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Carbon stock assessment of three different forest covers in Panaon, Misamis Occidental, Philippines

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Key words: Carbon pools, Allometric equation, Biomass density, Carbon stock.

Abstract

Carbon pools play significant roles in reducing the carbon dioxide in the atmosphere which is one of the identified greenhouse gases. For climate change monitoring schemes, studies on C sinks are being conducted to estimate the global C stock inventories. In this study, non-destructive method was used (except for the vegetation) to assess the C stock of the three different forest covers in Panaon, Misamis Occidental. These three covers are secondary forest, riparian forest and plantation. Using the mean of the three allometric equations (Brown, Banaticla and Kenzo), biomass densities of the trees were determined. Carbon stocks were then calculated for each forest cover. Results showed that secondary forest had a mean tree biomass density of 641.04 MgC/h (57.53%), mahogany plantation with 280.82 Mg/h (25.19%) and riparian with 192.59 Mg/h (17.28%). The C stocks estimated on the three forests covers were: 400.57 MgC/h (55.11%), 166.18 MgC/h (22.92%) and 159.70 MgC/h (21.97%) – for secondary, riparian and plantation forests, respectively. In the secondary forest, the aboveground C stock estimated was 288.47 MgC/h (72.03%) while the soil had 112.04 (27.97%) MgC/h. In the riparian forest, 86.69 MgC/h (54.28%) is accounted by aboveground biomass while 73.01 MgC/h (45.72%) was stored in the soil. Meanwhile, in the plantation, the aboveground biomass had C stock of 126.42 MgC/h (75.89%) while the soil had 40.17 MgC/h (24.11%). The present study could contribute to the Philippine's growing database considering the few C stocks assessments done in the country.

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Introduction

Increase concentration of greenhouse gases in the atmosphere intensifies earth's warming due to its radiative blanketing effect and CO_2 effectively increases this radiative energy (Robinson *et al.*, 2007). Following this global warming effect are various catastrophes such as floods, droughts, heat waves and tornadoes which possess threats to humans (Venkataramanan *and* Smitha, 2011). Thus, there is an enormous need to mitigate such phenomena by reducing this greenhouse gases in the atmosphere. Under the article 12 of Kyoto Protocol, Clean Development Mechanism (CDM) mandated some developed countries to meet their obligation in reducing the GHG emissions by supporting developing countries to enhance their carbon sinks. Tropical forests are identified to be an efficient and effective carbon sink, thus, an attractive option for CDM (Lasco and Pulhin, 2000).

Carbon sequestration is the process of taking up carbon dioxide during photosynthesis and transferring the fixed carbon into the vegetation, litters and soils where it will be stored for longer period of time (Nair, 2012). This important function is effectively being carried out by forests which are the main sink of CO_2 in the terrestrial system. Trees sequester carbon at maximum rate on its 10-20 years (Johnson and Coburn, 2010) but older stands have greater C stocks compared to younger ones (Fonseca *et al.,* 2011). The Carbon flow in the forests is, however, a continuous recycling process where carbon is being sequestered and released back in the atmosphere through photosynthesis and decomposition process respectively (Dixon *et al.*, 1994). In many tropical forests, 50% of C is stored in the aboveground biomass and the other half is stored in its soil counterpart (Dixon *et al.*, 1994). However, in another study, 74% of the total C is stored in the forest soil (Fonseca *et al.*, 2011). Many studies also showed varied results in the C stock assessment of forest C pools (Lasco *et al.*, 2004; Gibbon *et al.*, 2010; Djomo *et al.*, 2011; Saner *et al.*, 2012). This variation in C storage in tropical forest is due to several factors including species composition, site conditions, disturbances and management practices (Dixon *et al.*, 1994). In agricultural areas, C sequestration capacity is enhanced through incorporating agroforestry practices (Schoeneberger, 2009). The application of Carbon sequestration practices offers other benefits aside from reducing the accumulated C in the atmosphere. Such practice is also associated with biodiversity conservation, soil stabilization and water and nutrient retention which in turn beneficial to local people (Murthy *et al.*, 2013).

Carbon sequestration was already discussed in number of literatures worldwide. However, Nair (2011) uncovered the gaps and challenges from the system itself down to the methodological approach for measuring carbon sequestration. Many literatures also agree on the weaknesses involved on the developed carbon estimates usually applied (Chave *et al.*, 2004; Sarmiento *et al.*, 2005). In this context, three estimates (Brown, 1997; Banaticla *et al.*, 2007; Kenzo *et al.*, 2009) in determining the tree biomass density were applied and compared. This study aimed on assessing the Carbon stored in the three different forest covers (secondary, riparian and plantation forest) in Panaon, Misamis Occidental. Each carbon pool was analysed with regards to the carbon they stored and the possible reasons that brought the differences were also discussed. Additional studies exploring new areas of research (this present study) will certainly enrich the growing database for future reference, fill in the data gaps and bring the topic into much wider audience and recognition.

