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Carbon stocks of second growth forest and reforestation stands in Southern Philippines: baseline for carbon sequestration monitoring

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Abstract. The purpose of this study is to generate baseline quantitative estimates of carbon stocks of natural and common tree plantation species necessary for future carbon sequestration monitoring using permanent monitoring sample plots. Standard sampling techniques and forest/species-specific allometric equations were used to estimate the biomass and carbon stocks of tree plantations and natural stand. The study showed that even without appropriate management interventions, the five stands can store carbon ranging from 112.72 to 226.80 Mg C ha^{-1} or a total of 914.61 Mg C ha^{-1} in its biomass and soil comparable to managed tree plantations and natural forest in the country. As observed, frequency distribution for aboveground carbon followed a trend: Second growth forest > Mahogany > Mangium > Teak > Yemane. Of the carbon pools, aboveground biomass obtained the bulk of carbon stored except in Teak stand where most of the carbon was stored in the soil which totally influenced the total storage potential of the site. Teak registered highest in soil organic carbon (SOC) with 134.58 Mg C ha^{-1} or about three times higher as compared to the SOC of second growth forest and the other tree plantations. It is very interesting therefore to know how appropriate ecosystem management would affect the potential of these stands/forests for carbon sequestration.
Key Words: carbon, permanent plot, tree plantations, second growth forest, Mindanao.

Introduction. The increasing intensity of weather events and its devastating impacts such as that of the recent super typhoon Haiyan in the Philippines, with reported death toll close of more than 6,000 and total damage of around PhP36.0 billion to agriculture and infrastructure (Cahinhinan 2013), only prove that the threat of climate change remains a serious concern especially among developing countries whose economic means are too limited. This scenario is expected to worsen since the Philippines ranked third in the world and first in Asia in the list of most vulnerable countries to climate change (UNU-EHS 2011). Based on the downscaling made by PAGASA using the Hadley Center's global climate model PRECIS, the country's annual mean temperature is projected to increase by 0.9^{o}C–1.2^{o}C by 2020 and 1.7^{o}C-3^{o}C by 2050 (PCCC 2009). The impact of this change in temperature is expected to be worst in Mindanao, the country's food basket. Such trend definitely has economic, ecological, and health risks that must be recognized and addressed.

While there are viable options for climate change mitigation, mitigation through forestry remains a feasible alternative for the country in reducing net concentrations of atmospheric greenhouse gases (GHGs), especially carbon dioxide, which account at least half of the effect that causes global warming. The wide interest for forests particularly as carbon sink is due to its cost effectiveness, high potential rates of carbon uptake, and associated environmental and social benefits (Moura-Costa 1996). According to Schroeder (1992), about 70% of the entire exchange of carbon that passes through the earth's terrestrial vegetation occurs through the forest ecosystem. However, maintaining the carbon stocks through forest protection is a huge challenge in the country because of the population's overwhelming dependence on forests in terms of goods and services. An estimated 100,000 ha year^{-1} of forestlands in the country were lost due to deforestation which translate a loss of 8.8 million tons of carbon per year (Lasco & Pulhin 1998). Hence, reforesting the Philippines' 1.5 million ha of degraded grassland areas that constitute part of its public domain could play an important role in sequestering atmospheric carbon. Brown et al (1991), however, stressed that this role of forests in the global carbon cycle is not only a function of the present land-use but also of past and future disturbance.

Since considerable differences in the allocation of carbon between living biomass and soil pools, both within and between biomes, exist (Omoro et al 2013) and may change over time; the use of permanent monitoring areas are critically important not only to understand the range of variation but also to establish temporal baseline from which quantitative record of the changes may be detected and sustainable management interventions are identified (Jenkins et al 2003). Monitoring in this context is a critical component of adaptive ecosystem management and may identify the need for scientific research to explain the causes of temporal change especially issues with relevance to carbon sequestration or any greenhouse gas inventory process (Jenkins et al 2003; Vanguelova et al 2007). MacDicken (1997) regards the use of permanent monitoring plots as statistically superior means of evaluating changes in carbon fixation over time and a relatively low cost design in the implementation of a project's carbon monitoring plan. Furthermore, generation of long-term empirical data using permanent sample plots is critical to explore the possible consequences of alternative forest management actions as regards greenhouse gas emissions. Unfortunately, while there is vast information today on carbon stocks of various forest ecosystems and tree plantations, data are limited on forest carbon sequestration in the country. This is because carbon stocks can be easily calculated using allometric equations, while biomass change or carbon sequestration requires long-term monitoring (Lasco & Pulhin 2003). The purpose of this study is to generate baseline quantitative estimates of carbon stocks of natural and common tree plantation species necessary for future carbon sequestration monitoring using permanent monitoring sample plots within the same geographical location.

