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Early Growth of 11 Native and Three Alien Tree Species in Northeastern Mindanao, Philippines

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Abstract: Early growth performances of 11 native tree species were investigated in three different sites in Mindanao, Philippines, to evaluate their adaptability and potential for plantation development. Three alien species were added to assess how native species could potentially compete with these alien species based on survival rate, diameter growth rate (DGR), and height growth rate (HGR). A year after planting, the native species common to all sites that obtained >80% survival rate were *Casuarina equisetifolia* L. *Alstonia macrophylla* Wall. ex. G.Don., *Alstonia scholaris* (L.) R.Br., and *Parkia javanica* (Lam.) Merr. and were comparable to an alien species *Acacia mangium* Willd. The species with the lowest survival rate (30%) across all sites was *Duabanga moluccana* Blume. Native species *P. javanica*, *Eucalyptus deglupta* Blume, and *A. macrophylla* all had a DGR of 34 mm year^{-1} and were comparable with the alien species *Schizolobium parahyba* (Vell.) S.F.Blake with 38 mm year^{-1}. However, the HGR of native species *E. deglupta* (245 cm year^{-1}) and *Melia dubia* Cav. (230 cm year^{-1}) were higher than an alien species *S. parahyba* (222 cm year^{-1}). No native species can compete with the DGR (52 mm year^{-1}) and HGR (384 cm year^{-1}) of *A. mangium*. Rainfall significantly explained 13%–97% of DGR, HGR and survival rate of >70% of the species while air temperature explained about 17%–96% of the variations of similar variables. This early assessment provides a strong basis to better predict the early performances of native species in the Philippines. Through this, appropriate silvicultural intervention can be recommended towards improving the growth and survival of the native seedlings as alternative industrial tree plantation species in the country.

Keywords: native species; alien species; tree plantation; growth performance; Philippines

Citation: Marquez, C.; Aguilos, R.; Bacsal, R.; Adornado, H.; Aguilos, M. Early Growth of 11 Native and Three Alien Tree Species in Northeastern Mindanao, Philippines. *Forests* **2021**, *12*, 909. https://doi.org/10.3390/f12070909

Academic Editor: Julien Fortier

Received: 5 June 2021
Accepted: 9 July 2021
Published: 13 July 2021

1. Introduction

Foresters, environmental researchers, and tree farmers face challenges in revitalizing our native tree species in degraded forest lands in the quest to manage productive, profitable, and fully functional ecosystems. Decades ago, the Philippines was one of the major exporters of logs of native trees from natural stands [1]. However, as with many other Asian countries, it lost its forest cover rapidly through heavy logging, upland migration, and agricultural expansion [2–4]. As a result, the country faces timber shortages and relies on imports to meet a large proportion of its demand [5].

The Caraga region of the Northeastern Mindanao, Philippines is the major contributor to the logging industry. Dubbed as the Timber Capital of the country, the Caraga Region provides 58%–72% of the country's log requirement [4] due to social inclination to tree planting, favorable climate, and existing wood processing plants. However, plantation species have been limited to alien trees such as *Falcataria moluccana* (Miq.) Barneby & J.W. Grimes (Falcata), *Acacia mangium* Willd. (Mangium), *Eucalyptus deglupta* Blume (Bagras), and *Swietenia macrophylla* King. (Mahogany). Tree farmers focus on planting alien species due to their excellent growth productivity, market availability, short rotation, absence of government administrative constraints in marketing, and availability of seedlings [6]. However, a continuous cropping cycle using the same species in the same unit area may deplete the soil nutrients, affecting its productivity. Fast-growing species such as *S. macrophylla* and *Acacia* spp. are also considered plant invaders [7–9]. Invasive species are a hidden threat to native species and lead to eventual plant extinction [10,11]. It has also been shown that alien plants interact with the soil microbial community and modify mutualistic interactions within the native vegetation [8,12–14]. The use of a greater variety of reforestation species will reduce the risk of species invasion, improve ecosystems' resilience, promote plant biodiversity, and amend soil condition [15,16]. From a socio-economic point of view, increasing the species options may enhance adaptability to changing market opportunities and offer a wider variety of products and services [17].

This early growth assessment is a crucial phase in any field trial. At this stage, silvicultural interventions should be given more emphasis [18]. Early species survival is related to their structural and morphological attributes, soil physical and chemical properties, nutrient availability, climate, and many other factors [18–23]. These various components interact to facilitate the establishment and development of newly-planted seedlings.

With the foregoing, we conducted this study with the following questions: (1) How do height and diametric growth and survival of the species behave at the early stages of development? (2) Is the early growth of native seedlings at par with alien species in areas with varying site conditions? (3) How do climatic factors (rainfall and air temperature) affect the growth and survival of the species under trial? To answer these questions, we assessed the early growth performances of 11 native tree species and three alien tree species (for comparison) in three different sites of Northeastern Mindanao, Philippines a year after planting. We examined the survival, diameter-at-ground level growth rate (DGR), and height growth rate (HGR) for species level and inter-site comparison. We also evaluated the effect of rainfall and air temperature on the growth and survival of seedlings.

2. Materials and Methods

2.1. Study Sites

We planted eleven native and three alien tree species in three different provinces of Northeastern Mindanao (Caraga Region), Philippines (Figure 1). The characteristics of each site are summarized in Table 1. The San Luis field trial site is within the Casilayan Softwood Development Corporation (CSDC) in San Luis, Agusan del Sur. The area was previously covered with wild *A. mangium* and was clear-cut for this study. The site topography was slightly sloping [8], and the elevation was 159 m a.s.l. The site has an average temperature of 26.12 °C and an average rainfall of 2152 mm. [24]. The Bislig site was established within the 3248-hectare Bislig Experimental Forest in Bislig, Surigao del Sur. This site has an elevation of 220 m a.s.l. with a moderately steep slope. The soil was unclassified mountain soil (BSWM Map Soil Classification) with heavy texture and reddish-brown color. The site has an average temperature of 26.3 °C and an average rainfall of 3458 mm. [24]. The Butuan field trial site was within the 100-hectare JAKA Inc. industrial tree plantation site. The area was previously planted with *Gmelina arborea* Roxb. ex Sm. Upon harvest, the vegetation cover succession was dominated with *Imperata cylindirica* (L.) P.Beauv. (cogon) and *Saccharum spontaneum* L. (Talahib) grasses. The terrain is moderately steep, with an elevation of 171 m a.s.l. The soil classification was Butuan loam which developed from the older alluvial terraces [25]. The average temperature of the Butuan site is 26 °C and it has an average rainfall of 2127 mm [24]. The three sites fall to 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 [24].

Figure 1. Map showing the location of the study in Northeastern Mindanao, Philippines.

2.2. Species Information

We evaluated eleven native tree species for their early growth field performances. We added three alien species for comparison purposes between the native trees and alien fast-growing trees. We based our selection of native tree species on a previous tree domestication study [18]. We collected the seeds mainly in different places in Mindanao except one species (Batino, Alstonia macrophylla Wall ex G.Don), which was collected in Palawan, Philippines. We sowed and raised the seeds in the Bislig Clonal Nursery of ERDB-FWRDEC, Maharlika, Bislig City. Taxonomic information is shown in Table 1. Scientific names and their authorships were obtained from Plants of the World Online (http://powo.science.kew.org, accessed on 21 June 2021).

