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Tree biomass and carbon stock of Falcata (*Falcataria moluccana* (Miq.) Barneby & J.W. Grimes) along different altitudinal gradients in the Province of Agusan Del Norte, Philippines

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Abstract

Estimation of the tree biomass and carbon stock of *F. moluccana* along different altitudinal gradients was conducted at Agusan del Norte, Philippines. It followed a non-destructive method of sampling and used the allometric equation by ERDB 2008 and Cairns *et al.* (1997) for aboveground biomass and carbon stock, and belowground computation, respectively. Based on these results, *F. moluccana* planted at <150 masl had the highest aboveground biomass with 144.95Mg ha^{-1}. The ANOVA at $P<0.05$ showed no significant difference in the aboveground biomass at different altitudinal gradients. However, the belowground biomass of *F. moluccana* at <150 masl was significantly higher than that of those planted at higher elevations. The carbon stock of *F. moluccana* is also highest at <150 masl and lowest at >450 masl with 90.57Mg C ha^{-1} and 54.44Mg C ha^{-1}, respectively. ANOVA also suggested no significant difference in carbon stocks at different altitudinal gradients. Furthermore, correlation tests suggested a negative relationship between tree biomass, carbon stock, and altitudinal gradients.

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Introduction

Biomass quantification is required as the primary inventory data to understand C pool changes and forest productivity (Thockhom and Yadava, 2020). Consequently, forest biomass estimation, its spatial distribution, changes over time, and strategies for the increase and conservation of forests have been the subject of intensive research (Brown & Lugo 1984). Aboveground biomass stocks vary widely among tropical forests owing to regional differences in stem size distribution, soil fertility, topography, and disturbances (Castilho *et al.*, 2006; Dewalt and Chave 2004; Murthy *et al.*, 2016; Salunkhe *et al.*, In 2016, Urquiza-Haas *et al.*, 2007). Several environmental factors change systemically with altitude (Thockhom and Yadava 2020). Thus, altitudinal gradients are among the best tools for testing the ecological and evolutionary responses of organisms to environmental changes. Information on the allocation of carbon stocks along different altitudinal gradients will help predict the responses of regional and global C balances to future climate change. Additionally, the altitudinal pattern of biomass and carbon stocks in forest ecosystems has been reported by several researchers in different parts of the world (Alves *et al.*, 2010; Dar and Sundarapandian, 2015; Do *et al.*, 2017; Ensslin *et al.*, 2015; Gairola *et al.*, 2011; Sharma *et al.*, 2010; Thockhom and Yadava, 2020).

Similar to tropical forests, plantations play a vital role in protecting natural forest carbon pools (Chauhan, 2019). Planting trees to sequester carbon is considered the most cost-effective, long-lasting, and significant strategy to address global warming. Carbon sequestration in tree biomass and subsequent locking of forest-based products for a long time is considered a viable option for reducing atmospheric carbon through fast-growing tree species (Chauhan *et al.*, 2016).

In the Philippines, one of the fastest-growing species is the *F. moluccana* (Miq.) Barneby & J.W. Grimes) (Lantican & Sy, 2010; PCAARRD, 2004). This species is commonly used in forest plantations, reforestation, and agroforestry (ERDB 2008). The government and private sector are establishing small-scale and large-scale forest plantations to increase the raw material base of the wood industry while also addressing ecological concerns through the rehabilitation of denuded or open lands (Tandug, 2012). However, there is little data on the tree biomass and carbon stock of plantation species, specifically *F. moluccana*, to account for how much they contribute to carbon sequestration. However, some studies related to carbon sequestration rates and biomass were not specific to conditions at different altitudinal gradients. Hence, this study was undertaken with the aim of estimating the tree biomass and carbon stock of *F. moluccana* along different altitudinal gradients and determining the significant effects of different altitudinal gradients on tree biomass and carbon stock of *F. moluccana*.

Materials and methods

Study site

The study was conducted at the 2015 *F. moluccana* plantations of National Greening Program-Peoples Organization (NGP-POs) with a planting distance of 2m x 3m in the province of Agusan del Norte as shown in Fig.1. Agusan del Norte is situated in Mindanao's western section of Caraga. It is bordered on the northwest by the Butuan Bay, northeast by Surigao del Norte, mid-east by Surigao del Sur, southeast by Agusan del Sur, and southwest by Misamis Oriental. It lies at 9° north latitude and 125°- and 30-minutes east longitude on the northeastern part of Mindanao Island, Philippines.