Material and Method

Study site. The study was conducted from June to December 2014 in a second growth forest and four stands of mahogany (*Swietenia macrophylla* King), teak (*Tectona grandis* L.f.), mangium (*Acacia mangium* Willd.), and yemane (*Gmelina arborea* Roxb.) of Central Mindanao University (CMU) located in Musuan in the Province of Bukidnon, Philippines (Figure 1). The four stands were established as part of the reforestation program of CMU within its landholdings which were previously dominated by grasses such as *Imperata cylindrica* (L.) Raeusch. Historical records indicate that among the stands, mahogany is the oldest at an average age of 29-year old as this was established in 1985. This is followed by yemane, mangium and teak stands with an average age of 25, 16, and 15 years old, respectively. Each stand covers an area of at least 10 hectares. The second growth forest is estimated to be 34 years old at the time of sampling in 2014 as it is one of the logged-over areas in Mindanao where logging was a profitable business until 1980. At least one-hectare of these second growth forest and reforestation stands was delineated in 2012 and is now reserved to serve as permanent site for research purposes.

The Province of Bukidnon is geographically located between the parallels of 07°25' and 8^{o}38' North latitude and 124^{o}03' and 125°16' East longitude with an average elevation of 915 m and slope gradient that peaks at 2,938 m above sea level (Province of Bukidnon 2012). Climate in the province based on the modified Coronas classification, falls under type IV with no dry season or the rainfall is more or less evenly distributed throughout the year (Province of Bukidnon 2012). Data from the closest climatological stations indicate that Bukidnon has mean annual rainfall of 2,800 mm, mean annual temperature ranging between 20°C and 34°C, and relative humidity that range from 90.86% to 92.85% (Province of Bukidnon 2012).

