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EVALUATING THE FUNCTIONAL TRAITS OF THE PIONEERING SPECIES: INSIGHTS TO FOREST RESTORATION

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Abstract

The influence of plant traits on interspecific demographic rates to growth and mortality has recently received an increasing attention because it allows understanding of the underlying determinants of species success especially in open degraded areas. This study examined the trait-based approach in selecting potential species for forest restoration. Five (5) native/indigenous pioneer species were evaluated for functional traits such as plant height, branching architecture, leaf dry matter content, specific leaf area, stem density, and bark thickness. All samples were collected from healthy and well grown mature trees growing in secondary forest of Central Mindanao University. The range of values for the various functional traits as observed by Ostertag and Perez-Harguindeguy were used to evaluate. Based on the result, three species such as Phyllantus albus, Polyscias nodosa, and Buchanania arborescence showed to fit in those values hence we recommend that these species should be considered as primary restoration species in various denuded areas of the Philippines. Our result suggests that multiple functional traits (i.e. Leaf anatomical traits, leaf morphological traits and leaf stomatal traits) are still required to be measured to select appropriate plant species for restoration.

Keywords: degraded areas; forest restoration; functional traits; pioneer species.

1. Introduction

The extensive forest loss and degradation in many tropical countries are among the key drivers of global warming. In response, large-scale forest restoration programs were initiated to mitigate the associasted ill-effect of climate change. However, forest restoration on heavily degraded areas has become one of the emerging challenging research interests (Hernandez et al. 2019), It is a complex undertaking which requires holistic and integrated approaches while compounded by the lack of information on how ecological processes influence natural forest re-growth. Thus, one of the significant challenges in restoration programs is the selection of suitable species that can survive in restoring degraded lands. Relative to this, the influence of plant traits on interspecific demographic rates to growth and mortality has recently received an increasing attention because it allows understanding of the underlying determinants of species success especially in open degraded areas. Numerous studies prove positive evidence of using plant functional traits in the selection of appropriate target species for restoration programs and, therefore can predict the performance and survival of the species (Bochet & García-Fayos, 2015; Charles, 2018; Guimarães et al., 2018; Martínez-Garza et al., 2013; Ostertag et al., 2015; Rayome et al., 2019; Wang et al., 2020; Werden et al., 2018).

Plant functional traits (FTs) can be defined as plant characteristics that respond to the dominant ecosystem processes (Nock et al. 2016). Examples of FTs are leaf size, toughness and longevity, seed size and dispersal mode, canopy height and structure, ability to re-sprout and capacity for symbiotic fixation of nitrogen, and others (Díaz et al. 2016). According to Ivanova et al. (2019), a plant's survival should depend on the ability to match anatomical structures and functions to withstand desiccation. For instance, species in arid areas showed specific adaptive traits and mechanisms against dry conditions (Hernandez et al. 2016).

The morpho-anatomical of Wrightia candollei with the observed presence of trichomes, multiple layers of storage cells and mechanical cells, sclerenchymatic phloem cap, multiple vascular bundles, living xylem parenchyma, and steep leaf inclination were interpreted as important leaf and stem structural traits that conforms to characteristics of plants adapted to dry areas and can be used commonly for restoration (Hernandez et al. 2019). Among the principal requirement for restoration success is the ability of species to survive and quickly form canopies to obtain site capture (Charles, 2018). Understanding the importance of functional traits of plants will help in the long run in restoring our remaining forests because functional traits can influence the survival, growth, and fitness of an individual within a given environment.

In an attempt to further understand the role of FTs in forest restoration, five (5) pioneer species were investigated because these species could accelerate canopy closure and outcompeted resident grass and weed species and the eventual establishment of climax species over time (Charles, 2018). These five candidate species were earlier identified by Aribal et al. (2015) as "potential framework species" (FS) which exhibited the ability to restore degraded areas by hastening natural succession. These include Phyllanthus albus (Phyllanthaceae), Polyscias nodosa (Araliaceae), Buchanania arborescens (Anacardiaceae), Antidesma ghaesembilla (Euphorbiaceae), and Cratoxylum formosum (Hypericaceae). We aim to study the plant height, branching architecture, specific leaf area, leaf dry-matter content, stem density and bark thickness relative to their ability to survive in open and degraded areas and provide understanding of how these traits will play an important role in the choice of species for restoration efforts in the Philippines.

2. Methods

2.1. Location of the Study

The study was conducted in the successional forest at the north-western foothills of Mt. Musuan (also known as Mt. Kalayo) of Central Mindanao University, in Bukidnon, Philippines, with coordinates 7.8706°N and 125.0691°E adjacent to the vast grassland area dominated by Imperata cylindrica (Poaceae). Based on the Modified Corona classification of Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the general climatic condition of the area falls under Type III characterized as having a seasonal variability that is not very well pronounced, with a dry season from November to April and wet during the remaining months of the year. Furthermore, the collection and examination of plant specimens were conducted in the months of March to April, 2020.

