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Carbon stock assessment of three different vegetative covers in Kapatagan, Lanao del Norte, Philippines

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Abstract. Climate change is a core challenge of the century as a result of relentless emissions of greenhouse gases into the atmosphere. Carbon dioxide is one of the leading gases causing this climatic anomaly. With this, interests on carbon sequestration studies have intensified in terrestrial ecosystems for their capability to deposit carbon over long periods of time positively mitigating climate change. In this paper, the potential of three selected vegetative covers to accumulate carbon was estimated by measuring carbon stored in various carbon pools including tree, herbaceous vegetation, and litter layer considered as aboveground biomass and the soil. The study site included mahogany plantation, secondary forest and grassland located in the Municipality of Kapatagan, Lanao del Norte, Philippines. Results revealed that among the vegetative covers, mahogany plantation ranked the highest having a total carbon stock of 228.15 MgC ha^{-1} of which 58% was in the aboveground biomass and 42% in the soil. Secondary forest followed next with 210.89 MgC ha^{-1} total carbon accumulation of which 59% was contained in the aboveground biomass and 41% in the soil. Grassland measured the lowest at 32.59 MgC ha^{-1} with shared carbon in the aboveground biomass and soil reversed with the former results with < 1% in the aboveground biomass and 99% in the soil expectedly because of the absence of tree stand. This suggests that a vegetative cover with stand of trees accumulates and preserves more carbon than an open land. Therefore, prevention of deforestation and promoting effective management practices such as afforestation and reforestation are proposed to enhance ecosystem carbon stocks.
Key Words: climate change, carbon sequestration, terrestrial ecosystem, carbon pool.

Introduction. The rising levels of greenhouse gases notably carbon dioxide (CO_2) and the consequent climate change is widely recognized as a significant threat in the twenty-first century affecting the humanity and environment (Kumar & Nair 2011). Global climate change threats may include biodiversity and habitat loss, occurrence of wildfire outbreaks and even the uncontrollable emission of CO_2 in the atmosphere (Mosquera-Losada et al 2011). Stavins & Richards (2005) as cited by Bijaya (2008), reported that the rate at which human activity contributes to increases in atmospheric carbon is accelerating. Tropical forests as carbon sink are considered as inexpensive repositories of carbon which has captured the interest of climate change mitigation strategists (Kunhamu et al 2011). For instance, forest ecosystems potentially defer climate change for its capacity in storing high rates of carbon for longer periods of time known as carbon sequestration. Forest vegetation and soils are therefore important terrestrial carbon pools playing both as sources and sinks of CO_2 (Tagupa et al 2010; Kaul et al 2010).

In recent years, carbon sequestration in plant parts and soil in land use systems became an important area of research (Kumar & Nair 2011). Carbon capture and storage may vary within different forest types and would depend on factors such as structure, age, vegetation, land-uses and management practices (Montagnini & Nair 2004; Henry et al 2009). It was found out that reforestation and afforestation are effectively used as mitigation strategies, since combination of carbon (C) storage and wood production can occur at the same time (Kaul et al 2010). However, enhancing carbon stocks through programs where forest protection is the fundamental approach is a huge challenge in the country because it is the main source for timber production and other basic services (Tulod 2015). Recognizing the alarming state of climate change, Kyoto Protocol was ratified to fight against it through reducing GHG emissions (UNFCCC 1997). The protocol provides flexible mechanisms, where Clean Development Mechanism (CDM) is most relevant for developing countries such as the Philippines (Lasco & Pulhin 2003).

At present, there are limited number of studies on carbon sequestration in the Philippine forests particularly in Mindanao. The country, therefore, has yet to enhance and widely promote research that will aid awareness and understanding on the role of forest ecosystems in mitigating climate change. In particular, this provides additional information on carbon storage capacity of ecosystems regardless of the practice of good land and management. The potential of carbon-rich ecosystems in providing social benefits is well known. They generate income while simultaneously increasing carbon stocks (Albrecht & Kandji 2003; Montagnini & Nair 2004). This study was undertaken to estimate and compare the actual contribution of the three different ecosystems in accumulating carbon and to identify which type of ecosystem stored more carbon. This also serves as a baseline data for the area and results shall supplement new details relating carbon stocks of different land use cover in the Philippines.

Material and Method

Location and description of the study. The study was conducted within the months of July and August 2015, in three selected barangays situated in the municipality of Kapatagan, Lanao del Norte. The municipality is located 7°53'56" North latitude and 123°46'14" East longitude. Kapatagan is positioned about 17 km south of Tubod, the province capital. The province of Lanao del Norte is bounded on the North by Iligan Bay, the province of Misamis Occidental on the East, the province of Lanao del Sur on the south and Panguil Bay borders on the west and the boundary of Zamboanga del Sur. The climatic condition in the province falls under Type III climate, characterized with no pronounced maximum rain period. Rainfall occurs throughout the year with heavier precipitation from May to December and lesser precipitation from January to April. The municipality has a clayey to fine loamy type of soil. The three ecosystems studied were: secondary forest, plantation area (mahogany plantation) and grassland. All study sites covered an area of at least a hectare. These are located in Barangay Mahayahay, Barangay Poblacion and Barangay Maranding-Annex, respectively (Figure 1). The main carbon pools measured in the sampling area were the following: tree biomass, herbaceous vegetation, litter layer and soil.

Establishment of sampling sites. A research design formulated by Hairiah et al (2001) (Figure 2), which has been applied in several studies on carbon stock assessment in the Philippines, was followed. Two rectangular plots measuring 5 m x 40 m (200 m^2) was laid out in the area of at least a hectare. Data on geo-position of each plot were also be obtained using a Global Positioning System (GPS).

