Carbon Storage and Sequestration Potential of Urban Trees in Cebu City, Philippines

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Abstract

This research was conducted as a baseline study to estimate carbon density and gross sequestration rate of trees in urban areas of Cebu City, Philippines. A total of 16 sampling plots with an area of 500 m^2 were established in the north and south districts. All trees inside the plot were identified and measured. Tree biomass is the adjusted sum of aboveground biomass (AGB) using Chave's improved allometric equation and root biomass as 0.26 ratio inferred from the AGB. Pearson's correlation was performed to examine the relationship between wood density, diameter at breast height (DBH), tree height, and tree biomass. Results showed that urban tree community had low diversity and dominated by Swietenia spp., Gmelina arborea, and Pterocarpus indicus Willd. (narra). Tree biomass density and stored carbon were 195.13 Mg/ha and 87.81 Mg C/ha, respectively, lower than in primary growth and secondary forest but relatively similar to other cities in the world. Tree biomass was significantly correlated (r=0.84; p value=0.00) with DBH and (r=0.54; p value=0.00) with height but not with wood density. Gross carbon sequestration was at 9.45 Mg C/ha/yr. Using this value, it is projected that the trees at the vegetated urban areas of Cebu City can sequester approximately 14,807 Mg of carbon annually, which may be very low compared to the carbon emission of the city. Aside from source reduction and offsite carbon sequestration, it is suggested that native species such as P. indicus Willd. be given priority for the greening of Cebu City.

***Keywords**:* allometric equation, carbon stock, carbon sequestration, aboveground biomass, root biomass

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1. Introduction

Trees in the forest are valued as an important resource in the provision of goods and ecological services beneficial to humans. However, in an urban environment, trees are sometimes seen as a displaced structure and often undervalued because their ecosystem services are not quantified and understood. They are cut and eliminated to give way to new developments such as highways, buildings and others that will lead to more tangible economic benefits. Discounting the ecological services, these trees can provide in moderating greenhouse gas emission by fixing carbon dioxide during photosynthesis. They can decrease air temperatures and reduce energy consumptions in buildings and establishments, and consequently alter the level of carbon emissions from power plants (Nowak, 1993). Trees can also play a significant role in maintaining environmental quality by modulating the amount of pollutant in air and water, and reduce the volume of storm water, thus protecting humans against negative health effects and flooding (Harrabin, 2016). Moreover, when trees perform photosynthesis, they use carbon and store it as biomass, thereby acting as a sink (Lin *et al*., 2018). Increasing the number of trees might potentially slow the accumulation of atmospheric carbon and reduce the effects of global warming. This ecological benefit, however, cannot be overstated since limited evidence supported this claim (Velasco *et al.*, 2016). Scientific studies need to clearly assess this benefit in order to gain better understanding of their value in the urban setting.

Results from the study of Tang *et al.* (2016) suggested that the street trees in Beijing were carbon sink, which stored 77.1 ± 4.1 Gg C and sequestered 3.1 ± 1.8 Gg C per year, although carbon density and sequestration rate was about 1/3 ~ 1/2 magnitude compared to the non-urban forests in China. In tropical cities, vegetation may act as carbon sink (e.g. Mexico City served as a sink of 1 Mg km^2 per day) or source of carbon (e.g. Singapore contributed 0.8 Mg km^2 per day of CO_2) depending on trees species and their characteristics and soil conditions (Velasco *et al.*, 2016). In Bolzano, Italy, carbon stored ranged from 134.89 to 179.14 Mg C, whereas sequestration rate was estimated from 5.73 to 8.27 Mg C per year (Russo *et al.*, 2014). In the U.S., total carbon stored in trees of the urban forest was estimated between 597 million to 690 million tons and total annual net carbon sequestration rate was estimated at 18.9 million tons with sequestration rates per square meter tree cover of 0.28 kg $C/m^2/y$ (Nowak *et al*., 2013). Carbon stock varies from different cities. Generally, greatest positive effect in removing CO_2 from the atmosphere occurred in cities widely vegetated with healthy, large trees that have long life spans (Nowak *et al.*, 1994).