2.3. Experimental Design, Establishment and Data Collection

We used a randomized complete block design (RCDB) in this study. The planting distance was 2 m × 2 m with 36 plants per species (six plants in rows and six plants in columns) and replicated five times (blocks). Each study measures 1.08 hectares. We eliminated the weeds and undesirable trees before planting and every two months thereafter. We outplanted the seedlings in the trial sites from August to November 2019. We applied complete fertilizer (14-14-14), which is a ratio, or equal percentages, of nitrogen (N), phosphorus (P), and potassium (K). We used 100 g for each plant every six months.

Table 1. Taxonomic information and provenances of native and alien species under this study.

	Local Name	Order	Family Name	Scientific Name	Place of Seed Collection	Geographical Coordinates		Seed Collection Date
						Latitude	*Longitude*	
				Native species				
1	Kaatoan bangkal	Gentianales	Rubiaceae	*Anthocephalus chinensis* (Lam.) Hassk.	Surigao del Sur Butuan City	8°13′46.06″ 8°56′43.47″	26°16′38.05″ 125°35′55.24″	April 2018 December 2018
2	Batino	Gentianales	Apocynaceae	*Alstonia macrophylla* Wall. ex G.Don	Palawan	9°41′56.60″	118°29′30.91″	February 2018
3	Dita	Gentianales	Apocynaceae	*Alstonia scholaris* (L.) R.Br.	Surigao del Sur Misamis Oriental	8°15′32.28″ 8°35′56.58″	126°16′34.44″ 124°49′8.61″	April 2018 December 2018
4	Tuai	Malpighiales	Phyllanthaceae	*Bischofia javanica* Blume	Misamis Oriental	8°37′57.02″	124°56′44.64″	January 2019
5	Agoho	Fagales	Casuarinaceae	*Casuarina equisetifolia* L.	Agusan Norte; Surigao del Sur	9°26′17.26″ 8°11′18.12″	125°33′10.70″ 126°21′45.87″	May 2018 May 2018
6	Loktob	Myrtales	Lythraceae	*Duabanga moluccana* Blume	Surigao del Sur Butuan City	8°17′56.00″ 8°56′36.39″	126°17′21.00″ 125°35′51.03″	July 2018 July 2018
7	Bagras	Myrtales	Myrtaceae	*Eucalyptus deglupta* Blume	Bukidnon Agusan del Norte	8°7′33.64″ 9°26′20.44″	125°5′58.35″ 125°33′9.53″	May 2018 July 2018
8	Bagalunga	Sapindales	Meliaceae	*Melia dubia* Cav.	Agusan del Sur Cabadbaran City Butuan City Zamboanga del Sur	8°37′27.00″ 9°5′55.00″ 9°0′38.00″ 6°58′31.08″	125°54′33.00″ 125°38′8.00″ 125°39′12.00″ 122°4′8.52″	August 2018 August 2018 September 2018 September 2018
9	Kupang	Fabales	Fabaceae	*Parkia javanica* (Lam.) Merr.	Bukidnon Butuan City Laguna	8°9′57.75″ 8°57′7.00″ 14°9′20.88″	125°7′5.73″ 125°29′29.00″ 121°14′9.13″	June 2018 April 2018 April 2018
10	Talisay gubat	Myrtales	Combretaceae	*Terminalia foetidissima* Griff.	Misamis Oriental	8°32′43.00″	124°19′11.00″	February 2018
11	Kalumpit	Myrtales	Combretaceae	*Terminalia microcarpa* Decne.	Butuan City Cagayan de Oro City	8°57′16.70″ 8°25′29.50″	125°35′49.70″ 124°41′42.64″	July 2018 August 2018
				Alien species				
12	Mangium	Fabales	Fabaceae	*Acacia mangium* Willd.	Agusan del Norte Cagayan de Oro	9°26′14.75″ 8°23′56.95″	125°33′12.38″ 124°42′45.74″	April 2018 April 2018
13	Brazillian Fire Tree	Fabales	Fabaceae	*Schizolobium parahyba* (Vell.) S.F.Blake	Bukidnon	8°9′24.64″	125°7′59.73″	April 2018
14	Mahogany	Sapindales	Meliaceae	*Swietenia macrophylla* Willd. ex Vogel	Butuan City Bislig City	8°56′36.82″ 8°14′40.03″	125°35′49.91″ 126°16′38.55″	December 2018 December 2019

2.4. DGR, HGR, and Survival Rate Determination

The initial height (cm) and the diameter at ground level (dgl; mm) were obtained two months after outplanting. We performed subsequent measurements every six months. We used a vernier caliper to measure the dgl and a calibrated pole to measure the height. The total height and dgl were instantaneous data at the time of measurement. To avoid biases and inherent differences in scale between contrasting species at the time of planting, we standardized them using the relative annual growth rate, termed as diameter growth rate (DGR, mm $year^{-1}$) for dgl and height growth rate (HGR, cm $year^{-1}$) for height. These growth rates were calculated following the equation [26]:

$$\text{DGR or HGR} = \frac{W_2 - W_1}{t_2 - t_1} \quad (1)$$

where W represents either dgl or height at t_1 at the beginning of the experiment and t_2 at the end of the experiment in an annual basis.

Survival rate was calculated by counting the number of plants of each species that had survived divided by the number of plants originally planted of that species, expressed in percentage survival.

2.5. Climate Data Collection

We installed a Davis Vantage Pro2 automated weather monitoring station (AWMS) at each site to determine the micro-climatic condition, particularly the temperature and rainfall. We retrieved these climate data once a month.

2.6. Data Analysis

We used a two-way analysis of variance (ANOVA) with interaction effect to determine significant differences in survival rate, diameter-at-ground (dgl) level, and height growth rates at species and site levels and their interactions.

Local climatic variables (rainfall and air temperature) were plotted against survival rate, DGR, and HGR using the linear regression in the *ggplot2* package. All analyses were processed in R version 4.0.3 (R Core Team, 2020) [27].

3. Results

3.1. Survival Tendencies of Native and Alien Tree Species

3.1.1. Species Level

Across all sites, the highest survival rate was attained by an alien species *A. mangium* (95%), although the survival rate of native species such as *A. scholaris* (93%), *C. equisetifolia* (93%), *P. javanica (91%),* and *B. javanica* (90%) were close and did not differ significantly ($p > 0.05$). The overall average survival rate across sites was 84%, yet other alien species such as *S. macrophylla* (82%) and *S. parahyba* (79%) fell below this average level. All native and alien species attained >75% survival rate except for *D. moluccana,* where only 30% of the planted seedlings survived (Figure 2).

3.1.2. Site Level

Overall, the average survival rate in Bislig, Butuan, and San Luis were 79%, 86% and 86%, respectively.