Materials and methods

Study site

Misamis Occidental is a province located in the northern part of Mindanao. It is separated from Lanao del Norte by Panguil bay to the south, from Misamis Oriental by Iligan bay to the east, by Mindanao sea in the northeast and bordered Zamboanga del Norte and Zamboanga del Sur in the west. Since the province is surrounded by bodies of water, it has long coastal area. The province also has hilly and rolling lands. One of its 14 municipalities is the municipality of Panaon. It is a fifth class municipality of Misamis Occidental with 16 barangays. Panaon has tropical climate and has significant amount of rainfall annually. Its average rainfall is 2,698 mm/year and its average temperature is 27.3ºC/year. The driest month is in April and most precipitation falls during November. The study area involved three different forest covers in Panaon Misamis Occidental (Figure 1).

Fig. 1. Map showing sampling areas.

The first site is a secondary forest situated in barangay Baga (8º 36' N and 123º 785' E). It has an elevation of 256 masl and is estimated to cover 2 ha of the vegetation. The second site is a riparian forest (8º 359' N and 123º 83' E) located in barangay Villalin with the elevation of 19 masl. The third site is a Mahogany plantation (8º 36' N and 123º 82' E) in barangay Mohon. It has an elevation of 69 masl and covers an area of 1.5 ha.

Methodology

For plot selection, a "nested" sampling approach (Fig. 2) was followed as applied by Hairiah *et al.* (2001). Nested plots suit better to stands with wide range of diameters and trees growing at different rates (Pearson *et al.*, 2007). A 200 m² (5m × 40m) was established in each of the sampling site. In all forest types sampled, trees with DBH (diameter at breast height) greater than 30 cm were observed thus, bigger 2000 m² (20m × 100m) quadrats were established in each of the sampling areas. Two 2000 m² quadrats were laid out in each forest type and each tree's DBH inside the quadrat were noted.

Tree Biomass

Tree biomass with DBH >5 cm was calculated using the general allometric equation formulated by Brown (1997):

$$Y\,(kg) = \exp\{-2.134 + 2.53 * \ln * D\}$$

Where:

Exp {...} = "raised to the power of"

ln = natural log of (...)

Y = biomass per tree in kg

D = diameter at breast height

Tree Biomass Density = Tree biomass/sample area in hectare.

However, the use of Brown's general formula can lead to overestimation of C stock (Hairiah *et al.*, 2001;

Labata *et al.*, 2012). Thus, in the study, two other estimates were employed. Banaticla's equation from Philippine wood samples was used (Banaticla *et al.*, 2007) with the following allometric equation:

$Y = 0.342\ D^{2.073}$
Where: Y = Biomass of the tree
D = Diameter at breast height

Another allometric equation derived from the information taken in the secondary forests in Sarawak, Malaysia was also employed in the study of Kenzo *et al.* (2009) which is as follows:

$Y = 0.1044 * D^{2.36}$
Where: Y = Biomass of the tree
D = Diameter at breast height

Carbon density in tree biomass was calculated using the following formula with a default value of 45% (Sales *et al.*, 2004).

C stored (MgC ha^{-1}) = Tree biomass density * Carbon content.

Mean values from the estimates applied were used to estimate the C stock or C density of the tree biomass.

Understory biomass and litter layer
Within the established 200 m^2 (5m × 40m) quadrat, four 1 × 1 m quadrats and eight 0.5 × 0.5 m quadrats (Fig. 2) were established for sampling the understory vegetation and litter layer respectively (Mcdicken, 1997; Hairiah *et al.*, 2001). Vegetation which had a dbh of <5 cm was harvested. The collected plants were weighed in the field and a sample of about 300 g was taken for oven-drying. Litter layer was collected and a sample of 300g was taken for oven drying. Oven drying was set at 80°C for at least 40 hours or until stable weight was reached. The total dry weight was calculated using the following formula (Hairiah *et al.*, 2001):

$$\text{Total dry weight (kg/m}^2) = \frac{\text{Total fresh weight (kg)} \times \text{Subsample dry weight (g)}}{\text{Subsample fresh weight (g)} \times \text{Sample area (m}^2)}$$

The carbon content of the vegetation and the litter layer was determined at the International Rice Research Institute Analytical Service Laboratory (IRRI-ASL) using the ROBOPREP C-N Biological Sample Converter. After determining the carbon content, carbon storage was calculated using the formula (Lasco *et al.*, 2006; Labata *et al.*, 2012):

