Research article

Rapid Carbon Stock Appraisal (RACSA) Implementation in Wahig-Inabanga Watershed, Bohol, Philippines

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Abstract. The study aimed at assessing the biomass and carbon stocks of all major land uses in Wahig-Inabanga Watershed, Bohol, Philippines and to estimate its total carbon budget. The "*A priori* stratification *cum* purposive sampling" was used. Field measurements were conducted following the destructive and non-destructive methods. The total C stored in the different land uses surveyed in the watershed was estimated at 3.89 Megatons, 83.23% of which was held in the cultivated perennial crops. Among the land uses assessed, it was only mangrove which had lower carbon density estimate relative to previously reported values indicating substantial degradation of mangroves vegetation over the years. The possibility of increasing its potential to store more carbon could only be improved if appropriate management and alternative livelihood interventions, coupled with conservation and protection measures are properly implemented.

Keywords RACSA, carbon stock, carbon budget, Wahig-Inabanga Watershed

INTRODUCTION

Carbon stock assessment is not new to science. Many researchers have attempted to document and quantify carbon stocks of almost every land use in the Philippines since the late 1990s, and even earlier in other countries. Lasco and Pulhin (2003) provided a list of several studies which have investigated the carbon stocks of forest ecosystems and other land cover types in the Philippines. Most of the carbon stock assessments were conducted in plantations where dynamics were only affected by the choice of species, management styles and decisions, silvicultural operations and environmental factors. Few have even designs species-plantation/stand-based allometric equations (Codilan et al., 2009). These were all triggered by the increasing importance of carbon stock assessment in policy and the possible consequences for economic incentives (C markets) (Hairiah et al., 2001 and Hairiah et al., 2011). In Bohol, carbon stock studies were implemented in a 2-hectare rubber plantation at Magsaysay, Talibon (Reyes et al., 2011) and oil palm plantations in Carmen, Sierra Bullones, and Pilar (Pulhin, personal communication).

The RACSA appraisal tool, which was used in this study, was designed to provide a basic level understanding of carbon appraisal and it introduced a scientifically sound methodological framework of accounting carbon sinks; while focusing on activities that could improve local livelihoods and alleviated rural poverty (Hairiah et al., 2011). Its application in the Wahig-Inabanga Watershed provided an idea of how much carbon was stored in the watershed and its potential in sequestering more carbon dioxide from the atmosphere.

This report focused only on the rapid carbon stock estimation of Wahig-Inabanga Watershed in Bohol, Philippines based on the current scenario. It assessed the biomass and carbon stocks of all major land uses in Wahig-Inabanga Watershed, Bohol, Philippines and determined the watershed's total carbon budget.

METHODOLOGY

Study Site

The study was conducted in Wahig-Inabanga Watershed, Bohol, Philippines. This watershed is the biggest in Bohol Province embracing a total land area more than 610 km^2 or over 15 % of the total land area of the Province. It is geographically located between 124º 3' 36" and 124º 23' 24" East longitude, and between 9º 43' 48" to 10º 4' 48" North latitude. It has two headwaters namely the Wahig and Pamacsalan Rivers and its outlet is geographically located at 10º 4'12" North latitude and 124º 4'12" East longitudes (Fig. 1). It traverses the municipalities of Garcia Hernandez, Jagna, Duero, Sierra Bullones, Pilar, Alicia, Carmen, Dagohoy, San Miguel, Sagbayan, Trinidad, Talibon, Jetafe, Buenavista, Danao, and Inabanga.

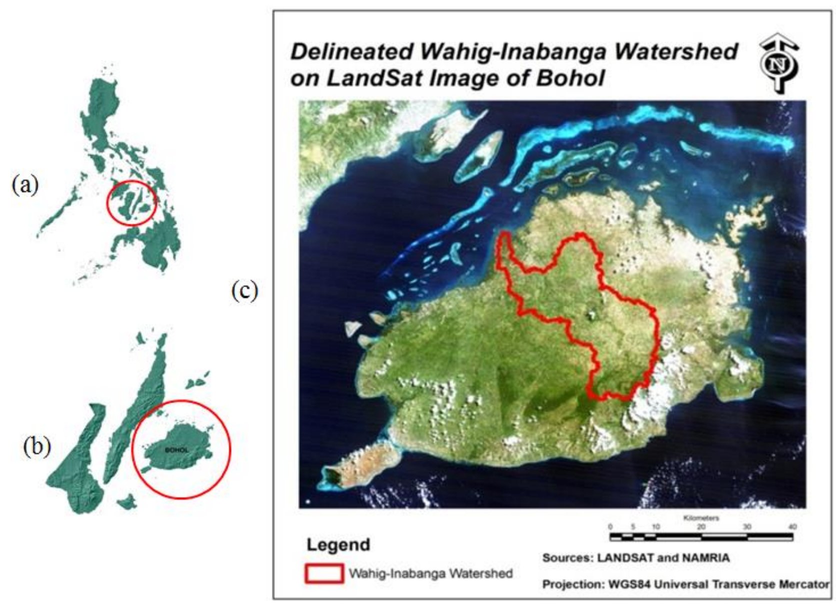

Fig. 1 Location of the study area: (a) map of the Philippines showing the Central Visayas; (b) map of the Central Visayas showing Bohol; and (c) map of Bohol showing the Wahig-Inabanga Watershed

Site Selection and Sampling Procedure

The rapid carbon stock appraisal was carried out only in four identified municipalities of Wahig-Inabanga Watershed. Among the 16 municipalities within the watershed, Pilar, Sierra Bullones, Danao, and Inabanga were selected for this study. These are municipalities which cover large areas in the watershed. Selection criteria considered were the variability of land cover and land uses, elevation differences, and geological features which would represent the characteristics of the whole watershed.