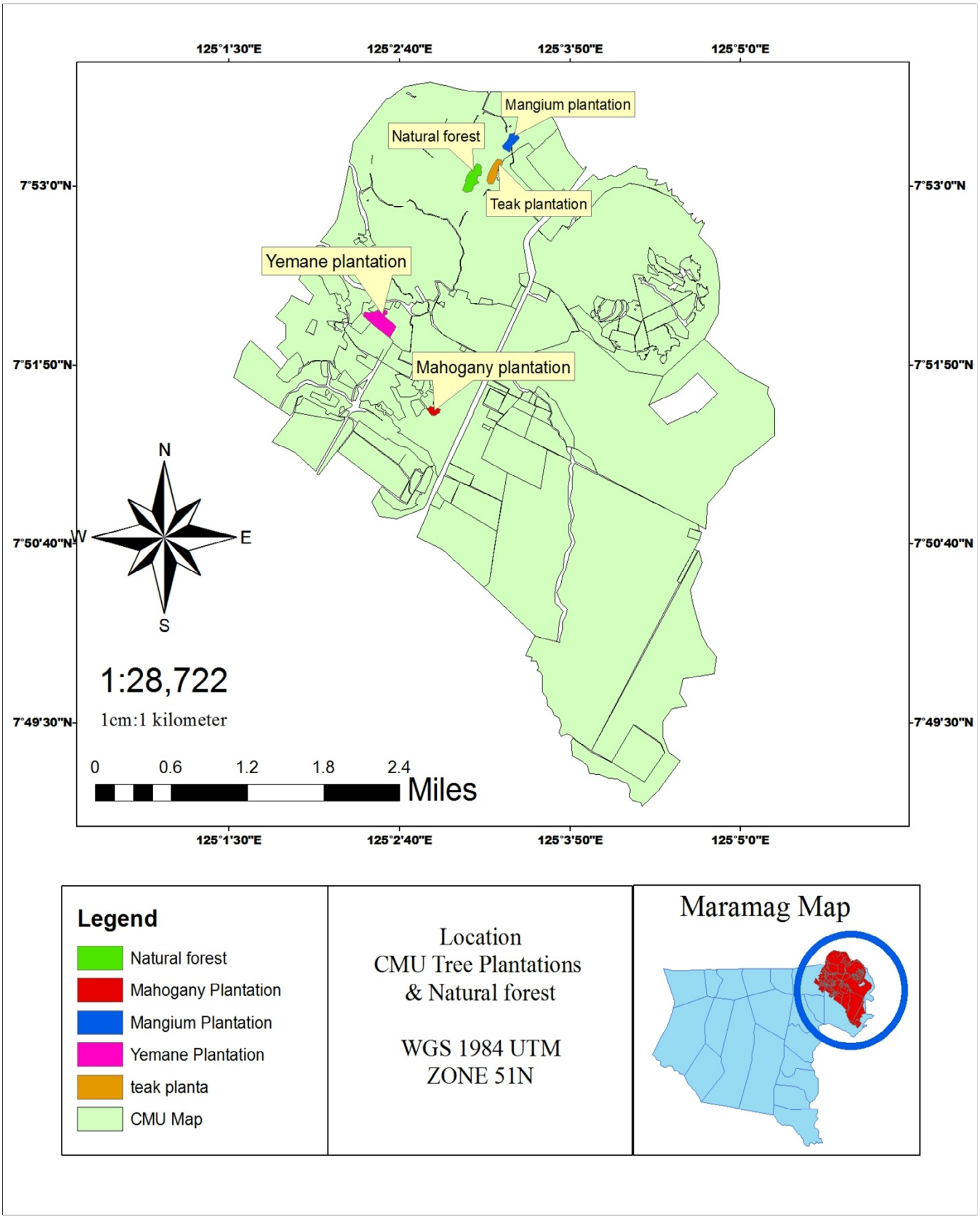

Figure 1. Location of the second growth forest and four plantations in the study.

Biomass and carbon density. Biomass and carbon density were estimated following the nested plot sampling method described by Hairiah et al (2001) (Figure 2).

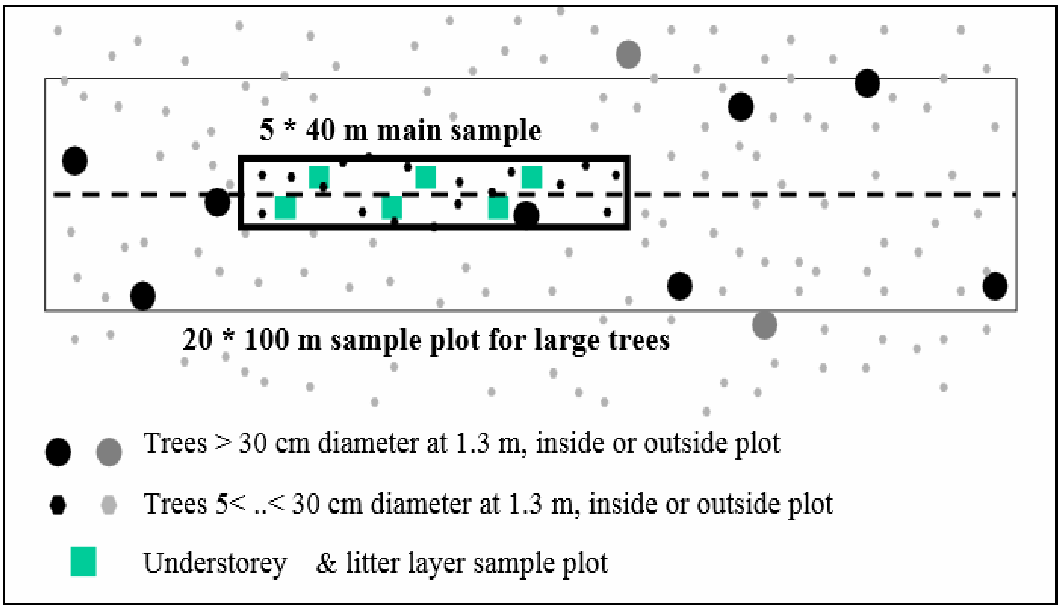

Figure 2. Nested sampling plot design for sampling the different forest carbon pools (Hairiah et al 2001).