The lowest survival rate in the Bislig site was 29%. This 71% mortality was observed in *D. moluccana*. *A. mangium*, had the highest survival rate (90%). However, *P. javanica* (89%), *B. javanica* (86%), and *C. equesitifolia* (87%) did not differ significantly to *A. mangium* ($p > 0.05$). Out of the 14 native and alien species, 9 of them had >80% survival percentage (Figure 3).

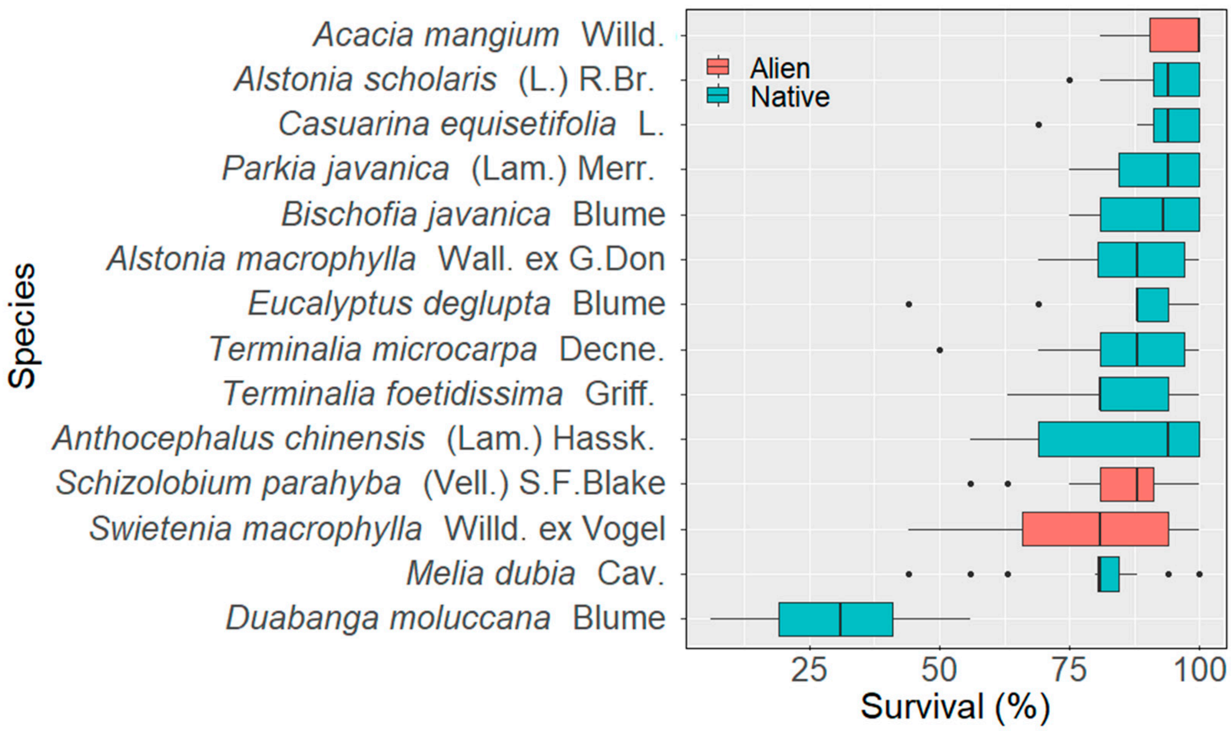


Figure 2. Overall survival performances of native and alien tree species averaged across the three trial sites in Northeastern Mindanao, Philippines. Native species are green color boxes and red indicates alien species. In the box plot, the thick vertical line shows the median, and the box extends to the left for lower quartiles and to the right for the upper quartiles. Horizontal thin lines indicate the nominal range, open circles indicate points that lie outside the nominal range.

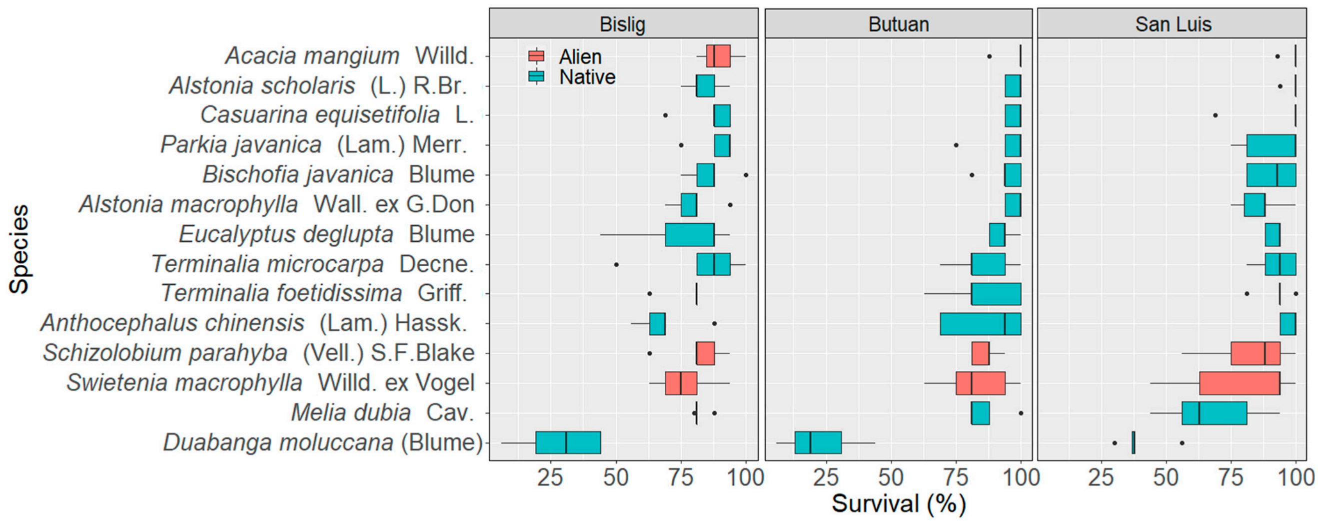


Figure 3. Survival performances of native and alien tree species planted at three trial sites in Northeastern Mindanao, Philippines. Native species are green color boxes and red indicates alien species. In the box plot, the thick vertical line shows the median, and the box extends to the left for lower quartiles and to the right for the upper quartiles. Horizontal thin lines indicate the nominal range, open circles indicate points that lie outside the nominal range.

In the Butuan site, the minimum survival rate was again observed in *D. moluccana* (23%) while the rest had >80% survival rate. The maximum survival percentage in the Butuan site was 98%, not only exhibited by *A. mangium* but also for *A. scholaris*, *C. equisetifolia*, *P. javanica*, and *A. macrophylla* (Figure 3).

In the San Luis site, *D. moluccana* still had the lowest survival rate (39%), however this rate is high compared to its performances in the Bislig (29%) and Butuan (23%) sites

($p < 0.05$). The maximum 98% survival rate of *A. scholaris*, *C. equisetifolia*, *P. javanica*, *B. javanica*, and *A. chinensis* were relatively at par with *A. mangium* (99%) in the San Luis site. Alien species such as *S. parahyba* (82%) and *S. macrophylla* (79%) fell below the average survival rate of 86% for this site. Out of 14 species, 12 had >80% survival rate in the San Luis site (Figure 3).