It has a total land area of 2,730.24 square kilometers or 1,054.15 square miles. When Butuan is included for geographical purposes, the province's land area is 3,546.86 square kilometers (1,369.45 sq mi). The climate is tropical, with significant rainfall. There was no definite dry season in this region. Rainfall is pronounced throughout the year, with the maximum rainfall occurring from November to January. According to Köppen and Geiger, this climate was classified as Af. The province is made up of flat rolling lands and is surrounded by mountains, the highest of which is Mt. Hilong-Hilong, 2,012 m above sea level. The soil types in the province are San Miguel clay loam covering 10,021.54 hectares, Bolinao silt loam type with coverage of 14,695.58 hectares, and the most abundant of all is the Camanesa clay loam (59,371.39 hectares).

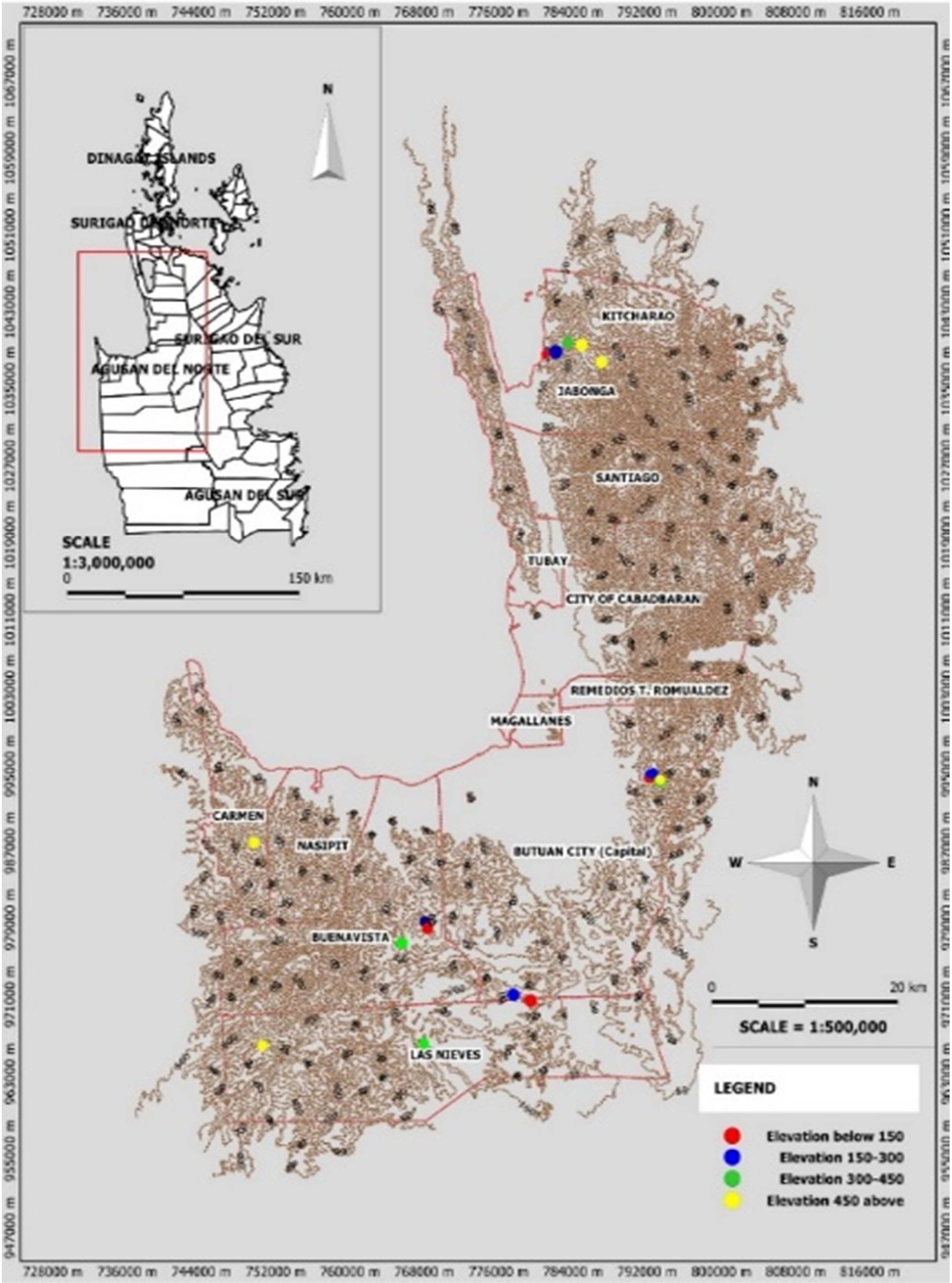

Fig. 1. Map showing the sampling sites.

