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Estimation of Aboveground Biomass (ABG) Using Allometric Equation: Case Study of Colo-I-Suva Forest Park in Fiji

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Abstract

Forests play an important role in reducing greenhouse gases in the atmosphere, thereby mitigating the impact of climate change. Estimating the accumulated biomass in a forest ecosystem is important for assessing the productivity and sustainability of the forest. Allometric models for above ground biomass (AGB)are linear regression equations based on the relationships between biomass and diameter at breast height (DBH), tree height (H), and/or wood density. This study estimates AGB in the Colo-I-Suva Forest Park by applying the allometry of Chave et al (2005& 2015) and the diameter: height ratio derived from Payton & Weaver (2011) for height estimation in a plot of 20m × 20m. 116 trees of 15 different species were measured and AGB was predicted from different diameters (0.4 to 19.4 cm) and heights (1.1 to 16 m). The R^2 result for each species ranged from 0.504 to 0.952, showing that the model fits the data and the spatial distribution of AGB shows a positive correlation between AGB and DBH. Above-ground carbon stocks calculated in the study area ranged from 0.03 to 3.5 t C per species with an average of 0.31 t C/species. The total above ground biomass estimated for 1 hectare is 3.7 t C/ha.

Keywords: Above Ground Biomass, Allometric Equation, Forest Conservation, Climate Change Mitigation, Biomass, Carbon Dioxide, Carbon Sequestration

Introduction

Carbon is the basic molecule of all living things. It is stored as biomass and in the terrestrial ecosystem, five carbon pools can be identified, namely aboveground biomass (AGB), belowground biomass (BGB), litter, woody debris and soil organic matter [1]. Carbon also exists in the atmosphere as a gas, attached to two oxygen molecules, it forms carbon dioxide (CO2) [2]. CO2 is the most important GHG with about 77% of total GHG emissions (taking into account its global warming potential) in the world [3].Terrestrial ecosystems gain carbon through photosynthesis and lose it mainly in the form of CO2 through the respiration of autotrophs (photosynthetic plants and bacteria) and heterotrophs (fungi, animals and certain bacteria) [4]. When these plants or trees die or are burned, the carbon they contain is released into the atmosphere. This natural carbon cycle is maintained and controlled by a dynamic balance between biological and, but the addition of billions of tons of greenhouse gases C to the atmosphere by burning fossil fuels and altering the Earth's surface is altering its ability to trap heat, which in turn alters the state of the Earth. climate [5, 6].

Among the carbon pools, AGBs represent the major part and are mainly made up of trees which play a major role in climate change mitigation by sequestering carbon [7]. They absorb CO2 from the atmosphere and store carbon through the process of photosynthesis in their leaves, stems, roots and branches. Forest biomass is organic matter resulting from primary production through photosynthesis minus consumption through respiration and harvesting [8]. In addition to their biodiversity and their status as ecosystems for other species, forests play a dual role of sequestration and storage of carbon in the form of biomass. It is estimated that about 86% of terrestrial AGB and 73% of terrestrial soil carbon are stored in forests [9]. Rainforest can store up to about 46% of the global terrestrial carbon pool and about 12% of the global soil carbon pool, acting as a carbon pool and functioning as a constant atmospheric reservoir (Grace, 2004). This amount of sequestration mayincrease if the forest is not disturbed by human activities (Joshi et al., 2020).

Estimating the accumulated biomass in a forest ecosystem is important for assessing the productivity and sustainability of the forest. Biomass is attractive for a number of reasons which are: it is the raw material for food, fiber and firewood, it is important for soil, fire and water management, it is related to vegetation structure, which in turn influences biodiversity, it determines the extent and rate of autotrophic respiration and, finally, biomass density (the amount of biomass per unit area, or Mg dry weight ha−1) determines the amount of carbon emitted into the atmosphere (in the form of CO2, CO and CH4 through combustion and decomposition) when ecosystems are disturbed Biomass is measured in KgC or tC[10, 11, 12]..

Indeed, being able to accurately estimate the amount of forest biomass is very crucial for tracking and estimating the amount of carbon lost or emitted during deforestation, and it will also give us an idea of the sequestration potential of the forest's potential to sequester and store carbon in the forest ecosystem. Estimates of forest carbon stocks are based on estimated forest biomass [13, 14].

AGB can be estimated using biomass estimation equations, also called allometric equations or regression models. Allometric models are linear regression equations based on the relationships between biomass and diameter at breast height (DBH), tree height (H) and/or wood [15]. Allometric equations are developed and applied to forest inventory data to estimate forest biomass and carbon stocks [16, 14]. There are three methods of data collection which are field measurements, remote sensing and GIS methods [17, 18]. In the field measurement approach, there are two main types of methods available, namely destructive methods which involve harvesting all trees in an area on a small scale, but this excludes the forest which contains endangered species and non-destructive methods that involve the estimation of trees without the need for felling [13].

Non-destructive methods are mainly used in protected areas where tree harvesting is not possible. The non-destructive method takes into account the taper of the tree (shape of the tree), the components of the tree (trunk, branches and leaves) and the dendrometric measurement of the various components. It also includes different measurement techniques. Some required climbing the tree to measure the different parts or simply measuring DBH, H and ρ [13, 19].