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

Soil Samples
The bulk density was determined by collecting undisturbed soil cores with the soil corer having a diameter of 5.5 cm and a length of 7.2 cm. Soil sample was initially air-dried and oven-dried at 102 °C for at least 40 hours or until stable weight. Bulk density was computed using the following formula (Patricio and Tulod, 2010):

Bulk density (g/cc) = Oven-dried weight of soil/Volume of soil corer
Where: Volume of soil core $= \pi r^2 h$

A soil sample of 1 kg from the depth of 0-30 cm was taken from the sample plot (Hairiah *et al.*, 2001). The soil was sieved through 5-mm mesh screen and was mixed to uniform color and consistency. A sample of 0.5 kg was taken to the College of Agriculture Analytical Service Laboratory of the Mindanao State University (MSU) - Main Campus for chemical analysis. The analysis of soil organic carbon (SOC) content was determined using the Walkley-Black procedure (FAO, 2002). Carbon density was determined using the following formula (Patricio and Tulod, 2010).

Carbon density (Mg ha^{-1}) = weight of soil * %SOC

Where: Weight of soil (mg) = Bulk density * Volume of 1 hectare
Volume of 1 hectare = 100 m × 100 m × 0.30

Statistical analysis
Data were analysed using Excel 2007 and PAST

software. Simple descriptive statistics were employed to describe the data gathered. Data were tested for normal distribution using Shapiro-Wilk test. Analysis of variance (ANOVA) was used to differentiate the biomass estimated out of three allometric equations applied (Brown, Banaticla and Kenzo), as well as the mean C stocks of the three estimates were computed. Mean separation was done using the Tukey's test at 5% level of significance.

Results and discussion

Stand density, DBH and tree biomass density

Among the three forest types, plantation forest had the highest stand density of 2,410 trees/h (Table 1).

Table 1. Comparison of stand density and DBH of the three forest types.

Forest type	Number of trees/h	DBH range (cm)	Mean DBH (cm)
Secondary Forest	1,815	1.59-181.53	16.16
Riparian Forest	1,795	1.91-112.10	11.70
Plantation Forest	2,410	1.91-57.32	18.55

This is understandable because compared to the other two natural forests, plantation forest is following a certain spacing required for certain species. On the other hand, secondary and riparian forests have almost the same stand density of 1, 815 and 1,795 trees/h, respectively. This can be explained by the random arrangement of trees in these forest types where some patches may only be dominated by understory vegetation. Table 1 shows that plantation forest was found to have the highest mean DBH of 18.55 cm. However, it can be observed that it also had the narrowest DBH range of 1.91-57.32 cm. Trees in the plantation forest are most likely of the same age resulting to almost uniform DBH. Meanwhile, secondary forest with DBH range of 1.59-181.53 cm and riparian forest with DBH range of 1.91-112.10 cm. indicates that old stands still exists in the area while younger stands are starting to be established naturally.

Table 2. Analysis of variance for the differences in the total and mean tree biomass densities (Mg/h) from the three allometric estimates among three forest types.

Forest type	Brown	Banaticla	Kenzo	F-value	P-value
Secondary Forest	6.01^{a}	2.16^{b}	2.42^{b}	5.675	<0.005
Riparian Forest	1.67^{a}	0.80^{b}	0.75^{b}	4.294	<0.02
Mahogany Plantation Forest	1.64^{a}	1.03^{b}	0.82^{c}	47.37	<0.001
Mean	3.11	1.33	1.33		

Note: mean values followed by different letters indicate significant difference (Tukey's test, $p<0.05$).

Fig. 3 shows the distribution of DBH classes in each forest type. In secondary forest, the greatest percentage of the trees (71%) was accounted by DBH class of 1-10 cm. It was followed by 10-20 cm DBH class composing 12% of the trees. It is important to note that 8% of the trees have DBH of 50 cm above which implies that old aged trees, as indicated by large DBH, are still present while young trees dominated the area. The maximum DBH recorded was 181.53 cm. In the riparian forest, 63% of the trees were under the DBH class of 1-10 cm, 23% for 10-20 cm DBH class and 6% for 20-30 cm DBH class. Meanwhile, in the plantation forest, the distribution in each DBH class did not differ widely. The greatest percentage of 32% are accounted by 20-30 cm DBH class, 27% for 10-20 cm DBH class, 25% for 1-10 cm DBH class, 14% for 30-40 cm DBH class and only 2% of the trees have DBH 40 cm above. This variation in the DBH classes indicates that the trees are not planted all at once as reported.

