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Domesticating Commercially Important Native Tree Species in the Philippines: Early Growth Performance Level

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Abstract: Selection of native tree species for commercial purposes is a continuing challenge and an opportunity in tropical silviculture. Because of this, we explored domesticating 33 native species in the Philippines that were tested for survival rate, total height, and diameter-at-ground-level (dgl) increments. The first five years (2014–2018) of assessment showed that 13 species (40%) of the 33 native species reached a survival rate of more than 80%. Grouped as 'slow'-, 'medium'- and 'fast'-growing field trial species, a 709 cm average total height at five years was attained by the fast-growing cluster where Bagalunga (*Melia dubia* L.) and Kupang (*Parkia javanica* (D.C.) Merr.) were among the fastest-growing species. Slow-growing trees like Tindalo (*Afzelia rhomboidei* (Blanco)) and Kamagong (*Diospyros blancoi* (Willd)) were among the slowest-growing with an average height of 193.8 cm. Dipterocarps like Yakal (*Shorea stylosa* (Foxw.)), Tanguile (*Shorea polysperma* (Blanco)) and Mayapis (*Shorea squamata* (Blanco) Merr.) had the lowest diameter at ground level (dgl) increments (average 25.9 mm) while diametric expansion of fast-growing species spanned up to 93.5 mm. Overall, height and dgl increments were almost five times the original measurement five years after planting. A sudden surge in the rate of change in total height (83%) and dgl (72%) occurred a year after planting, yet a sudden decline occurred in the fifth year with only 21% for height and 23% for diameter growth suggesting the first 3–4 years as the crucial stage in seedling development. Survival rate is better correlated with the changes in dgl increment (R^2 = 0.19, $p < 0.05$) than the height growth (R^2 = 0.12, $p < 0.05$). Increasing rainfall and optimum air temperature significantly correlated with height and diameter growth while any increase in recorded wind speed slightly reduced the growth of the species. Our findings are initial steps towards developing appropriate silvicultural and management interventions when planning for the massive plantation development of domesticated Philippine native trees in the future.

Keywords: tree domestication; Philippine native tree species; dipterocarps; fast-growing species

1. Introduction

For decades, there have been calls for native rainforest trees to be domesticated and planted [1] as an alternative to the large-scale mixed and monocultures which dominate in the tropics [2,3]. Currently, the norm remains a small number of exotic species grown as monocultures, despite the associated risks [4]. Domesticating native species will allow the reduction of economic dependence on a few 'wood commodity' species. Yet, opportunities are being lost because of a lack of awareness about the potential of domesticating native tree species for timber production, which greatly limits expanded use of native species [5] that might be useful and of commercial quality. Hence, tropical foresters have a continuing need to explore, evaluate and domesticate native tree species for reforestation, especially on degraded lands, where not all introduced species perform well [6].

The Philippines has a total land area of 30 million hectares where one-third (~10 million hectares) is considered timberland composed of mixed forests and plantations mainly planted with *Falcataria moluccana*, *Acacia mangium*, *Eucalyptus deplupta* and other species [7]. However, thousands of hectares of primary and secondary forests have been transformed into barren lands and other land uses [8]. This scenario poses the threat of depletion to native species [9]. It is one of the reasons why the National Greening Program (NGP) was implemented by the Department of Environment and Natural Resources of the Philippine Government—to restore the productivity and ecosystem services of many native species especially those of ecological and economic importance [10]. Reforestation in the Philippines relies mostly on a few species, which are often planted in mono-specific stands. Such stands contribute little to conservation [3]. Studies addressing the need for scientific information on more appropriate tree species selection and species mixtures are being currently promoted [11,12]. Fortunately, with NGP, the reforestation approach emphasizes the use of mixed stands and the preference for some native species supplemented by fruit trees, especially in protection forests. Many farmers under the Community-Based Forest Management (CBFM) Program of the country prefer such an approach because some native species are advantageous not only for timber production but also multiple uses.

Interest in establishing plantations of native species has grown in recent years [13]. The use of a greater variety of species in reforestation may improve the resilience of ecosystems, decrease sensitivity to pests and diseases, increase functional diversity, promote plant biodiversity and amend soil conditions [3,6]. From a socio-economic perspective, increasing species choice may preserve a range of management options, enhance adaptability to changing market opportunities, and provide a wider variety of products and services [14]. Therefore, selection of native tree species for domestication purposes in commercial plantations is a continuing challenge, along with the testing of large numbers of species in screening trials whose importance has long been recognized [5,14]. Yet, only a few large trials have actually been established across the tropics [5,11,15].

Some metrics to assess successful domestication efforts commonly include survival rate, as well as height and diameter growth. These can then be related to environmental conditions such as light, soil moisture, temperature, nutrient availability, soil types, and many other factors that drive the survival and growth of species [15]. Whether or not these ranges of site conditions meet the physiological and morphological requirements (e.g., form and structure) of seedlings is a matter of interest that must be assessed to determine the quality of domesticated seedlings that can meet the desired level of growth and survival upon outplanting [16].

Within this context, we examined the adaptation and early growth performances (survival rate, total height, and diameter at ground level increments) of 33 native species for domestication over five years from 2014 to 2018. We also examined how growth performances relate to survival tendencies and we evaluated some key climate drivers on the growth of native species in the trial site in a common garden experiment. This investigation is the initial part of the long-term tree domestication program with the goal of assessing the potential of a diverse list of native species of paramount commercial importance, and in developing a gene bank for species conservation.