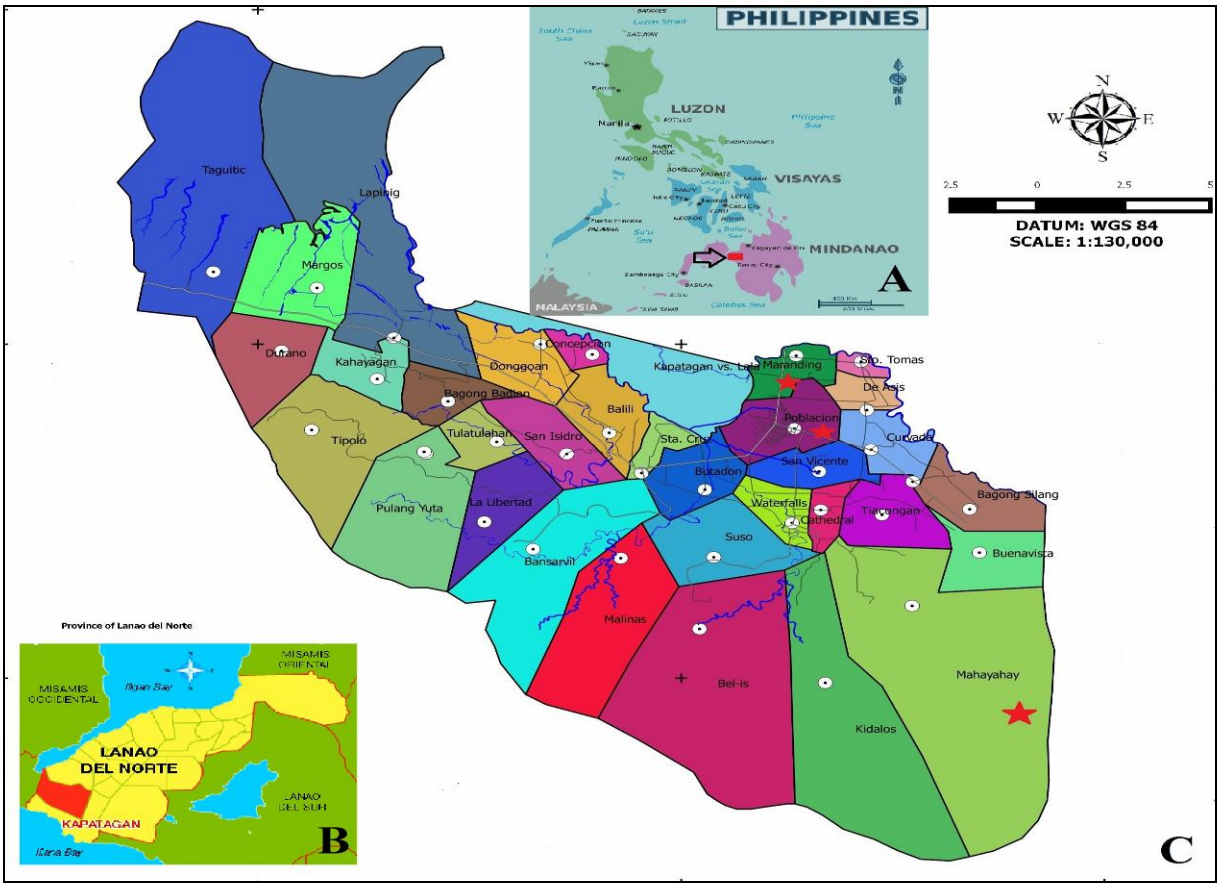

Figure 1. Inset is the map of Philippines pointing Lanao del Norte (A) and B is the Province of Lanao del Norte with Municipality of Kapatagan marked in red. The three selected Barangays were Mahayahay, Poblacion and Maranding-Annex, each emphasized with a red star (C). Source: A & B (http://www.google.com); C (Municipality of Kapatagan - MPDO 2014).

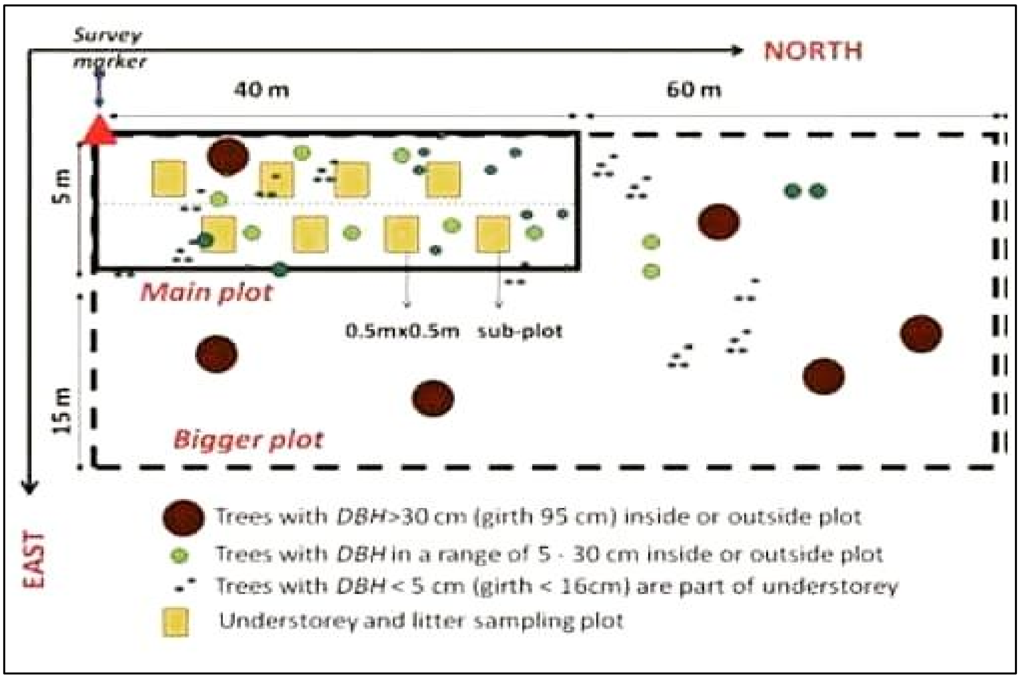

Figure 2. Illustration of nested rectangular plot established in the sampling area (Hairiah et al 2001).