Table 3. The contribution of DBH classes to the tree biomass densities of the three forest types.

DBH class	Tree Biomass Densities Mg/h			
	Secondary Forest	Riparian Forest	Plantation Forest	Mean Biomass
0-10	7.78	4.68	1.04	4.5 (1.21%)
10-20	8.04	14.74	33.00	18.59 (5.01%)
20-30	15.80	13.68	109.57	46.35 (12.48%)
30-40	9.56	14.83	105.79	43.39 (11.68%)
40-50	29.72	21.56	26.10	25.79 (6.94%)
50 above	570.13	123.08	5.26	232.82 (62.68%)
Total tree biomass	641.04	192.56	280.76	371.45

The choice of allometric equation to be applied can significantly affect the tree biomass calculation (Moore, 2013). Brown's estimate which is generally used in calculating tree biomass has been applied in various studies (Lasco *et al.*, 2002; Labata *et al.*, 2011). However, the equation tends to overestimate tree biomass density (Banaticla *et al.*, 2007; Labata *et al.*, 2012). In this study, other two estimates were employed, specifically Banaticla (2007) and Kenzo (2009). Banaticla's estimation was derived from the destructive sampling of plantations in several parts of the Philippines (Banaticla *et al.*, 2007) while Kenzo's estimation was formulated by sampling the tropical secondary forest of Sarawak, Malaysia (Kenzo *et al.*, 2009).

Table 4. Aboveground biomass densities of the three forest types.

Forest type	Biomass densities in various aboveground C pools (Mg/h)			Total biomass density (Mg/h)
	Tree biomass	Herbaceous layer	Litter Layer	
Secondary Forest	641.04	0.02	0.02	641.08
Riparian Forest	192.56	0.01	0.01	192.58
Plantation Forest	280.76	0.03	0.03	280.82
Mean	371.45 (99.9%)	0.02 (0.005%)	0.02 (0.005%)	371.49

Fig. 4 shows the effect of allometric equation applied to the tree biomass density. In each allometric equation, increasing DBH shows an increase in biomass estimates (Moore, 2013). It can be noticed that Brown tend to overestimate tree biomass and among the three estimates, it is the most sensitive to DBH change as shown in its slope. Meanwhile, Banaticla's estimate can be described as the most conservative estimate (Moore, 2013) which is the least sensitive to DBH change. Brown gives the mean estimation of 3.11 Mg/h on the three forests. This is more than twice Banaticla and Kenzo with equal mean estimation of 1.33 Mg/h (Table 2). In secondary forest, there's no significant difference observed between Kenzo and Banaticla. However, Brown's estimate of 6.01 Mg/h is significantly higher than the Banaticla and Kenzo with estimates of 2.16 and 2.42 Mg/h, respectively.

Table 5. Carbon stored in the carbon pools of the different land covers.

Forest Type	C stored in various pools (MgC/h)				Total C stored(MgC/h)
	Tree Biomass	Herbaceous Layer	Litter Layer	Soil	
Secondary Forest	288.47 (72%)	0.0084 (<0.1%)	0.0532 (<0.1%)	112.044 (27%)	400.57
Riparian Forest	86.65 (54%)	0.0054 (<0.1%)	0.0328 (<0.1)	73.007 (45%)	159.70
Plantation Forest	126.34 (76%)	0.0130 (<0.1%)	0.0674 (<0.1%)	40.166 (24%)	166.59
Mean	167.15 (68.99%)	0.01 (0.004%)	0.05 (0.02%)	75.07 (30.98%)	242.28

The same comparison was also observed in riparian forest where Brown's estimation of 1.67 Mg/h is higher than Banaticla (0.08 Mg/h) and Kenzo (0.75 Mg/h). For plantation forest, the three estimates significantly differ from each other and among the three, Brown had the highest estimation of 1.64 Mg/h.

Table 3 shows that the highest biomass density of 641.04 Mg/h can be observed in secondary forest. 570.13 Mg/h (88.94%) of its total tree biomass was accounted by the trees with DBH range of 50 cm above. This is followed by 40-50 cm DBH class with mean tree biomass density of 29.72 Mg/h. However, the 0-10 cm DBH class which comprises the 71% (Fig. 3) of the trees in the secondary forest had the biomass density of 7.78 Mg/h. The highest biomass density is attributed by trees with the large DBH, specifically, 50 cm above. Although such DBH class represents only 8% of the trees, it contributes the highest biomass among other DBH. These results indicate that tree biomass in the secondary forest is being determined by the tree DBH. In the riparian forest, from the mean tree biomass density of 192.56 Mg/h, the highest percentage of 123.08 (63.92%) was estimated from trees with DBH 50 cm and above which contributed 4% of the trees in the forest. It was then followed by 40-50 cm DBH class with biomass density of 21.56 Mg/h.