2. Materials and Methods

2.1. Study Site

The study site was located within the Lantawan Park in Kitcharao, Agusan del Norte, Philippines specifically at 9°28′ N, 125°35′ E. The area is within the 477-hectare forest overlooking Lake Mainit. The park is managed by the local government unit of Kitcharao. The terrain is moderately sloping with a gradient of 8–10 degrees. Prior to planting, the site was vegetated with Falcata (*Paraserianthes mollucana*) and Mangium (*Acacia mangium*). A few stands of coconut (*Cocos nucifera*) were also present. The site is characterized by a tropical wet rainforest climate with an average annual rainfall of 2400 mm [17]. The site has a type II climate according to the modified Coronas classification which is characterized by the absence of a dry season but with a maximum rain period from November to February [18]. On rare occasions, rainfall may be <50 mm during very dry months in June and July. The average maximum and temperatures are 32.5 °C and 23.46 °C, respectively, with an average maximum prevailing wind speed of 9.3 m^{-2} s^{-1}. The site has heavy soil texture, Andisols with loamy texture and medium to high fertility with a soil pH of 5.5–7.5. A recent soil survey conducted identified the soils as Butuan series which developed from the older alluvial terraces [19].

2.2. Selection of Native Species

Thirty-three species native to the Philippines [20,21] were considered in this study (Table 1). Species selection was based on potential economic value, seed/seedling availability, discussion from local upland dwellers/farmers, and personal field observations made by researchers of the Department of Environment and Natural Resources—Ecosystems Research and Development Bureau (DENR-ERDB annual report 1997–2018). Most of the seeds were collected across the eco-zones of the Caraga Region, Mindanao while some were collected in Luzon. All the species were raised at Bood Clonal Nursery at Pinamanculan, Butuan City with a distance of 50 km away from the field trial site.

Table 1. Native species considered for tree domestication purposes.

Species Code	Common Name	Family Name	Scientific Name
1	Agoho	Casuarinaceae	*Casuarina equisetifolia* L.
2	Antipolo	Moraceae	*Artocarpus blancoi (Elmer)* Merr
3	Bagalunga	Meliaceae	*Melia dubia* L.
4	Balakat Gubat	Euphorbiaceae	*Sapium luzonicum* (Vidal)
5	Bani	Fabaceae	*Pongamia pinnata* (L) Merr
6	Banlag	Annonaceae	*Xylopia ferruginea* (Hook. F & Thoms)
7	Bitanghol	Clusiaceae	*Calophyllum blancoi* (Pl & Tr.)
8	Bitaog	Clusiaceae	*Calophyllum inophyllum* L.
9	Bogo	Burseraceae	*Garuga floribunda* (Decne)
10	Dungon-late	Malvaceae	*Heritiera littoralis* Ait.
11	Katoan bangkal	Rubiaceae	*Antocephalus chinensis* (Lamk)
12	Kalumpit	Combretaceae	*Terminalia microcarpa* (Decne)
13	Kamagong	Ebenaceae	*Diospyros blancoi* (A. DC)
14	Kupang	Mimosaceae	*Parkia javanica* (D.C) Merr
15	Lamio	Anacardiaceae	*Dracontomelon edule* (Blanco) Skeels
16	Lanipau	Combretaceae	*Terminalia copelandii* Elmer
17	Lingo-lingo	Lamiaceae	*Viticipremna philippinensis* Merr.
18	Malabayabas	Myrtaceae	*Tristaniopsis decorticata* (Merr)
19	Mayapis	Dipterocarpaceae	*Shorea squamata (Blanco)* Merr
20	Molave	Lamiaceae	*Vitex parviflora* Juss.
21	Narra	Fabaceae	*Pterocarpus indicus* Wild
22	Pangi	Achariaceae	*Pangium edule* Reinw.
23	Red Nato	Sapotaceae	*Pouteria macrantha* (Merr.)
24	Sagimsim	Myrtaceae	*Syzygium brevistylum* (C.B. Rob) Merr.
25	Tagkan	Sapotaceae	*Palaquium pinnatinervium* Elmer
26	Talisay Gubat	Combretaceae	*Terminalia foetidissima* Griff.
27	Tanguile	Dipterocarpaceae	*Shorea polysperma* (Blanco) Merr.
28	Tindalo	Fabaceae	*Afzelia rhomboidea* (Blanco)
29	Toog	Lecythidaceae	*Petersianthus quadrialatus* (Merr.) Merr.
30	Tuai	Phyllanthaceae	*Bischofia javanica* Blume
31	White Lauan	Dipterocarpaceae	*Shorea contorta* Vidal
32	Yabnob	Myristicaceae	*Horsfieldia megacarpa* (Miq.) Warb
33	Yakal	Dipterocarpaceae	*Shorea astylosa* Foxw.

2.3. Experimental Design, Planting and Measurements

An incomplete block design was used with five seedlings per plot replicated four times. Randomization of the treatment was done through Cyc design software. Plot spacing measurements were 2 m by 3 m (Figure 1). Buffer plants (*Eucalyptus deglupta*) were planted in the perimeter of the plots to eliminate the boundary effect of the observation plants situated in the border plots. Experimental plots were established during the onset of rainy season in October 2013. The understory vegetation was cleared manually across the whole plot in all plots six times during the first two years and thereafter four times a year. Planting was done in November–December 2013, and measurements of each individual seedling diameter at ground level (dgl) and height were taken initially two months after planting and thereafter twice a year every February and August each year. Tree height was measured in centimeters using a height measuring pole while dgl was measured using a Vernier caliper. Surface soil samples at 5 cm depth were taken for analysis at the Department of Agriculture Soil Laboratory in Taguibo, Butuan City. Climate data were obtained from the nearest station of Philippine Atmospheric, Geophysical and Astronomical Service Administration (PAG-ASA). PAG-ASA used a thermometer and thermograph to measure air temperature, a tipping bucket raingauge for precipitation and a pin balloon/theodolite to measure wind speed and direction. A monthly record of climate parameters from PAG-ASA was used in this study.