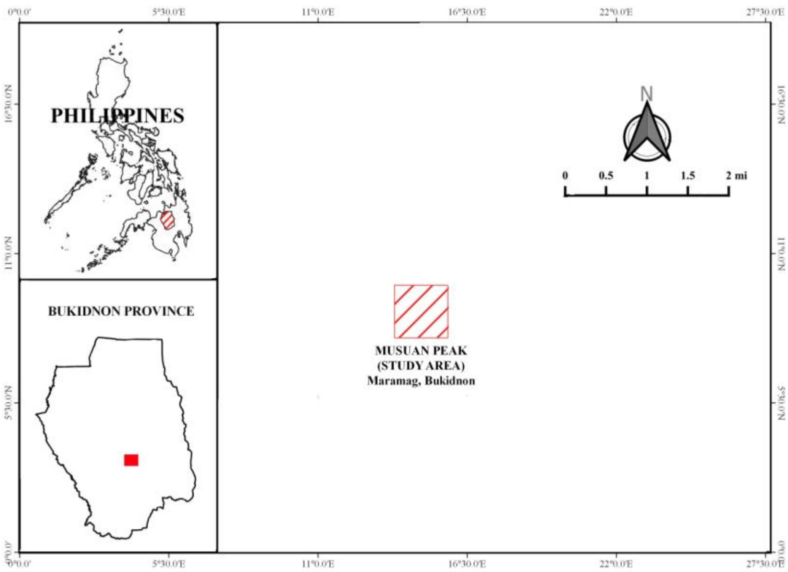

Figure 1. Map of the study area

2.2. Sampling

FTs such as plant height (PH), branching architecture (BA), specific leaf area (SLA), leaf dry-matter content (LDMC), stem density (SD) and bark thickness (BT) of the five (5) candidate pioneer species were determined from the 50 samples. All samples were collected from healthy and well grown mature trees growing in secondary forest of Central Mindanao University. The

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replicates and examining of all specimens were done following the procedures of Perez-Harguindeguy et al. (2016) for standardized measurements of FTs of plants.

1) Plant height. The height measured was the height of the foliage of the species, not the height of the inflorescence (or seeds, fruits), or the main stem. Furthermore, a clinometer was used to determine the height.
2) Branching architecture. The base of the branch was the starting point for measuring (1) the total length of the branch, which is the distance from the starting point to the tip of its longest-living terminal; and (2) the number of ramification points that lead to living branches; from each ramification point, move towards the tip, always following the most important branch (the main branch).An indicator of branching architecture, called apical dominance index (ADI), was used by dividing the number of ramifications by the total length of the branch in meters.
3) Leaf dry-matter content. Leaves were placed between damp papers, resealed in a plastic bag and maintained at 5°C in the dark using a cool box and overnight to produce a standard degree of turgor. The sample of leaves lamina were blotted dry with tissue paper to remove any surface water, then immediately weighed to produce a value for saturated weight. The samples were dried in a paper envelope at 80°C for 72 hours and reweighed to produce a value for dry weight. Values for dry matter content were calculated as dry weight, expressed as a percentage of saturated weight. Any petiole was removed, and for compound leaves the individual leaflets were removed to include only laminar material. For leaves with massive midrib support structures, a sample of lamina was excised from a leaf. While the specific leaf area (SLA) was made on the same samples as used for water content (procedure in LDMC). After measurement of fresh weight, the area of the sample was measured with an (Image J, Software) area measurement system. In particularly large-leaved species, samples of lamina were removed for measurement of SLA. The dry weight and measured leaf area of the samples were used to calculate the specific leaf area.
4) Stem-specific density. A pie-shaped slice from the trunk is removed at approximately 1.3 m for trees over 4 m in height. The pie-shaped slice (2 to 10 cm in height) needs to represent a cross-section area of approximately 1/8thof the total cross-section. Hard-wooded samples were stored cool in a sealed plastic bag. Finally, volume replacement method was used to quantify the SSD. While the bark thickness (BT) to minimize damage, the recent samples in measuring SSD were used, mostly flaked off, warts,

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thorns or other protuberances barks were avoided. The bark is including everything external to the wood (i.e., any vascular cambium, secondary phloem, phelloderm or secondary cortex, cork cambium or cork). Bark probes were used to enable fast and accurate measurements of the bark thickness.

2.3. Data Analysis

After testing the normality of residuals, the principal component analysis (PCA), analysis of variance (ANOVA), and post hoc Tukey's HSD test in R software) were used to show how the selected species are arranged, relative to one another, and to provide an idea of each species' FTs profile.