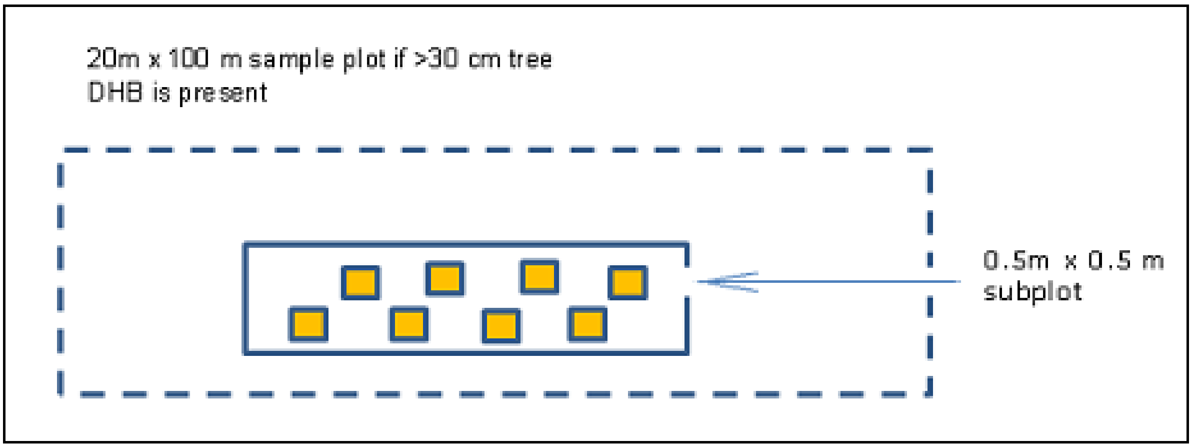

Fig. 2. Nested plot sampling design for tree, herbaceous and litter biomass (Hairiah *et al.*, 2001).

The DBH class of 0-10 cm which comprised 63% of the trees in the riparian forest had the lowest biomass density of 4.68 Mg/h. Like the secondary forest, the biomass density was being determined by tree DBH in this forest type. The presence of large trees in the area greatly affects the total biomass density estimation. The estimated biomass density of the riparian forest is 192.56 Mg/h. In the plantation forest, the biomass densities of trees under the DBH classes 20-30 cm and 30-40 cm with values 109.57 Mg/h and 105.79 Mg/h, respectively, are almost the same. The DBH class 20-30 cm represented 32% of the mahogany trees and the 30-40 cm comprised 14%. It was followed by 10-20 cm DBH class with biomass density of 33 Mg/h. The 0-10 DBH class had the least value of 1.04 Mg/h. The mean tree biomass of the three studied forest covers is 371.45 Mg/h. The result that 98.79% of the mean biomass is accounted by trees with DBH >10 cm is found to be consistent in the general pattern of forest biomass where trees with DBH >10 cm contained ≥96% of the forest biomass (Gillespie *et al.*, 1992 as cited by Lasco *et al.*, 2006). The greatest biomass of 232.82 Mg/h (62.68%) is accounted by trees with DBH >50 cm.

Aboveground biomass densities

Table 4 shows that the tree biomass had the mean biomass density of 371.45 Mg/h which contributes 99.9% of the total biomass density in the aboveground. The herbaceous layer had mean biomass density of 0.02 Mg/h accounting 0.005% of the total aboveground biomass. This value is lower compared to Mt. Makiling which had biomass density of 0.22 Mg/h in the herbaceous component comprising the 0.04% of the total aboveground biomass (Lasco *et al.*, 2004). Plantation forest was found to have the highest herbaceous biomass density of 0.03 Mg/h compared with 0.02 Mg/h in the secondary forest and 0.01 Mg/h in the riparian forest, respectively. This is because sufficient light can still penetrate in the plantation forest floor while the closed canopy in the secondary forest limits the herbaceous vegetation growth.