Sampling

Three 20m x 50m plots were laid out for each identified altitudinal gradient: (a) <150 masl, (b) 150masl-300 masl, (c) 301masl-450masl, and (d) >450 masl, totaling 48 plots for the four sampling sites (Fig.1).

This study used non-destructive sampling. Diameter-breast-height (DBH) which is 1.3m from the surface, and the total tree height of all trees inside the plot were measured using a diameter tape and clinometer, respectively. The units for DBH and tree height were in centimeters and meters, respectively, and measured at (±0.1).

Data Analysis

The aboveground biomass of *F. moluccana* was computed using the allometric equations of ERDB (2008), adopting Tandug (1986). That is, $AGB = 10 \wedge [0.9836 + 1.8036 \times \log (D)\ 0.8702 \times \log 10\ (H)]$. where *AGB* for Fresh biomass (kg per tree), *D* is the DBH (cm), and *H* is tree height (m). In the absence of a specific allometric model of Belowground Biomass (BGB) for plantation forests, the equation for tropical forests by Cairns *et al.* (1997) was used. That is, $BGB = Exp\ [-1.0587 + 0.8836 * Ln\ (AGB)]$. where *BGB* is the belowground biomass (kg ha^{-1}), *LN* is the natural logarithm, and *AGB* is the aboveground biomass (kg ha^{-1}). The Carbon stored in each tree, expressed as kg C per tree, was determined by multiplying biomass per tree with a conversion factor of 48.30% average carbon content of *F. moluccana* in percent using ERDB (2008). That is, $C = \%C * B$. The total tree biomass and carbon stock of trees were determined using the same computation per hectare expressed in megagrams per hectare (Mg ha^{-1}). Furthermore, one-way Analysis of Variance (ANOVA) in Randomized Complete Block Design (RCBD) and linear comparison of treatment means by Duncan Multiple Range Test (DMRT) were used. A paired t-test of correlation was used to identify the relationship between tree biomass, carbon stock, and altitudinal gradients.

Results

Aboveground biomass

Aboveground tree biomass was calculated using the allometric equation developed by ERDB (2008). Fig. 2 shows a graphical representation of the aboveground tree biomass of *F. moluccana*. Based on these results, *F. moluccana* planted at <150 masl had the highest aboveground biomass with 144.95Mg ha^{-1}. It is followed by AG4 (>450 masl) with 128.14Mg ha^{-1}, AG3 (301-450 masl) with 115.11Mg ha^{-1}. and AG2 (150-300 masl) at 104.24Mg ha^{-1}.

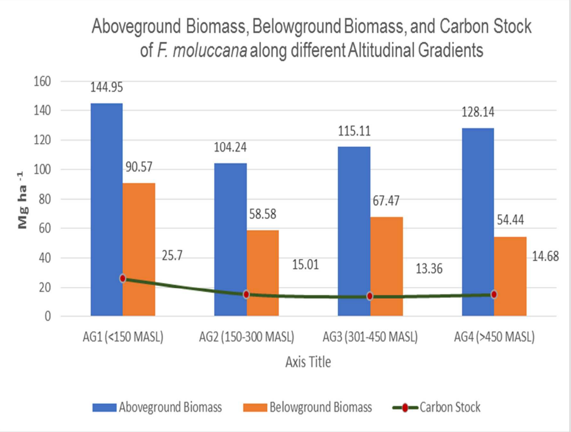

Fig. 2. Aboveground Biomass, Belowground Biomass, and Carbon Stock of *F. moluccana* along different Altitudinal Gradients.

On the other hand, Table 1 shows that the effects of altitudinal gradients (AG1, AG2, AG3, and AG4) on the aboveground biomass of *F. moluccana* were not significantly different. This result suggests that the aboveground wood biomass of the trees was not significantly different, even when they were planted at different altitudes.

Table 1. Analysis of Variance for aboveground biomass of *F. moluccana*.

Source of Variation	SS	df	MS	F	P-value	F crit
Blocks	99989186	3	33329728.68	2.372187117	0.138151	3.862548
Treatments	36887113.7	3	12295704.58	0.875125996^{NS}	0.489301	3.862548
Error	126451896	9	14050210.64			
Total	263328196	15				

^{NS} means not significant at $P<0.05$ level of significance.