Data collection and computation

Carbon determination in tree biomass. In each plot, trees with DBH (diameter at breast height which is 1.3 m above the soil surface) 5-30 cm located within 2.5 m on each side of the centreline perpendicular to the 5 m side of the plot were sampled. 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 (Hairiah et al 2001). The number of trees found were recorded, classified and identified up to its species name. However, in grassland, the dominant vegetation was only identified. Further, DBH were measured using a diameter tape or caliper. The different species of trees, regardless of age, were classified into sapling (DBH < 10 cm), pole-sized (DBH between 10–30 cm), and standard trees (DBH > 30 cm) (Tagupa et al 2010). Stand density was calculated by counting the number of trees for each classification and divided by the area of the plot. Moreover, carbon estimation in tree biomass were applicable only in the two vegetation covers with stands. For the grassland, the collection of data was limited in herbaceous vegetation, litter layer and the soil.

In this study, instead of performing destructive sampling which is cost and labor intensive, we used an alternative method. The equation only needed the measured variable DBH as a basis to estimate the biomass of individual trees (Hairiah et al 2001). According to Ketterings et al (2001) and Van Noordwijk et al (2002), the equation of Brown (1997) was found to overestimate the actual factor (Labata el al 2012). Banaticla et al (2007), on the other hand, also formulated an equation using the secondary data from Philippine studies involving destructive sampling by Kawahara et al (1981) and Tandug (1986) and observed to improved estimates compared with generic equation of Brown (1997). In this study, we followed the idea of Labata et al (2012) in which the two equations were used as high and low estimates for tree biomass.

Brown's allometric equation:

$$Y\ (kg) = \exp\{-2.134 + 2.53 * \ln D\} \text{ for natural forest and plantation}$$

Where:
exp {...} = "raised to the power of";
ln = "natural log of (...)";
Y = biomass per tree in kg;
D = diameter at breast height (1.3m) in cm.

Banaticla's allometric equation:

$$Y = 0.342\ D^{2.073}$$

Where:
Y = biomass of the tree;
D = diameter at breast height

Tree biomass density and C stored were calculated using the following equations:

$$\text{Tree Biomass Density} = \text{Tree biomass/sample area in hectare}$$
$$\text{C Stored (MgC ha}^{-1}) = \text{Tree biomass density x C content}$$

C content is assumed to be 45%, IPCC default value (Sales et al 2005). It is an average content of carbon on wood samples collected from several secondary forests (Lasco & Pulhin 2000; Labata et al 2012) and tree plantations located in the Philippines (Kawahara et al (1981) as cited by Lasco & Pulhin (2003)).

Herbaceous biomass and litter layer. In assessing the carbon stock of herbaceous vegetation and litter layer, destructive sampling technique was applied (Hairiah et al 2001). Sampling frames measuring 1 m x 1 m were set in each quarter of the length of the central rope or centerline within the established 5 m x 40 m or 200 m^2 quadrat. Herbaceous biomass included all understorey vegetation both woody and non-woody plants such as vines and lianas, these were collected within the 1 m x 1 m quadrat. Partially decayed or undecomposed plant material including all unburned leaves, wood, stems and branches are referred to as litter layer (Patricio & Tulod 2010). These were harvested in the 0.5 m x 0.5 m quadrat on a random location within the 1 m x 1 m understorey sample plot. The total fresh sample of herbaceous vegetation and litter layer were weighed separately and directly in the field using a digital scale and recorded, after which a sub-sample of about 300 g was taken for moisture content determination. The samples collected underwent air and oven drying. Oven drying was set at 80°C and observed for at least 40 hours or until the samples reached their constant weight. Oven-dried weights of sub-samples were determined. Total dry weights were calculated using the formula (Hairiah et al 2001):

$$\text{Total dry weight (kg m}^{-2}\text{)} = \frac{\text{Total fresh weight (kg) * subsample dry weight (g)}}{\text{Subsample fresh weight (g) * sample area (m}^{2}\text{)}}$$

For carbon content determination, small samples (2 grams) of plant tissues from each herbaceous vegetation and litter layer were analyzed at the International Rice Research Institute Analytical Service Laboratory (IRRI-ASL) using the ROBOPREP C-N Biological Sample Converter. Carbon storage in herbaceous vegetation and litter layer were calculated using the formula (Lasco et al 2006):

$$\text{C stored (MgC ha}^{-1}\text{)} = \text{Total dry weight * C content}$$

Soil sampling and analysis. The same quadrats sampled for litter collection, which is 0.5 m x 0.5 m was used for soil sampling and analysis. The samples were obtained at 0-30 cm depth from soil surface. The soils were sieved through a 5-mm mesh screen until mixed to a uniform color and consistency then a subsample of 500 g was used for C content analysis. The 500 g subsample was also taken from each of the 5 m x 40 m quadrat. Soil samples in each quadrat were brought to the College of Agriculture, Analytical Service Laboratory of the Mindanao State University - Main Campus, Marawi City for chemical analysis of Soil Organic Carbon (SOC) using Walkley-Black method (MacDicken 1997). Bulk density was determined by collecting undisturbed soil using soil corer with a diameter of 5.2 cm and length of 10 cm (MacDicken 1997; Patricio & Tulod 2010). The soil samples were initially air-dried and oven dried until stable weight for 40 hours at ±102°C. To calculate the carbon density (Mg ha^{-1}), the following formulae were used (Patricio & Tulod 2010):