Different strategies are used for biodiversity conservation in the Pacific region, the best known being the conservation concession used in the Solomon Islands where a payment is made to the local community to recognize them and encourage them for their participation in conservation. conservation of its area without deterioration [20], or the Payment for Ecosystem Services (PES) used by some programs such as the Nakau program under REDD where incentives are offered to farmers or landowners in exchange for managing their land to provide some kind of ecological service [21]. Globally, we have a Forest Carbon Trading or Emissions Trading (ETS) system under which Kyoto compliant forest owners will receive/give back units for increases/decreases in carbon stocks from their plantations from which each unit represents a ton of carbon dioxide (CO2) and can be marketed [22, 23].

Carbon trading takes two main forms: "cap and trade" and "offsetting". "Cap and trade" occur when governments or intergovernmental bodies like the European Commission distribute licenses to industries who can then trade those permits with another that could make "equivalent" changes at lower cost and " offsetting " occurs when, instead of reducing emissions at source, corporations and sometimes international financial institutions, governments and individuals fund "emissions reduction projects" outside the capped area[24].Indeed, estimating forest carbon stock is important both ecologically and economically. The need to use a non-destructive method is mandatory in conservation areas. This project applies the allometric models given by[13] for biomass estimation and the diameter/height ratio derived from [25] for height estimation to estimate carbon stock in a Colo-I-Suva forest Park.

Background

Various studies have developed and used allometric equations to estimate the biomass of different forest types and species [26, 27, 28, 19]. [15] did a tremendous job developing their biomass regression model using a large dataset of 2,410 trees (with DBH ≥ 5 cm) directly harvested from 27 study sites across the tropics. They started with the simple geometric relationship below:

$$AGB = f \times p \times \left(\frac{\pi D^2}{4}\right) \times H$$

(With AGB =above ground biomass, f = taper (shape) of the tree, p= wood specific density, D = Diameter at breast height and H = tree height) Once the tree volume is calculated, they compare different linear regression curves and choose the best one with a high value of R² (coefficient of determination) then determine the following equation:

$$AGBEsi = exp\,(-2.977 + ln\,(\rho D2\ H)) = 0.0509 \times \rho D2\ H \ \text{(equation 1)}$$

also developed other models based on the different forest types (wet, humid and dry) and also based on the specific tree species. To select the best statistical model, they used a penalized likelihood criterion, more precisely a penalization on the number of parameters, the Akaike information criterion (AIC). The equation is written: $AIC = -2ln(L) + 2p$ (With L is the likelihood of the fitted model, p is the total number of parameters in the model). The best statistical model should have the lowest AIC value.

Did the same work and they propose another model taking into account the specific density of wood in Sumatra and propose their regression equation: $B = 0.042\ PD^2H$ (with b= biomass; P = wood density; D= diameter at breast height and H= height) [29]. With adjustment of wood density, they proposed B (^{kgper}*tree*) = 0.066 D2.59 with D in cm. The proposed equation is most suitable for trees having a diameter at breast height of 8-48 cm.

The Pacific Island forest (moist forests) is very dense and the trees are very close together, making it difficult or impossible to measure the angle from the height of the trees. Found that H=1.70D0.535 (for H in meter and D in centimeter; converted from H=20.6D0.535 for both H and D expressed in m) applies to a wide range of plant sizes [30]. Developed an equation with DBH as a predictor to estimate tree height H. The study showed that for individual species, height: diameter relationships accounted for more than 75% of the variability in the dataset.

The IPCC Guidelines on National GHG Inventories contain a large data set on wood density. Show that even though the wood density of many tropical tree species is unknown, it is still possible to conduct ecosystem studies for wood density models based on a combination of known species-specific wood density values and estimations derived from genus averages [31].Studies have shown that the combination of (DBH)H and ρ best predicts biomass. Developed seven AGB equations relating AGB to diameter at breast height (DBH), height (H) and density (ρ) individually and in combination [32]. They show that AGB is strongly correlated with DBH and also with the combination of DBH and height; DBH and wood density; and the combination of DBH height and wood density. Also show that the combination of DBH and H best predicts total AGB and component (stem and branch) biomass [33]. [26] Only use DBH as predicted in their equation and show that other site-specific variables need to be taken into account to get a better estimate of biomass. Studies such as [34].Show that a general allometric model can be developed and a general biomass regression equation for a species in a region can be developed if the relevant variables (DBH, H, density wood) are taken into account.In their work in Canada showed that it was possible to derive generalized regional equations based on sampling similar stands widely distributed over well-defined vegetation regions [35]. Compare the species-specific site equation and the general equation and conclude that there are no differences between them but point out that the more extreme the site, the more development will be required to developed site-specific equations [36].