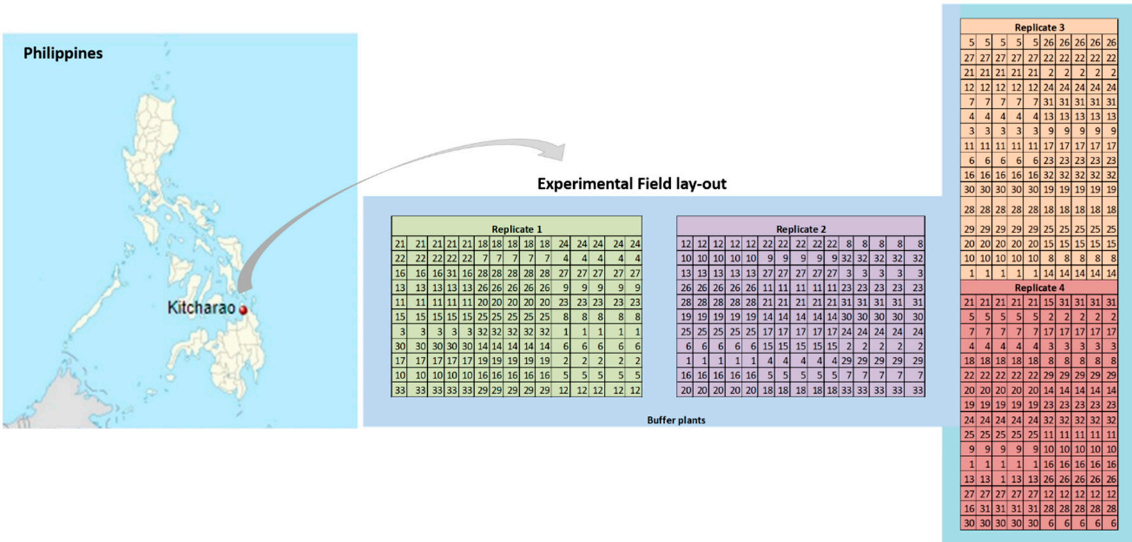

Figure 1. Field trial site of 33 native species for domestication and their experimental layout in Kitcharao, Agusan del Norte, Philippines.

2.4. Data Analysis

One-way analysis of variance (ANOVA) was used to determine the statistical significance for differences in total height and dgl increments. Tukey's pair-wise comparisons were used to determine statistically significant differences within each variable at a 95% confidence level. Regression analysis was employed to determine the effect of height and diameter on the survival of tested species or the effect of climate on height and diameter growth.

Since the diameter and height of seedlings varied upon outplanting, we standardized them for comparison purposes. Total height (cm) and dgl (mm) change were computed as the difference between the total height and dgl of the present year measurement to the previous year record. The rate of increase in total height and dgl is expressed as:

$$Rate\ of\ change = \frac{Value_{present} - Value_{previous}}{Value_{previous}} \times 100 \quad (1)$$

where $Value_{present}$ is the present year measurement record and $Value_{previous}$ is the previous year measurement of total height and dgl.

K-Means clustering analysis using the cluster functions in R was used to categorize the 33 native species. Using this approach, we used mainly the total height and dgl increments at age 5 years as clustering variables in the algorithm to automatically categorize the species. The *pamk* function in the *fpc* package was used to determine the optimum number of clusters. We set the optimum number of clusters as three and called these (slow, medium, and fast) referring to the diameter and height growth performances of the species. This is regardless of whether these species have been previously reported as slow or fast-growing, shade-tolerant, or intolerant or any other characteristics. All analyses were processed in R version 3.4.2.

3. Results

3.1. Survival Percentage of Species on Trial

At age 5 years, a total of 13 species, equivalent to 40% of all native species reached more than 80% survival rate (Figure 2). Native species like Kupang (*Parkia javanica*), Talisay gubat (*Terminalia foetidissima*) and Toog (*Petersianthus quadrialatus*), Lanipau (*Terminalia copelandii*), Bogo (*Garuga floribunda*) and Bitanghol (*Calophyllum blancoi*) had high survival tendencies. However, Yakal (*Shorea astylosa*), Malabayabas (*Tristaniopsis decorticata*), Agoho (*Casuarina equisetifolia*) Bitaog (*Calophyllum inophyllum*), Tanguile (*Shorea polysperma*), Tindalo (*Afzelia rhomboidei*), Mayapis (*Shorea squamata*) and Narra (*Pterocarpus indicus*) did not survive well in an open plantation condition and suffered higher mortality rates (>75%) after planting.

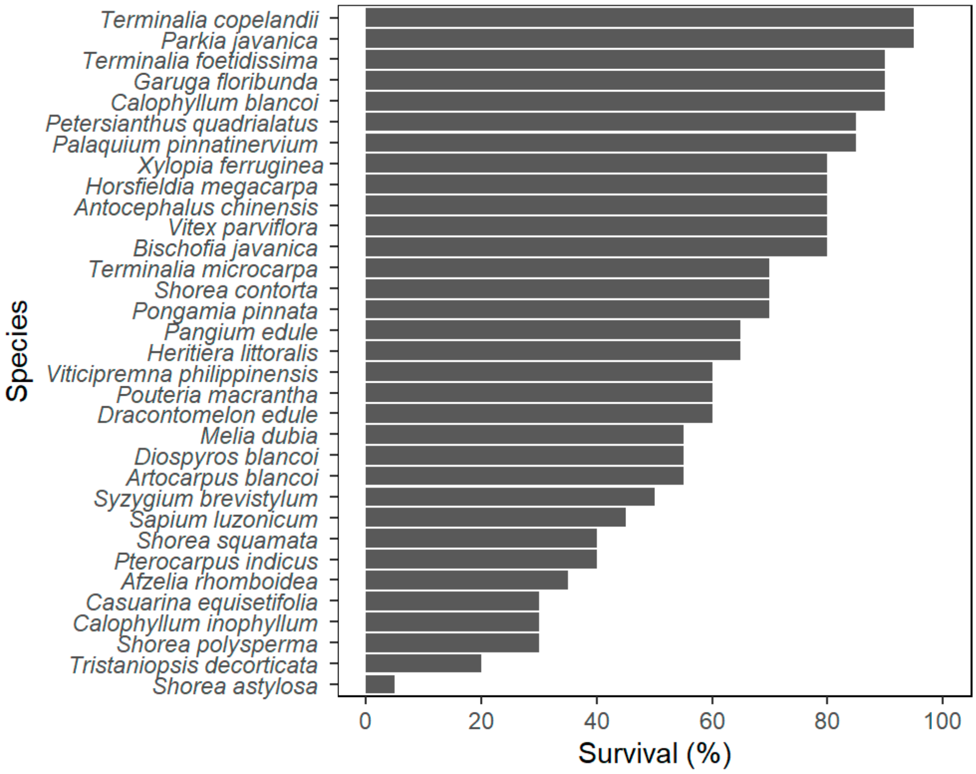

Figure 2. Survival percentage of 33 native species under field trial for domestication purposes. Bars represent the survival rate at the end of measurement period in 2018.