$$\text{Carbon density (Mg ha}^{-1}\text{)} = \text{weight of soil x \% SOC}$$

Where:
Weight of soil (mg) = BD (bulk density) x volume of 1 hectare;
BD (g/cc) = oven-dried weight of soil/volume of soil core;
V (volume of soil core) = 212.26 cc;
Volume of 1 ha = 100 m x 100 m x 0.30 m.

Data analysis. Data gathered were analyzed with the use of descriptive statistics such as total, mean and percentage in comparing the biomass density and carbon accumulated in different carbon pools within and among study areas. Analysis of variance (ANOVA) was done to assess the differences in mean carbon stocks among sapling, pole and standard-sized trees for each vegetative covers with stands. Tukey's test was also performed to determine which pair of means were significantly different from each other.

Results and Discussion

Species of plants and trees present in the three selected vegetative covers*.* The secondary forest consisted of the most diverse plant species found in the area where hardwood species, mainly used for timber production, are abundant. Other tree species particularly *Ficus septica (*Lagnob) is known for its medicinal value as an alternative form of antimicrobial (Vital et al 2010). Mahogany plantation apparently has only one species, *Swietenia macrophylla.* Meanwhile, the grassland was dominantly covered with *Paspalum* *conjugatum* (Kurawraw or carabao grass). Table 1 shows a summary of the different species found in the study area.

Tree classification and stand density. The stand density of pole-sized trees had the highest registered component; followed by sapling and the standard-sized trees for the two stands (Table 2). In general, the mahogany plantation showed a higher stand density (1256.67 trees ha^{-1}) than the secondary forest with 793.33 trees ha^{-1}. In this study, the variation can be accounted to the fact that the plantation forest follows uniform spacing and more trees are present per unit area compared to the secondary forest where trees grow and are distributed at random as a result of secondary succession. In connection, Lutz et al (2012) expressed that competition theory also predicts spatial patterns and accounts for the variation of accumulated biomass between tree sizes. Such that, as large diameter trees and small diameter trees compete asymmetrically, their corresponding spatial location become segregated because seedlings favourably emerge and survive into understorey trees where they are not suppressed by larger competitors. Although, further affirming that competition theory alone was insufficient and ambiguous to explain tree spatial relationships and consequent tree population dynamics. Meanwhile, inclusion of factors that affect stand density was not in the scope of our study, and we can suspect that the secondary forest had lesser stand density probably because of different tree species occurrence requiring distinct amount of resources resulting to the survival of the most or larger competitor species.

Table 1

Species of plants and trees present in the three selected vegetative covers

Family name	*Scientific name*	*Philippine common name*	*Local name*
		Seconday forest	
Apocynaceae	*Alstonia scholaris*	Dita	Dita
Dipterocarpaceae	*Shorea almon*	Almon	Bagtikan
Euphorbiaceae	*Antidesma ghaesembilla*	Bignai	Inyam
	Macaranga orbicularis	Binunga	Balanti
	Melanolepis multiglandulosa	Alim	Alom
Fabaceae	*Erythrina orientalis*	Dapdap	Dapdap
	Pterocarpus indicus	Narra	Narra
Hypericaceae	*Cratoxylum sumatranum*	Pag-uringon	Pag-uringon
Lauraceae	*Litsea perrottetii*	Marang	Bakan
Moraceae	*Artocarpus blancoi*	Antipolo	Tipolo
	Ficus congesta	Malatibig	Tubog
	Ficus minahassae	Hagimit	Hagimit
	Ficus septica	Lagnob	Hauili
Myrtaceae	*Xanthostemon* sp.	N/A	Magkuno
Rubiaceae	*Neonauclea formicaria*	Himbabalod	Hambabalod
	Nauclea orientalis	Bangkal	Bangkal
Sterculiaceae	*Kleinhovia hospita*	Tan-ag	Bitan-ag
	Pterospermum diversifolium	Bayok	Bayog
Ulmaceae	*Trema orientalis*	Anabiyong	Hanagdong
Urticaceae	*Leucosyke capitellata*	Alagasi	Alagasi
	Dendrocnide meyeniana	Lipa	Alingatong
Verbenaceae	*Premna odorata*	Alagaw	Abgaw
	Vitex parviflora	Molave	Tugas
		Mahogany plantation	
Meliaceae	*Swietenia macrophylla*	Mahogany	Mahogany
		Grassland	
Poaceae	*Paspalum conjugatum*	Kurawraw	Carabao grass

*Scientific names reference: Madulid (2001).

Table 2

Classification and density of trees in the three different vegetative covers

	Stand density (trees ha^{-1})		
Tree classification	*Secondary forest*	*Mahogany plantation*	*Grassland*
Sapling	163.33 (20.59%)	186.67 (14.85%)	0 (0%)
Pole	486.67 (61.35%)	976.67 (77.71%)	0 (0%)
Standard	143.33 (18.07%)	93.33 (7.43%)	0(%)
Total	793.33	1256.67	0

Note: Enclosed in parentheses are percent composition of each tree classification for each vegetative cover.