3.2. Diametric and Height Growth Rates of the Species

3.2.1. Species Level

It is not surprising that alien species *A. mangium* attained the highest DGR (mean = 61 mm year^{-1}) across all sites (Figure 4a). Following *A. mangium* were alien species *S. parahyba* and *S. macrophylla* with a DGR of 38 mm year^{-1} and 31 mm year^{-1}, respectively. Native species such as *A. macrophylla*, *E. deglupta*, *P. javanica*, and *M. dubia*, with DGR ranging from 32–35 mm year^{-1}, grew at rates close to that of *S. parahyba* and *S. macrophylla*. The species with the lowest DGR was attained by *D. moluccana* (14 mm year^{-1}).

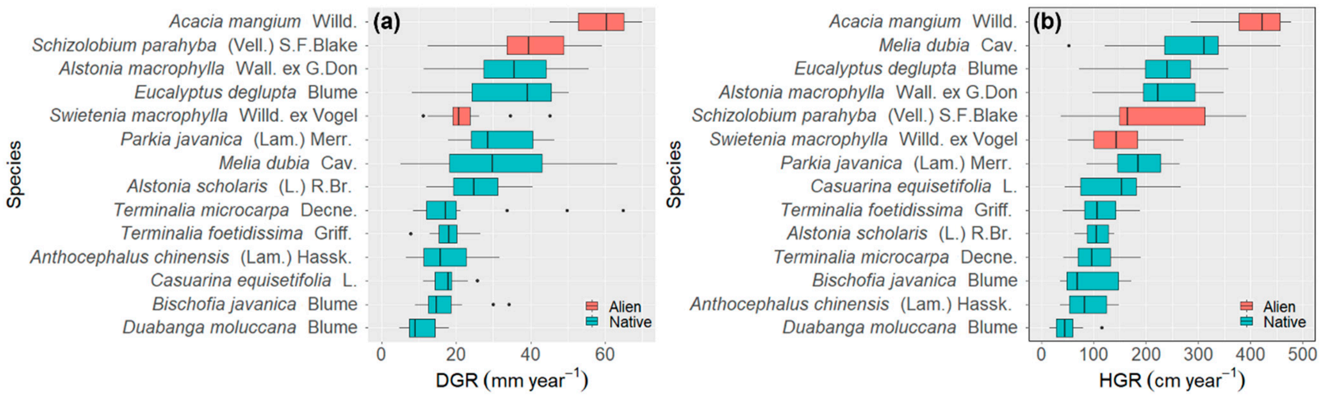
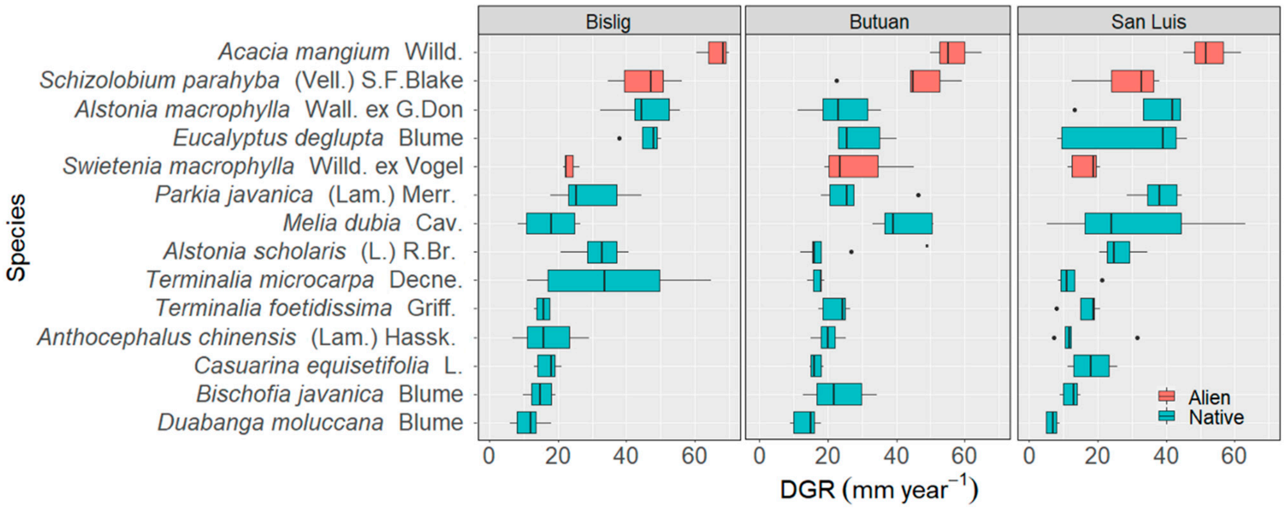


Figure 4. DGR (**a**) and HGR (**b**) of native and alien tree species averaged across all three trial sites. Native species are green color boxes and red indicates alien species. In the box plot, the thick vertical line shows the median, and the box extends to the left for lower quartiles and to the right for the upper quartiles. Horizontal thin lines indicate the nominal range, open circles indicate points that lie outside the nominal range.

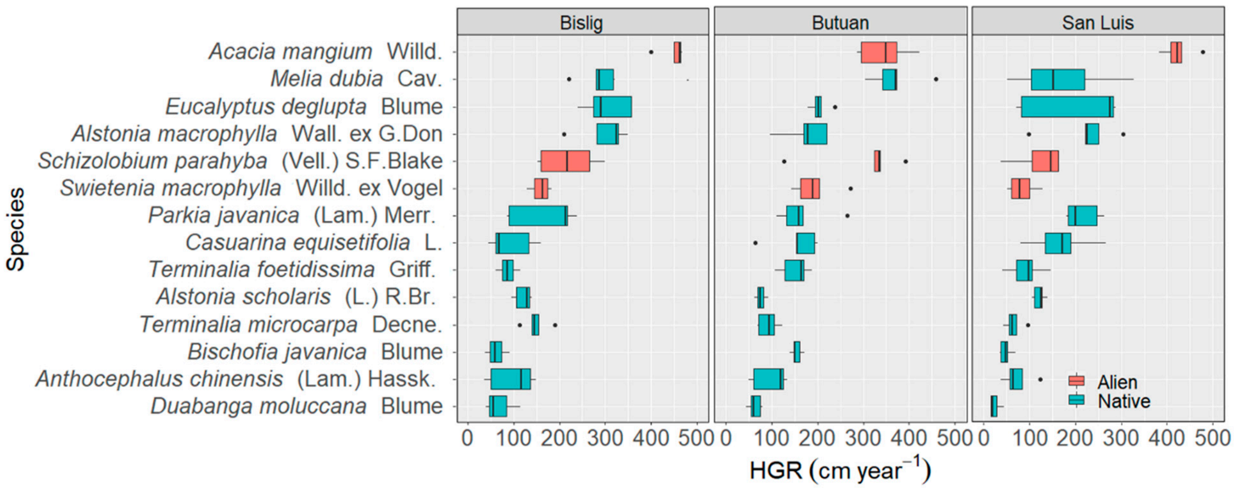
A. mangium also attained the highest average height growth (HGR = 406 cm year^{-1}, Figure 4b) followed by *M. dubia* (301 cm year^{-1}). The average HGR of native species *E. deglupta* (235 cm year^{-1}) and *A. macrophylla* (232 cm year^{-1}) were higher than alien species *S. parahyba* (215 cm year^{-1}). Again, *D. moluccana* had the lowest HGR of only 57 cm year^{-1}.