While these studies are becoming popular in major cities elsewhere (Jo, 2002; Chaparro and Terradas, 2009; Zhao *et al*., 2010; Strohbach and Haase, 2012; Nowak *et al.*, 2013), similar studies are scarce in the Philippines. Carbon stock assessment focused on secondary growth forest, tree plantation and agroforestry (Lasco and Pulhin, 2003; Schneider *et al.*, 2003). Urban trees in major cities such as Cebu City are unaccounted for their potential contribution as carbon sink or source of emission.

Cebu City, being the center of manufacturing, service industries and economic activity in the south is attracting both foreign and domestic investment to generate products for world markets. As a consequence, more population flock to the city to seek for jobs. In 2015, the total population reached 923,000. Rapid population growth contributes to increased carbon emission from transportation sector to around 38% in 2000 (Fabian and Gota, 2009). Competing demands of land for residential and commercial spaces lead to clearing of remaining patches of trees in urban areas because they are undervalued and ecological benefits are not understood.

World Wide Fund for Nature (2014) ranked Cebu City as sixth out of the 16 cities in the Philippines in terms of vulnerability to climate change impacts such as floods, storm surge, and more frequent and intense storms. It is widely believed that presence of urban trees can mitigate the effects of these disasters directly (e.g. reducing flood water, acting a buffers to big waves) or indirectly (e.g. sequestering carbon and slow down its accumulation in the atmosphere, acting as a sink by fixing carbon dioxide in the atmosphere and storing it as tree biomass) thus, preventing the effects of global warming.

This study is aimed to generate quantifiable data of carbon density and sequestration of urban tree community as baseline information for future studies (e.g. photographic imaging) in monitoring urban tree community in Cebu City and other urban areas elsewhere. The findings from this study may also be of help to inform policymakers so they can formulate sound decisions beneficial to humanity.

2. Methodology

2.1 Research Environment

The study was conducted in the urban area of Cebu City, the central eastern part of Cebu Province. It is located at 10^0 17' north and 123^0 54' east. In the north, it is bounded by Mandaue City and in the South by Talisay City while on its East is Mactan channel and the Municipality of Balamban. On its west is Toledo City. The Köppen-Geiger system classified Cebu City's climate as "Am", which is characterized by short dry season with significant rainfall in most months of the year. The average temperature is 27.5 °C while annual precipitation is about 1,607 mm.

Cebu City is classified as a highly urbanized city under the Local Government Code of 1991 (R.A. 7160) with 20% of the land area of Cebu Province (291.2 sq. km.). Sixty percent of the population (798,809 inhabitants) makes it the fifth most populous city in the entire country (National Statistical Coordination Board, 2007).

2.2 Plot Establishment and Measurement

Using the satellite image of google map, the sampling plots were purposively selected in vegetated but highly urbanized areas of Cebu City. A total of 16, 500 square meter plots (Figure 1) were established in the north (nine plots) and south (seven plots) districts of Cebu City. For open area spaces such as parks and cemeteries, a circular plot was established while along the streets, a 25 m x 20 m plot quadrat was more appropriate. A handheld Global Positioning System (GPS) (Garmin) was used to record the location of the selected plots.