3.2. Growth Performances of Domesticated Species Per Cluster

Cluster analysis revealed that nine species belonged to the slow cluster. Surprisingly, species under slow cluster are mostly dipterocarp species. Fifteen species belonged to the 'medium' cluster, while nine fast-growing native species belonged to the 'fast' cluster. Their height and dgl increment ranges are found in Table 2 and Figure 3.

Table 2. Clustered species and their annual average total height and diameter at ground level increments from 2014 to 2018 (Years 1 to 4). Survival rate was determined at the end of the measurement period in 2018.

Cluster	Scientific Name	Height Increment (cm)				Diameter at Ground Level Increment (mm)				% Survival
		Year 1	Year 2	Year 3	Year 4	Year 1	Year 2	Year 3	Year 4	(Age 5 Years)
Fast	*Casuarina equisetifolia*	152	211	470	577	13	23	39	46	30
Fast	*Artocarpus blancoi*	92	222	442	588	7	34	57	84	55
Fast	*Melia dubia*	214	527	912	1061	28	61	106	132	55
Fast	*Xylopia ferruginea*	106	231	485	655	18	32	64	88	80
Fast	*Calophyllum inophyllum*	202	378	509	569	20	37	49	63	30
Fast	*Garuga floribunda*	87	404	520	562	16	37	54	64	90
Fast	*Terminalia microcarpa*	114	273	510	675	18	38	70	108	70
Fast	*Parkia javanica*	208	465	786	1001	39	60	120	151	95
Fast	*Terminalia foetidissima*	147	330	533	699	23	44	70	106	90
Medium	*Sapium luzonicum*	76	190	376	411	10	32	51	67	45
Medium	*Antocephalus chinensis*	71	180	377	369	22	37	65	83	80
Medium	*Pongamia pinnata*	123	256	350	450	8	20	36	47	70
Medium	*Calophyllum blancoi*	97	187	384	468	15	24	47	61	90
Medium	*Dracontomelon edule*	110	204	377	460	15	31	52	63	60
Medium	*Terminalia copelandii*	94	158	315	399	13	34	55	67	95
Medium	*Viticipremna philippinensis*	69	148	249	399	12	19	32	46	60
Medium	*Tristaniopsis decorticata*	126	245	320	389	7	14	25	32	20
Medium	*Vitex parviflora*	96	168	286	403	16	21	35	51	80
Medium	*Pangium edule*	85	154	280	335	10	21	41	57	65
Medium	*Pouteria macrantha*	25	71	235	312	6	12	30	40	60
Medium	*Palaquium pinnatinervium*	67	167	278	347	11	24	42	58	85
Medium	*Petersianthus quadrialatus*	89	184	285	386	12	22	40	50	85
Medium	*Bischofia javanica*	72	185	349	474	15	27	47	62	80
Medium	*Shorea contorta*	67	153	343	400	12	18	40	53	70
Slow	*Heritiera littoralis*	17	75	149	191	1	9	14	17	65
Slow	*Diospyros blancoi*	40	58	126	156	3	10	22	25	55
Slow	*Shorea squamata*	29	55	150	231	6	9	19	26	40
Slow	*Pterocarpus indicus*	56	144	234	292	3	18	28	33	40
Slow	*Syzygium brevistylum*	49	103	193	238	6	15	20	21	50
Slow	*Shorea polysperma*	35	100	146	181	2	15	16	23	30
Slow	*Afzelia rhomboidea*	41	51	89	107	2	5	8	24	35
Slow	*Horsfieldia megacarpa*	27	53	122	185	7	10	20	32	80
Slow	*Shorea astylosa*	57	59	124	164	10	13	23	25	5