3.2.2. Site Level

Figure 5 shows the DGR of all species across sites from a minimum of 6.7 mm year^{-1} to a maximum of 66.3 mm year^{-1} and all sites were significantly different ($p < 0.05$). Across all sites, *A. mangium* performed the best in terms of DGR with 66.3 mm year^{-1}, 56.5 mm year^{-1}, and 60.9 mm year^{-1} for Bislig, Butuan, and San Luis, respectively, whereas *D. moluccana* performed the poorest across all sites with only 11.5 mm year^{-1}, 13.6 mm year^{-1}, and 6.7 mm year^{-1} for Bislig, Butuan, and San Luis, respectively. At the Bislig site, the DGR of native species *A. macrophylla* (45.4 mm year^{-1}) and *E. deglupta* (45.9 mm year^{-1}) was at par with the alien species *S. parahyba* (45.6 mm year^{-1}). The DGR of *M. dubia* in Butuan (42.0 mm year^{-1}) can also compete with the DGR of *S. parahyba* (43.7 mm year^{-1}) at the same site, although the average DGR of native species *A. macrophylla* (24.0 mm year^{-1}), *E. deglupta* (29.3 mm year^{-1}), and *P. javanica* (27.6 mm year^{-1}) were close to the DGR of alien species *S. macrophylla* (28.0 mm year^{-1}). In the San Luis site, native species *A. macrophylla*, *E. deglupta*, *P. javanica*, and *M. dubia* (average DGR ranges 29.2 mm year^{-1} to 37.7 mm year^{-1}) slightly outperformed the DGR of *S. parahyba* (28.7 mm year^{-1}).



(**a**)



(**b**)

Figure 5. DGR (**a**) and HGR (**b**) of native and alien tree species planted at three trial sites. Native species are green color boxes and red indicates alien species. In the box plot, the thick vertical line shows the median, and the box extends to the left for lower quartiles and to the right for the upper quartiles. Horizontal thin lines indicate the nominal range, open circles indicate points that lie outside the nominal range.

The San Luis site exhibited the lowest HGR (150.8 cm year^{-1}) while the Bislig site exhibited the highest (201.5 cm year^{-1}). The average HGR across all species in all sites varied from 25.6 cm year^{-1} to 426.9 cm year^{-1}, and all sites were significantly different ($p < 0.05$). *A. mangium* had the highest HGR in Bislig (448.5 cm year^{-1}) and in San Luis (424.5 cm year^{-1}). The HGR of *A. mangium* in Butuan (345.2 mm year^{-1}) was only second to *M. dubia* (369.1 cm year^{-1}) of the same site. In Bislig and San Luis, three native species namely, *M. dubia*, *A. macrophylla*, and *E. deglupta*, with HGR ranging from 199.9 cm year^{-1} to 303.8 cm year^{-1}, outperformed two other alien species *S. parahyba* and *S. macrophylla* with the HGR ranging from 83.7 cm year^{-1} to 219.1 cm year^{-1}. Still, *D. moluccana* attained the poorest HGR with only 69.5 cm year^{-1}, 63.0 cm year^{-1}, and 24.3 cm year^{-1} for Bislig, Butuan, and San Luis, respectively.

3.3. Site-Species Interactions

Using the two-way ANOVA test with interaction effect, we found significant differences among blocks, sites, and species, as well as interactions between the sites and species in terms of DGR, HGR, and survival rate ($p < 0.0001$~$p < 0.04$, Table 2). The interaction between site and species was highly significant ($p < 0.0001$), which indicates that relationships between species and DGR, HGR, or survival rate depends on the site condition. This prompted us to dig into the sources of variations in species growth and survival as affected by any condition at the site. We used the available climatic data for each site and evaluated how these affect the DGR, HGR, and survival rates of the species as discussed in the succeeding sections.

Table 2. Summary of two-way analysis of variance (ANOVA) of DGR, HGR, and survival rate. Degrees of freedom (DF), F-statistic (F), and P values (Pr) are shown for each of the block, site, and species and the interaction between site × species. Significant differences are shown by (*). Significance level: *, 0.05; **, 0.01–0.001; ***, <0.001.

Parameter	Source of Variation	DF	F values	Pr (>F)
DGR				
	Block	4	3.97	0.04 *
	Site	2	8.67	<0.0001 ***
	Species	13	14.90	<0.0001 ***
	Site × Species	26	3.50	<0.0001 ***
HGR				
	Block	4	3.98	0.04 *
	Site	2	5.83	<0.001 **
	Species	13	21.47	<0.0001 ***
	Site × Species	26	4.05	<0.0001 ***
Survival Rate				
	Block	4	4.57	0.03 *
	Site	2	3.48	<0.0001 ***
	Species	13	4.47	<0.0001 ***
	Site × Species	26	3.87	<0.0001 ***

3.4. Climatic Factors Affecting the Growth and Survival of the Species

3.4.1. The Response of DGR, HGR, and Survival to Rainfall

In terms of DGR-rainfall relationship, 43% of the species were sensitive to rainfall, although the sensitivity and the trajectory of the slope varied ($R^2 = 0.16$~$R^2 = 0.92$, Figure 6). Among them, *E. deglupta*, a fast-growing native species, was the most sensitive ($R^2 = 0.92$), with higher rainfall slowing down its DGR. Some of the species that benefited from the high rainfall amount were alien species such as *A. mangium* and *S. macrophylla*, but at a lower extent, with $R^2 = 0.16$ and $R^2 = 0.19$, respectively.

Similarly, the HGR of fast-growing native species *E. deglupta*, *B. javanica*, and *A. scholaris* (R^2= 0.66~0.88) were highly affected by rainfall, although they exhibited different response trajectories. For example, high rainfall lowered the HGR of *E. deglupta* and *B. javanica*, and *A. scholaris* grew faster with high rainfall. In contrast, the HGR of the alien species *S. macrophylla* ($R^2 = 0.17$) were less likely affected by rainfall and the HGR of *A. mangium* was not affected at all ($R^2 = 0.01$, $p > 0.05$).

The survival rates of *Terminalia foetidissima* Griff., *P. javanica*, *B. javanica*, *E. deglupta*, and *C. equisetifolia* were very sensitive to rainfall ($R^2 = 0.91$~0.97). However, the survival of *T. foetidissima* and *C. equisetifolia* were high when rainfall was low and declined when it was the opposite. The survival of *A. mangium* was less sensitive to rainfall ($R^2 = 0.16$). The survival of *D. moluccana*, the slowest growing species with the lowest survival, was not at all affected by rainfall ($R^2 = 0.01$, $p > 0.05$).