3. Results and discussion

3.1. Plant height and branching architecture

Among the five species evaluated, the tallest species were *C. formosum* (24.90±6.30 m) and *B. arborescence* (21.00±5.75 m) while the shortest plant was *P. nodosa* (19.60±4.25 m), *P. albus* (15.75±5.23 m), and *A. ghaesambilla* (10.85±2.29) (Figure 2). Comparing our result with that of Ostertag et al. (2015) and Perez-Harguindeguy et al. (2016) showed that the plant heights of the five species fall within the range (Table 1).

Hietz et al. (2017) explained that pioneers must invest in tree height growth to continually acquire more light resources at least early in their lifetime, thus producing lower stem density. However, as wind stress likely increases upon reaching the canopy, further height gains seem no longer essential. Instead, these now-adult pioneer trees' priority is to invest in strengthenen their ability to resist windthrow, which could achieve by producing a higher stem density. Studies by Chen et al. (2017) revealed that a pioneer species has a greater height (> 12 m) with lower stem density is necessary because it can benefit those climax species to develop their mechanical strength by producing high stem density, withstand injury from a falling branch, the potential damage from pests and pathogens in the humid understory. Further studies by sated that pioneer tree species tend to grow very well in temporarily lighted conditions produce low-density wood to maximize height growth and stem diameter in early successional habitats. These traits are essential for restoration planting and species selection to achieve the highest survival rates.

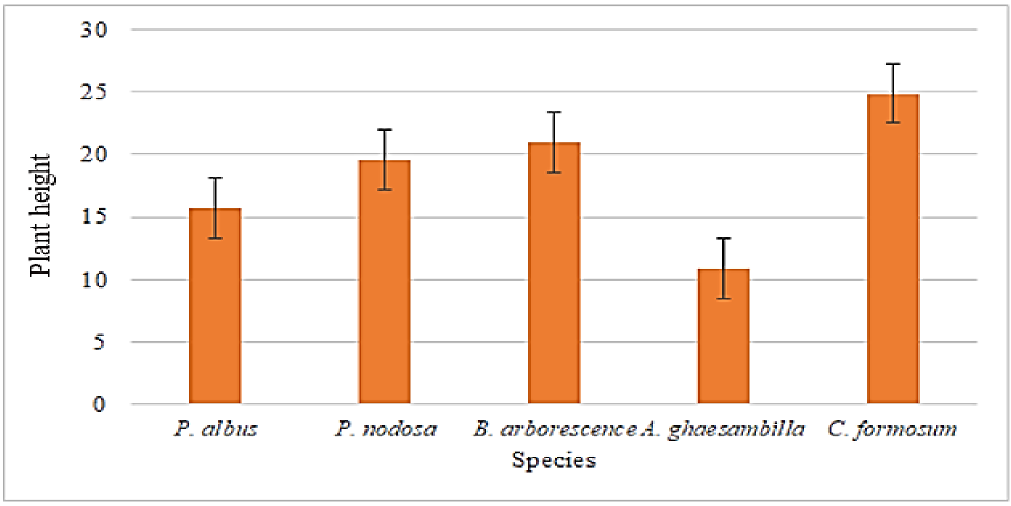

Figure 2. The plant heights of the pioneering species.

Table 1. List of FTs measured and compared in different forest type.

	Biological significance	Trait range (This study), all traits measured.	Ostertag *et al*. (2015), not all traits were measured	Perez-Harguindeguy et al. (2016), all traits are measured.
Plant height (m)	Competitive vigor, plant fecundity and light acquisition	8.00 - 30.00	5.00 - 30	< 0.01-140
Branching architecture (ADI)	Light interception and stability	0 - 12.00	Not included	0 - > 100
% Leaf-dry matter content	Greater leaf and root longevity	0.800 - 27.600	Not included	50-700
Specific leaf area (cm^2/mg^{-1})	Photosynthetic capacity and resource allocation (high CO^2 and N uptake)	3.631 - 25.313	2.8 - >1000	< 1-300
Stem specific density (g/cm^3)	Diameter growth rate, mortality rate, hydraulic capacity and carbon storage	0.1348 - 0.5263	0.16 - 1.51	0.1-1.3
Bark thickness (mm)	Structural support, defense against herbivores or pathogens	2.00-5.00	Not included	0.1 - > 30

The species obtained the highest number of ramifications per meter for the branching architecture, was *A. ghaesambilla* 8.7±1.06, while no identified apical dominance index (ADI) for *P. nodosa* (Figure 3.) Our result shows that the five pioneer species' branching architecture is lower than the study of Perez-Harguindeguy et al. (2016) (Table 1). Moreover, the result shows that the amount of variation explained by each principal component (PC) was the largest for plant height and branching architecture (Figure 4). While about 32.72% variation for plant height and 30.59% for branching architecture were examined based on the PC eigenvalue (Table 2). These results show that the five pioneer species tend to invest in tree height growth to acquire more light resources continually and out-compete the colonizing light-demanding weeds aggressively to provoke forest succession (Table 2).