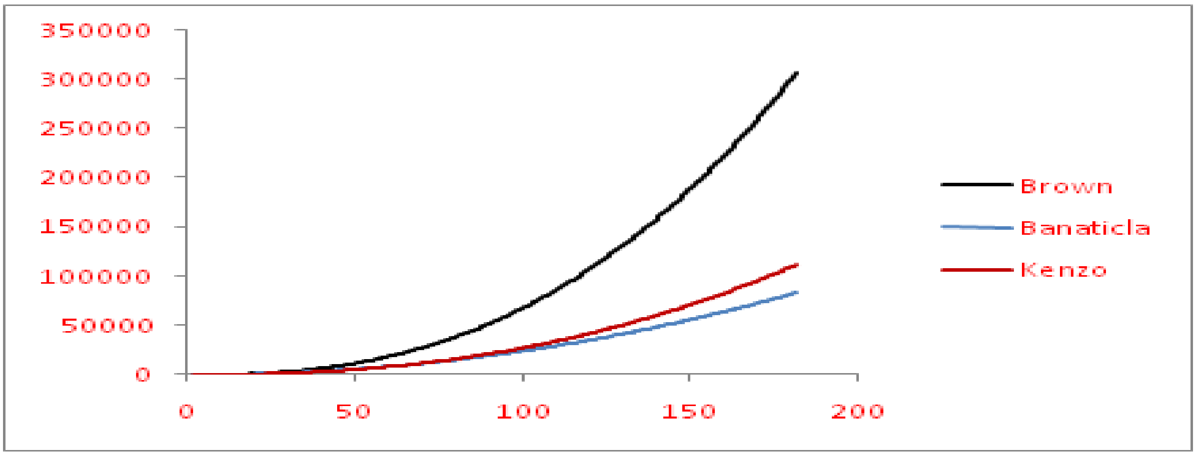

Fig. 3. Effect on biomass density estimates with the allometric equations (Moore, 2013).

The riparian forest had the least herbaceous biomass density (0.01 Mg/h) because compared to the other two forests types, it is the most disturbed one. It served variety of purposes for the residents nearby such as for recreation, agriculture and domestic purposes. The litter layer had a mean biomass density of 0.02 Mg/h. The order of magnitude in the litter layer is the same with the order in herbaceous component. Plantation forest had still the highest biomass of 0.03 Mg/h in the litter layer followed by 0.02 Mg/h in the secondary forest and the riparian with the least value of 0.01 Mg/h. This can be attributed by the number of trees present in the area. Plantation forest had the highest stand density of 2,410 trees/h. This means that more litters can be inputted by this dense plantation forest compared to secondary and riparian forest, respectively. Riparian forest with the least stand density of 1,795 trees/h had also the lowest biomass in the litter layer. In general, the highest biomass density in the aboveground can be accounted by the tree biomass which is supported by various studies in Philippine forests (Lasco *et al.*, 2004; Lasco *et al.*, 2006).

The highest biomass density of 641.08 Mg/h observed in the secondary forest is smaller compared to the three secondary forest patches in Bukidnon which ranges from 935- 1, 096.42 Mg/h (Patricio and Tulod, 2010). These secondary forest patches in Bukidnon were assumed to be around a hundred years old and therefore their biomass densities are expected to be high considering the accumulation of biomass with age. The result is higher when compared to the tree biomass density of 538.05 Mg/h estimated in Mt. Makiling forest reserve (Lasco *et al.*, 2004).

The estimated aboveground biomass density in the secondary forest falls within the range of biomass densities in old-growth forest in the Philippines which range from 446 to1,126 Mg/h (Lasco *et al.*, 2000 as cited by Lasco *et al.*, 2006). This highest biomass density estimated in the secondary forest when compared to the plantation and riparian forest is due to the presence of trees with higher DBH as shown in Table 2. Logging was strictly prohibited in the area, that is why large trees were preserved and these trees continued to accumulate carbon over time.