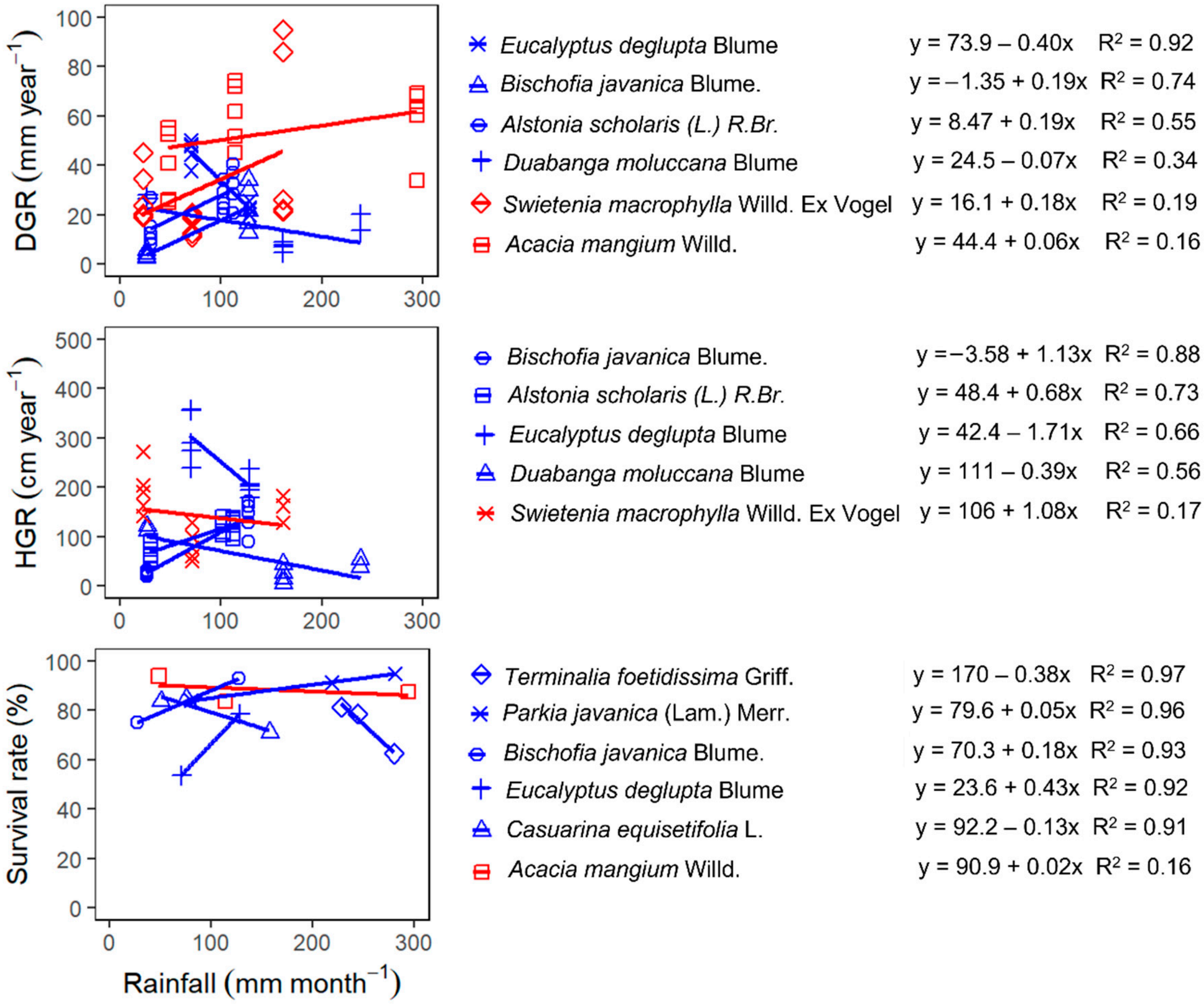


Figure 6. Relationships between DGR, HGR, and survival rate to rainfall. Native species are represented by blue symbols and lines and red indicates alien species. Each symbol represents the average data per species per plot in each trial site. Linear regression equations are presented after each species in the legend in the right side of each panel.

3.4.2. The Response of DGR, HGR and Survival to Temperature

The temperature-DGR relationships were significant to only 36% of all the species. *D. moluccana*, the slowest growing native species, was mostly affected by temperature (R^2 = 0.76) indicating that high temperature environment induces greater diametric expansion of the species (Figure 7). Interestingly, the DGR of *E. deglupta*, a fast growing native species, was less sensitive to changes in temperature regime (R^2 = 0.17). The DGR of alien species such as *A. mangium*, *S. macrophylla*, and *S. parahyba* were not affected at all by changes in temperature (R^2 = 0.01, $p > 0.05$).