The t-test for aboveground biomass in Table 2 shows a weak correlation between altitudinal gradients and the corresponding tree biomass. The non-significant t-statistics also show this trend.

The t-test results conformed with the ANOVA results for aboveground biomass. A graph of stand density and basal area is shown in Fig. 3. Trees at the lowest altitude (<150m) had the highest stand density.

Table 2. Paired t-test for aboveground biomass of *F. moluccana*.

t-Test: Paired Two Sample for Means		
	Variable 1	Variable 2
Mean	217.7954	215.6499065
Variance	26668.75	31926.43379
Observations	30	30
Pearson Correlation	0.251436	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.056071 ^{ns}	
P(T<=t) one-tail	0.477835	
t Critical one-tail	1.699127	
P(T<=t) two-tail	0.95567	
t Critical two-tail	2.04523	

^{NS} Not Significant.

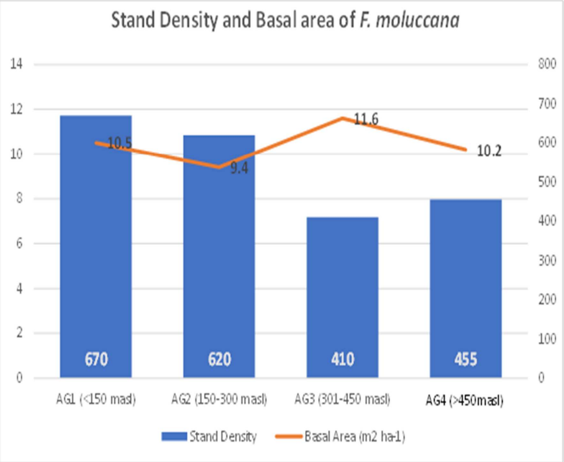

Fig. 3. Stand density and basal area of *F. moluccana* along altitudinal gradients.

However, in terms of basal area (m^2 ha^{-1}), AG3 had the highest basal area because of the larger trees compared to the other sites. Furthermore, the high biomass content at lower altitudes may be attributed to the stand density and basal area. Altitude is one of the important physiographic factors that affect plant growth and development since functional traits could show great variance depending on the altitude level. Trees growing at low altitudes have taller stems because they are more inclined to grow vertically in order to capture more light. However, trees growing at higher altitudes have thicker stems because the temperature is colder at higher altitudes. Therefore, stems are more likely to grow radially (BriceÃ ± o *et al*., 2000; Cavieres, 2000; Keles, 2020).

Belowground Biomass

Belowground biomass was computed using the formula proposed by Cairns *et al.* (1997). It uses the results of the aboveground biomass. Based on the result, the belowground biomass of 6-year-old *F. moluccana* plantations ranges from 13.36Mg ha $^{-1}$ to 25.70Mg ha^{-1}. Trees planted at altitudes of <150 masl had the highest total belowground biomass. As shown in (Fig.2), the trend line also suggests a decrease in the average amount of biomass with increasing altitude.

Meanwhile, Table 3 shows that altitudinal gradients have significant effects on the belowground biomass of *F. moluccana*, suggesting that soil depths at different altitudes might have affected the volume or biomass of roots. The results of the Duncan Multiple Range Test (DMRT) shown in Table 4 indicate that trees at the lowest altitude (<150 masl) have the largest belowground biomass than those at higher altitudes. This means that the biomass of trees at <150 masl was significantly different from that at higher altitudes.

Although there was a significant difference ($P < 0.05$), the results in Table 5 show a weak correlation between altitudinal gradients and their corresponding belowground tree biomass. The t-statistics also showed the weak effects of varying altitudes on tree biomass.

Table 3. Analysis of Variance for belowground biomass of *F. moluccana*.

Source of Variation	SS	df	MS	F	P-value	F crit
Blocks	2528878	3	842959.2	2.910828273	0.093326	3.862548
Treatments	3927525	3	1309175	4.520721799*	0.03392	3.862548
Error	2606348	9	289594.3			
Total	9062751	15				

* means significant at P<0.05 level of significance.

Table 4. Summary of Duncan Multiple Range Test (DMRT) for belowground biomass of *F. moluccana*.