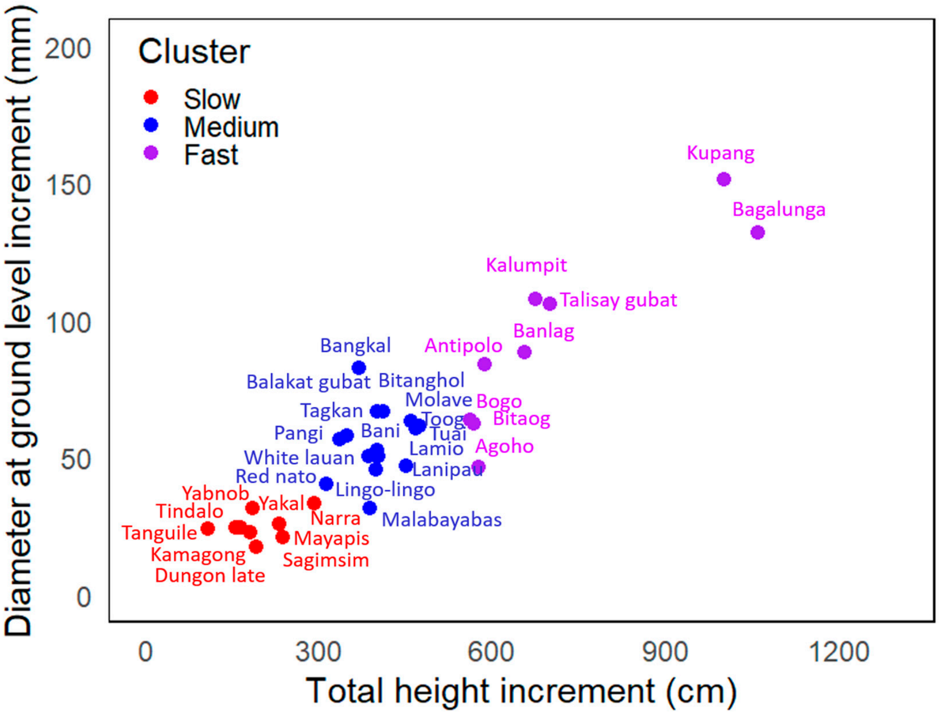

Figure 3. Result of K-means clustering analysis for 33 native domesticated species based on total height and diameter at ground level (dgl) increments obtained at the end of measurement period in 2018. Each cluster was assigned with colored circles and species local names were used to label each datapoint.

3.3. Variations in Growth Performances of Clustered Domesticated Species

At age 5 years, results showed that clustered species were significantly and statistically different (Figure 4; $p < 0.05$) in terms of total height and dgl increments, as well as survival rate. The average total height increment varied from 193.8 cm (ranges from 107.0 cm to 291.9 cm) for the slow cluster, 400.2 cm (312.4 cm–473.8 cm) for the medium cluster and 709.5 cm (562.4 cm–1060.6 cm) for the fast-growing cluster. In the same manner, the average dgl increment varied from 25.9 mm (17.4 mm–33.2 mm) for the slow cluster, to 55.7 mm (316 mm–82.7 mm) for the medium cluster and 93.5mm (46.3 mm–151.4 mm) for the fast cluster. The highest rate of survival (70%) was attained by the medium cluster while the slow cluster species had the lowest (44%). The fast cluster had a 60% survival percentage.

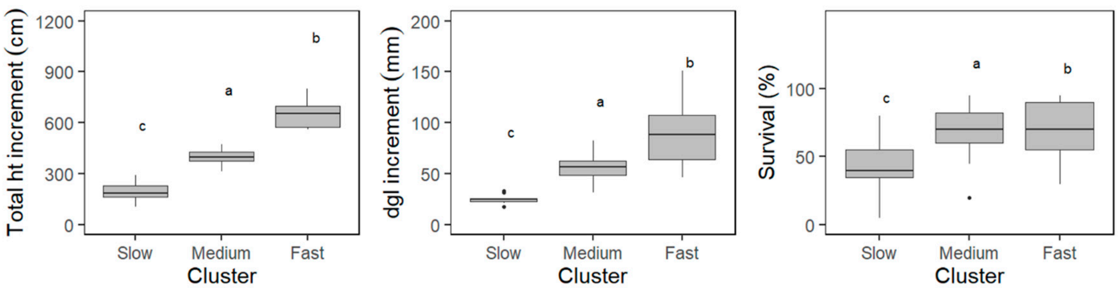

Figure 4. Variations in growth performances of clustered domesticated native species at the end of measurement period in 2018. In the boxplots, the thick horizontal line shows the median, the box extends to the upper and lower quartiles, the thin vertical lines indicate the nominal range and the small circles indicate points which lie outside of the nominal range. For a given graph, different letters denote significant differences among clustered species ($p < 0.05$) using the Tukey's HSD (Honest Significant Difference) test.

Clusters of native trees exhibited significant differences in their growing habits interannually with considerable increases from Year 1 to Year 4 ($p < 0.05$). The fastest growing species in terms of height were Bagalunga (*Melia dubia*) and Kupang (*Parkia javanica*) in the fast-growing cluster while Tindalo (*Afzelia rhomboidea*) and Kamagong (*Diospyros blancoi*) were the slowest growing among all the species (Figure 5). Yakal, Tanguile and Mayapis which belong to the Dipterocarpaceae family were among those with lowest dgl increment in the slow cluster. Fast-growing native species (Kupang, Kalumpit and Talisay-Gubat) were among those with highest diameter growth annually. Overall, most native species increased five times in height and basal diameter over 5 years.