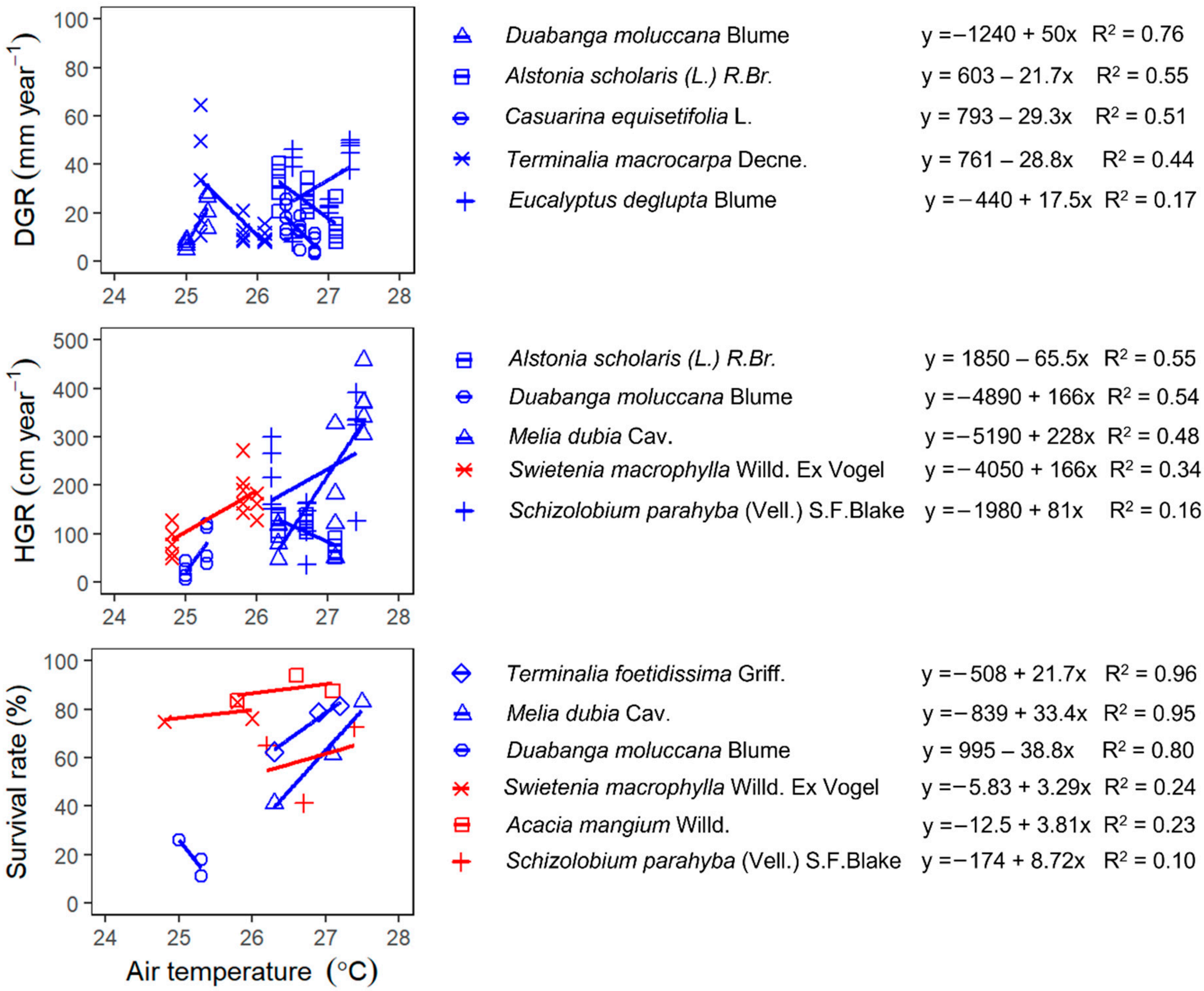


Figure 7. Relationships between DGR, HGR, and survival rate to air temperature. Native species are represented by blue symbols and lines and red indicates alien species. Each symbol represents the average data per species per plot in each trial site. Linear regression equations are presented after each species in the legend in the right side of each panel.

In terms of HGR-temperature relationship, 35% of the species were highly limited by temperature, which was one of the most limiting factors on their height growth. However, the variance explained is only up to about 50% (R^2 = 0.16~0.55), indicating that factors other than temperature were driving the HGR of these species. The HGR of *D. moluccana*, a slow growing native species, was highly affected by temperature (R^2 = 0.54), whereas *S. parahyba*, an alien species, was the least affected (R^2 = 0.16).

In terms of survival rate-temperature relationships, the survival rates of all species were highly limited by temperature (R^2 = 0.10~0.96). *T. foetidissima*, *M. dubia*, and *D. moluccana* were highly affected by temperature, although the slope varied significantly even at a small temperature range (25~28 °C). Alien species such as *S. macrophylla*, *A. mangium*, and *S. parahyba* were among those species that were less likely to be affected by temperature (R^2 = 0.10~0.24).

4. Discussion

4.1. Survival of Native and Alien Species

4.1.1. Species Level

Acacia mangium, a fast-growing tree from Indonesia, Papua New Guinea and Australia, has been cultivated outside its native environment and introduced into humid tropical lowland regions of Asia, South America and Africa over the last few decades [28]. It is a promising plantation species [2,29]. The survival rate of *A. mangium* is high and can reach >79% even 4 years after planting [29]. Thus, in the Philippines, many logging concessionaires and private tree growers prefer *A. mangium* due to its short rotation period, timber quality, marketability, and high survival rate [4,30], even though native species in the Philippines can also attain high survival rates comparable to *A.mangium*. For example, our previous study showed that *P. javanica* and *B. javanica* achieved 80%–90% survival rates 5 years after planting, which proved the ability of these native species to survive well as that of *A. mangium*.

While all species at our study sites attained >75% survival rate, *D. moluccana* had the lowest survival tendency (~30%). Generally, *D. moluccana* thrives well near bodies of water such as perennial gullies and streams. Micro-climate, soil water, nutrient availability, and physical soil properties change strongly from gullies and stream ecosystems to open sites [31], posing very distinct barriers to the growth and survival of newly established *D. moluccana*. However, if this species is used as planting material in an undulating terrain plantation site near gullies and streams with a high groundwater table, *D. moluccana* may thrive well, which has been observed in East Kalimantan, Indonesia [32].

Overall, seedling mortality was low at the three sites. One plausible explanation for the low mortality rates in our sites is that seedlings were fertilized when planted and at two months post-planting to ensure establishment. Fertilization may have ameliorated nutrient stress initially, while the same does not apply for moisture stress as rainfall is not a limiting factor in all sites.

4.1.2. Site Level

Our results showed that although *A. mangium* generally had high survival when planted in a wetter bioclimatic zone such as in the San Luis site, its survival can be lower in drier and sloping sites, such as the Bislig and Butuan sites. This lower survival of *A. mangium* in drier conditions in our study is consistent with the study of Hardie et al., 2018 [33].

The high survival rates of *P. javanica, B. javanica, C. equisetifolia, A. macrophylla,* and *A. scholaris* in our three study sites which were consistent with *A. mangium*, which demonstrates the potential of these native species to compare favorably with that of alien species under appropriate ecological conditions. Our previous species trial performed in Agusan del Norte, Philippines also showed a very high survival tendency of *P. javanica* [18] planted in sloping terrain with favorable climate, such as our present study sites. *P. javanica* is an agroforestry tree species in most tropical regions. In the Philippines, the tree can grow luxuriantly in the wild and in shifting agriculture lands [34]. *P. javanica* is a large tropical tree that grows well under full sunlight, although it also thrives well in cooler tropical conditions, making it an excellent candidate native species for plantation establishment. *B. javanica, A. macrophylla,* and *C. equisetifolia* belong to species that existed in old-growth and secondary forests in the Philippines but are now vulnerable to shifting cultivation and land-use change [3]. These species are used presently for assisted natural regeneration and many forest structure recovery efforts in the Philippines. It may still be too early to draw conclusions about the fate of *P. javanica, B. javanica,* and *C. equisetifolia* on this upland condition at its early stage of development. Long-term monitoring is needed to understand better the species adaptation of these native species.

4.2. Height and Diameter Growth Rates of the Species

4.2.1. Species Level

Among all native and alien species planted, *A. mangium* had the highest DGR and HGR. This is not surprising, because *Acacia* species are prime candidates as they are fast-growing, even in poor soils [35,36], and can grow in high-light environments and vice versa under low-light conditions [37]. *A. mangium* was introduced as a plantation tree in the Philippines in the early 1980s to contribute to the timber industry alongside *Falcataria moluccana* [4]. However, it has become increasingly clear that some alien tree species used in industrial tree plantation development can cause major problems as invaders of natural and semi-natural or disturbed ecosystems [7,37–39]. This species may accrue costs to the ecosystem that may far outweigh its benefits [36,38,40,41]. Thus, the use of native species has been increasingly promoted as an alternative for industrial tree plantation development in the Philippines.