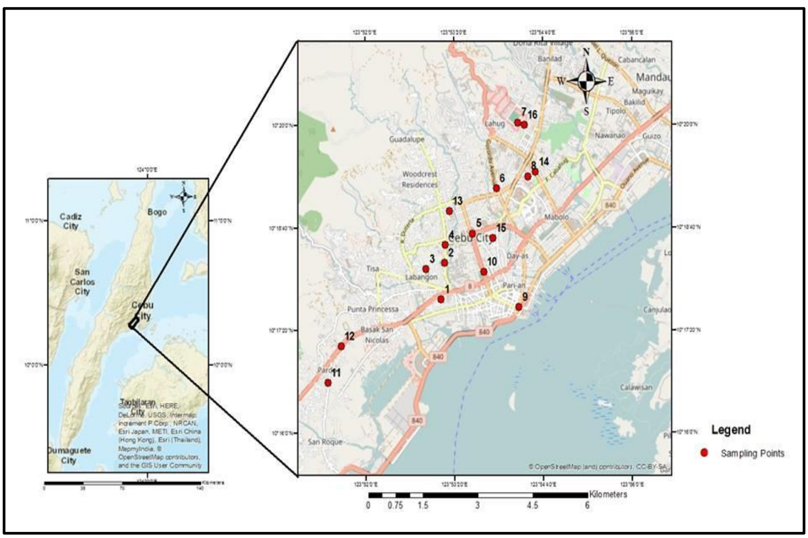

Figure 1. Location of sampling plots in Cebu City

This study did not utilized destructive method (felling of the tree to get the actual measurements) due to practical reasons. Data on measurements were gathered on a standing tree within the plot such as tree height, stem diameter at 1.37 m above the ground (diameter at breast height) and tree condition following the method as described by Nowak (2008). All trees inside the plot that have a diameter at breast height (DBH) of >5 cm were measured and identified using vegetative and reproductive characteristics. Tree height was measured using a range finder Leica Disto 510.

2.3 Estimating Tree Biomass and Carbon Stored

Tree biomass was computed as the sum of aboveground biomass (AGB) and root biomass (RB). AGB was calculated using the improved allometric model for tropical trees of Chave *et al.* (2015), while RB was derived according to root-to-shoot ratio estimate by Cairns *et al.* (1997) as 0.26. The result for tree biomass computation was adjusted by a factor 0.8 (Nowak, 1994) to account for reported difference between forest and urban trees. Urban trees were observed to have lesser biomass than the forest trees based on the computation made by Nowak (1994) for trees of the same diameter at breast height. Pearson's correlation was performed to assess the relationship between wood density, DBH, height, and tree biomass.

AGB was calculated following Chave's *et al.* (2015) allometric equation:

$$AGB\ (\text{kg}) = 0.0673 \text{ X } (\rho D^2 H)^{0.976} \tag{1}$$

where:

D (cm) = diameter at breast height
ρ (g/cm^3) = wood specific density
H (m) = height of the tree

The measure for wood specific density is retrieved from the Food and Agriculture Organization (FAO) website.

While RB and Tree biomass (TB) were estimated using the following equations:

$$RB\ (\text{kg}) = AGB\ (\text{kg}) \text{ X } 0.26 \tag{2}$$

$$TB\ (\text{kg}) = (AGB + RB) \text{ X } 0.80 \tag{3}$$

Then, TB density and carbon stored in the tree were computed using the following formula:

$$TB\ density\ (\text{kg C/m}^2) = TB\ (\text{kg}) \,/\, Sample\ area\ (\text{m}^2) \quad (4)$$

$$C\ stored\ (\text{kg C/m}^2) = TB\ density * 0.45 \quad (5)$$

A default value of 45% in tree biomass was used to estimate for the stored carbon. This value was the average carbon content of wood sampled from various areas in the Philippines in the study of Lasco and Pulhin (2000). Tree biomass was converted from kilogram to megagram unit and the sampling area from the square meter into hectare unit for comparability with other data.

2.4 Computing the Annual Rate of Sequestration

To estimate tree diameter and height in year x+1, an annual increment value of 1.19 cm/year and 1.05 cm/year, respectively, were added to the existing tree diameter and height based on the study Schneider *et al.* (2013) on the mean annual increments for diameter (MAID) at breast height and main annual increments for height in limestone-soil reforestation sites in Leyte, Philippines. Their study computed the average annual increment value of common reforestation tree species in the Philippines including the three dominant species in Cebu City: *Swietenia* spp., *Gmelina arborea* (Roxb.), *Pterocarpus indicus* Willd. Slight difference may, however, exist considering environmental condition (reforestation sites vs. urban setting). For example, in the current survey, *Swietenia* spp. has a DBH of 17.29 cm and a height of 8.06 m. To estimate tree diameter for next year, current DBH of 17.29 cm was added with 1.19 cm and the sum (18.48 cm) was the estimated DBH for the next year which was then used as the basis in the computation of the AGB for the succeeding year. Similarly, for height, current height of 8.06 m was added to 1.05 m and the sum (9.11 m) was the estimated increase in height for the succeeding year.

