropical rainforest climate (Af)	Tropical rainforest climate (Af)	Tropical rainforest climate (Af)
Elevation (m.a.s.l.) [3]	206 to 817	577 to 582	29 to 384
Ecosystem [4]	Tropical lowland forests	Tropical lowland forests	Tropical lowland forests
Date since last logging intervention [5]	1989	1989	1989

Sources: [1] References [41–43], [2] References [44,45], [3] Reference [46], [4] References [32,40], and [5] Reference [29].

The study sites fall under the Af (tropical rainforest climate) Köppen climate classification that experience precipitation of at least 60 mm per month for all the months of the year [44,45]. This climate classification is characterized by a pronounced maximum rain period from December to February and no distinct dry season during the rest of the year. The mountainous part of Southern Leyte is composed of Ultisols or weathered soils that have developed from andesite, basalt and other igneous rocks and Inceptisols, while Leyte Island where the mixed-species plantations can be found, is composed of Entisols and Vertisols [41–43].

The study sites were once covered mostly by lowland Dipterocarp forests [47,48], but commercial logging in the island that started as early as the 1950s have left the sites in a logged-forest condition. The last documented logging operation from the Timber Producer Marketing Corporation stopped in 1989 [29]. Since then, the logged forests (temporary plots), logged forests (permanent research plot) and mixed-species plantations have been regenerating. In addition, dynamic forest data was derived from the logged forests (permanent research plot) and mixed-species plantations (Figure 1).
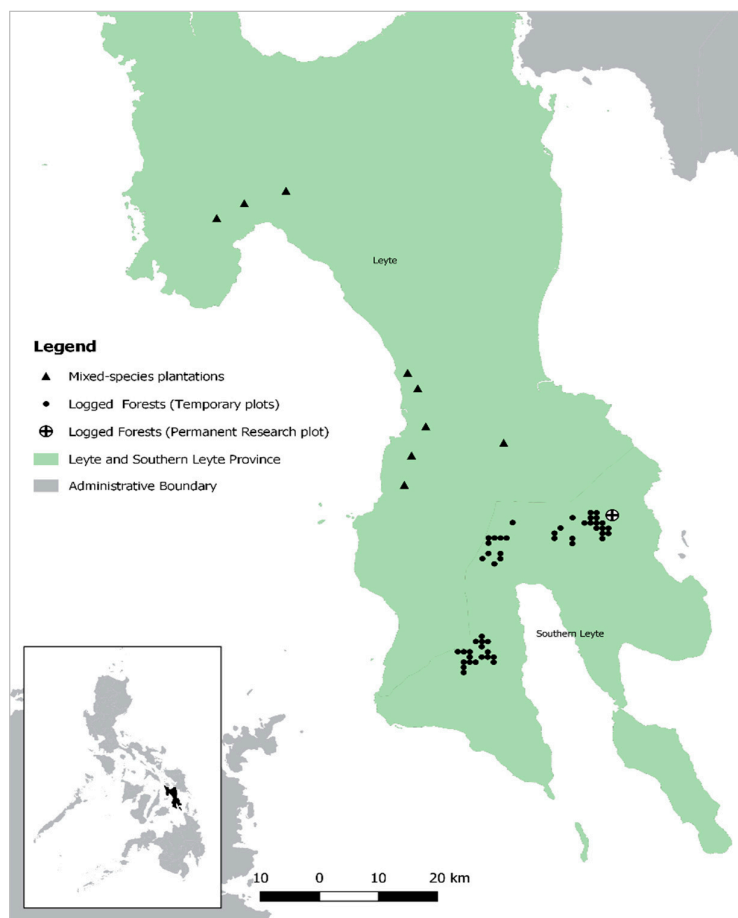

Figure 1. Location map of the study sites in Leyte and Southern Leyte Provinces.

2.1.1. Study Sites: Logged Forests (Temporary Plots)

We have utilized this demonstration site composed of 6 and 12 m nested circular plots to represent the conditions of logged forests that have been experiencing natural regeneration under the premise of a logging ban regulation [49]. Trees with 6.00 to 19.99 cm diameter at breast height (dbh) were measured inside the 6 m plot, while trees with dbh of ≥20 cm were measured from the 12 m nested plot. Trees measuring ≥10.0 cm in diameter were used for succeeding analysis to be consistent with the other study sites. Total and merchantable height were measured using hypsometer. Information about tree species (identified to species level) was also collected.

2.1.2. Study Sites: Logged Forests (Permanent Research Plot)

The initial measurement was conducted in 2012. Diameter at breast height (dbh) of trees measuring ≥10 cm was labelled and measured using diameter tape, and trees were identified to species level. Total and merchantable height were also recorded. Re-measurement of the trees was conducted from June to July 2016. Missing and dead trees, as well as recruitment, were also recorded during the re-measurement of the trees. The dynamic data derived from this plot provided the basis for the discussion of growth potential in the natural forests of the area. Despite limited size, it is the only empirical data available for estimating growth potential of natural forests on Leyte Island.

2.1.3. Study Sites: Mixed-Species Plantations (Rainforestation Plots)

Rainforestation data were collected in 2016 from a total of 51 plots of known age (from 19–27 years), distributed throughout Leyte province and each plot with a radius of 5 m. Trees were counted and identified to species level in each plot. Diameter at breast height was also recorded. Total and merchantable height of trees were measured using hypsometer.