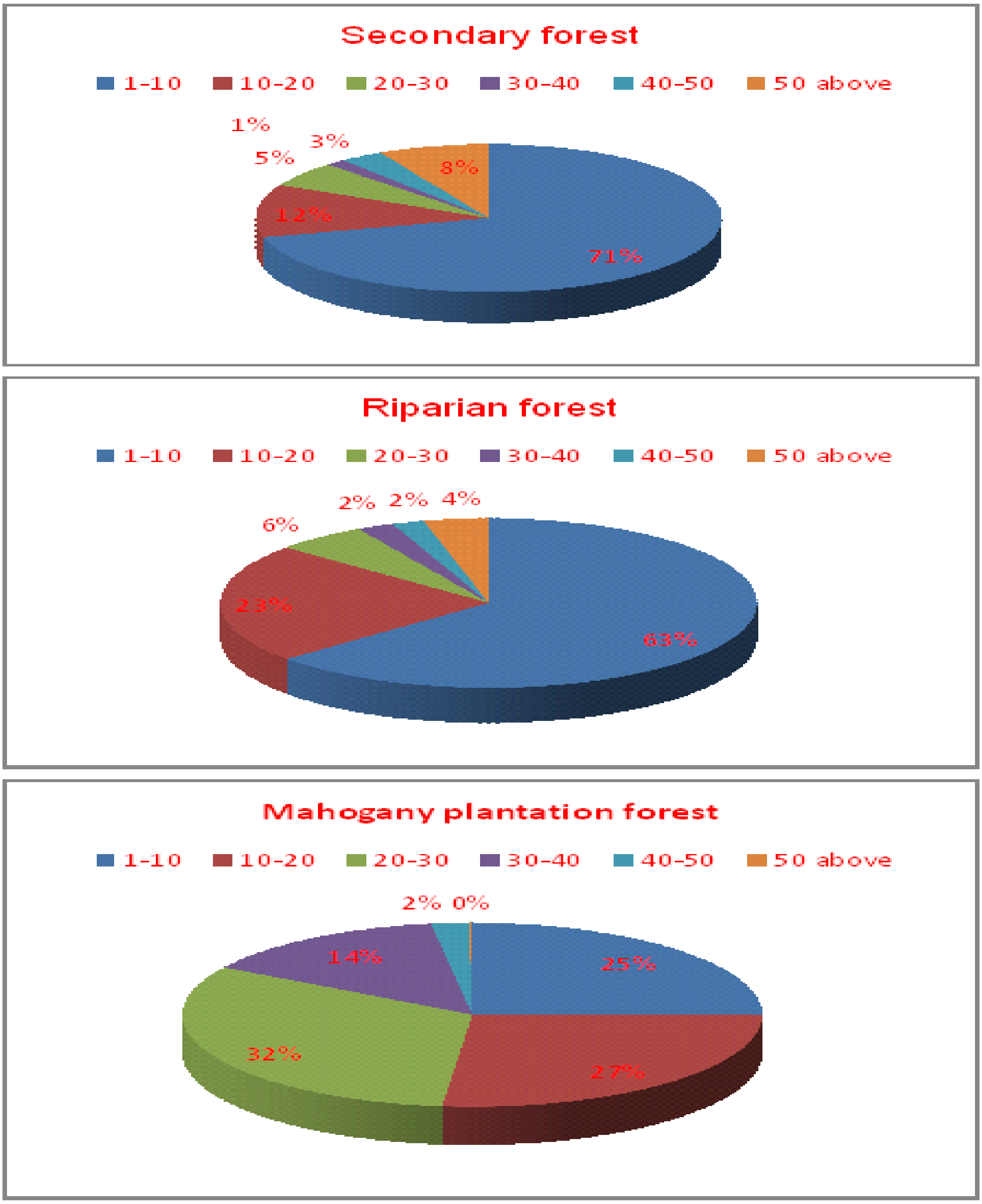

Fig. 4. DBH class composition in each forest type.

Following the secondary forest is the plantation forest. Its biomass density of 280.76 Mg/h is comparable to a 14-year old Mahogany plantation in Leyte which had an estimated biomass density of 282.66 Mg/h (Sales *et al.*, 2004). It is also comparable to various mahogany plantations in the Philippines with mean biomass density of 264 Mg/h (Lasco *et al.*, 2000 as cited by Lasco and Pulhin, 2009). Riparian forest had the least aboveground biomass density of 192.58 Mg/h. It is lower from the biomass density estimated in several natural forests in the Philippines which is 518 Mg/h (Lasco *et al.*, 2000 as cited by Lasco and Pulhin, 2009) but is comparable to *Acacia mangium* plantation in Leyte with mean biomass density of 195.84 Mg/h (Lasco *et al.*, 1999 as cited by Lasco and Pulhin, 2009). The low biomass density estimated in the riparian forest can be attributed by the trees in which 86% have DBH 20 cm and below (Fig. 3).

Total Carbon Stock

Table 5 shows that the mean carbon stock of 242.28 MgC/h of the three studied forest types, the highest carbon stock of 167.15 MgC/h (68.99%) is accounted by the tree biomass. The herbaceous layer had mean carbon density of 0.01 Mg/h which comprise 0.004% of the total carbon. Lower carbon stock results from the lower biomass density which can be brought about by limited availability of sunlight the understory vegetation needed. The mean carbon density in the litter layer is 0.05 MgC/h making up 0.02% of the total carbon. Typically, bacteria and fungi in the forest soil breaks down the litters (Liski, 2004 as cited by Patricio and Tulod, 2010). This could explain the low carbon stored in litter layers as observed in other studies (Lasco *et al.*, 2005; Patricio and Tulod, 2010; Labata *et al.*, 2011) in the country. During decomposition process of litter layer, the carbon stored in the litter layer is eventually transferred in the soil reducing the carbon stock in the litter layer and increasing the carbon stock in soil pool. Meanwhile, the soil carbon pool had the mean carbon density of 75.07 Mg/h which comprised 30.98% of the total carbon stock. This shows consistency from carbon stock assessment in various dipterocarp forests in the Philippines where a carbon stock ranging from 30-106 MgC/h was estimated in the soil pool comprising 31-52% of the total carbon in the forest (Lasco *et al.*, 2006). According to Lugo and Brown (1992) as cited by Sales *et al.* (2006), the soil pool contains at least 30% of total carbon stored in an ecosystem. The mean C stock of 242.28 MgC/h in the study is comparable to the unlogged forest in Surigao del Sur with C stock of 258 MgC/h, 34% of which is comprised by the soil pool (Lasco *et al.*, 2006) comparable with the 30.98% in the present study.