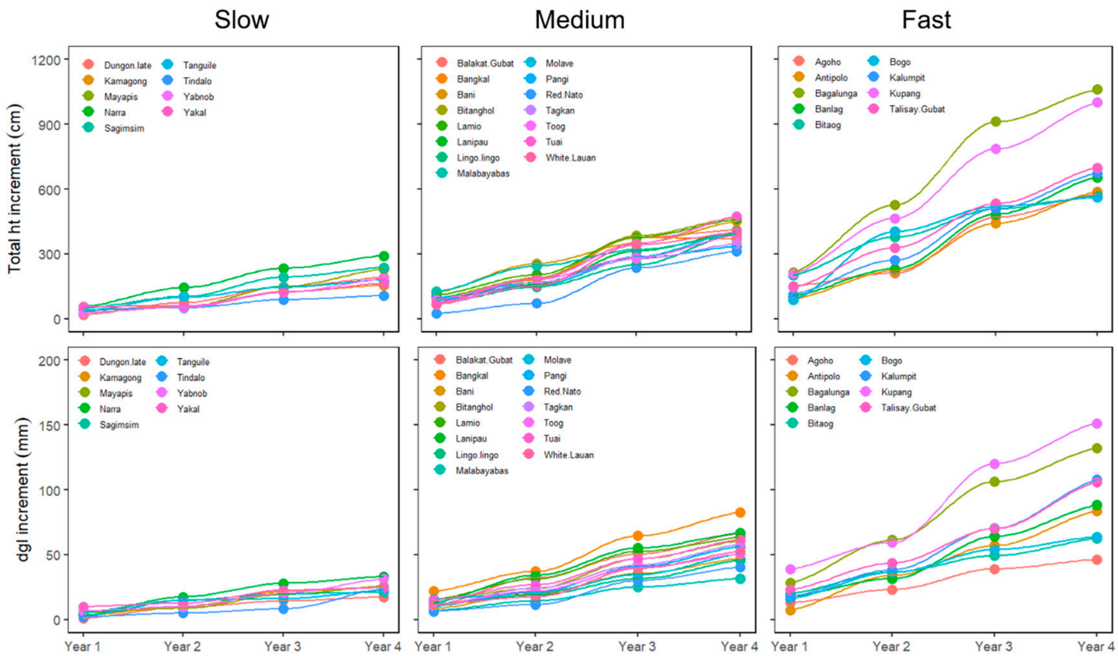

Figure 5. Cumulative height and dgl increments of 33 native species from Year 1 to Year 4. Each graph represents the species by cluster (slow, medium, and fast). Increments were taken based from previous year measurement. Data point and incremental line for each species within a cluster are represented by different colors.

In terms of the annual rate of the increases, a sudden surge in total height incremental growths in 2015 was observed a year after planting (Figure 6). This year marked the highest rate of change among all years at 83% (ranges from 65% to 104%). The growth was maintained from 49% to 52% in 2016 and 2017, respectively, but had a sudden decline in 2018 with only 21% (Figure 6). A similar case of highest dgl increment (72%) measured in 2015 compared to 42% in 2016, 44% in 2017, and only 22% in 2018. More years are needed to verify whether or not the fourth year will be the peak for early growth at our field trial site and if the fifth year is to be the period at which growth dynamics should start to slow down.

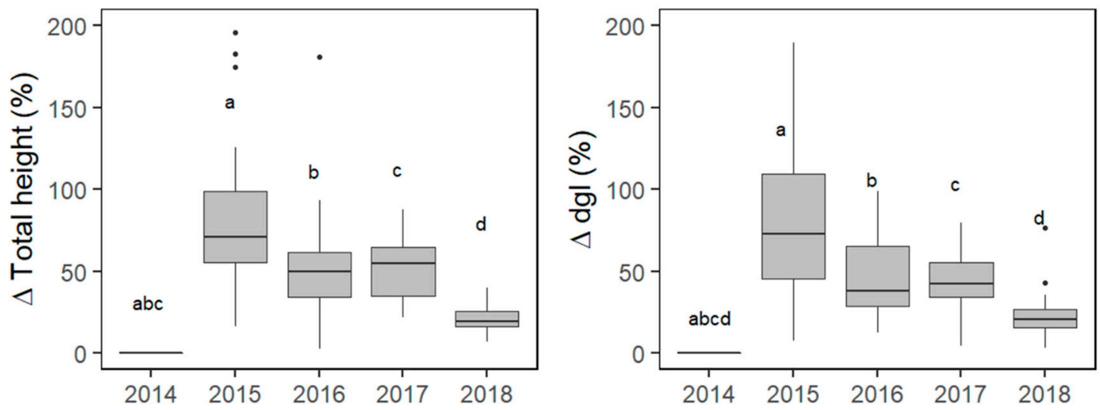

Figure 6. The annual rate of change in total height and diameter at ground level (dgl) of 33 native species from 2014 to 2018. In the boxplots, the thick line shows the median, the box extends to the upper and lower quartiles, the thin vertical lines indicate the nominal range and the small circles indicate points which lie outside of the nominal range. For a given graph, different letters (a, b, c, and d) denote significant differences among clustered species ($p < 0.05$) using the Tukey's HSD test.

3.4. Sources of Variations in Survival Rate of Clustered Species

Survival of the species correlated better to the diameter growth changes than their total height increment at an age of 5 years (Figure 7). Variances explained by dgl increment ($R^2 = 0.19$, $p < 0.01$) and total height increment ($R^2 = 0.12$, $p < 0.05$) were, small suggesting other biophysical factors affecting the survival rate of all species. Generalized Additive Modelling analysis showed coupled dgl and total height growth explained 53% of the changes in survival of the fast-growing cluster while only explaining 37% for medium cluster and 14% for slow cluster species. In all cases, dgl increment is the key predictor over the total height increments.

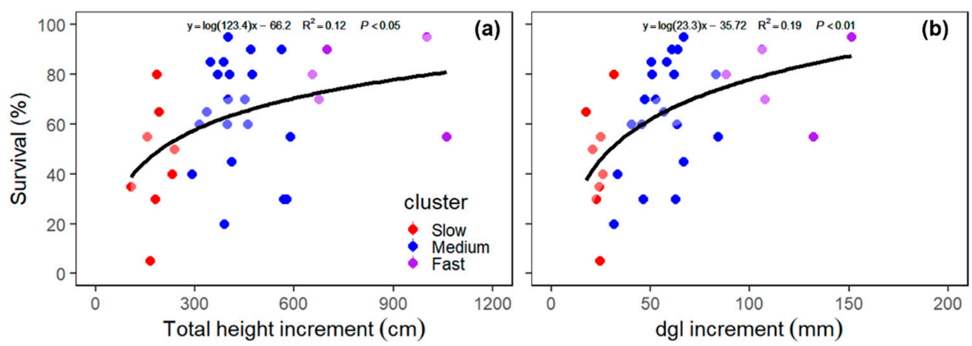

Figure 7. Relationship between survival percentage and (**a**) total height and (**b**) dgl increments at age 5 years. Each colored symbol represents the species of each cluster (slow, medium, and fast).