Live tree biomass. Three (3) 5 m x 40 m or 200 m^2 sampling plots were established in each study site. Each plot was set out by running a 40 m line through the area and then sampling of the trees with 5 cm to 30 cm diameter at breast height (DBH) that are within 2.5 m of each side of the 40 m centerline was conducted. For each tree, species name and DBH (1.3 m above the soil surface) were determined; the latter with the use of a diameter tape. If trees with > 30 cm in DBH are present in the sampling plot, whether or not they are included in the 5 m x 40 m transect, an additional larger plot of 20 m x 100 m (2,000 m^2) was established where all trees with DBH of > 30 cm were measured.

Tree biomass and carbon density were then computed using the following allometric equations:

$Y = \exp\{-2.134+2.53*Ln*D\}$ (for Natural forest by Brown (1997));
$Y = 0.153D^{2.217}$ (for yemane by Kawahara et al (1981));
$Y = 0.022D^{2.920}$ (for mahogany by Kawahara et al (1981));
$Y = 0.0477D^{2.6998}$ (for mangium by Heriansyah (2005));
$Y = 0.0581D^{2.523}$ (for teak by Buvaneswaran et al (2006)).

Where: Y = tree biomass (kg $tree^{-1}$)
D = diameter at breast height (cm) at 1.3 m
Ln = natural logarithm
exp = exponential

C stored = tree biomass density x C content

Where: tree biomass density = Tree biomass/sample area in hectare;
C content = A default value of 45% was used to determine the carbon stored in tree biomass, which is an average carbon content of wood samples collected from secondary forests from several locations in the Philippines (Lasco & Pulhin 2000).

Understorey herbaceous biomass. Destructive sampling technique was employed for understorey herbaceous biomass. All plants such as trees and shrubs with < 5 cm DBH, vines, lianas, and grasses were harvested using four randomly established 1 m x 1 m subplots within the 5 m x 40 m plot. The total fresh sample was weighed in the field after which a sub-sample of approximately 300 g was taken for subsequent oven drying. Oven dry weights of sub-samples were determined to compute for total dry weights. Oven drying was set at 80°C and was observed for 40 hours or until the samples reached their constant oven-dried weight. Then, a small sample of plant tissues was analyzed for carbon content.

For litter layer. Litter layer is undecomposed plant materials or crop residues including all unburned leaves and branches. These were collected in the 0.5 x 0.5 m sub-plots on a random location within the understorey sample plot. All undecomposed (green or brown) material were collected and weighed. Similar to understorey, sub-sample of about 300 g was taken for oven drying and carbon content analysis.

The carbon stored (ton ha^{-1}) in the biomass was then computed using the following equations:

$$\text{Total Dry Weight (kg m}^{-2}) = \frac{\text{Total fresh weight (kg) x sub-sample dry weight (g)}}{\text{Sub-sample fresh weight (g) x sample area (m}^2)}$$

$$\text{C density (Mg ha}^{-1}) = \text{Total Dry Weight x C Content}$$

Roots biomass. Since the method for determining the root biomass of live tree is not yet standardized, allometric equation was used. Root biomass was calculated using the following allometric equation by Cairns et al (1997).

$$\text{Root Biomass density (Mg ha}^{-1}) = \text{Exp}[- 1.0587 + 0.8836 * \ln (\text{AGB})]$$

Where: Exp = exponential
Ln = natural log;
AGB = Aboveground biomass (Mg ha^{-1});
C stored (Mg ha^{-1}) = Root biomass density x C content.

A default value of 45% was used to determine the carbon stored in root biomass (Lasco & Pulhin 2000).

Soil organic carbon (SOC). The total amount of soil organic carbon stored in each stand was quantified based on the soil's carbon content, bulk density and sampling depth. All soil samples were collected within the 0.5 m x 0.5 m sample grid on random locations within the understorey sample plot. For the bulk density, the samples were collected using a canister with 5 cm in diameter and 0.3 m height. For soil organic carbon analysis, about 1 kg soil samples were obtained from 0-30 cm soil depth.