Branching architecture can also be adaptive in the forest ecosystem. Previous studies found that the more shade-tolerant saplings such as *Dryobalanops lanceolata* which is a climax species tend to produce long branches to increased light interception. This further suggests that in selecting pioneer species for restoration, a less branched species must be considered. Based on the available literature, few studies concerning these traits have been conducted on pioneer species in the tropical forest.

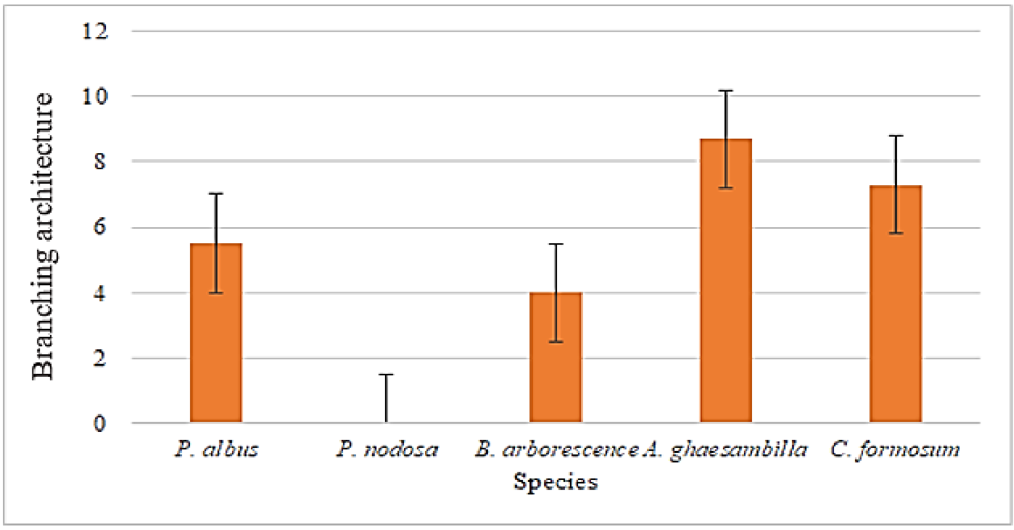

Figure 3. Showing the branching architecture of pioneer species.

Table 2. Shows the eigenvalues are large for the first and second PCs and small for the subsequent PCs.

	Eigenvalue variance.percent	Cumulative.variance.percent
Dim.1	32.72	32.72
Dim.2	30.59	63.31
Dim.3	18.36	81.67
Dim.4	9.53	91.20
Dim.5	6.49	97.69
Dim.6	2.31	100.00

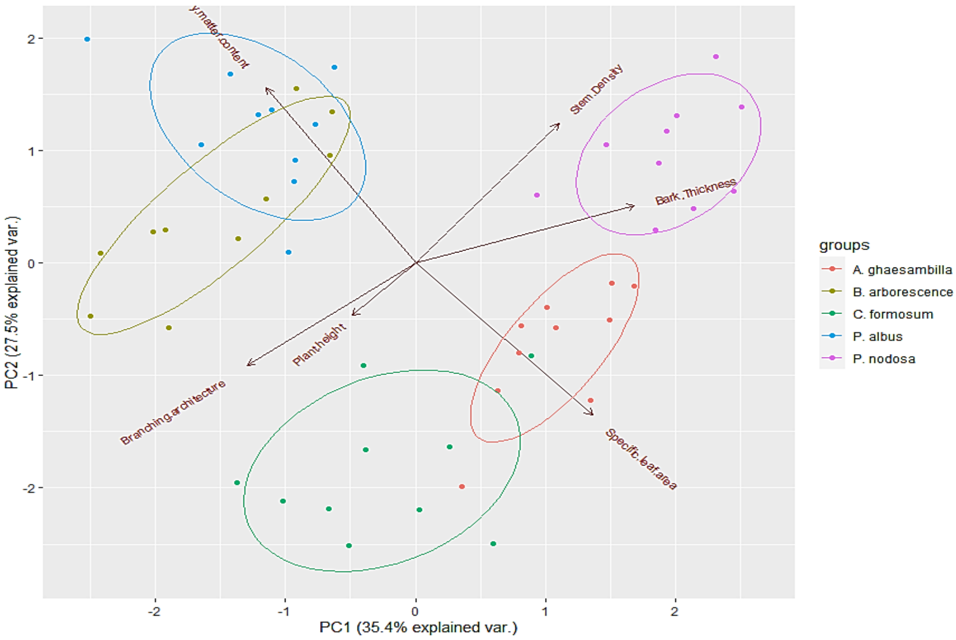

Figure 4. Shows that plant height and branching architecture are varied among species.