Secondary forest had the highest carbon density of 400.57 MgC/h among the three forest types. This estimate is quiet high from Lasco *et al.* (2002) estimation on the different land use in the Philippines where they estimated 111.1 MgC/h in the secondary forest. The result, however, is comparable to a reserved secondary growth forest in Mt. Makiling with calculated carbon stock of 418 MgC/h (Lasco *et al.*, 2004) and the estimated carbon stock of 393 tC/h in Leyte (Lasco *et al.*, 2002). It is also consistent with the carbon stock assessed in the secondary forest patches in Bukidnon which ranged from 450-529 MgC/h (Cubillas, 2009 as cited by Patricio and Tulod, 2010). The tree biomass had an estimated carbon density of 288.47 Mg/h contributing 72% of the total carbon in the secondary forest. Herbaceous and litter layer contributed 0.008 MgC/h (<0.1%) and 0.0532 (<0.1%) respectively. In the soil pool, a carbon stock of 112.04 Mg/h (27%) was estimated. The organic carbon in the soil is being used up by plants for their growth, thereby, transferring the carbon from the soil to the tree biomass (Chan, 2008). Cutting down these large trees could create drastic change in the carbon stock of this forest (Lasco *et al.*, 2004;Lasco *et al.*, 2006) as enormous amount of carbon is being stored in tree biomass. Next to secondary forest is the plantation forest which had carbon stock of 159.70 MgC/h. It is comparable to a 25-year old mahogany plantation in Leyte with carbon stock of 166.59 MgC/h (Sales *et al.*, 2004). The obtained estimation of plantation forest also lies within the range of C stocks analysed from the various plantations in Philippines which ranged from 35-264 MgC/h (Lasco and Pulhin, 2009). From the total C stock of 166.59 MgC/h, 126.34 MgC/h (76%) is attributed by the tree biomass, 0.01 MgC/h (<0.1%) in the herbaceous layer, 0.07 MgC/h (<0.1%) in the litter layer and 40.17 MgC/h (24%) in soil pool. The riparian forest's C stock (159.70 MgC/h) is comparable to the mahogany plantation in the study with 166.59 MgC/h. Unlike its upland counterparts, riparian forest exhibits wide range of physical variability including the canopy condition and inundation frequency and generally has lesser dense vegetation (Palik *et al.*, 2003). In a study conducted in Donau-Auen National

Park in Austria for a riparian forest, a C stock of 114.12 MgC/h was estimated (Rieger *et al.*, 2013). However, the two values are much lesser compared to C stock estimated in Danube Floodplain National Park in Austria which averaged to 428.9 MgC/h (Suchenwirth *et al.*, 2012). The tree biomass in the riparian forest stored 86.65 MgC/h(54%) carbon, 0.005 MgC/h (<0.1%) in the herbaceous layer, 0.03 (<0.1) in litter layer and 73.01 (45%) in the soil. The higher percentage contributed by the soil pool can be accounted by the lower biomass density in the riparian forest's trees as indicated by its low mean DBH and stand density (Table 1).

Conclusion

From the results of this present study, it is concluded that trees and soil, had the greatest potential to store carbon among the carbon pools while the herbaceous and litter layer stored insignificant amount of carbon. The bigger the tree DBH is, the greater the carbon stored in its biomass. The use of allometric equation in estimating the tree biomass density can provide easier and practical way of quantifying carbon stock but the choice of suitable allometric equation should be considered. In this study, Brown overestimated the biomass density and showed significant difference when compared to the other two allometric equations applied. Meanwhile, Banaticla's equation which was derived from Philippine forests secondary data could be more appropriate for carbon stock studies in the country. However, for more accurate estimation, a local allometric equation can also be developed. Additional studies quantifying C stored in other forests would be helpful to assess the overall carbon storage potential of the country.

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