2.2. Forest Data

Forest data was taken from the (1) logged forests (temporary plots), (2) logged forests (permanent research plot) and (3) mixed-species plantations. Each dataset includes the tree species identified to the species level, diameter at breast height (dbh), height and volume. The logged forests (temporary plots) and logged forests (permanent research plot) datasets were used as the reference data for formerly logged forests that have been under logging ban conditions for nine years since the ban was implemented in 2011. Additionally, species richness, Fisher's alpha (for alpha diversity) and Jaccard index (for beta diversity) were used to evaluate the biological importance of each of the species present in the three study sites [50,51]. Fisher's alpha diversity was selected since it is suited for analyzing samples (with varying sizes) between sites [51]. Jaccard index was used to estimate the beta diversity and compositional (dis)similarity of the study sites [51–53] to assess the resemblance of the mixed-species plantations with the conditions of the formerly logged forests. Endemicity of the identified species [54–56] was also considered using the following classification: (1) Endemic means that the species originated in and can only be found in the Philippines; (2) indigenous means that the species originated in and can be found in the Philippines and Asia-Pacific region; and (3) exotic means that the species originated from outside the Philippines and the Asia-Pacific regions.

Both static and dynamic data were used in our study. As static data, we refer to information from the study sites that have gone through a one-time measurement of the trees ≥10 cm dbh. This was applicable for all the three study sites. We refer to dynamic data as those having gone through re-measurement of trees ≥10 cm dbh. This was only the case for the logged forests (permanent research plot) and the mixed-species plantations. When it comes to dynamic data, only the logged forests (permanent research plot) and mixed-species plantations were used for comparison since the logged forests (temporary plots) were not marked properly, hence, no re-measurement was recorded. There are only two permanent plots in the country that have dynamic data, one is the logged forests (permanent research plot) that we have analyzed in this study, and the other one is the Palanan Permanent plot located in Luzon Island (north of the country) [57]. Thus, the combination of dynamic data with structural and floristic data of the forest inventory plots provides a valuable opportunity to get a deeper understanding of the restoration potential of logged natural forests.

2.3. Methods

Normality of distribution was tested for the three sets of forest inventory data to ensure the most suitable statistical analysis for the datasets. Each tree identified that is ≥10 cm dbh was used to derive basal area, dry biomass and carbon (Equation (1)) and volume (merchantable: Equation (2) and total: Equation (3)).

Basal area is the cross-sectional area of a tree measured at diameter at breast height (1.3 m above ground) and is one of the common parameters measured in forest management [51–53]. Basal areas

of all trees ≥10 cm in dbh were calculated, and the stand basal area was calculated from the sum of all individual tree basal areas found in the plots and converted into per hectare value.

Dry biomass content was calculated for all trees ≥ 10 cm using Chave's equation [58]:

$$Y = 0.0673 \times (\varrho D^2 H_t)^{0.976} \tag{1}$$

where Y = above ground dry biomass (kg); ϱ = Wood density (g cm^{-3}); D = dbh (cm); H_t = Total height (m).

Chave's equation was used due to the lack of existing country-specific allometric equation in the country [59] to estimate biomass, and due to the robustness of this equation based on various biomass and carbon estimation studies [30,59,60]. Subsequently, carbon values were calculated as 50% of the dry biomass values [61].

Volume of trees was calculated using the following equations:

$$V_m = BA * H_m * 0.42 \tag{2}$$

where V_m = Merchantable Volume (m^3 ha^{-1}); BA = Basal Area (m^2 ha^{-1}); H_m = Merchantable height of the tree (m); 0.42 = conversion factor for volume [62].

$$V_t = BA * H_t * 0.50 \tag{3}$$

where V_t = Total Volume (m^3 ha^{-1}); BA = Basal Area (m^2 ha^{-1}); H_t = Total height of the tree (m); 0.42 = conversion factor for volume [63].

Volume of the forest stand was calculated from the sum of the individual volume of the trees from each of the plots and converted into per hectare value.

Growth of the trees from the logged forests (permanent research plot) and the mixed-species plantations were assessed to determine the potential capacity of the areas in terms of future basal area, carbon and volume. Mean annual dbh increments were calculated and formed as the basis for further calculations of basal area, carbon and volume increments per year. The following equations were used to estimate the DBH increments:

Logged Forests (Permanent Research plot):

$$MAI = (dbh_{2016} - dbh_{2012})/4 \tag{4}$$

where MAI = Mean annual dbh increment; dbh_{2016} = Diameter at breast height in the second measurement period (2016); dbh_{2012} = Diameter at breast height in the first measurement period (2012); 4 = number of years from the first to the second measurement period.

Mixed-species plantations:

$$MAI = dbh_{2016}/\text{Age of the plot} \tag{5}$$

where MAI = Mean annual dbh increment; dbh_{2016} = Diameter at breast height in the latest measurement period (2016); Age of the Plot = Age (years) of each of the mixed-species plantations.

The species diversity index for trees ≥10 cm dbh was calculated using Fisher's alpha (alpha diversity) which is relatively insensitive to sample size differences between sites [51]. For beta diversity, a Jaccard similarity index (C_J) [50,51] was calculated for trees ≥10 cm dbh. A non-metric multidimensional scaling (NMDS) technique was used to visualize further the (dis)similarity found in the study sites. NMDS is a flexible technique that allows the use of different kinds of data since it uses rank orders of the species from the study sites [64,65].

2.4. Statistical Analyses

Corresponding statistical analyses and graphical data visualization were performed using R version 3.5.3 (11 March 2019) [66], and RStudio version 1.1.463 [67]. Assumptions for normality and homoscedasticity were evaluated. Shapiro-Wilk's test [68] was performed to test for normality of the data. Brown-Forsythe's test performed in RStudio was used to evaluate homoscedasticity. Data were log (10) transformed to fit into the assumptions needed for Gaussian analysis and to address the different sampling designs and a number of samples of the study sites. The Welch two-sample t-test was used to evaluate the dynamic data. Analysis of variance considering the effect of forest types (study sites) was used to evaluate the static data. Significant results were further subjected to Tukey HSD test.