Tree biomass density. Standard method for biomass determination is unavailable and assumed to be time and cost intensive. In this research, tree biomass density was derived from the average of two allometric equations formulated by Brown (1997) & Banaticla et al (2007) (Table 3). In the secondary forest, biomass accumulation is highest in standard-sized (164.15 Mg ha^{-1}) followed by pole (109.29 Mg ha^{-1}) and sapling-sized (3.01 Mg ha^{-1}) trees. Similar with the observation of Tagupa et al (2010) in Tampilisan forest, where all stands generally follow the same pattern of biomass production: standard>pole>sapling-sized. The mahogany plantation on the other hand, showed biomass densities in the following order: pole>standard>sapling-sized, with values 215.80 Mg ha^{-1}, 75.95 Mg ha^{-1} and 3.23 Mg ha^{-1}, respectively. This indicates that the sampled plantations are uneven-aged with majority of the trees still in their intermediate growing stage. The mean tree biomass density of the 10-15-year-old mahogany plantation (294.98 Mg ha^{-1}) was slightly higher than the 5-8-year-old secondary forest (276.45 Mg ha^{-1}). This is comparable with the 232.81 Mg ha^{-1} biomass of a 29-year-old mahogany plantation of Central Mindanao University (CMU) in Bukidnon studied recently by Tulod (2015). On the contrary, it is distantly smaller than a 44-year-old mahogany in Mt. Makiling Forest Reserve with a biomass density of 540.09 Mg ha^{-1} (Racelis et al 2008). These results are supported by the observations of Lasco & Pulhin (2009) as cited in Tulod (2015) that biomass production for tree plantations may differ with age such that older plantations contained larger biomass density than younger stands. The sampled secondary forest in this research is lower when compared with the 34-year-old secondary growth forest studied by Tulod (2015) in Central Mindanao University with 431.16 Mg ha^{-1} biomass production. Yet, is comparable with the 221 Mg ha^{-1} biomass analyzed by Lasco et al (2002) from the various Dipterocarp forest ecosystems in the Philippines. As a result, it is projected that trees possessing higher biomass production has a greater capability to sequester more carbon (Baguinon et al 2007; Patricio & Tulod 2010). Furthermore, stands in this secondary forest were also collected for wood production preventing stabilization of carbon stored. However, based on Lasco et al (2006), forests have the ability to recover after timber harvesting since total biomass increases with increasing number of years after logging, but is still lower than the mature forest. This connotes that the capacity of regenerated forest to restore carbon with regards to age is not commensurate with the amount of carbon lost from deforestation. Thus, such activity needed to be controlled when prevention is difficult and impractical. Moreover, the grassland in this study, covering two (2) hectares was an agricultural area few years back. In fact, the area is surrounded by nearby crop plantations such as corn, banana and coconut but the study is limited with the grassland community which was observed to be devoid of any tree species. The site is utilized solely for domestic grazing animals where carabao grass *(Paspalum conjugatum)* is the present dominant vegetation. Lamentably, grazing is known to induce CO_2 release prior to the increased microbial activities, increased in soil temperature and respiration as a result of reduced leaf area and extensive penetration of light into the soil surface (Acharya et al 2012). Although, residues and excretion in the grasslands contribute to an enhance SOC (soil organic carbon) (Bol et al 2004; Sheikh et al 2014), the challenge is application of intensive management practices, specifically afforestation or reforestation which are able to absorb and fix carbon in tree biomass. In another manner, among land-use covers, grasslands are more evident contributor to the unyielding emission of atmospheric carbon due to non-development of forest stands which are potentially considered to store most of the carbon other than the soil.

Table 3

Tree Biomass Density for each tree classification using Brown & Banaticla estimates

Biomass density (Mg ha^{-1})			
Secondary forest	*Brown*	*Banaticla*	*Mean*
Sapling	2.85	3.17	3.01
Pole	128.95	89.63	109.29
Standard	216.34	111.95	164.15
Total	348.14	204.76	*276.45*
Mahogany plantation	*Brown*	*Banaticla*	*Mean*
Sapling	2.99	3.47	3.23
Pole	253.64	177.95	215.80
Standard	97.39	54.51	75.95
Total	354.02	235.93	*294.98*

Aboveground biomass density. Table 4 presents the aboveground biomass production showing the mahogany plantation (295.02 Mg ha^{-1}) having the highest value followed by the secondary forest (276.50 Mg ha^{-1}) and the grassland with the lowest (0.11 Mg ha^{-1}) mainly contributed by the herbaceous vegetation and litter. Of the three aboveground biomass carbon pools, trees ranked the highest with biomass density of 99.97% followed by herbaceous vegetation of 0.02% and litter layer of 0.01%. This order of magnitude followed the pattern in aboveground biomass density of previous carbon sequestration studies which identified trees having large percentage of biomass density while herbaceous or understorey vegetation contributing the least (Pulhin 2007; Racelis et al 2008). In several studies, more than 90% of biomass is settled in bigger trees were reported (Gillespie et al 1992; Lasco 1998; Lasco et al 2005). The study of Patricio & Tulod (2010) indicated that the rate of litter layer formation and decomposition are dependent on the number of trees and area of the understorey vegetation. Adding that the process of decomposition is faster during warmer days resulting to the release of carbon sequestered in the litter layer (Patricio & Tulod 2010). In this study, the mahogany plantation is observed to be in contradiction with the latter statement, because the area is cooler due to canopy closure. Hence, slower decomposition of litter layer in the plantation and has comparable biomass with the secondary forest but slightly higher than the grassland. Even so, all the selected vegetation covers had minimal litter biomass because decomposition is a progressive activity regardless of sunlight amount. On the other hand, the overlapping crowns causing low light availability to the forest floor has led to the suppressing growth of ground vegetation and seedling emergence (Racelis et al 2008; Odiwe et al 2012), which is also the reason in the minimal growth of herbaceous vegetation in the mahogany plantation consequently obtaining the very least (0.01 Mg ha^{-1}) in biomass production for this carbon pool among other vegetative covers.