	Y
AG_1 (<150 masl)	2570.071 a
AG_2 (150-300 masl)	1500.931 b
AG_3 (301-450 masl)	1468.023 b
AG_4 (>450 masl)	1335.572 b
Pr > F(Model)	0.069
Significant	No

Carbon Stock

The carbon stock was computed using the ERDB (2008) carbon stock equivalent for *F. moluccana*, which was 40.20% for the whole tree. Based on the result, trees planted at <150 masl have the highest C content with 90.57Mg C ha^{-1} (Fig. 2). Table 5, found below, is the Analysis of Variance (ANOVA) for the carbon stock that shows no significant difference in the amount of carbon stock with the different altitudinal gradients.

Table 5. Analysis of Variance for carbon stocks of *F. moluccana*.

Source of Variation	SS	df	MS	F	P-value	F crit
Blocks	1409.4818	3	469.827291	1.1358913	0.38564	3.86254
Treatments	3127.5716	3	1042.52387	2.52048755^{NS}	0.12362	3.86254
Error	3722.5793	9	413.619923			
Total	8259.63279	15				

^{NS} means not significant at P<0.05 level of significance.

Discussion

Aboveground Biomass

The aboveground standing crop biomass of woody vegetation is frequently regarded as a major carbon sink in the world (Sheikh *et al.*, 2011). The aboveground biomass values of woody vegetation observed in this study varied from 104 to 144Mg ha^{-1} (AG1). These values were closer to those reported by Sarmiento *et al.* (2015). Few studies have found that aboveground biomass declines with increasing elevation (Moser *et al.*, 2007; Leuschner *et al.*, 2007, as cited by Khadanga & Jayakumar, 2020). Other studies have reported that biomass and C increase with increasing altitude (Yadava *et al.*, 2015; Yadava *et al.*, 2017). The study proved otherwise, as a result, showing a multimodal pattern of biomass along different altitudinal gradients. The statistics *(Table 3)* suggest that different altitudes had weak effects on the aboveground biomass of the trees planted therein. This result is supported by the study of Khadanga and Jayakumar (2020), as biomass has no correlation with altitudinal gradients.

Trees can adopt various morphological, anatomical, and physiological characteristics. Trees can morphologically adjust to different altitudinal gradients by varying their stem height and diameter, quantity and size of leaves and needles, internode length, and bark thickness (Poorter, 2001; Huber *et al.*, 2009). *F. moluccana* trees are nitrogen-fixers, being leguminous plants. Nitrogen-fixing bacteria usually associate mutually with rootlets, which are usually formed in the upper soil horizon. Despite variations in soil depth, nitrogen promotes vegetative growth. This fact may explain the non-significant difference in the aboveground biomass of the trees despite the differences in altitude.

Belowground Biomass

Belowground biomass and litter are the smallest fractions of total carbon in most forests (Brown 2002). Deep soil at lower altitudes promotes the formation of a higher volume of roots than at higher altitudes, with shallower soil depths brought about by erosion. This explains why the belowground biomass differs across different altitudes. This result is also affected by specific factors such as site quality and silviculture treatment (Rodríguez-Soalleiro *et al.*, 2018). Additionally, we found that the proportion of root biomass decreased gradually with increasing tree diameter. This was caused by natural pruning of the root component. The primary function of the root system is to absorb water and other nutrients. When the root grows older, it regenerates naturally to guarantee water and nutrient absorption (Jing *et al.*, 2018). This finding satisfies the assumption that trees with larger basal areas have less belowground biomass than those with smaller basal areas. This outcome is similar to that of previous studies conducted in different forest locations (Mendoza-Ponce & Galicia, 2010, as cited by Pandu *et al.*, 2020).

Carbon Stock

Deep-rooted crops such as trees positively affect the conservation of natural resources, including carbon sequestration (Kell 2011). The carbon stock of *F. moluccana* plantations contributed a generous amount of carbon sequestration, given its value varied from 58.58Mg C ha-1 to 90.57Mg C ha^{-1}. These values are comparably larger than those reported by Tandug (2006), 66.1Mg C ha^{-1} for *F. moluccana* plantations of ages 5-25 years old. However, compared to other plantation species such as *Samanea saman*, the C stored in *F. moluccana* is comparatively lower (314.28Mg /ha, which appears at six years old), and the lowest value was 193.31Mg/ha) (Fajariani *et al.*, 2020).

Conclusion

The study revealed that the biomass and carbon stocks showed distinct variation along different altitudinal gradients. However, the different altitudinal gradients did not play a significant role. It was concluded that aboveground biomass and carbon stocks at different altitudinal gradients did not differ significantly. In contrast, belowground biomass is significantly higher at <150 masl or at lower elevations.

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Conflict of interest

The authors declare no conflicts of interest regarding the publication of this manuscript.

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