3. Results

3.1. Forest Site Factors

A total of 5874 individuals belonging to 259 tree species (≥10 cm dbh) and 57 plant families were measured across all study sites (Table 2). In terms of tree species' extent of distribution in the study sites, the logged forests (permanent research plot) has the highest percentage of endemic species (33.3%), followed by the mixed-species plantations (24.2%) and logged forests (temporary plots) (19.6%).

Table 2. Endemicity of species found in the study sites in Southern Leyte and Leyte, Philippines.

Category	Logged Forests (Temporary Plots) n = 100, A = 13.4 ha		Logged Forests (Permanent Research Plot) n = 25, A = 1 ha		Mixed-Species Plantations n = 51, A = 2.49 ha	
	Absolute Value	%	Absolute Value	%	Absolute Value	%
Family	48		29		27	
Species	235		66		62	
Endemicity of Species						
Endemic	46	19.6	22	33.3	15	24.2
Indigenous	100	42.5	23	34.9	27	43.6
Exotic	24	10.2	1	1.5	17	27.4
Not Known	65	27.7	20	30.3	3	4.8

Note: Endemicity of species are expressed in an absolute number of unique species and percentage (%) from total number of species from each study site. n: Number of sample plots; A: Cumulative sampled area in hectares.

Among all study sites, indigenous species comprised most of the plot tree composition in the mixed-species plantations (43.6%), followed by logged forests (temporary plots) (42.5%) and logged forests (permanent research plot) (34.9%). Exotic species comprised less than 11% of species in logged forests (temporary plots, 10.2%) and logged forests (permanent research plot, 1.5%), while it was two-fold in mixed-species plantations (27.4%).

3.2. Diameter Class Distribution

All study sites have the same trend in the distribution curves of the diameter classes, which follows the inverse J-curve, that is expected in un-even naturally growing stands. The majority of the trees present in all study sites belonged to the smaller diameter classes (i.e., 10–20 and 21–30), while the rest of the trees were larger in diameter, but fewer in number. The greatest number of individuals was from the 10–20 cm diameter class range of the mixed-species plantations followed by logged forests (permanent research plot) and logged forests (temporary plots) (Figure 2).
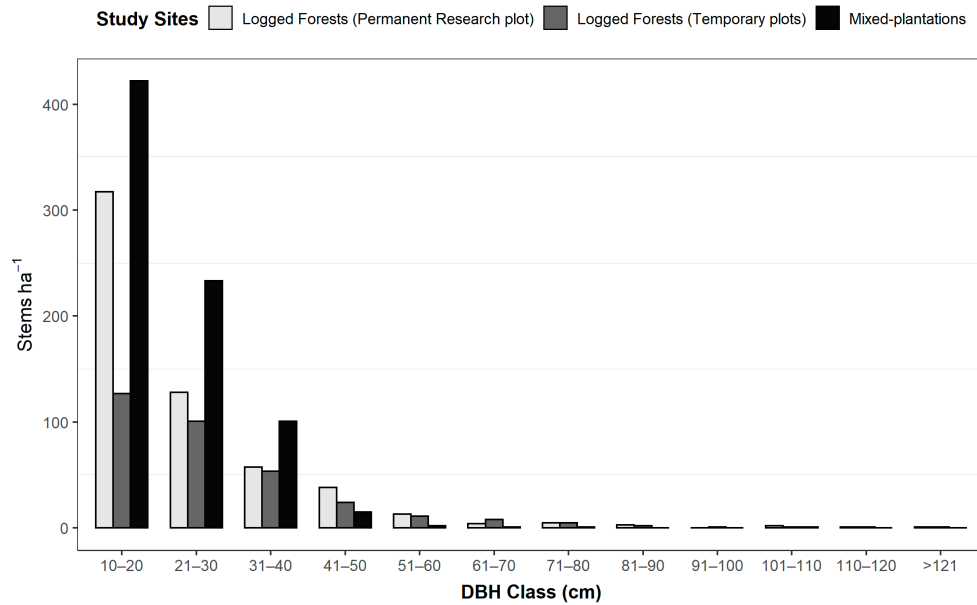
Figure 2. Diameter classes found in the three study sites.