In the South Pacific region, the previously mentioned Nakau program used the model proposed by for the estimation of AGB [15]. The Nakau Program is an indigenous forest conservation program funded through Payments for Ecosystem Services (PES). Three projects in the Pacific operate under the Nakau programme, namely the Drawa Rainforest Conservation Project in Fiji, the Loru Rainforest Conservation Project in Vanuatu and the Sasaboe Rainforest Project in the Solomon Islands. Each project of the Nakau program is developed by applying two methodological components that are the Nakau methodological framework and a module of technical specifications for each type of activity and ecosystem service measured. The project activities are to avoid deforestation and protect forests that would be subject to deforestation in the absence of payment for ecosystem services (PES) funding and apply to all Pacific countries and territories served by the Secretariat of the Pacific Community (SPC). Each project that applies this technical specification module involves the legal protection of eligible forests in the project area. The technical specifications module provides a methodology for estimating AGB, below-ground biomass (BGB), dead wood and harvested wood products. The program was set up to avoid the conversion of deforested land to non-forest land and instead to protected forest [21].

The purpose of this project is to research on how to conduct an allometric study by following the guideline given by the Nakau methodology and to estimate aboveground biomass (AGB) by applying the above allometric equation. This study is a first to be conducted in Colo- i- Suva forest park. The objective of this study is to:

- Establish a forest inventory in the location plot
- Collect the DBH for each tree in the plot
- Apply the allometric equation to estimate the AGB for the plot
- Estimate for 1 hectare

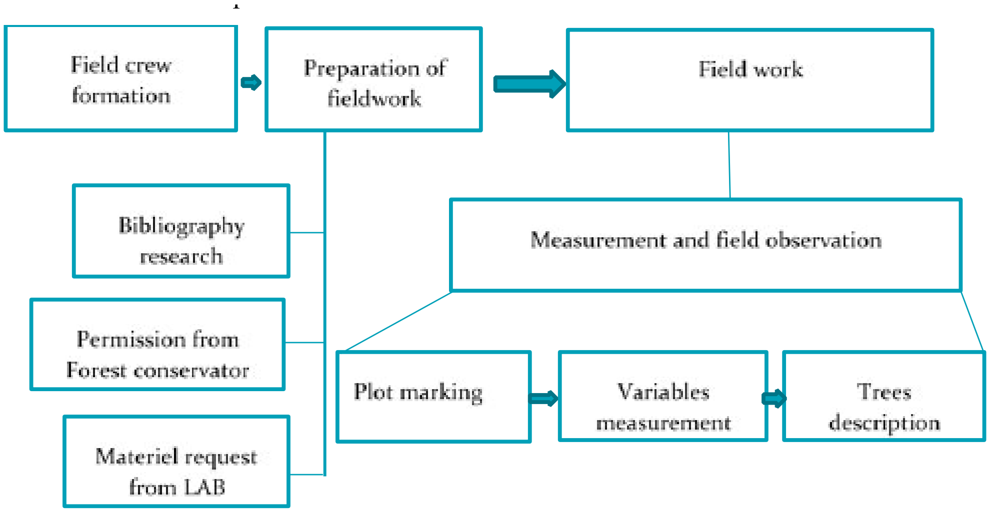
Methodology

Study area and Sampling

The study area is located at 18°03’874”S 178°.095”E in the Colo-i-Suva Forest Park, Suva, Fiji. The forest park was created in 1872 and is managed by the Ministry of Forestry. The park is diverse with 14 different bird species and 2.5 km^2 of verdant rainforest. The average annual rainfall is 4020 mm (humid forest). Among the trees, mahogany and pine were planted after a period of aggressive logging in the 1940s and 1950s to stabilize topsoil without encroaching on native vegetation.

This study uses probability sampling to estimate AGB by carrying out an inventory in a plot of 0.04 ha (20m×20m) which would represent 1 ha (100m×100m) of the forest park.
Field measurements

Overview of Data collection process



The DBH measurement methodology followed the method given in the Nakau Program Technical Specification Module (Weaver, 2015). They measured DBH at 1.3 m for all live trees ≥ 5 cm and where measured on the uphill side in a sloping plot. For forks of a tree below breast height they label each stem individually and on the plot sheet they bracket stems belonging to the same tree and when stem splitting occurs at height of chest, they measure the rod or rods to the nearest convenient point either above or below chest height. When stems are malformed at chest height, they are measured as close to chest height as possible, where the shape of the stem becomes more regular. Also, when tree trunks are fluted or braced, they measure the diameter of the stem just above the height at which the shape of the stem becomes more regular.Finally, when tree trunks are supported by aerial root structures, they measure the stem 1.3 m above the top of the aerial roots.
This project measured tress with circumference ≥ 5 cm and H is estimated using the diameter/height ratio below derived from [25].
1. $H\ (indegenousforestspecies)$ = 1052 × (DBH)^0.31 (Weaver S, 2011) (equation 2)
2. $H(mahogany)$ = 2.58 × (DBH)^0.62 Height estimation equation developed by (Weaver S, 2011) (equation 3)

The IPCC Guidelines for National GHG Inventories have a comprehensive set of wood density data. Work by (Slik, 2006) shows that even though the wood density of many tropical tree species is unknown, it is still possible to conduct ecosystem studies for wood density models based on a combination of known species-specific wood density values and estimations derived from genus averages. By destructive methods, the density of wood can be found by calculating the ratio between the dry weight of the wood divided by the green volume of the same wood.