3.2. Leaf Dry-Matter Content and Specific Leaf Area

The species that obtained the highest % leaf dry-matter content were *P. albus* (17.37±5.04) and *B. arborescence* (14.60±1.13) (Figure 5). Our result shows that the five pioneer species' leaf dry-matter content is lower than the recommended range by Perez-Harguindeguy et al. (2016) (Table 1). In these study, *P. albus* and *B. arborescence* have higher % leaf dry-matter content and lower specific leaf area (cm^2/mg^{-1}). It suggests that the understory (climax species) will benefit from this pioneer, especially in restoration setting. Moreover, this fact shows that it has the potential to acquire more resources (CO_2 and nitrogen uptake), compared to other species such as *C. formosum*, *A. ghaesambilla* and *P. nodosa* with low % leaf dry-matter content and high specific leaf area (cm^2/mg^{-1}).

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Leaf dry-matter content, as opposed to specific leaf area, was the superior predictor of average net primary production or NPP, which defined as the rate at which plants convert CO_2 and water in dry matter, is the basis for life on earth and is a fundamental ecosystem function supporting food production, soil formation and climate stabilization (Smart et al. 2017). According to Onoda et al. (2017) pioneer species growing in light tend to possess higher leaf dry-matter content and lower specific leaf area as compared to the individuals of the same species growing in shade conditions.

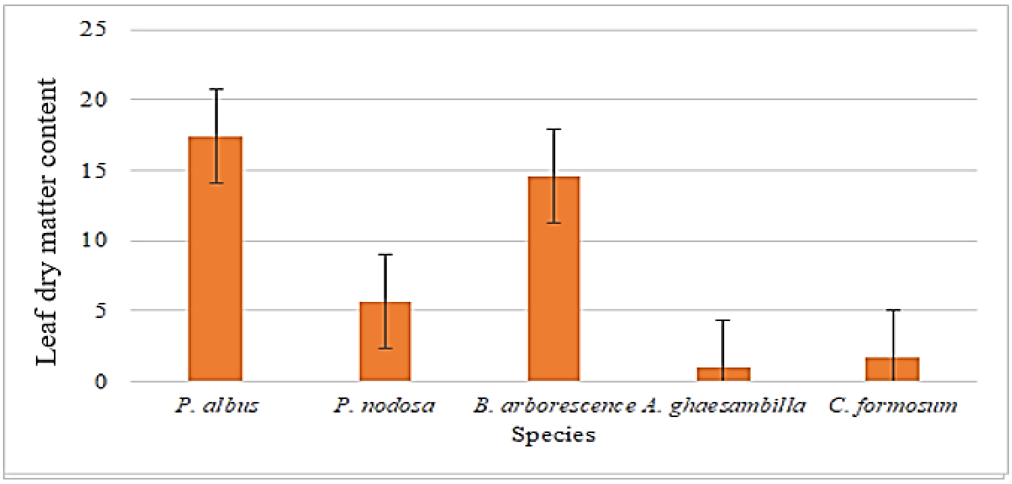

Figure 5. The %leaf dry matter content of pioneer species.

For the specific leaf area, the species that obtained the highest was *C. formosum* (17.17±4.22 cm^2/mg^{-1}) (Figure 6). Moreover, the result shows that variation based on principal component (PC) was smallest for specific leaf area and leaf dry matter content (Figure 7). While about 18.36 % variation for specific leaf area and 9.53 % for leaf dry-matter content based on the eigenvalue (Table 2). Our result shows that the five pioneer species' specific leaf area is lower than the recommended range by Ostertag et al. (2015) and Perez-Harguindeguy et al. (2016) (Table 1).

It was believed that specific leaf area and leaf dry matter content are essential traits in plant ecology because it is associated with many critical aspects of growth and survival of plants (Kramer-Walter et al., 2016). Recent study of He et al. (2018), both SLA and LDMC are involved in the exchange between rapid biomass production (high SLA, low LDMC species) and efficient conservation of nutrients (low SLA, high LDMC species). Because specific leaf area and leaf dry-matter content are indicator traits of resource-use strategies. It is crucial to evaluate these traits for different plant species in various environments (de Assis Monteiro et al., 2017). Generally, high specific leaf area species are characterized by high concentrations of nitrogen, high CO_2 and N uptake per unit leaf and root mass, respectively, and a high rate of photosynthesis per unit leaf N (Diaz et al. 2016).