3.5. Climatic Effects on Total Height and Dgl Increments of Clustered species

Increasing amount of annual rainfall significantly correlated with the annual total height growth of slow-growing species ($R^2 = 0.85$) and the correlation was higher than the medium ($R^2 = 0.76$) or the fast-growing ($R^2 = 0.64$) clusters (Figure 8). Similarly, annual dgl increment was also significantly correlated with the amount of precipitation and the effect was greatest for the slow-growing ($R^2 = 0.84$) cluster. Any increase in annual average air temperature increased annual total height growth exponentially in this order: fast > medium > slow with $R^2 = 0.70$, $R^2 = 0.62$ and $R^2 = 0.56$, respectively (Figure 8). Even a minimal change in annual average air temperature can also trigger increased annual dgl growth in the fast-growing cluster ($R^2 = 0.70$), while only about half of the variations in annual average air temperature can explain the changes in annual dgl in slow-growing clustered species

(R^2 = 0.50). Significant increases in annual wind speed can reduce annual total height growth of clustered species (R^2 = 0.50~R^2 = 0.61). Fast-growing species were observed to be the most sensitive to annual average wind speed (Figure 8).

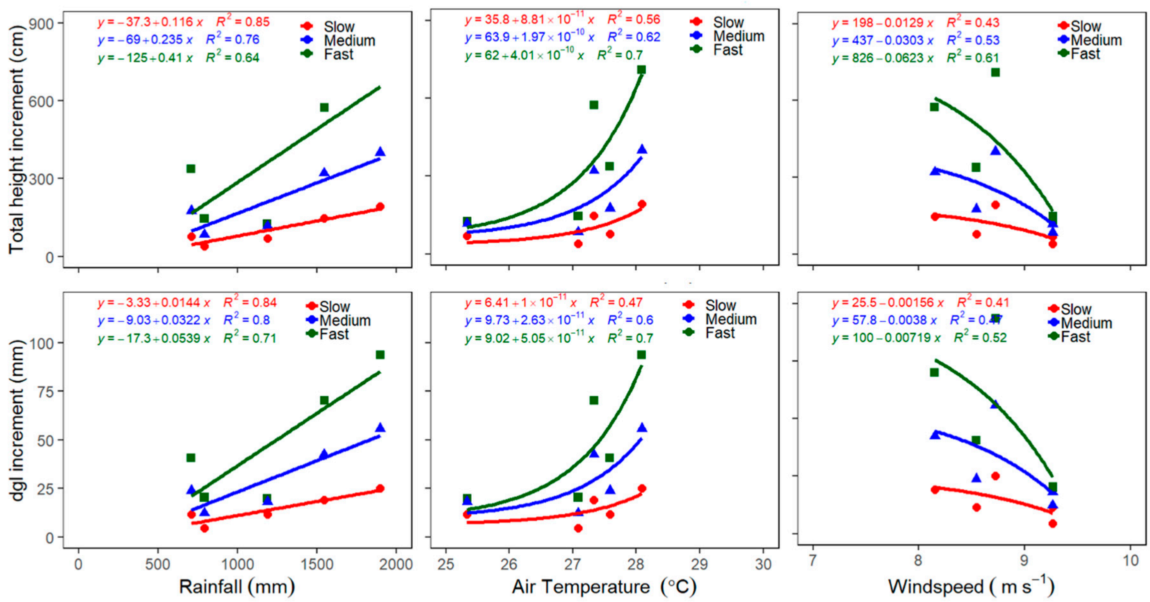

Figure 8. Relationship between annual total height and dgl increments with annual rainfall and annual averages of air temperature and wind speed. Each colored symbol represents the average annual data of all species clustered into slow, medium, and fast categories.

4. Discussion

4.1. Survival Tendencies of Native Species

Most of the species showed >60% survival rates five years after establishment. Species with high survival potentials were also observed to have existed predominantly in Mindanao, e.g., Kupang (*Parkia javanica*), Talisay gubat (*Terminalia foetidissima*), and Toog (*Petersianthus quadrialatus*). These species showed high survival tendencies even when planted outside their usual growing condition. Toog, which showed >85%, survival is a species mostly remaining in the field after the logging activities in the 1960s to 1970s. Toog remained mainly due to post-harvest processing difficulties. If appropriate wood processing into profitable products is achieved, the wood of Toog could command a high market value. Toog is a very good structural support for housing and other infrastructure construction. High survival percentage, especially for medium- and fast-growing species in our study suggests the quick adaptation and acclimatization of these native species to new growing conditions. These are good predictors for the species survival at an early stage; although having five years of observation time may not be enough as more information that could explain the growth potential versus its environment still has to be established [5].

Difficulty in adapting to their new environment for some species could cause high mortality rates of some native species in the trial site. Lack of adaptation to plantation conditions was also found in other domestication studies [6]. We observed that Yakal (*Shorea stylosa)*, Mayapis (*Shorea squamata*), Tindalao (*Afzelia rhomboidea*) and Tanguile (*Shorea polysperma*) belonging to the slow cluster suffered high mortality rates with survival rates of less than 25%. Yakal and Mayapis do not tolerate full sunlight exposure as they prefer partial shade-conditions [22,23]. Previous studies reported poor survival and slow growth among Dipterocarp species [24]. It appears that these species struggled to survive the unfavorable open canopy condition despite the presence of buffer trees at the edges of the field trial site. Although, other studies have reported that shade-tolerant species are able to survive in high light condition provided nutrients are adequate [16,22]. Thus, in any domestication efforts, it is therefore necessary to be cognizant of the seedling tolerance or intolerance to direct sunlight to ensure survival upon outplanting.

4.2. Early Stage of Development of Native Species

As mentioned earlier, species like Yakal, Tanguile, Sagimsim, Mayapis, Tindalo and Narra are slow growing trees. Yet these mentioned species were mostly preferred in Southern Leyte, Philippines for domestication purposes [9]. Farmers found these species lucrative due to their high market values. High wood quality compensates for the slow growth of these species [13,25]. These aspects along with many environmental and biological factors must be considered when dealing with native tree domestication for commercial purposes.