Table 4

Aboveground biomass density of the three different vegetative covers

Aboveground biomass density (Mg ha^{-1})				
Land cover	*Tree*	*Herbaceous vegetation*	*Litter layer*	*Total AGB density*
Secondary forest	276.45	0.03	0.02	276.50
Mahogany plantation	294.98	0.01	0.02	295.02
Grassland	0	0.09	0.01	0.11
Mean	190.48 (99.97%)	0.04 (.02%)	0.02 (0.01%)	190.54

Note: Tree Biomass Density in the different covers are mean values from two equation estimates. Shown in parentheses are composition of carbon pools for the aboveground biomass.

Moreover, the tree biomass of the mahogany stand in CMU (Tulod 2015) and the mahogany plantation in this study showed similar results as to the total aboveground biomass with 262.10 Mg ha^{-1} and 295.02 Mg ha^{-1}, respectively. The herbaceous vegetation and litter layer in both studies shared insignificant amounts in the final aboveground production of biomass and is consistent with the observations of Lasco et al (2005) & Pulhin (2007). The secondary forest in this study having a total of 276.50 Mg ha^{-1} aboveground biomass is comparable with the results reported from the tropical forest of Thailand (Terakunpisut et al 2007) and Singapore (Ngo et al 2013) with corresponding values of 275.46 Mg ha^{-1} and 209.04 Mg ha^{-1}, respectively. But, far lower than the second growth forest studied by Tulod (2015) with 451.17 Mg ha^{-1} total aboveground biomass. While the grassland in this study which had carabao grass (*Paspalum conjugatum*) as the dominant vegetation cover had lesser aboveground biomass (0.11 Mg ha^{-1}) compared with the grassland abundantly inhabited with *Imperata cylindrica* as observed by Lachica-Lustica (1997) which had 1.7 Mg ha^{-1} (Lasco & Pulhin 2009) and a grassland in Indonesia with 6.0 Mg ha^{-1} (Prasetyo et al 2000 as cited by Lasco 2002).

In addition, the total aboveground biomass in the mahogany plantation and the secondary forest were most likely similar due to small difference in number of trees recorded. Nevertheless, the mahogany plantation held the highest since tree harvesting is restricted in the area, allowing stands to reach their mature stage, accumulating much greater biomass density. Secondary forests, on the other hand, are the main source of logs and timber (Lasco & Pulhin 2003) as a result of severe pressure typically initiated by logging activities in the Philippines (Lasco & Pulhin 2009). In this study, the secondary forest had moderate cutting of trees used for timber production; hence, lesser biomass production. In the grassland, its total aboveground biomass is much lesser compared with the two stands because of magnitude of disturbance from grazing animals and non-cultivation of forest trees. These findings affirm the inferred statement of Lugo & Brown (1992), that the more disturbed a forest is, the lesser biomass accumulated and vice-versa (Racelis et al 2008).

Carbon stock in trees. Standard-sized trees in the secondary forest recorded the highest biomass (164.15 Mg ha^{-1}) (Table 3) which accounted also the highest carbon accumulation (73.87 Mg ha^{-1}) (Table 5). The same pattern can be gleaned from the mahogany plantation where pole-sized trees accumulated the highest biomass density hence, more carbon is stored (97.11 Mg ha^{-1}) among other sizes. These results are in agreement with the findings of Tulod (2015) where carbon stock usually varies with the amount of biomass produced; hence, the larger the biomass, the larger is the stored carbon. Furthermore, the average carbon stock in trees is consistent with the order of magnitude in biomass density for both sampling areas. In this regard, the mahogany plantation as a whole, obtained the highest biomass density directly implying the largest carbon stocks were in trees, amounting to 132.75 Mg ha^{-1}.

Table 5

Carbon stored in each tree classification of the three selected vegetative covers

	Carbon stored (Mg ha^{-1})			
Vegetative covers	*Sapling*	*Pole*	*Standard*	*Total*
Secondary forest	1.36	49.18	73.87	124.41
Mahogany plantation	1.46	97.11	34.18	132.75
Grassland	0	0	0	0

In comparing the mean carbon stored among sapling, pole and standard-sized trees, ANOVA was used (Table 6). Results revealed a p value < 0.05 for the two forest covers, which indicated significant difference in carbon accumulation among younger to older stands. Specifically, the capacity of trees in secondary forest to store carbon does not vary from sapling to pole but revealed a significant difference when it reached standard-sized. While in the mahogany plantation, carbon accumulation varies only between sapling and standard-sized trees. This can be further explained by the fact that secondary forest and mahogany plantation both have great differences in carbon accumulation from sapling to standard sized, where sapling stage in both covers accumulated the least. It was also noted that mature trees contained most of the carbon which is reflected in the secondary forest; but in the case of the mahogany plantation, it was influenced by higher number of pole trees resulting to a greater total carbon stock compared with the standard-sized trees (Table 5).

Table 6

Analysis of variance for differences in the mean carbon stored among tree classifications in the two stands

	Secondary forest		*Mahogany plantation*	
	Total carbon stored	*Mean carbon stored*	*Total carbon stored*	*Mean carbon stored*
Sapling	1.36	0.16[a]	1.46	0.34[a]
Pole	49.18	2.56[a]	97.11	2.04[ab]
Standard	73.87	9.63[b]	34.18	3.31[b]
F-value	22.18		5.24	
P-value	< 0.01		0.006	

Note: Means followed by the same letter are not significantly different from each other at 5% level. Total carbon stored in each tree classification are values from Table 5.