When it comes to volume, the majority of the trees belong to the smaller diameter classes (i.e., 10–20, 21–30 and 31–40). The merchantable volume comprises almost half of the total volume from the logged forests (permanent research plot) and mixed-species plantations (Figure 3).
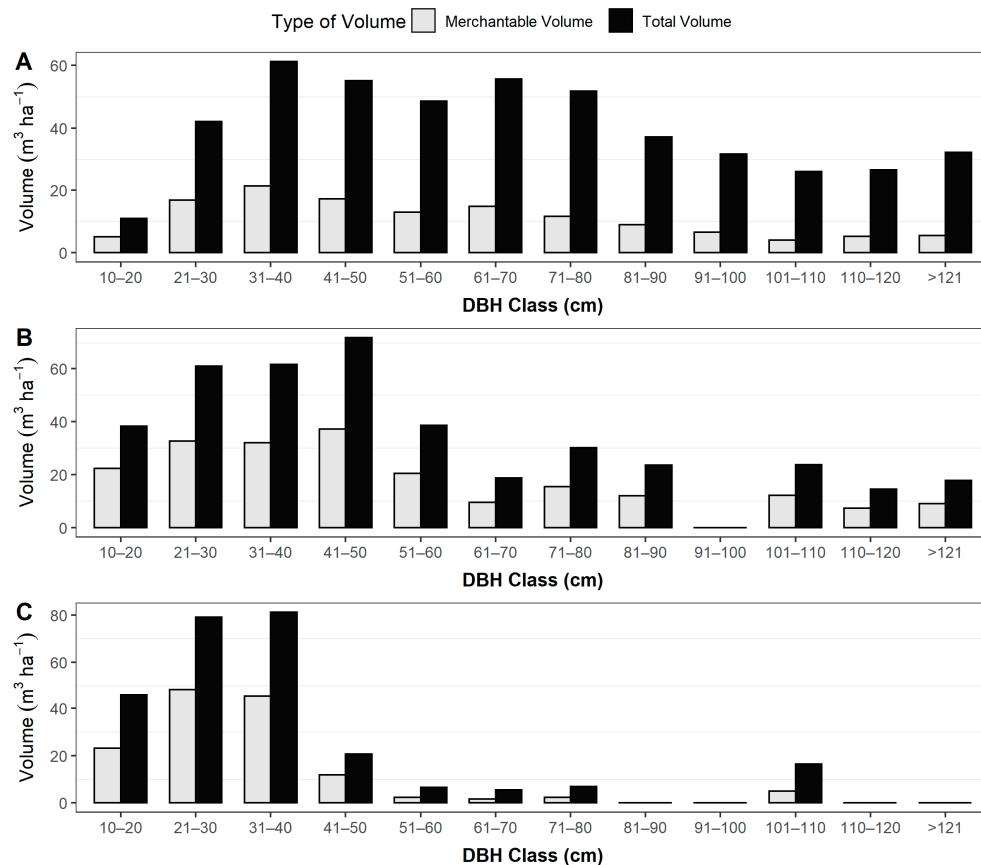

Figure 3. Total and merchantable volume (m³ ha⁻¹) per diameter class of trees found in (**A**) logged forests (temporary plots), (**B**) logged forests (permanent research plot) and (**C**) mixed-species plantations.

3.3. Basal Area, Carbon Stocks and Volume of the Trees (Static Data)

Based on the analysis of variance and the succeeding Tukey HSD test, there was no significant difference among the study sites in terms of basal area (Table 3). Carbon stock and volume of the logged forests (permanent research plot) were significantly different (adj. $p \leq 0.05$) from the mixed-species plantations (Table 3). On the other hand, the logged forests (temporary plots) and logged forests (permanent research plot) do not have significant differences from each other in terms of basal area, carbon and volume.

Table 3. Pairwise comparison of the study sites using Tukey HSD test for basal area, carbon stock and volume of the three study sites.

Study Sites		Forest Structural Indicators		
		Basal Area $(m^2\ ha^{-1})$	Carbon $(t\ ha^{-1})$	Total Volume $(m^3\ ha^{-1})$
		adj. *p*-Value	adj. *p*-Value	adj. *p*-Value
Logged Forests (Temporary plots)	Logged Forests (Permanent Research plot)	0.452	0.889	0.744
Logged Forests (Permanent Research plot)	Mixed-species plantations	0.413	0.020 **	0.023 **
Mixed-species plantations	Logged Forests (Temporary plots)	0.114	0.310	0.465

Note: ** adj. *p*-value is ≤ 0.05.

The mean basal area of the logged forests (permanent research plot) was the highest among the study sites, but was not significantly different from the logged forests (temporary plots) and mixed-species plantations (Table 4). The mean carbon stock ($89.30\ t\ ha^{-1}$) of mixed-species plantations were significantly lower compared to the logged forests (permanent research plot) ($141.15\ t\ ha^{-1}$). The same trend was observed from the mean volume ($262.56\ m^3\ ha^{-1}$) of the mixed-species plantations being significantly lower compared to the logged forests (permanent research plot) ($400.63\ m^3\ ha^{-1}$).

Table 4. Basal area, carbon stock and volume of the three study sites.

Variables	Logged Forests (Temporary Plots)		Logged Forests (Permanent Research Plot)		Mixed-Species Plantations	
	Mean	SEM	Mean	SEM	Mean	SEM
Basal Area $(m^2\ ha^{-1})$	29.05 [a]	2.43	34.51 [a]	3.58	24.70 [a]	1.48
Carbon $(t\ ha^{-1})$	156.24 [a,b]	18.90	141.15 [a]	15.19	89.30 [b]	7.06
Total Volume $(m^3\ ha^{-1})$	479.73 [a,b]	62.81	400.63 [a]	45.83	262.56 [b]	20.62

Note: SEM: Standard Error of the Mean. Different lowercase letters denote statistical difference at 5% based on analysis of variance (study/forest types) and Tukey HSD test.

The mean basal area ($29.05\ m^2\ ha^{-1}$), carbon ($156.24\ t\ ha^{-1}$) and volume ($479.73\ m^3\ ha^{-1}$) of the logged forests (temporary plots) were the highest among the study sites, but were not significantly different compared to the logged forests (permanent research plot) (Table 4).

3.4. Growth of Basal Area, Carbon Stocks and Volume (Dynamic Data)

Based on the analysis, increments of basal area, carbon and volume from the mixed-species plantations were lower compared to the logged forests (permanent research plot); however, the values were not significantly different from each other (Table 5). Total volume increments of the logged forests (permanent research plot) and mixed-species plantations (11.98 and $10.47\ m^3\ ha^{-1}\ yr^{-1}$, respectively) had the highest value compared to the rest of the variables tested (i.e., basal area and carbon increments).

Table 5. Basal area, carbon and volume increment in logged forests (permanent research plot) and mixed-species plantations.