Data Analysis

H were calculated for mahogany using equation 3 and other native species with equation 2. AGB were calculated using equation 1. All data was entered and analyzed in Excel.

First, a descriptive statistic is performed for each species, then an inferential statistic to see the spatial distribution and the correlation between DBH and AGB. Linear regression curves and R^2 were calculated.The calculated AGB for the sampling area is then estimated for 1 hectare.

Results and Discussion

116 trees were measured and 15 species (Table 1) were identified in the sample plot. Tree species have different wood density and this is an important wood property for solid wood and fibrous products of conifers and hardwoods [37, 38]. Indeed, the density indicates the weight but also the storage capacity of a tree. It indicates whether a tree is leafy or resinous. In this study area, *Parinari insularum* is the densest tree species with 650 kg/m^3 (hardwood) and *Pandanus tectorius* the least dense with 330 kg/m^3 (softwood). Figure 1 shows that *Pandanus* tectorius is more abundant in the sample plot with 35 trees followed by Mahogany with 26 trees, *Dysoxylumsp* and *Gnetum gnemon* with 14 trees, *Gonostylus punctatum* with 7 trees and the rest with less than 3 trees per species.

Table 1: Tree species and their wood density (kg/m³)

Tree species		**Wood density**
Local name	**Botanical name**	**Kg/m³**
Mahogany	*Swietenia macropylla*	490
Pandanus	*Pandanus tectorius*	330
kaudamu	*Myristi ca castaneifolia*	490
Damanu	*Calopylum sp.*	500
Bau	*Palaquium sp.*	535
Kauvula	*Endospermum macrophylum*	400
Maletawa	*Dysoxylum sp.*	340
Duvula	*Masti xiedendron robustum*	430
Kaunigai	*Haplolobus florinbundus*	540
Mavota	*Gonostylus ponctatus*	570
Tiri vanua	*Crossostylis seemani*	535
Sa	*Parinari insularum*	650
Vutu kana	*Baringtonia edulis*	480
Sukau	*Gnetum gnemon*	340
Vasa ni vei kau	*Amororia soulameoides*	340

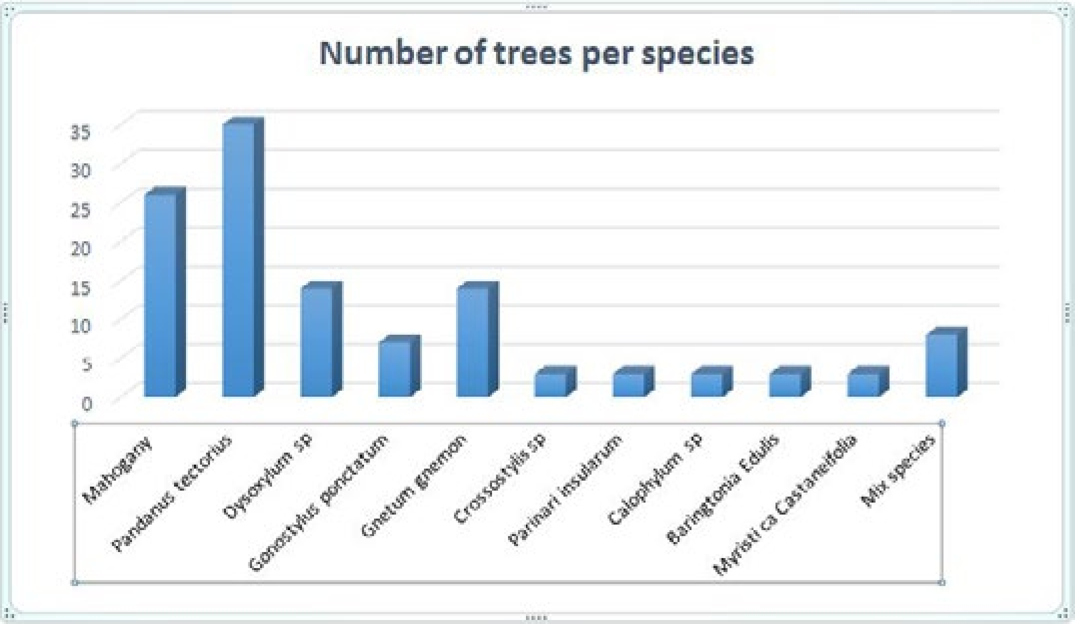
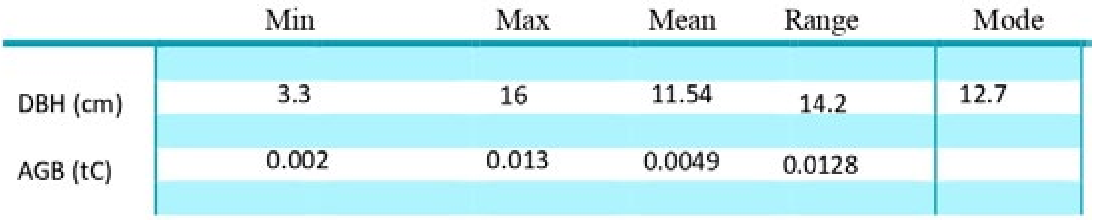