Past studies in the Philippines reported that native species such as *A. macrophylla*, *A. scholaris*, *P. javanica*, *B. javanica*, and *C. equisetifolia* were used in reforestation efforts. These species were proven to help rapidly recover abandoned land areas left after shifting cultivation [3]. These were the same species that exhibited relatively higher DGR and HGR in our study sites, capable of competing with alien species such as *A. mangium*, *S. parahyba*, and *S. macrophylla*.

4.2.2. Site Level

Slow growing native species such as *A. chinensis*, *D. moluccana*, and *T. foetidissima* mostly thrive in a habitat different from our trial sites in Bislig, Butuan, and San Luis. They usually grow in wetland areas, along the coastal plains, and near streams. Difficulty in adapting to a new environment could cause high mortality rates and poor growing performances [16], such as what we observed in our study.

Many species with better DGR, HGR, and survival rates are found in upland forests similar to our study sites. These include *C. equisetifolia*, *A. macrophylla*, and *P. javanica*, among others. The growth of these species was comparable to that of other alien species such as *S. macrophylla* and *P. parahyba*. These native species that have the ability to grow comparatively with alien species should be monitored closely since they may have better chances of becoming alternative species for industrial plantation development.

Overall, height and diameter may not always be accurate predictors of performance after outplanting. Root system morphology and physiological status may also come into play [20]. Management interventions must then focus on attaining good growth patterns by avoiding weed competition and applying silvicultural and fertilizer treatments that ensure better structural form and growth of planted seedlings.

4.3. Climatic Factors Affecting the Growth and Survival of Native and Alien Species

Despite similar maintenance operations and silvicultural interventions applied in our sites, native and alien species' growth and survival differed due to the varying biological and environmental factors such as micro-climate, soil biota, nutrient availability, soil physical and chemical attributes, the quality of planting materials, topography, hydrology, pest and diseases, and weed competition, as well as the adaptation of the plants to the new environment [17,42–45].

Accordingly, light is one of the key drivers for plant growth, coupled with soil moisture and temperature [46–53]. In our trial sites, we do not have solar radiation data, although we found that local rainfall and temperature drove the increase in DGR and HGR of most of the species. Our results suggest that if there is not much prolonged rainfall, and as well as longer dry days due to a slight increase in temperature, the planted species can attain optimum structural growth.

Rainfall and air temperature are not primarily a limiting factor for most alien species (*A. mangium*, *S. macrophylla*, and *S. parahyba*) in our study sites, indicating that their seedling growth and survival may be affected more by poor soil nutrients and soil health conditions, as reported by many authors [16,54,55].

Most fast-growing native species (e.g., *E. deglupta* and *B. javanica*) were less affected by temperature. *E. deglupta* are trees that take a wide range of physical forms and occupy a broad range of climatic and ecological niches [56]. Hughes et al. [57] reported that even in 1 °C to 2 °C annual mean temperature difference, the actual climatic tolerance of the eucalyptus species is wider, although questions arise as to level of tolerance of the species and its adaptability/plasticity in a future warmer climate. Nevertheless, our study revealed the tolerance of *E. deglupta* and other native species when subject to changing thermal conditions. However, we do not undermine the fact that temperature had positive and negative effects on tree growth through physiological processes (e.g., photosynthesis, respiration, absorption, translocation and transpiration) as evidenced on the contrasting slope of the line between the temperature and the DGR, HGR, and survival rates. Air temperature is usually confounded by light, CO_2 availability, soil temperature, soil moisture, and other environmental factors that all together affect the physiological and biological mechanisms in plants [58].

Temperature explained up to 76% of the variations in DGR in our study. Increased temperature enhances tree diameter [59,60], leading to a positive relationship between temperature and the DGR of most species. All sites received high rainfall each year (>2000 mm per year). An adequate soil moisture coupled with sufficient light intensity as in most of tropical ecosystems [43] but with a smaller degree of change in air temperature may have confounded and overshadowed the effect of temperature on the diameter growth of seedlings, thus a weaker relationship of DGR with air temperature.

The variance explained by the temperature-HGR relationship is only 16%–55%, indicating that other factors such as soil nutrients, topographical aspects, and other climatic factors individually or in combination may play a more significant role in the changes in height growth of the planted species.

We have only considered rainfall and temperature regimes as factors in the growth performances of the planted trees. However, we concur with the common notion that climate alone may not reflect seedling adaptations in our trial sites, but also the interaction of soil nutrients and soil fertility conditions with co-varying variables such as soil physical attributes, microbial activities, and root dynamics [47,53]. These compounding effects complicate our understanding of the growth dynamics of planted trees. The growth of planted trees is thus a complicated physiological and morphological mechanism that requires an in-depth investigation.

5. Conclusions

This early-stage assessment of some native and alien species in Northeastern Mindanao, Philippines, is important as an initial activity for long-term native tree species field trial and domestication efforts. Our results showed that some native species could potentially grow and survive at the rate closer to those fast-growing alien species. The genetic conservation of these species is of high importance as they can augment the diminishing log supply of the country and act as a refuge for the dwindling tropical forest biodiversity. Although it is too early to predict with certainty, our results reinforce the much-needed information on the early performances of native trees in the Philippines. Thus, prolonged monitoring is necessary so we can conclude with certainty the potentials of these native species for commercial use.

The diametric increment, height growth, and survival of native and alien species across all sites is related in part to differences in climatic condition (rainfall and temperature), although we firmly maintain that the relative importance of plant structural attributes, soil fertility/nutrients, and phenotypic variability are equally important. Therefore, in growth performance assessment, our result suggest that attention must be focused on environmental forcing, such as the positive impact of the future warmer climate on the rainfall-abundant environment or the negative impact of reduced rainfall and global warming to seedling growth. Our study provides a strong basis in assessing the early growth and survival of native species and recommend appropriate silvicultural management intervention at an early stage to improve the growth and survival of native seedlings selected as alternative species for industrial tree plantation development in the Philippines.

Author Contributions: Conceptualization, C.M., R.A., R.B. and H.A.; methodology, R.A., R.B. and C.M.; software, M.A.; validation, C.M., R.A. and M.A.; formal analysis, M.A.; investigation, C.M., R.B.; resources, H.A.; data curation, R.A. and R.B.; writing—original draft preparation, C.M. and R.A. and R.B.; writing—review and editing, M.A. and H.A.; visualization, R.A., C.M. and M.A.; supervision, C.M. and H.A.; project administration, C.M. and H.A.; funding acquisition, C.M., R.A. and H.A. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by Department of Science and Technology-Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development.

Acknowledgments: We acknowledge DOST-PCAARRD's ISP Manager for ITP, Dalisay E. Cabral, FER Division, Laila C. America, and Florintino O. Tesoro for their support. We are also thankful to ERDB, especially to Emmanuel M. Cuison and FWERDEC, Metes Agunat, Edgardo M. Bilbao, Orlando Villamor and Manuel P. Algones, Gil Andipa, Francisco Anasco and Jessie Preglo. We also thank JAKA Corporation and Casilayan Softwood Development Corporation their land area utilized for field trial establishment. Special thanks to Liberty Asis of ERDB and Deanna Hardesty of United States Environmental Protection Agency for editing/proofreading the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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