However, final growth rates can be influenced by tree condition. Nowak (2008) based the tree conditions on the health of the crown. As basis for adjustments of final growth, he classified the trees into fair to excellent condition (less than 25% of crown dieback); poor condition (25-50% crown dieback); critical trees (51-75% crown dieback); dying trees (76-99% crown dieback) and dead trees (100% dieback). Final growth rates of the tree were multiplied by the following factors: 1 (no adjustment) for fair to excellent condition; 0.62 for poor condition; 0.37 for critical trees; 0.15 for dying trees and 0 for dead trees (Table 1). In the preceding example, if *Swietenia* spp. is categorized as having a poor condition, the annual increment value of 1.19 cm/year for DBH and 1.05 m/year for height is adjusted by multiplying these with 0.62. So for DBH, estimated increment for the succeeding year is 0.74 cm, while for height it is 0.65 m.

The gross amount of carbon sequestered on the succeeding year was estimated as the difference of stored carbon between year x and year x+1.

Table 1. Annual growth of trees in limestone soil based on its condition

Tree Condition	Adjustment factor	Annual Growth	
		DBH (cm)	Height (m)
Fair to excellent	1.00	1.19	1.05
Poor	0.62	0.74	0.65
Critical	0.37	0.44	0.39
Dying	0.15	0.15	0.14
Dead	0.00	0.00	0.00

3. Results and Discussion

3.1 Urban Tree Community Composition and Structure

A total of 409 trees were counted and 23 species (Figure 2) were identified in the 16, 500 m^2 plots established from the north and south districts of Cebu City. Majority of these trees belong to *Swietenia* spp. (55.7%), *G. arborea* (Roxb.) (15.4%), *P. indicus* Willd. (12.7%) and the rest comprise the 16.2%. About one half (50.86%) of these trees have a DBH of less than 20 cm while most trees (45.97%) have a height of less than 10 m and 43.28% have a height of less than 20 m (between 10 and 20 m). As to crown condition, 54.28% of the trees are categorized as having fair to excellent condition while some 35.7% are observed to have a poor condition.

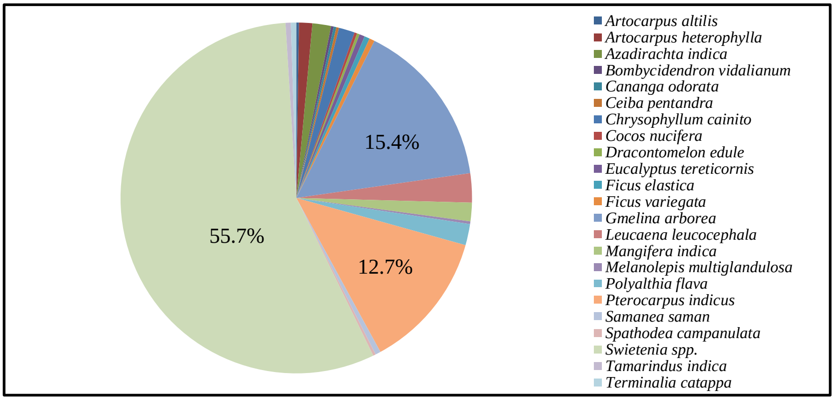

Figure 2. Species composition and abundance of trees in the sampling sites of Cebu City

3.2 Tree Biomass, Carbon Stock and Gross Annual Carbon Sequestration

The estimated tree biomass density from the sampling sites is 195.13 Mg/ha (Table 2). While Carbon stored in these trees is estimated to 87.81 Mg C/ha (Table 2). Gross carbon sequestration for the next year is approximated as 9.45 Mg C/ha/yr (Table 2).