Variables	Logged Forests (Permanent Research Plot)		Mixed-Species Plantations	
	Mean	SEM	Mean	SEM
Basal Area Increment (m^2 ha^{-1} yr^{-1})	1.08 [a]	0.31	0.99 [a]	0.25
Carbon (t ha^{-1} yr^{-1})	4.06 [a]	1.21	3.67 [a]	1.11
Total Volume (m^3 ha^{-1} yr^{-1})	11.98 [a]	3.85	10.47 [a]	3.21

Note: Tree mortality and recruitment were considered on the calculation of increment values for the logged forests (permanent research plot). Same lowercase letters denote not statistically different at a 5% significance level.

3.5. Floristic Similarity of Natural Secondary Forests and Mixed-Species Plantations

Biological importance of the tree species was assessed using Fisher's alpha and Jaccard's index. Fisher's alpha indicated that there is a statistical difference between logged forests (temporary and permanent research plots) and the mixed-species plantations (Table 6). However, this is only applicable for the alpha diversity found in each of the study sites, when beta diversity was tested, similarities were found among the sites.

Table 6. Alpha diversity (Fisher's alpha) of the three study sites.

Study Sites	Fisher's Alpha	
	Mean	SEM
Logged Forests (Temporary plots)	9.06 [a]	1.80
Logged Forests (Permanent Research plot)	11.50 [a]	1.70
Mixed-species plantations	4.20 [b]	0.70

Note: SEM: Standard Error of the Mean. Different lowercase letters denote statistical difference at 5% based on analysis of variance (study/forest types) and Tukey HSD test.

Based on the resulting NMDS plot (Figure 4), the logged forests (temporary plots) and logged forests (permanent research plot) share a considerable number of species. On the other hand, the logged forests (temporary plots) and mixed-species plantations have a smaller overlap as compared to the other two study sites.

4. Discussion

One of the main objectives of the "rainforestation" approach as a form of a mixed-species plantation is the rehabilitation of structural and floristic integrity similar to natural conditions. The results from the study indicate that from the forest structural indicators assessed (i.e., basal area, carbon stocks, volume and biological importance [69–72]) the "rainforestation" approach is partly comparable to that of the previous forest conditions. Standardization approaches were applied to the samples, due to varying sizes and collection protocols. Corresponding analyses that allow these conditions were used to evaluate the differences found in the study sites. Results might have limitations despite the standardization approaches used to address the aspect of various data collection protocols utilized in the study. In the succeeding sections, we will discuss further the implications of the results of the study to the ongoing reforestation and sustainable management initiatives in the region.

4.1. Forest Structural Indicators for Use Potential

4.1.1. Carbon

Based on our results, the logged forests (temporary plots) and logged forests (permanent research plot) contain total mean carbon contents of 156.24 t ha^{-1} and 141.15 t ha^{-1}, respectively (Table 6). These carbon estimates are comparable with other studies that also used various forest data

sources and have been conducted in the country and in the Asia-Pacific region [19,20,73,74]. Despite the standardization approach applied to the dataset to address the various data protocols used, some caution is advised for generalizing our results. Carbon stock estimates from various forest types and datasets found in natural forests in the Philippines range from 86–260 t ha^{-1} [59,75,76]. In other parts of Southeast Asia, mature lowland forests in Malaysia have 216 t ha^{-1} of carbon [77], while tropical forests in Thailand contain an estimated 72–182 t ha^{-1} [78]. The carbon storage of the natural forests in our study site is relatively high compared to mixed-species plantations, indicating a considerable recovery from previous logging interventions and natural disturbance (e.g., typhoons). In a permanent research plot in the Philippines where about nine typhoons occur every year, Hogan et al. [57] estimated a carbon stock change of 44 t ha^{-1} yr^{-1} four years after a typhoon's occurrence. Lasco and Pulhin [59] estimated that carbon stock in the Philippines declined by 53% after logging operations, thereby reducing carbon stocks from 196.3 Mg ha^{-1} (undisturbed forests) to 93.2 Mg ha^{-1} (logged forests). Additionally, findings from Brown and Lugo [79] indicate that there is a decline of 22–67% of carbon density after logging activities.
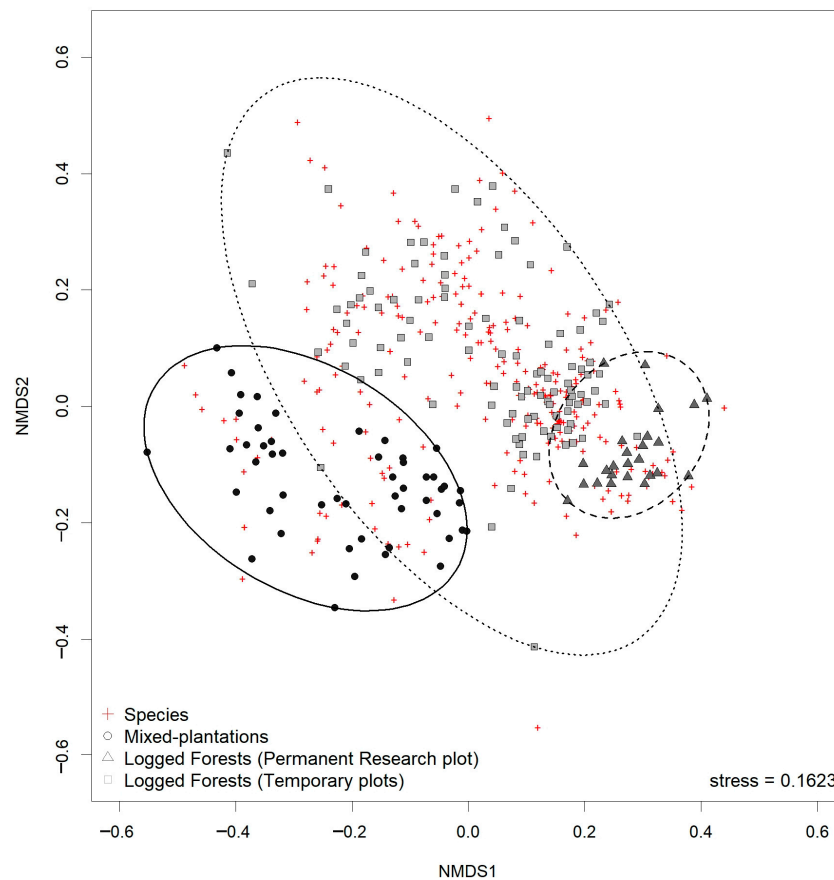

Figure 4. NMDS plot using Jaccard's index of tree species from the three study sites.