Soil organic carbon was determined using the computations below:

Carbon density (Mg ha^{-1}) = weight of soil * %SOC
Where: Weight of soil (Mg) = bulk density * volume of 1 hectare;
Bulk density (g/cc) = Oven-dried weight of soil / Volume of canister;
Volume of canister = $\pi r^2 h$;
Volume of one ha = 100m * 100m * 0.30 m;
Total C stored = C stored (Mg ha^{-1}) * area (ha).

Data analysis. Data obtained were analyzed using simple descriptive statistics such as mean, percentage, sum or total and standard deviation to compare the biomass produced and carbon stored in different carbon pools within and among study sites. Mean annual increment (MAI, Mg ha^{-1} $year^{-1}$) was computed by dividing the mean stand biomass or carbon by the age of each stand.

Results and Discussion. Table 1 presents the diameter and height characteristics of the five stands and their corresponding number of stems per plot and stand density. The stand of teak, although the youngest among the stands, registered the highest number of trees with stems per plot ranging from 97 to 255 or an equivalent of 860 stem ha^{-1} resulting to smaller sizes of DBH at 15.98 ± 5.66 cm. Mangium stand tallied the biggest and tallest trees with mean DBH and height of 34.50 ± 2.42 cm 13.49 ± 1.83 m, respectively, despite receiving the lowest number of stems per plot among the man-made stands. The least values in mean height was registered in Yemane with only 9.71 ± 1.35 m, which is very surprising knowing its ability to have rapid early growth and high adaptation on a wide ecological range (Lauridsen & Kjaer 2002). The stand density, on the other hand, followed a trend: teak > mahogany > yemane > second growth forest > mangium.

Table 1

Description of the five stands

Stand	*Age (years)*	*Stem per plot*	*Mean DBH ± SE (cm)*	*Mean height ± SE (m)*	*Stand density/ hectare*
Mahogany	29	94-253	22.80 ± 1.06	11.21 ± 1.09	780
Teak	15	97-255	15.98 ± 5.66	10.14 ± 1.0	860
Mangium	16	36-41	34.50 ± 2.42	13.49 ± 1.83	193
Yemane	25	80-113	25.68 ± 0.86	9.71 ± 1.35	483
Second growth	34	67-93	21.56 ± 2.60	11.56 ± 2.45	402

Biomass and carbon stock. Biomass densities of the five forest stands in the study that were derived from allometric equations showed a range of 158.92 Mg ha^{-1} to 527.09.24 Mg ha^{-1} with the second growth forest being at the top of the estimates (Table 2). This was followed by the stands of mahogany, mangium, teak, and yemane with 309.19, 255.27, 199.93, and 158.92 Mg ha^{-1}, respectively, which are comparable to biomass densities of similar tree plantations and natural forests in the Philippines (Lasco & Pulhin 2003; Lasco et al 2004). For instance, second growth forests in other parts of the country have a mean aboveground biomass density (i.e. excluding root biomass) of 465.9 $Mgha^{-1}$ (Lasco & Pulhin 2003) or about 3% higher only as compared to the aboveground biomass of second growth forest in this study with 451.17 Mg ha^{-1}. However, for tree plantations, this study supported the observations of Lasco & Pulhin (2009) that biomass production may vary with age, species, and site. Generally, older plantations have larger biomass density than the younger stands as in the case between the 29 year-old mahogany plantation in this study (262.10 Mg ha^{-1}) and 44 year-old mahogany stand in Mt. Makiling (in Luzon) with 590.4 Mg ha^{-1} (Racelis 2000). With respect to site condition, the growth performance also varied among the tree plantation species in the study with mahogany species showing to be well adapted to the area. It has registered the highest mean annual increment (MAI) on biomass and tallied the second highest biomass density.