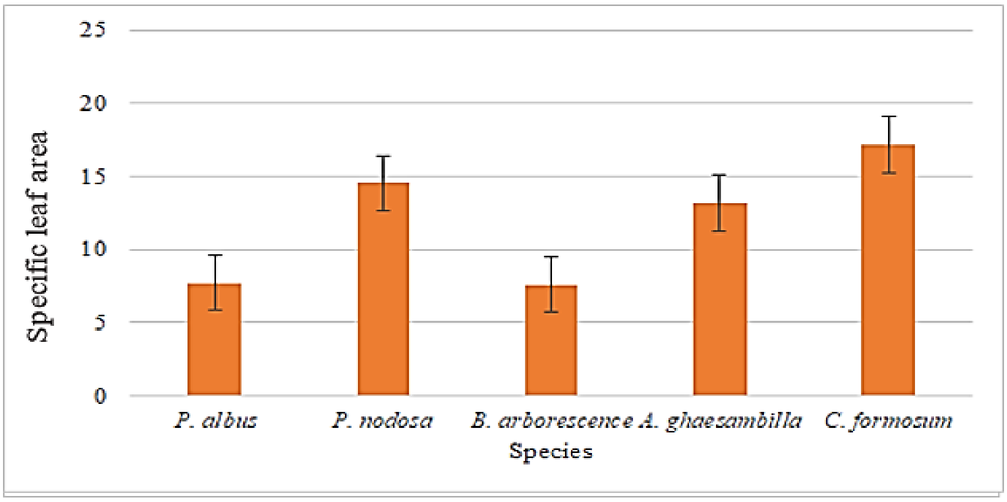

Figure 6. The specific leaf area of pioneer species.

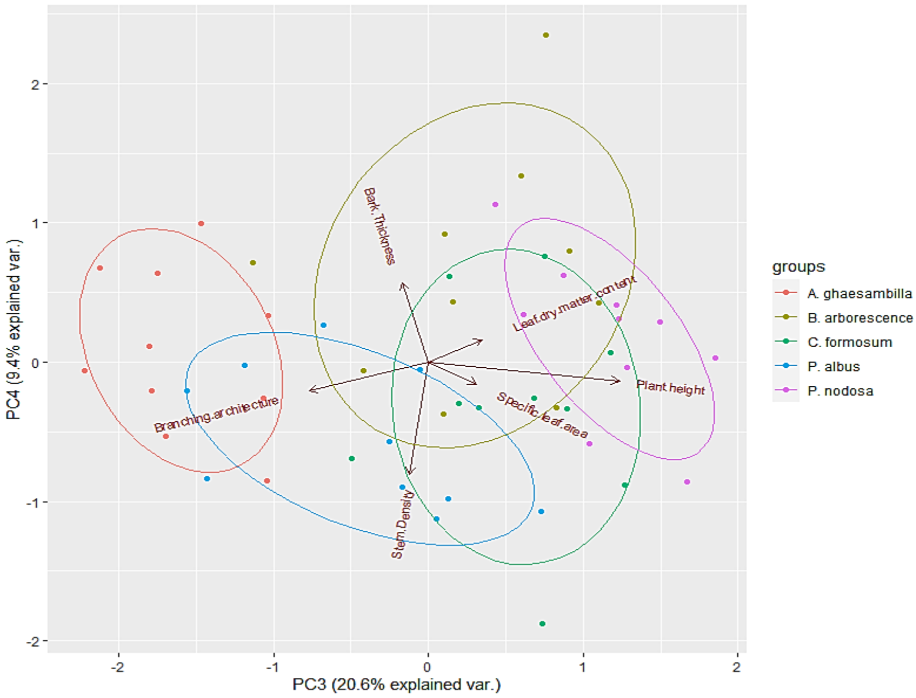

Figure 7. The specific leaf area and leaf dry matter content were less varied among species.

3.3. Stem Density and Bark Thickness

The stem density of the species obtained was highest for *P. nodosa* (0.45±0.07 g/cm^3) (Figure 8). Our result shows that the five pioneer species' stem density is lower compared to the recommended range by Ostertag et al. (2015) and Perez-Harguindeguy et al. (2016) (Table 1).

Because pioneer species tend to grow well in temporarily lighted conditions, they produce low-density wood to maximize height growth and stem diameter in early successional habitats (Longuetaud et al., 2017). These lower stem density trees have a higher mass growth rate than their neighbors (climax species), often at the expense of greater longevity (Plourde et al., 2015).