Carbon sequestration that occurred over the logged forests (permanent research plot) at 4.06 t ha^{-1} yr^{-1} (Table 5) is relatively high in comparison to the carbon sequestration estimates of wet, moist and dry forests (age range from 0–80 years after deforestation) from tropical countries, with an average of 2.89 t ha^{-1} yr^{-1} [80]. The same trend was also observed from the study by Letcher and colleagues [81] where biomass accumulation of secondary forests on former pastures (10 to 42 years) ranged from 1.10 to 11.74 Mg ha^{-1} yr^{-1}. Results from our study on carbon sequestration of mixed-species plantations (3.67 t ha^{-1} yr^{-1}) are comparable with the carbon content of reforestation examples

in Indonesia and the Philippines (3.41 to 6.70 t ha⁻¹ yr⁻¹) [59]. Martin et al. [82] further support this result through their study indicating that carbon pools recover faster compared to biodiversity found in a regenerating tropical secondary forest. It is further estimated that 80 years post-disturbance, the carbon stocks of secondary forests can be 77 to 81% of undisturbed forests [59,82]. In tropical moist forests, accumulation of biomass after 0.5 to 40 years of disturbance ranged from 31.4 to 90.2 t ha⁻¹ and in tropical wet forests, biomass accumulation ranged from 17.9 to 297.9 t ha⁻¹ after 0.7 to 60 years of disturbance [82,83].

It has been shown that mixed-species plantations, commonly as Dipterocarp logging concessions, have the capacity to provide timber and non-timber ecosystem services, including biodiversity and carbon stocks [84–87]. Studies [20,30,59] on the country's monoculture plantations revealed that carbon sequestration in these plantations ranges from 1.19 to 7.82 Mg ha⁻¹ yr⁻¹. Chazdon [88] cautions that new forests emerging in the midst of human-intercepted landscapes will not exactly match the original old-growth forests in species composition. However, "rainforestation" (mixed-species plantations) can, to a certain extent restore some forest ecosystem functions, specifically carbon sequestration potential. This was seen from the non-significant differences found between the logged forests (temporary plots) and mixed-species plantations (Table 5).

4.1.2. Timber Volume

Another factor that the study has taken into consideration is the potential timber production capacity of the study areas. In relation to timber volume production, the logged forests (temporary plots and permanent research plot) exhibited the reverse J-curve, a common indicator of uneven-aged mixed forests [89,90]. For the logged forests (temporary plots) the frequency of smaller diameter trees was fewer compared to that of the logged forests (permanent research plot) site. From the three study sites, the logged forests (temporary plots) had the lowest frequency (%) of smaller diameter trees (10–20 cm dbh).

This could be an indicator that the logged forests (permanent research plot) recovered considerably from logging, due to the limited anthropogenic disturbance, albeit the annual 19% occurrence of typhoons [29]. Our results further indicate that the mean volume (479.73 m³ ha⁻¹, Table 6) found in the logged forests (temporary plots) was significantly higher compared to the mixed-species plantations. Studies from Weidelt [91], Banaag [92], and Kawahara [93] indicated that forest volume in the Philippines ranges from 276.25 m³ ha⁻¹ (inside selective logging concessions) to 769.0 m³ ha⁻¹ (inside natural Dipterocarp forests). This is slightly higher compared with studies made by Cedergren et al. (2002) [94] that reported a standing volume of 399 m³ ha⁻¹ from dipterocarp forest in Sabah, Malaysia.

Timber production increment in logged forests (permanent research plot) is similar to that of carbon stock recovery as has been reported by Letcher et al. and Martin et al. [81,82]. The total volume increment (10.47 m³ ha⁻¹ yr⁻¹) of the mixed-species plantations is also comparable with previous studies in Leyte Island (11.6 to 21.3 m³ ha⁻¹ yr⁻¹) [38]. Interestingly the increment of timber volume in both logged forests (permanent research plot) and mixed-species plantations are relatively high, indicating a considerable recovery of use potential for the future. However, since dynamic data have only been available for the logged forests (permanent research plot) and not across all study plots (logged forests—temporary plots), the growth rates cannot be uncritically transferred. The basal area of the logged forests (permanent research plot) was considerably higher compared to the rest of the study sites, which would allow one to assume an even higher growth potential if these areas attain a more advanced stage of maturity. However, soil and climatic data are required in order to exclude the potential growth-limiting effects of site conditions. The permanent plot is characterized by the Ultisol soil type [95] that is dominated by silt-clay texture classes, due to its sedimentary rock parent material. The plot receives an average of 2600 mm of rainfall per year and has a pronounced rain period from December to February [95]. Studies mentioned above that showed similar growth rates also experienced annual precipitation from 1200 to 3900 mm [38,81,82]. These biophysical attributes could potentially contribute to the growth rate values. However, a lack of primary data of these biophysical attributes from our study means caution on this claim. Furthermore, one of the studies

[81] indicated that the soil type has little effect on species diversity, but contributed to the biomass increase. The situation in the permanent plot having a positive relationship between growth and diversity coincides with the results from studies of Goldberg [96,97] and Chazdon [98] where species richness and growth were observed after disturbance.