As expected, owing to its large size trunks, trees provided the bulk of biomass produced ranging from 58 to 75% or more than twice the combined biomass production of other carbon pools. This result is close to the average estimate by Tandug et al (2010), which put the main stem at 64.5% of the total dry mass of trees. However, the influence of tree diameter on the total biomass production as observed in previous related studies (e.g. Patricio & Tulod 2010; Camacho et al 2011; Marin et al 2015), did not seem to be significant in the study as indicated by the high biomass density of second growth forest despite having smaller DBH sizes. This may reflect the inherent spatial heterogeneity in ecological characteristics in forest that results from gradients in the substrate, microclimate, and local history of disturbance (Turner et al 2012; Brown et al 1991). Also, besides being the oldest among the stands, the high total biomass density in the second growth forest was largely influenced by a very high estimate of root biomass and higher MAI at 52.98 Mg ha^{-1} and 18.18 Mg ha^{-1} $year^{-1}$, respectively. This support the contention that, in both plantation and natural stand, root biomass increases monotonically with age and does not depend upon stand origin (Usoltsev & Vanclay 1995). However, unlike tree plantations, natural stands may show an abrupt decrease in foliage biomass at the time of canopy closure, but it increases again by age 40-50 years (Usoltsev & Vanclay 1995), suggesting the potential of silvicultural treatments such as thinning and pruning to further increase the productivity and consequently enhance biomass production of second growth forest in the study.

Table 2

Mean biomass density of aboveground pools and the roots of the five forest stands

Stand	*Mean biomass (Mg ha^{-1})*							
	Trees	*Understorey*	*Litter*	*Root*	*Total*	*Total aboveground*	*MAI (Mg ha^{-1} yr^{-1})*	*% in trees*
				Mahogany				
Plot 1	340.44	5.38	15	63.07	423.89	360.82		
Plot 2	278.44	16.25	16.13	55.28	366.10	310.82		
Plot 3	79.54	3.88	31.25	22.91	137.58	114.67		
Mean	232.81	8.50	20.79	47.09	309.19	262.10	10.66	75
SD	136.30	6.75	9.07	21.30	151.41	130.10		
				Teak				
Plot 1	180.24	10.40	25.52	40.11	256.27	216.16		
Plot 2	126.97	4.52	56.93	35.52	223.94	188.42		
Plot 3	38.42	14.93	46.03	20.18	119.56	99.38		
Mean	115.21	9.95	42.83	31.94	199.93	167.99	6.89	58
SD	71.64	5.22	15.95	10.43	71.45	61.01		
				Mangium				
Plot 1	206.49	19.63	13.88	43.99	283.99	240.00		
Plot 2	159.61	18.88	14.88	36.35	229.72	193.37		
Plot 3	161.07	36.13	15.38	39.52	252.10	212.58		
Mean	175.72	24.88	14.71	39.95	255.27	215.32	8.80	69
SD	26.65	9.75	0.76	3.84	27.28	23.44		
				Yemane				
Plot 1	101.77	15.25	10.25	25.12	152.39	127.27		
Plot 2	129.37	16.75	9.25	29.96	185.33	155.37		
Plot 3	94.15	14.38	7.38	23.12	139.03	115.91		
Mean	108.43	15.46	8.96	26.07	158.92	132.85	5.48	68
SD	18.53	1.20	1.46	3.51	23.83	20.31		
				Second growth forest				
Plot 1	185.29	6.88	6.88	37.29	236.34	199.05		
Plot 2	679.58	18.50	18.5	115.64	832.23	716.58		
Plot 3	374.61	31.63	31.63	74.83	512.70	437.87		
Mean	413.16	19.00	19.00	75.92	527.09	451.17	18.18	78
SD	249.39	12.38	12.38	39.19	298.21	259.02		

*MAI = Mean Annual Increment; Aboveground biomass = biomass densities of trees, understorey and litter.

On the other hand, carbon stock usually varies with the amount of biomass produced; hence, the larger the biomass, the larger is the stored carbon. This contention is clearly observed both for aboveground and root biomass carbon content of the five stands in the study (Figure 3). Frequency distribution for aboveground carbon followed a similar pattern with the aboveground biomass i.e. Second growth forest > mahogany > mangium > teak > yemane. Similarly, carbon stored in the root biomass registered highest in the second growth forest with 34.17 Mg C ha^{-1} and lowest in the yemane stand with 11.73 Mg C ha^{-1}. This supports previous findings of Lasco & Pulhin (2009) that even if the species used for plantation development are fast growing, C stored in the natural forests is observed to be far higher than the C contained in tree plantations. However, the inclusion of SOC in the total carbon storage has changed the trend with teak stand as the highest at 226.80 Mg C ha^{-1}, followed by second growth forest (217.46 Mg C ha^{-1}), mahogany (194.42 Mg C ha^{-1}), mangium (163.22 Mg C ha^{-1}), and yemane (112.72 Mg C ha^{-1}). SOC is a significant C sink because aside from the fact that it is not released by burning, it has the longest residence time among the organic carbon pools (Lugo & Brown 1992), suggesting that site local history still have significant inputs to the SOC content of an area. Teak registered the highest SOC with 134.58 Mg C ha^{-1} or about three times higher as compared to the SOC of second growth forest and the other tree plantations despite being the youngest among the stands in the study. This result did not support the contention of Jha (2003) that the standing state of nutrients (SOC included) increases with increase in age of the plantation. However, other studies noted that some species produce more litters and roots than other species, resulting to a much higher organic matter inputs, which eventually influences the amount of SOC (Brown et al 1991). Unfortunately, method for determining the root biomass of live tree is not yet standardized, hence, allometric equations for this purpose may either underestimate or overestimate the root biomass production.