Figure 1: Number of trees per species

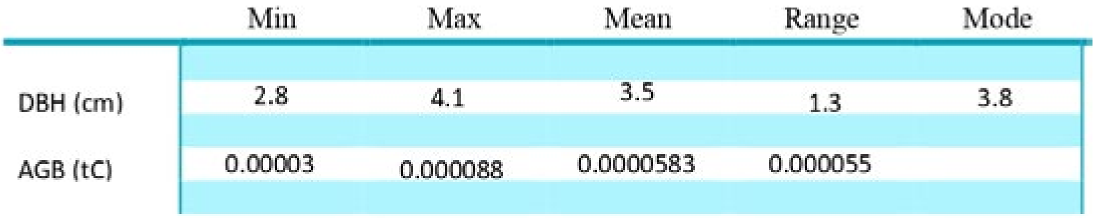
Descriptive statistics

A descriptive analysis was performed for each species. The following tables show the minimum (Min), maximum (Max), average, range and mode for each species



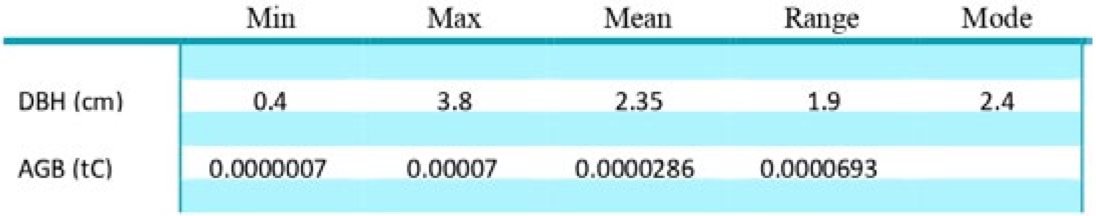
	Min	Max	Mean	Range	Mode
DBH (cm)	3.3	16	11.54	14.2	12.7
AGB (tC)	0.002	0.013	0.0049	0.0128	

Table 3: Descriptive analysis for Mahogany



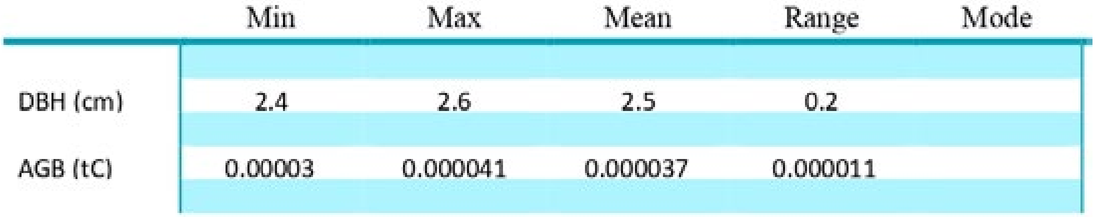
	Min	Max	Mean	Range	Mode
DBH (cm)	2.8	4.1	3.5	1.3	3.8
AGB (tC)	0.00003	0.000088	0.0000583	0.000055	

Table 4: Descriptive analysis For Pandanus tectorius



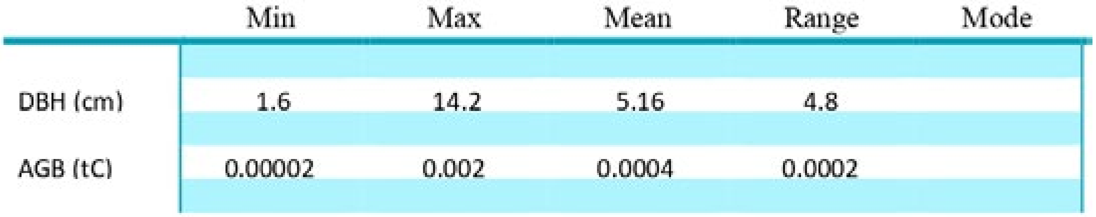
	Min	Max	Mean	Range	Mode
DBH (cm)	0.4	3.8	2.35	1.9	2.4
AGB (tC)	0.0000007	0.00007	0.0000286	0.0000693	

Table 5: Descriptive analysis for Dysoxylum *sp.*



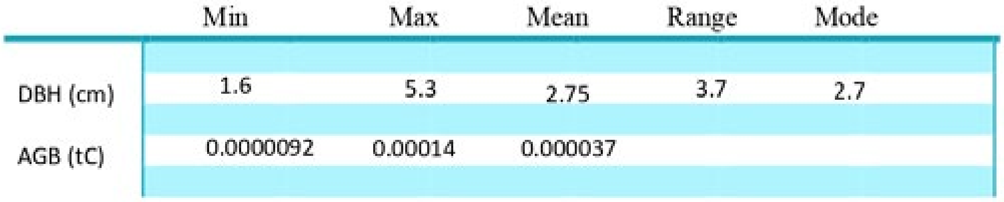
	Min	Max	Mean	Range	Mode
DBH (cm)	2.4	2.6	2.5	0.2	
AGB (tC)	0.00003	0.000041	0.000037	0.000011	