Table 2. Summary of tree biomass, biomass density, stored carbon and estimated annual carbon sequestration from the different sampling sites in Cebu City

Plot No.	Tree biomass (Mg)	Tree biomass density (Mg /ha)	C stored (Mg C/ha)	Carbon sequestration (Mg C/ha)
1	12.25	245.00	110.25	9.42
2	6.87	137.40	61.83	7.19
3	20.89	417.80	188.01	18.84
4	3.81	76.20	34.29	5.57
5	12.02	240.40	108.18	9.04
6	0.86	17.20	7.74	7.73
7	21.47	429.46	193.26	16.55
8	9.80	196.08	88.23	7.05
9	5.69	113.87	51.24	5.37
10	1.64	32.80	14.76	2.90
11	17.00	340.00	153.00	18.85
12	4.26	85.20	38.34	6.38
13	11.84	236.83	106.57	10.66
14	3.20	64.00	28.80	3.88
15	12.15	243.00	109.35	9.04
16	12.34	246.87	111.09	12.69
	Average	195.13	87.81	9.45

Urban trees of Metro Cebu are composed of relatively young trees with very few remaining century old trees as a result of development. Remaining century-old trees are localized especially in parks and cemeteries where competition for land use is not an issue. While along the roadsides, in the open spaces of schools, commercial and residential areas are new growth trees from the replanting as part of the greening program initiated by the government or as tree planting activities by private entities. Usually, fast-growing species such as *Swietenia* spp., *G. arborea, P. indicus* Willd., and *Acacia mangium* were promoted for planting (Lasco and Pulhin, 2003), thus, explain the species composition and low diversity of trees in the sampling sites.

Factors such as the type of tree, wood density, DBH and tree height influence the tree biomass (Chave *et al*., 2015). Tree biomass is significantly correlated (p value=0.00) to DBH and tree height, but not with wood density. This result is contrary to the previous finding of Chave *et al.* (2015) that wood specific gravity is an important predictor to AGB. The inconsistency can be explained by the low diversity of tree species found in the sampling sites. It is expected that little variation in wood density occurs in urban tree community with low species composition. Diameter at breast height has a stronger correlation ($r = 0.84$) than tree height ($r = 0.54$) to tree biomass. Tree biomass density (195.13 Mg/ha), as well as carbon density (87.81Mg C/ha) of urban trees in Cebu City, is found to be lower than AGB and carbon density of both the old growth (AGB: 336 to 472 Mg/ha and carbon density150 to 236 Mg C/ha) and secondary forest (AGB: 238 to 611 Mg/ha and Carbon density of 107 to 278 Mg C/ha) (Lasco and Pulhin, 2003) in the Philippines.

On the other hand, carbon density (8.78 kg C/m^2) in Cebu City is comparable to many cities in the world such as in the U.S. cities where average storage densities is 7.69 kg C/m^2 (Nowak *et al.*, 2013); in Leipzig, Germany, where carbon storage range is from 0.68 to 9.85 kg C/m^2 (Strohbach and Haase, 2012); and in Barcelona, Spain, where values range is from 1.53 to 9.67 kg C/m^2 (Chaparro and Terradas, 2009). Cebu City has higher carbon density than in three cities in middle Korea – Chuncheon, Kangleung, and Seoul – with average storage densities ranging from 0.47 to 0.72 kg C/m^2 (Jo, 2002); and in Hangzhou, China, where average storage density is 4.28 kg C/m^2 (Zhao *et al*., 2010). However, it is important to note that only 25.11% (or 15,674,341.8 m^2) of the city's urban area (62,426,064.6 m^2) is covered with trees (Ejares *et al.*, 2016). Hence, total carbon stock in the urban trees can be roughly approximated at around 137, 645 Mg C.

Trees are important carbon sequesters from the atmosphere, as they perform photosynthesis to produce new organic matter that they also use for growth. However, scientific evidence to support the direct potential of urban trees in removing carbon dioxide (CO_2) is complicated to obtain (Velasco *et al.*, 2010) and varied method is used in different studies due to particular characteristics of the site. Hence, this study adapted the allometric equation in assessing urban trees as an important carbon reservoir (Velasco *et al*., 2016) and sequestration rate is computed based on the reported average annual increments of trees in the reforestation sites in Leyte, Philippines. Uncertainties of the sequestration rate using this average value may be attributed to the actual growth performance of urban trees which may be slightly different from reforestation sites. Given that, several factors may influence the rate of accumulation of new organic matter such as the site conditions, soil, species of tree, age and health of the tree (Nowak *et al.*, 2013).