4.1.3. Biodiversity

Apart from carbon stocks, timber production and their corresponding increments, we have also considered biological diversity indicators. Our results indicate that both logged forests (temporary and permanent research plots) have a higher percentage of endemic species and alpha diversity compared to the mixed-species plantations, a trait that can also be seen from the study conducted by Martin et al. [82]. Factors, such as dispersal traits and establishment requirements, might have contributed to differences in biological diversity found in secondary forests experiencing various degrees of disturbance. Species found in undisturbed forests account for 6 to 67% of species that are also found in secondary forests [82]. Potential implications about this result could be an indicator that more importance should be placed in terms of addressing the aspect of biological conservation as part of the restoration initiatives in the region and in the country. Furthermore, the resulting NMDS plot of the Jaccard index indicates an overlap between logged forests (temporary plots) and mixed-species plantations (Figure 4). Thus, "rainforestation" can be a complementary component of landscape restoration, but cannot replace conservation functions of natural forests. Therefore, for the restoration of biodiversity on a landscape level, accompanying measures, such as conservation of remnants of natural forests might be essential too.

When it comes to biological diversity found in secondary forests, some studies [87,99] revealed that species' recovery of previously logged forested areas take almost 50 years with accompanying silvicultural treatments before they exhibit the pre-logging levels of species diversity. The silvicultural treatments used in Hu et al.'s study [87] were (1) low-intensity thinning (ringbarking large trees from 16–38 cm), (2) medium-intensity thinning (ringbarking large trees and brushing small trees from 0.9 to 6 m in height) and (3) high-intensity thinning (ringbarking and brushing of small trees around all of the commercial trees). Additionally, their study indicated that increasing the silvicultural intensity treatments led to longer recovery periods of species diversity and composition. Our study site (logged forests—permanent research plot) is an example of a logged forest area without any silvicultural treatments; hence, there is the possibility of a longer turnover period in terms of species diversity similar to what Guariguata and Ostertag [100] found in their study. This is especially true since effects of restoration on the recovery of forest functional indicators' use potential is poorly studied despite the already established and widely accepted links amongst biodiversity, functional traits and ecosystem services [101,102].

4.2. Structural Indicators between Logged Natural Forests and Mixed-Species Plantations

Our results indicate that mixed-species plantations had significantly lower carbon stocks and volume compared to the logged forests (permanent research plot). On the contrary, increments of basal area, carbon stocks and total volume were not significant. Species composition is partly comparable to formerly logged natural forests of the region. Based on the results and considering the potential limitations of the data collection protocols, "rainforestation" approach through mixed-species plantations have the possibility to be utilized as a restoration strategy focusing on multipurpose functions in the Philippines. Various studies have shown that the "rainforestation" approach has been able to address socio-economic aspects of reforestation and help increase the options for alternative livelihoods of people dependent on these areas [33,37,40,103,104]. In addition, the ecological aspect of the "rainforestation" approach to address issues related to maintaining or enhancing the diversity of the degraded conditions of the areas and other related biophysical aspects (e.g., soil conditions, water retention capacity, water use and physiological traits of mixed-species that may have relations to ecosystem functioning, etc.) have also been studied quite extensively [33,35,36,40,87,103,105–107].

Overall, the "rainforestation" approach can help to improve the quality of the site, i.e., species diversity, basal area, carbon and volume leading to considerably high values, but it is not yet fully comparable to formerly logged natural forests. However, management practices of "rainforestation" plots vary [35] which may affect the productivity and diversity of the areas in the long run. Bearing this in mind, planning for future restoration or sustainable forest management initiatives will need to incorporate information on recovery trends to better optimize the outcomes of the restoration or sustainable forest management activities. As mentioned in the previous section, attaining such conditions is likely to take time. Our results indicate that "rainforestation" cannot replace the functionality of natural forests, but they provide a surprisingly multifunctional tool for landscape restoration, providing both timber and non-timber use potential.

4.3. Disturbance Agents Can Affect Structural Indicators

This section provides examples of disturbance agents that should be considered for the interpretation of the results of the study. This includes the level of disturbance that the sites experienced (i.e., natural and anthropogenic). Natural disturbance frequently occurring, e.g., in the form of typhoons, can influence forest structures, and thus, the increment of the remaining stand. Since, there is no available primary data specific for the island, this factor could not be included in our analyses. Moreover, anthropogenic disturbance in natural forests, e.g., in the form of illegal logging, can influence forest structures and increment. However, the lack of primary information and monitoring of illegal activities occurring in the study sites makes it challenging to include this factor in our analyses. While studies indicated that increments could be higher in areas that experienced disturbance, due to reduced competition [98,108–110], our data indicate a very limited number of damaged or dead trees (both <1% for logged forests and mixed-species plantations), due to disturbance agents (e.g., typhoons and illegal logging). Although this indicates a small potential influence of these disturbance agents, we cannot completely exclude this possibility. Hence, this has to be taken into account for the interpretation of our results. Despite the lack of primary data collection of the abovementioned disturbance agents, we used the next best option to provide references of previous studies conducted at the country level [29,57,59,82,91–93] to provide context on the interpretation of our results.

4.4. Implications for Regional and National Restoration Initiatives and Sustainable Forest Management

The "rainforestation" approach as one method of forest restoration can restore multiple forest ecosystem services, such as carbon stocks, biodiversity and timber. With this information at hand and the current initiatives from the local and regional levels [19,111,112], it is the most opportune time to further enhance and implement the use of the "rainforestation" approach in terms of the implementation of reforestation programs in the province. While quick timber provision may also be achieved by monocultures, with potential advantages for commercialization, the timber growth potential of the "rainforestation" sites is relatively high with ecological side benefits attributed to structural and tree species diversity.