Total carbon stored. Table 7 shows the total carbon stored in the different carbon pools of the three vegetative covers. Mahogany plantation registered the highest with 228.15 Mg ha^{-1}. This value is similar with reported carbon stored of mahogany stand in Makiling, which obtained 254.2 Mg ha^{-1} (Lasco 2001). Both are higher than the estimated capacity of a 25-year-old mahogany farm in Leyte which stored a total carbon of 158.8 Mg ha^{-1} (Sales et al 2005), but lower than the large leaf mahogany in Mt. Makiling which registered a total of 542.05 Mg ha^{-1} carbon stock (Racelis et al 2008). The secondary forest accumulated 210.89 Mg ha^{-1}. Interestingly, it is in proportion with the carbon accumulated of the unlogged or mature dipterocarp trees in the Philippines with a total of 258 Mg ha^{-1} (Lasco et al 2005) and with secondary tropical forest in Singapore which reported a total carbon stock of 274.2 Mg ha^{-1} (Ngo et al 2013). In this study, it is interesting to note that the mahogany plantation is comparable to the secondary forest in its carbon accumulation capacity with a percent difference of only 7.86%. Although both forests had potential for carbon sequestration, better silvicultural practices enhancing carbon stocks is an advantage in plantation forestry over a natural forest (Baishya et al 2009; Kaul et al 2010).

Table 7

Carbon stored in the carbon pools of the different land covers

	Carbon stored (Mg ha^{-1})				
Land cover	*Tree*	*Herbaceous vegetation*	*Litter layer*	*Soil*	*Total*
Secondary forest	124.41	0.0108	0.007	86.46	210.89
Mahogany plantation	132.75	0.0031	0.01	95.39	228.15
Grassland	0	0.0323	0.0058	32.55	32.59

Note: Carbon stored in trees in each vegetative cover are total values from Table 5.

Meanwhile, the grassland yielded a total carbon of 32.59 Mg ha^{-1} (mainly from soil carbon pool), far higher than the grassland area of smallholder tree farms in Leyte which contained 12.1 Mg ha^{-1} (Sales et al 2005). Among the selected vegetative covers, grassland registered the lowest carbon stock. This can be attributed to the absence of trees, land-conversion, constant grazing and indifference of farmers to improve site conditions. Moreover, studies on deforested lands covered with grasslands had quantified carbon stocks but is way lower than the primary forest revealing deforestation as the main reason for the huge amount of carbon lost and due to the lack of economic activity such as tree farming or reforestation (Lasco & Pulhin 2009 as cited by Lasco et al 2007). Although the grassland in this study contained the least carbon stored, it is by no means considered less important. The solution is sustainable forest management with conservation strategies such as afforestation and reforestation which helps in alleviating the warming of the environment at the micro climatic and global levels (Sales et al 2005) while improving the potential of grassland ecosystem in carbon sequestration. It is therefore suggested to convert this land-use type with modest carbon stock into plantations. However, selection of tree species in activities as such must also be considered for its major factor in influencing carbon sink affecting the amounts of carbon accumulated in both biomass and soil which significantly contributes in mitigating CO_2 emissions (Perez-Cruzado et al 2012).

Vucetich et al (2000) and Pussinen et al (2002) determined that carbon stocks depend upon the tree species, site properties, spacing, micro climate conditions and age class distribution (Kaul et al 2010) in an area. Of the four carbon pools, most of the carbon were found in the soil and in the tree biomass (Figure 3). For instance, in the secondary forest, carbon stored in the soil comprised 40.9% while the rest were stored in the tree biomass. The same is true with the mahogany plantation with 41.8% in soil and the 58.2% in the trees. The results agreed with the data reported by Lugo & Brown (1992); Moura-Costa (1996), where the soil was found to store at least 30% of total forest carbon or as much as the biomass, as cited by Sales et al (2005) and Racelis et al (2008). However, it is a little lower compared with findings of Lasco & Pulhin (2006) who reported that more than 50% of total carbon stored in forest ecosystem is contained in the soil. Sales et al (2005) claimed that carbon storage in tropical soil decreases as the stand matures because carbon is locked up in the tree biomass. Therefore, both forest stands already have enough number of mature trees where higher amounts of carbon stored are expected in trees compared to the soil. Nevertheless, carbon stored in the soil is still high implying a good site condition. Furthermore, soil carbon stocks in these forest covers were enhanced by grass material present in the area since it incorporates more rapidly than forest floor material into soil organic matter (Andrade et al 2008; Laungani & Knops 2009; Perez-Cruzado et al 2012). Nevertheless, increase in litter production and harvest residues collectively known as forest floor material also influences increase in SOC, thereby improving the function of a forest as carbon sink (Kaul et al 2010).

On the contrary, most of the carbon stored in the grassland are found in the soil (99.9%) with only 0.1% in the herbaceous vegetation and 0.02% in the litter layer. Carbon accumulation in grassland ecosystems occurs mostly below ground (Soussana et al 2004; Sheikh et al 2014); in this research, only in the soil since root biomass is excluded. This is expected since the area had minimal herbaceous vegetation and no tree species were found. Soil organic carbon in the grassland is enhanced due to plant material consumed by herbivorous animals followed by excretion, which then enters the soil (Bol et al 2004; Sheikh et al 2014). Furthermore, Lugo & Brown (1993) stated, that carbon in the soil has the longest residence among other pools in the forest (Lasco & Pulhin 2009). Soil organic dynamics is also affected by the change in land use (Lasco 2002) and soil management practices, although the mechanisms and processes of carbon sequestration in soil are still not completely understood (Lal et al 1995; Bajracharya et al 1998 as cited by Bijaya 2008). Similarly, Ngo et al (2013) reported that soil carbon stocks may increase or decrease after land-use conversion depending on soil type and precipitation. In this regard, conservation, especially of mature trees and prevention in land-use degradation will positively accumulate biomass and carbon in the two most important pools, the tree and the soil.