However, upon reaching the canopy, a pioneer tree might invest more resources into a higher wood density than maintain rapid growth because its exposure t o wind stress is now greater. Based on a study conducted by Chen et al. (2017) on pioneer species in a secondary subtropical forest revealed that the average stem density of the pioneer species (0.497 ± 0.13 g/cm3) was lower than that of the shade-tolerant species or climax species (0.589 ± 0.12 g/cm3). Furthermore, pioneer trees should have a lower stem density early in ontogeny as seedlings, saplings, and poles. Accordingly, stem density proved to be a robust predictor of seedling survival, with high stem density species experiencing higher survival rates (Charles et al., 2018).

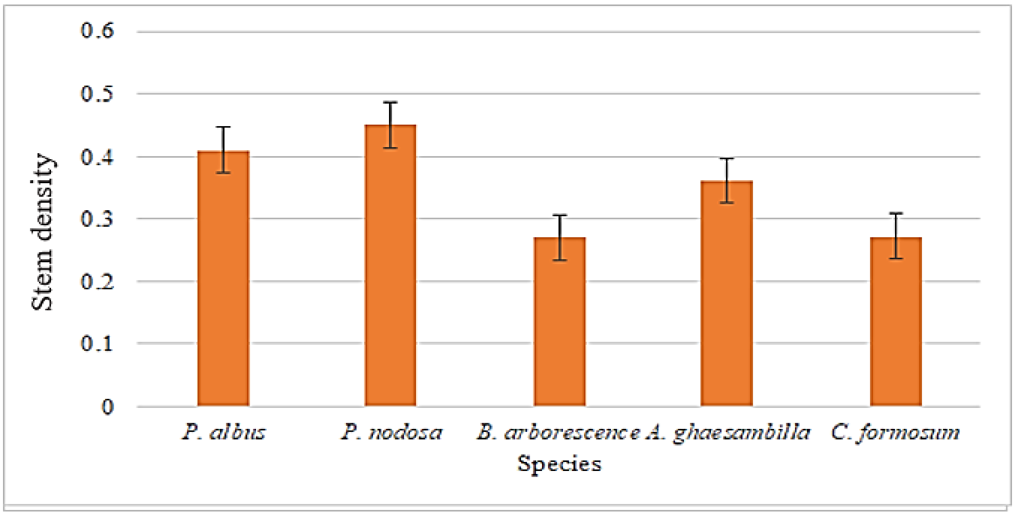

Figure 8. The stem density of pioneer species.

Our result for the bark thickness showed slight variations among species, the highest was obtained by *P. nodosa* (3.90±0.74 mm) and the lowest was *P. albus* (2.45±0.07 mm) (Figure 9). The bark thickness of these five species is lower to the recommended range by Perez-Harguindeguy *et al.* (2016) (Table 1). Moreover, the result shows that the amount of variation explained by the principal component (PC) was the smallest for stem density and bark thickness (Figure 10). In contrast, about 6.42% variation for stem density and 2.31 % for bark thickness were examined based on the eigenvalue (Table 2). These results show that the five pioneer species tend to produce lower stem density and bark thickness (Table 2).

Studies by Poorter et al. (2018) conducted in tropical dry and moist forest trees displayed a diversity of bark investment strategies suggesting that light-demanding pioneer species perhaps invest in thick bark for other reasons, such as structural support, defence against herbivores or pathogens that otherwise might attack their soft wood. Pioneer species tend to be fast-growing, and for them, the opportunity costs of resource investments in structural defense (such as bark) are high.

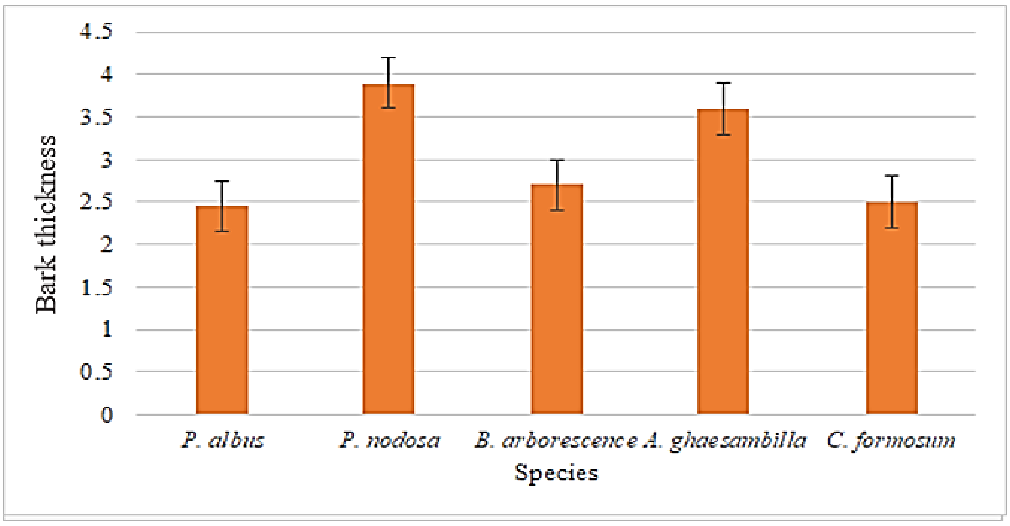

Figure 9. The stem density of pioneer species.