Earlier unpublished reports from ERDB-FWRDEC, Philippines showed that some fast-growing native species that are present in our study (e.g., Kalumpit, Banlag, Talisay-gubat, Bagalunga, Kupang, Agoho, Antipolo, Bitaog, and Bogo) have favorable stem and crown forms and superior diametric growth. These aforementioned species were reported to have shown potentials as alternative species to fast-growing exotic species common in most plantation forests in the Philippines such as Falcata (*Falcataria moluccana* (Miq.) Barneby & Grimes), Mangium (*Acacia mangium* (Willd.) Pedley) and Bagras (*Eucalyptus deplupta* Blume.) [9]. Our tree domestication study therefore serves as a pattern showing that in the long term, these native species can be managed in high-density plantings similar to that of the common fast-growing exotic species plantations [25].

Even though most of these native species in our study had high survival rates and satisfactory growth, some species are not being used in reforestation programs in the country due to difficulty in sourcing planting materials as most of their mother trees are rare and phenological information is lacking. In the National Greening Program of the Department of Environment and Natural Resources, Philippines, these native species with promising growth potentials have been initially explored and were found to be growing vigorously [10]. Yet, most community-based organizations still prefer the use of exotic species due to their fast-growing tendencies and market availability.

Successful seedling establishment right after outplanting is dependent on the ability of seedlings to rapidly initiate new roots [26] as this can mitigate the effects of transplant shock. This transplanting problem can be described as the reduction in growth of seedlings caused by slow acclimatization to new environmental conditions immediately after outplanting [16,27] due to water stress, high temperature, open canopies and other unfavorable environmental conditions that are not similar to nursery conditions. Thus, a sudden surge in total height and dgl growths a year after planting in our study suggests that our site conditions are conducive for seedings to acclimatize quickly. The combined impact of soil, climate, seedling quality, site preparation, weed control, quality of planting techniques and other biophysical factors have contributed to this sudden increase in growth of species a year after transplanting.

The decline in percent rate of change in total height and dgl increment of the species on the fifth year (2017–2018) measurement period suggests that the peak of early growth performances of native species may have occurred in the fourth year after outplanting. However, we cannot rule out human error or other environmental controls that may contribute to this decline. More years are needed to verify this account. Although, the peak in growth in the fourth year in our study is within the range of the reported peak in growth for *Acacia mangium* within 3–8 years after planting and which declines thereafter [28,29]. Nevertheless, this early growing pattern up to the fourth year in our study posed a pivotal period to be observed on the early growth evaluation of native trees that warrants appropriate management intervention to ensure the success of future tree domestication efforts.

4.3. Factors Affecting Survival, Total Height And Dgl Growth

Height and diameter at ground level can be used to assess the growth performances of seedlings, and in most cases these variables have been correlated with seedling survival or growth after outplanting [15]. Although these may not always be an accurate predictor of performance after outplanting, as root system morphology and physiological status may provide a more accurate indication of seedling potentials [16]. Height and diameter alone do not correlate with field performance in all cases [27,30]. The weak correlation between survival and height or diameter growth in our study has explained less of the variances that occurred. Although we have not measured root growth potentials in our study, we suppose that the production of seedlings with highly established root systems will enable seedlings to rapidly establish and thrive upon outplanting. Unfortunately, little research has focused intensively on root system assessment because of difficulty, time constraints, and inaccuracies due to their below-ground nature [31,32].

Light is one of the major drivers of plant adaptation and evolution, together with soil water and temperature [22,33–35]. Although, growth responses will depend largely on differences in irradiance intensity that sometimes may have little predictive power for other ecological characteristics [35]. Unfortunately, records of photosynthetic photon flux density (PPFD) were not available at our study site. Although, a study showed maximum growth for species occurred at an irradiance varying from 10% and 44% and that the inhibition of growth at higher irradiance was greater in the more shade-tolerant species [35]. Besides PPFD, other climate parameters like rainfall and temperature play a significant role in height and diameter growth [36,37]. In this study, we found an increasing height and diameter growth of all species (R^2 = 0.64~R^2 = 0.85) with increasing rainfall and a rather constant temperature. According to a study, where annual precipitation is high (>2000 mm per year) and temperatures more moderate due to higher elevation, native species had almost the same growth potential as the introduced species [6]. However, a study reported that neither low soil water nor high temperature were major limitations in seedling growth upon outplanting [22]. Our trial site is near a major lake system. This lake contributes to the substantial upcoming wind from the lakeside to the plantation site. As a result, we found a significant reduction in height and diameter growth with wind speed. The effects of wind on trees ranges from chronic to acute [38]. This airflow across the surface of leaves facilitates transpiration and the exchange of carbon dioxide and oxygen between the leaf and the atmosphere. Short-duration displacements of branches and leaves by wind leads to thigmomorphogenetic responses such as reduced shoot extension [39,40]. However, other studies reported positive growth responses to wind speed such as the production of shorter, thicker and therefore less slender stems and branches which better resist deflection [38] and improve root anchorage [41,42]. The seedling growth is a complicated physiological and morphological mechanism that requires an in-depth investigation.

5. Conclusions

This assessment of the initial stage of native species seedling development is a very crucial phase in any tree domestication study. It is at this stage where silvicultural interventions should be focused. Fast-growing species especially Kupang and Bagalunga adapted well to their new growing environment. These species are certainly of potential commercial importance since they have been planted by many farmers in some areas in the Philippines.

Our findings also show that slow-growing dipterocarp species (e.g., White lauan, Mayapis and Tanguile) can still survive even when planted in open areas outside their usual growing condition. This adaptation suggests that dipterocarps can be used successfully in reforestation provided proper silvilcultural interventions are administered. We should not underestimate the potential of slow-growing native species considering their premium wood quality, demand in the wood industries, and command of higher market values.

Since height and diameter parameters have not served as strong predictors of species survival, it is therefore recommended to incorporate below-ground morphological and physiological parameters and to include more climate variables in an attempt to better predict seedling performances following outplanting. These results presented here should be interpreted with caution due to varying growth patterns of the species, adaptation strategies, and ecological needs that were not fully studied. However, with the information we generated, we were able to provide initial steps towards developing sound silvicultural and management interventions for a more successful sustainable forestry production of goods and services with native species.

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