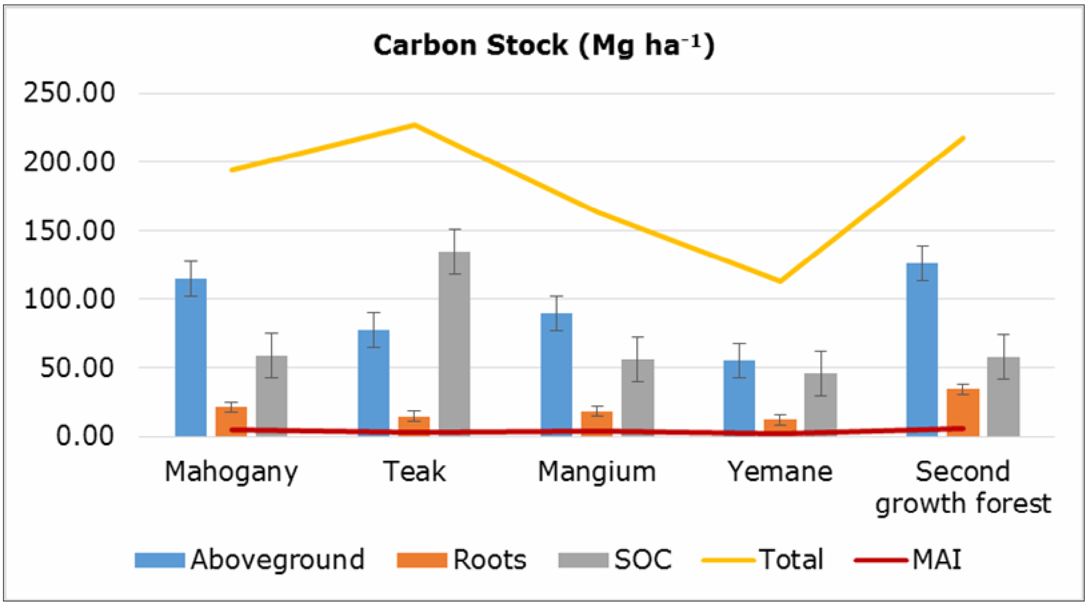

Figure 3. Above-and-belowground carbon storage of the five stands.

Conclusions and Recommendations. Overall, the study showed that even without appropriate management interventions, the five stands in the study can accumulate carbon ranging from 112.72 to 226.80 Mg C ha^{-1} or a total of 914.61 Mg C ha^{-1} in its biomass and soil comparable to managed tree plantations and natural forest in the country. As observed, frequency distribution for aboveground carbon followed a trend: second growth forest > mahogany > mangium > teak > yemane. Of the carbon pools, aboveground biomass obtained the bulk of carbon stored except in teak stand where most of the carbon was stored in the soil. Although the prevailing condition of each site may have affected the actual and/or maximum capacity of the five stands to store carbon, the study supported previous observations that age, species, and site local history may determine variations in the carbon storage potential of both tree plantations and natural stand. It is very interesting therefore to know how appropriate ecosystem management would affect the potential of these stands/forests for carbon sequestration. In addition, the observed variations both in the above-and-belowground carbon storage, simply underscore the importance of monitoring or periodic and consistent evaluation to understand the range of variations both in the production of biomass and storage of carbon over time and to precisely measure the contribution of these stands to sequestration of atmospheric carbon.

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