Urban trees in Cebu City is projected to sequester carbon at 9.45 Mg C/ha/yr. However, this value does not take into account soil respiration, decomposition of dead trees and parts of the trees removed from pruning as part of the urban trees management. Projected gross carbon sequestration rate in Cebu City is relatively higher to the natural forest (0.82 Mg C/ha/yr). These can be partly explained by the fast-growing tree species dominant in the area. Nonetheless, this value is much lower than the tree plantations from fast-growing species (15.88 Mg C/ha/yr) in the study of Lasco and Pulhin (2009). Gross annual carbon sequestration rate from the U.S. cities varies from 0.168 to 0.581 kg C/m^2/yr while net sequestration is estimated at 0.226 kg C/m^2/yr (Nowak *et al.*, 2013). In addition, gross annual sequestration rate in three cities in middle Korea – Chuncheon, Kangleung, and Seoul – are much lower (0.051 to 0.07 kg C/m^2/yr) (Jo, 2002) than the estimated values in Cebu City. This disparity is expected considering variation in climatic condition, the species of trees and other factors that affect the growth of trees. Urban trees in Cebu City are projected to sequester an additional 14,807 Mg of carbon next year.

In 2005, carbon emission in the Philippines was about 142 million tons, with power and transport sectors as principal sources of emission (World Research Institute, 2009) and cities contribute 60% to the carbon dioxide emissions (UN-Habitat, 2015). Inferring from these data, a conservative estimate of 1% contribution of Cebu City will mean that the city can emit 12,882,023 Mg C. If annual gross sequestration of urban trees in Cebu City is 14,807 Mg C, then it can sequester only less than 1% of its total carbon emission.

Doubling both the tree cover and the area allocated for tree planting cannot offset the total carbon emission. At the same time, demand for more land area for industrial, commercial and residential use makes it impossible to prioritize tree planting in this urban area. Policymakers, environmental agencies and climate change advocates may focus their effort in reducing carbon emission from the source, off-site tree planting and enhance protection and management efforts in the remaining critical forest habitats. Government and private organizations' efforts in managing protected habitats are constrained by limited environmental funds allocated for these areas. Cities, like Cebu, may create policies that will impose carbon tax per unit of emission to industries and business establishments to generate funds needed for this purpose and in prioritizing the use of native trees in all greening activities.

4. Conclusion and Recommendation

Urban tree community in Cebu City is dominated by young, fast-growing tree species, *Swietenia* spp., *G. arborea,* and *P. indicus* Willd. as a result of the replanting activities promoted by the government in the 1990s. Tree biomass density and carbon stored are at 195.13 Mg/ha and 87.81 Mg C/ha, respectively, and are lower than primary growth and secondary forest in the Philippines but comparable or higher than estimated values in other cities of the world. Diameter at breast height and tree height are significantly correlated to tree biomass but not to wood density. Furthermore, considering that only 25.11% of Cebu City area is vegetated, carbon stored in the urban trees is approximately 137, 645 Mg C/ha and annual gross carbon sequestration is projected at 14, 807 Mg C.

This carbon sequestration potential may be very low compared to the amount of carbon that Cebu City can emit if it contributes only 1% of the nation's carbon emission which is 12,882,023 Mg C. Additional clearing to other vegetated sites to give way to development will further diminish this ecosystem service. On-site mitigation of carbon emission may not be feasible due to competing land use but a reduction from the source and off-site carbon sequestration by reforestation projects in the denuded forest to offset carbon emission may be viable options to consider. Both passive (e.g. fund generation) and active (e.g. policy implementation and enhanced management strategies to protected areas) efforts may be important to successfully reduce carbon in the atmosphere and thus, the negative effects of global warming.

Relevant studies on carbon emission in Cebu City and monitoring the dynamics that affect urban tree structure are vital to arrive at a sound judgment that will guide policymakers.

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