Table 6: Descriptive analysis for Myristi ca Castaneifolia



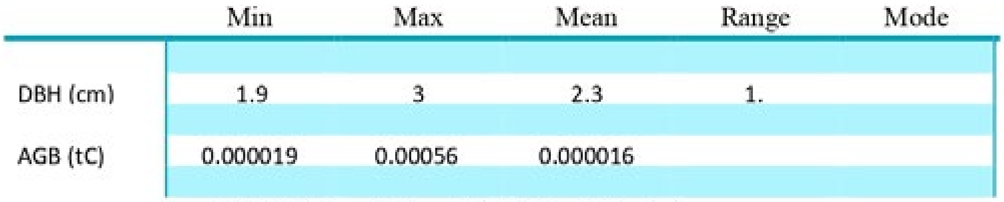
	Min	Max	Mean	Range	Mode
DBH (cm)	1.6	14.2	5.16	4.8	
AGB (tC)	0.00002	0.002	0.0004	0.0002	

Table7: Descriptive analysis for Gonostylus ponctatum



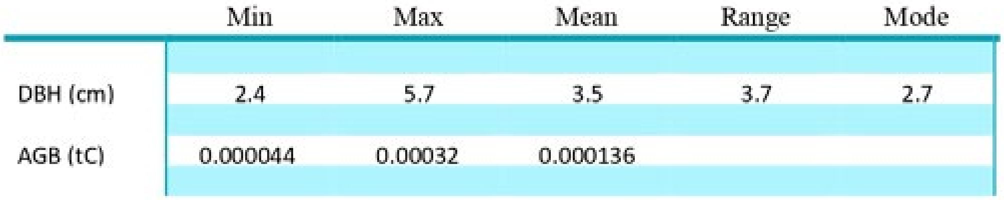
	Min	Max	Mean	Range	Mode
DBH (cm)	1.6	5.3	2.75	3.7	2.7
AGB (tC)	0.0000092	0.00014	0.000037		

Table 8: Descriptive analysis for Gnetum gnemon



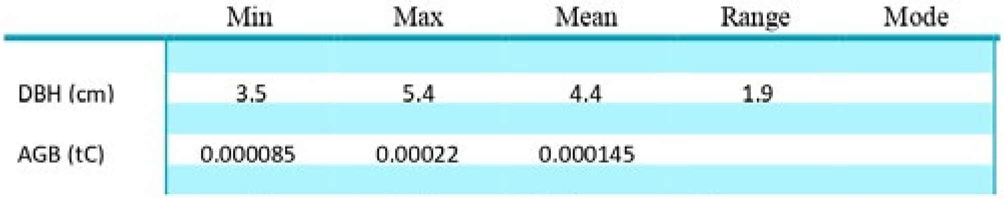
	Min	Max	Mean	Range	Mode
DBH (cm)	1.9	3	2.3	1.	
AGB (tC)	0.000019	0.00056	0.000016		

Table 9: Descriptive statistic for Callophylum *sp*.



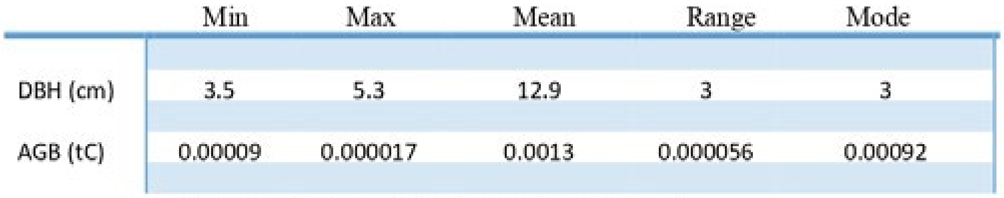
	Min	Max	Mean	Range	Mode
DBH (cm)	2.4	5.7	3.5	3.7	2.7
AGB (tC)	0.000044	0.00032	0.000136		

Table 10: Descriptive analysis for Parinari insularum



	Min	Max	Mean	Range	Mode
DBH (cm)	3.5	5.4	4.4	1.9	
AGB (tC)	0.000085	0.00022	0.000145		

Table 11: Descriptive analysis for Crossostylis *sp*.



	Min	Max	Mean	Range	Mode
DBH (cm)	3.5	5.3	12.9	3	3
AGB (tC)	0.00009	0.000017	0.0013	0.000056	0.00092

Table 12: Descriptive analysis for mix species

Descriptive statistics show that the maximum H in the sampling area is 16 m (mahogany) and the minimum H is 1.1 m (*Dysoxylum* sp) with an average of 3.9 m. The maximum DBH is 19.4 cm (mahogany) and the minimum DBH is 0.4 cm (*Dysoxylum* sp) with an average of 5.3 cm.