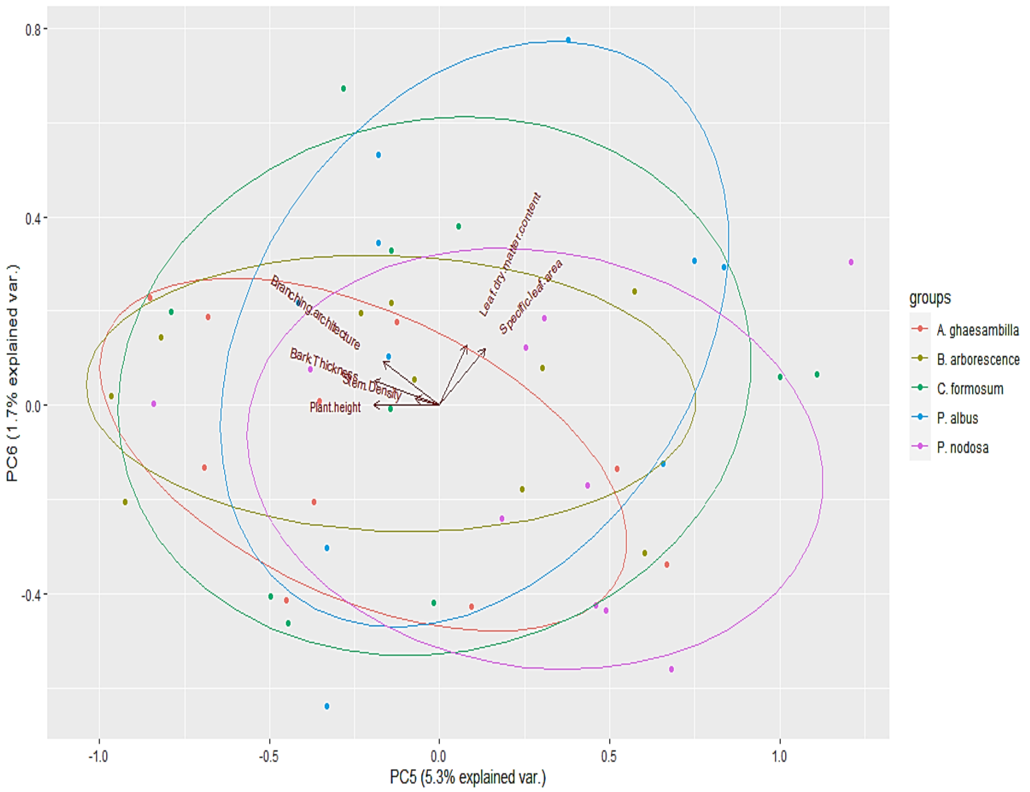

Figure 10. Shows that stem density and bark thickness were less varied among species.

4. Conclusion

Identifying plant functional traits is very useful in predicting the species' success in restoration. Selecting appropriate pioneer species is vital in restoration of degraded areas because these pioneer plant species signify opportunity for practitioners to accelerate plant succession and restoration. Leaf morphological traits such as plant height, branching architecture, specific leaf area, leaf dry-matter content, stem density and bark thickness provides significant role in the success of pioneer species in open degraded areas. In our experiment, some of the traits of the five pioneer species we examined do not conformed to the recommended range of values. However, overall *P. albus, P. nodosa, and B. arborescence somehow showed promising results hence* we further recommend that these species should be considered as primary species in setting the microclimatic conditions of denuded areas to hasten forest restoration particularly in the Philippines where extreme deforestation are rampant. Although our results explored only few functional traits for selecting appropriate pioneer species, further studies needed using more target traits for species screening to test the generality of the conclusion. Our result suggests that multiple functional traits (i.e., Leaf anatomical traits, leaf morphological traits and leaf stomatal traits) are still required to be measured to select appropriate plant species for restoration.

Acknowledgment

Rovana M. Jawani carried out the functional trait's studies, participated in the data gathering and drafted the manuscript. Nomar A. Ramoncito participated in the data gathering, help to draft the manuscript and performed the statistical analysis. Gretchen O. Quimson coordinated and performed the data gathering. All authors read and approved the final manuscript, and the authors gratefully acknowledge the DOST SEI strand II for the financial support.

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