Various forest restoration and rehabilitation initiatives [88] have been implemented worldwide with the local community at the forefront of its implementation. These studies [88,113] reiterate the importance of planting diverse species with ecological and economic importance and integrating the reforestation initiatives into the regional development strategies. Such studies further give emphasis on the importance of the "rainforestation" approach in the Philippines and the need to craft better forest management plans geared towards forest restoration. Using native commercial species will address the need for timber production (especially on "rainforestation" areas that are privately-owned), while ensuring that species diversity is maintained or enhanced in the areas. Pre-requisites for further expansion of this restoration approach is availability of the suitable planting material of good genetic quality, information about site conditions, as well as acceptance and willingness of local stakeholders.

A number of studies using mixed-species plantations for restoration provided advantages of this approach, including but not limited to the capacity of mixed-species plantations to (1) provide more

diverse products (e.g., timber, biodiversity, non-timber) than pure-species plantations [114,115]; (2) accelerate the recuperation of understory biodiversity [116–119]; (3) being well adapted to the native site conditions and useful for ecological, financial and mitigating natural hazard risks [120]; (4) higher market or social value to the local community, hence, more socially acceptable [115,121], and (5) restore the vegetation of a degraded area to something that approximates the original forest [115].

In contrast, studies have also demonstrated that mixed-species plantations have some disadvantages, such as: (1) Lack of operational-scale demonstrations needed for commercial or industrial uptake [122]; (2) potential production benefits were not always realized, and production losses have been observed [115,123,124]; and (3) locating viable seed sources and finding species that work well together in terms of germination requirements and growth rates [125–127].

Our data reflect some of these advantages and provide a potential gain in terms of timber, carbon and biodiversity. However, upscaling this approach at the national level needs careful design and applicable management skills, especially those on the aspect of potential losses, as these have been understudied. Despite the drawbacks for using mixed-species, identified benefits from various studies mentioned above provide a certain degree of restoration to degraded areas. This, in turn, could provide complementary benefits with other restoration efforts, while considering environmental, economic and social objectives.

Apart from the main aspect of restoration initiatives, the Philippines is also in the process of finalizing the ratification of the "Sustainable Forest Management Bill". Upon ratification, this new national policy will benefit from the results that have been accumulated from the experience of utilizing the "rainforestation" approach. Part of the sustainable forest management initiative in the Philippines deals with estimating potential timber harvesting from legally-owned community plantations, accounting of carbon stocks for forest conservation and maintaining the biological diversity found in the forested areas [128]. Bearing this in mind, results from the study contribute to the potential strategies the country can employ in order to properly allocate areas for conservation, restoration and reforestation initiatives.

Aspects related to sustainable forest management include, but are not limited to, dbh distribution, carbon stock, timber potential and biological diversity of forested areas. It is important to know the dbh distribution trend of forested areas since this will be a direct input on constructing management activities in the areas [123,124]. Analyzing species-specific population structures and their environmental context could be the next steps in order to develop management plans considering species-site interactions, as well as intra- and interspecific competition effects. For natural forests of Leyte, the logging ban has apparently contributed to considerable recovery of basal area, carbon and timber volume, at least in sites with reduced anthropogenic pressure. Our results do not indicate recovery of all forest areas across the Philippines, but rather indicate a promising restoration potential where anthropogenic interventions can be controlled. Thus, logging ban might further lead to higher carbon stocks and the recovery of biodiversity indices closer to the original conditions. On the other hand, with increasing maturity of the stands, the growth rates most likely will decrease with a lower potential of carbon sequestration per year and with a higher accumulation of timber volume per hectare. At latest, then, the policy could consider if landscape restoration has been successful enough to fulfill future demands for timber or if sustainable forest management guidelines and policies could be suitable tools for natural forests in certain areas.

5. Conclusions

Our results indicate that restoration initiatives like that of the "rainforestation" approach in the form of mixed-species plantations can recover considerable measures of biodiversity, carbon stocks and timber potential and consequently show good potential as a tool for landscape restoration. While natural regeneration is a potential option for reforestation, it will take longer to attain previous conditions. Hence, the need to provide multiple forest ecosystem services adds to the urgency to implement alternative strategies for reforestation. The "rainforestation" approach fills this gap, at least in the case of the Philippines, as it addresses both the ecological and economic aspects of reforestation. This makes it a suitable tool for multipurpose aims, especially for forest landscape

restoration. In combination with the national legislation that aims to reforest over 1.5 million hectares of land, the "rainforestation" approach provides important forest ecosystem services over a relatively short span of time (approximately two decades).

It should also be noted that "rainforestation" alone cannot address the problem of restoring all of the deforested and degraded lands in the country. Additional reforestation strategies can still be implemented that would complement the use of the "rainforestation" approach. Our results indicate that "rainforestation" cannot yet replace many functions of formerly logged natural forests. It will be hard, if not impossible, to reach the conservation value of old-growth forests. Results suggest that the logged forests of Leyte can have relatively fast recovery of structural integrity, but a larger network of permanent plots and consistent data collection and monitoring are necessary to allow generalization. Our results indicate that natural forests in areas without strong anthropogenic pressure can fulfil aims for both conservation purposes and timber provision in the near future, depending on national policy regimes. Further challenges are related to monitoring both the natural and "rainforestation" areas to further gain robust information on the differences and similarities in terms of species composition, forest functions and provision of forest ecosystems services over time.

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