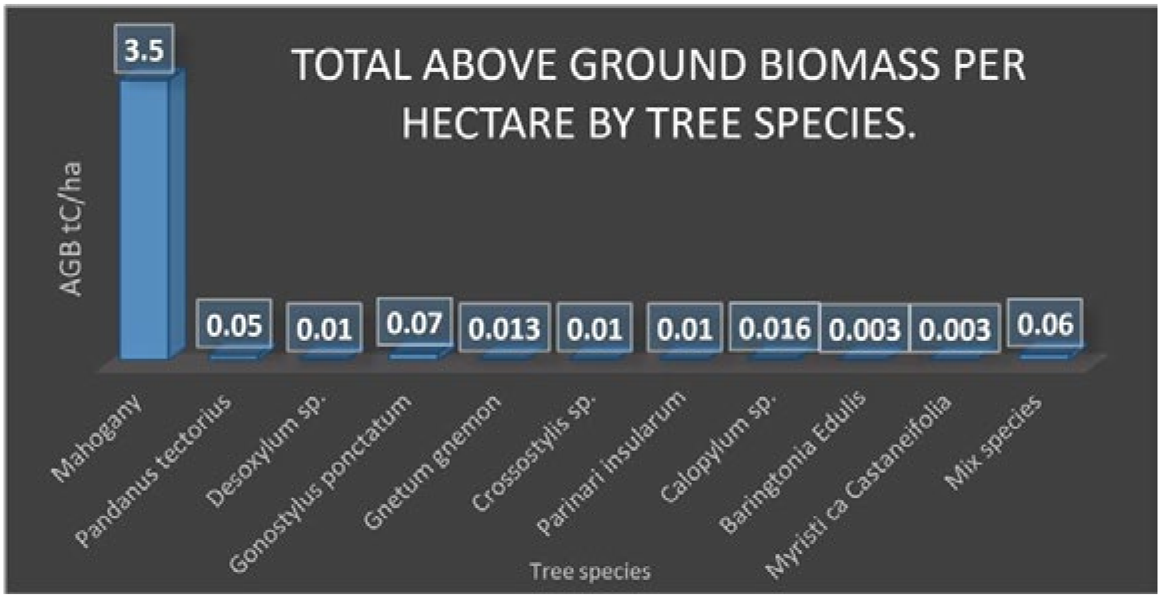
The AGB calculated with Equation 1 indicates that the maximum carbon stock in the sample plot is 3.5 tC for mahogany and the lowest is 0.003 tC for Myristica ca castaneifolia (Table 13).

Table 13: Overall descriptive analysis for H, DBH and AGB for the sample plot

	Min	Max	Mean	SEM
Height (m)	1.1	16	3.9	0.34
DBH (cm)	0.4	19.4	5.3	0.4
AGB (tC/ha)	0.003	3.5	0.31	

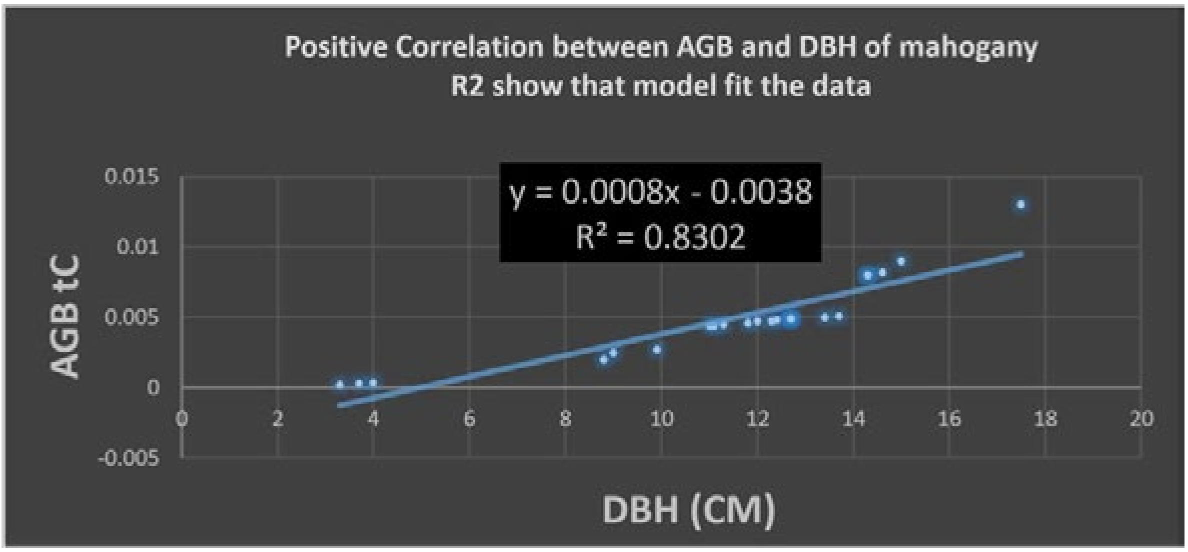
Inferential Statistics

Total AGB calculated for each species was estimated per hectare. Knowing that 20m×20m is 0.04 ha, so by total cross-product AGB/ha= AGB per species/o.o4. Graph 1 shows that Mahogany stores more carbon with 3.5 tC/ha and *Palaquium* stores less with 0.0023 tC/ha. *Pandanus tectorius* is the most abundant in the sample plot (35 trees), but *Gonostylus punctatum* (7 trees) has a higher AGB (0.07 tC/ha). This difference highlights the importance of wood density in estimating AGB.