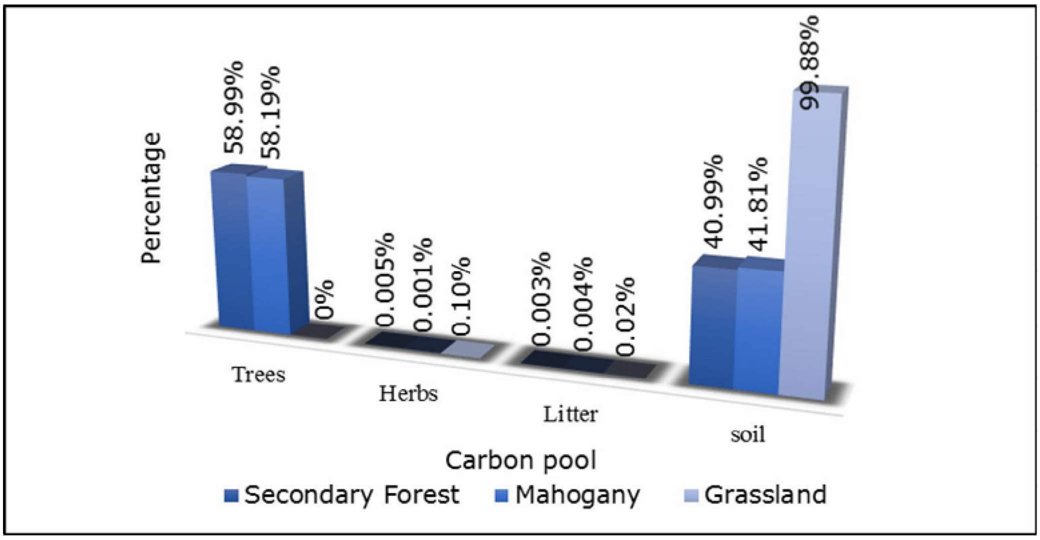

Figure 3. Percent distribution of carbon stored in carbon pools of the different vegetative covers.

The contribution of herbaceous vegetation and litter layer to the carbon stock for all vegetative covers were minimal which accounted to less than 1%. This is comparable with findings of percent carbon stored in herbaceous vegetation of the large-leaf mahogany and dipterocarp forest in Mt. Makiling forest reserves with 0.21% and 0.40% (Racelis et al 2008), respectively. However, carbon stored in the litter layer of the same study area is higher with 3.39% and 2.72%. These carbon pools are the lowest in carbon accumulation. Moreover, the secondary forest and the mahogany plantation contained high trees and large canopies preventing the sunlight to go through the understorey vegetation resulting to lesser growth of herbs and lesser carbon stored. The litter will gradually be accumulated on the forest floor and carbon will be transferred eventually to the soil through decomposition. For grassland, which is an open area, the herbaceous vegetation is constantly consumed by grazing animals. The litter layer is easily decomposed because of direct sunlight releasing carbon into the soil and to the atmosphere.

Conclusions and recommendations. Results of the study indicated that the three vegetative covers potentially accumulate carbon ranging from 32.59 Mg ha^{-1} to 228.15 Mg ha^{-1}. Total carbon stocks were greatest in mahogany plantation followed by secondary forest, then the grassland. It is also revealed that most of the carbon is settled in bigger trees, particularly in standard sizes. However, in the mahogany plantation pole-sized trees outnumbered the standard-sized trees influencing the total carbon stored. Of the carbon pools, majority of the carbon in the two stands (mahogany plantation and secondary forest) were found in trees than in the soil indicating mature trees in both sites where carbon is tied up which consequently decreased quantified carbon in the soil. In contrast, grassland soils held the largest amount of carbon, apparently because stands were not present in the area. Knowing the greater capacity of carbon build-up in the vegetative covers with stands, this study propose afforestation or reforestation in the grasslands. The study also showed that the variation in carbon accumulation may be due to tree species, age, site conditions and ecosystem management. Therefore, it is possible to select and establish one forest type in an area where it is most suitable for carbon sequestration. Further, secondary forests are cheaper to establish and maintain as compared to plantations and, at the same time it shows a higher potential for biodiversity conservation. However, plantation forests have an advantage over a secondary succession forests because the latter contains slow-growing species while plantation forests store carbon at a faster rate with shorter rotation increasing carbon accumulation. In this regard, reforestation programs should not only rely on fast growing species such as mahogany stand because its capability in sequestering carbon at faster rate is not an assurance that they can store higher carbon. In fact, they stored less than slow growing species for their lower wood density. Aside from that, the concept of biodiversity was not adapted following a uniform species being developed. With divergence in information, both plantation forest and secondary forest in this study are commendable since they conserved high rates of carbon which is considered a good practice. However, sustainable forest management still needs to be enhanced. Otherwise, it will not be an effective tool in mitigating climate change. Moreover, to refrain from deforestation or logging, protective measures should also be in the scope of implementation as a main policy preventing forest degradation.

Similar research should be conducted with an increased sampling area to enhance and provide more accurate data of these vegetative covers in carbon sequestration and storage potentials. Future assessment in the capacity of silvicultural management practiced in the area will also be an interesting area of study in relation to carbon storage.

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