Graph 1: Total AGB/ha for each species

Chart 2 illustrates a positive correlation between AGB and DBH. AGB increases as DBH increases. In terms of carbon stock, this indicates that the higher the DBH, the more carbon is stored.



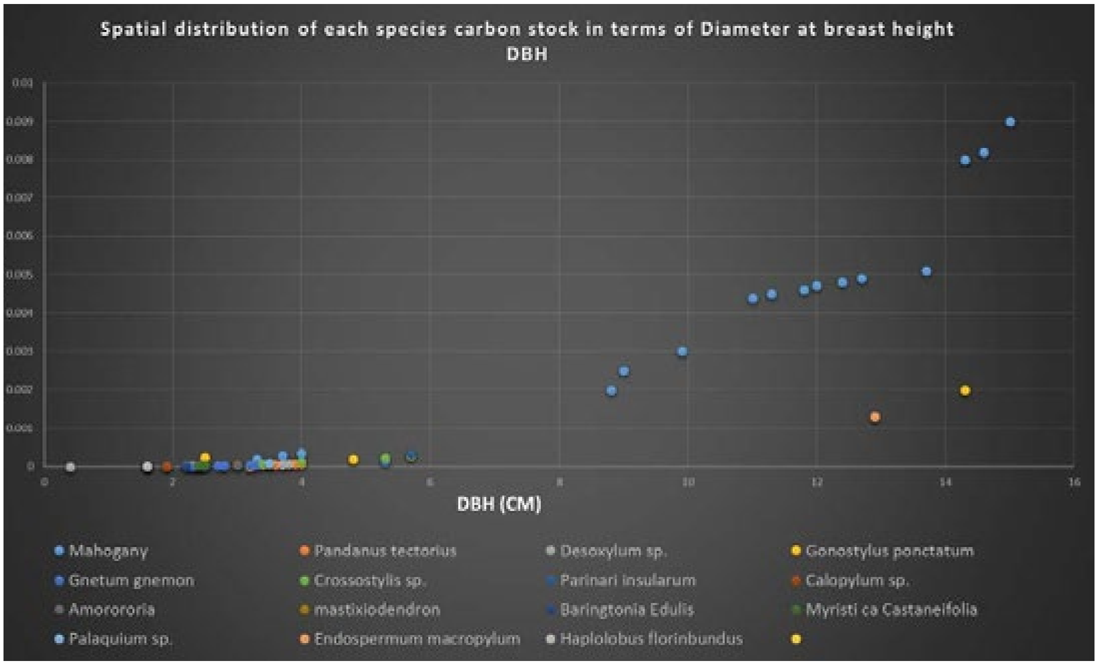
Graph 2: Correlation between AGB and DBH for mahogany

The R^2 result for each species ranged from 0.504 *to* 0.952, which shows that the model fits the data (the data fits the model) and the spatial distribution of AGB shows a positive correlation between AGB and DBH.

Figure 3 illustrates the spatial distribution of carbon stock in terms of DBH. It shows that mahogany has great carbon sequestration potential. Other species are more likely to have the same amount of AGB.

The reality on the ground confirms these results because *Endospermum macrophylum* (DBH=12.9, p=400 and H=9m) is a soft and very light wood despite its large diameter compared to Mahogany which is a hard wood, difficult to cut and very heavy to carry.

The estimated aerial total for 1 hectare is 3.7 tC/ha.



Graph 2: Spatial visualization of carbon stock in terms of DBH

Conclusion

Like a doctor doing a medical analysis for a patient, or a statistician doing a population census, an allometric study is done to assess a particular tree or an entire forest. Assessing this sample plot in Colo-i-Suva Forest Park, this small-scale study showed that the tallest tree in the sample plot is mahogany with 16 m in height (H) and the shortest is the *Dysoxylum* sp with 1.1 m. A maximum DBH of 19.4 cm (mahogany) and minimum 0.4 cm (*Dysoxylum* sp) with an average of 5.3 cm. The most common DBH present in the sample plot is 3.5 cm (*Pandanus tectorius*). The inferential statistic illustrates the dependence between AGB and DBH. The importance of wood density is also highlighted in the case of *Pandanus tectorius* (softwood) and *Gonostylus punctatum* (hardwood). The spatial distribution shows that mahogany has a large carbon storage potential of 3.5 tC/ha. The value of R^2 shows that the model matches the data (the data matches the model).

Biomass regression models are well studied and remain the simplest and non-destructive method. It is part of the Reed+ strategy not to harvest old and preserved trees. The goal of this project is to develop strategies for the preservation of biodiversity. Like the conservation concession or payment for ecosystem services (PES), incentivizing farmers to preserve their forest by engaging in carbon trading is a good conservation strategy for preserving Pacific island forests [39-42].

Abbreviations

AGB	Above ground biomass
cm	Centimeter
DBH	Diameter at breast height
GHG	Greenhouse gas
H	Height (tree)
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
KgC	Kilogram of carbon
m	Meter
REDD	Reducing Emissions from Deforestation and Degradation
tC	tons of carbon
ρ	wood density
PES	Payment for ecosystem services

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