The strategy used in this research was the "*Apriori* Stratification *cum* Purposive Sampling" (Hairiah et al., 2001) commonly known as preferential sampling patterned from the methodology suggested by Hairiah et al., (2011). This means that the sampling locations and plots are identified prior to successive field surveys. This approach was employed for the reason that it would be more expensive and very time consuming if one of the regular field survey methods, such as random sampling, systematic sampling, and stratified random sampling, is to be applied following a definite sampling intensity.

In this study, plots were laid in secondary forests; shrub/scrublands; cultivated perennial crops also referred in this paper as agroforestry areas; rice and cornfields; grasslands; mangroves; and existing tree plantations (i.e. *Swietenia*, *Gmelina*, *Tectona*, *Elaeis*, and *Acacia*s).

Sampling Layout and Plot Sizes

In this study, rectangular-shaped plots were chosen since these tended to include more of the within-plot heterogeneity, and thus, represented more heterogenic species than square or circular plots of the same area. Three different plots sizes were employed in the study based on Hairiah et al. (2001) and Hairiah et al. (2011). The 20m x 100m plot for trees with diameter at breast height (DBH) >30 cm and was used mainly in secondary forests, shrubs, and apitong (*Dipterocarpus grandiflorus*) natural stand. The 5m x 40m plot was established for trees in plantations, agroforestry farms (perennial crops), and mangrove sites. The same size of plot was also nested in the middle of the 20m x 100m plot to measure trees with DBH < 30 cm. On the other hand, plot with a dimension of 1m x 1m was employed to appraise undergrowths, agricultural crops (rice and corn), low stature weeds, and grasses.

Biomass Measurement of Aboveground Carbon Pools

Trees and other woody plants: Non-destructive measurement of trees, shrubs, and other woody plants as suggested by Hairiah et al. (2001) was adopted in this study. Diameter at breast height (DBH), merchantable height (MH), and total height (TH) were among the biometrics measured.
Understorey vegetation: Destructive or harvest method was used to determine the biomass of understorey vegetation. Total fresh samples were weighed and recorded, however only approximately 50-500 g of samples were collected for oven-drying. Oven-dried weight was again recorded in each sample after 3 days of drying.
Floor litter: Similar with the understorey vegetation, destructive or harvest method was also employed for floor litter. Total fresh samples were weighed and recorded, and only approximately 50-200g of samples were kept for subsequent oven-drying.
Cereals and weeds: The method applied to determine the biomass of the understorey vegetation was also used for land uses such as rice, corn, and grassland.

Estimation of Belowground Carbon Pool

Belowground biomass (root biomass): This is a fraction of aboveground biomass. An equation in Table 1 was used for this purpose.
Soil Stock Pool: Percent soil organic carbon and bulk density are important variables in the calculation of soil carbon. These values were derived from the ACIAR-BSWM project report (ACIAR, 2006) and results of BSWM soil chemical analysis on soils collected during the series of soil surveys done by the CSIRO-BSWM team.

Parameter values for percent soil organic carbon in each survey location were obtained using the Kriging interpolation function in ArcGIS. The values were derived employing the extract by sample function in the spatial analysis tool. On the other hand, bulk density values were directly taken from the BSWM soil survey report.

Data Analysis

Quantifying biomass and carbon stock: Allometric equations for trees and other plants suggested by Hairiah et al., (2011) for estimating above-ground and root biomass were used (Table 1). Biomass and carbon content were calculated in kilograms and then finally converted in tons (=mega grams [Mg]) per hectare.

Table 1 Allometric equations used to compute for the above-ground (AGB) and below-ground biomass (BGB)

Plant Type / Species	Allometric Equation	Source
Tree/shrub	AGB= ρ* EXP(-1.499 + 2.148 LN(DBH) + 0.207 $(LN[DBH])^2$ - 0.0281*$(LN[DBH])^3$)	Chave et al., 2005
Mangrove		
Rhizophora	AGB = 0.2453 – 0.2165*(DBH) + 0.0658*(DBH^2) + 0.0270*(DBH^2*TH)	Codilan et al., 2009
Sonneratia	AGB = 0.2301 – 0.5382*(DBH) + 0.3370*(DBH^2) + 0.0474*(DBH^2*MH)	Codilan et al., 2009
Avicennia	AGB = 0.0198 – 0.0013*(DBH) + 0.0097*(DBH^2) + 0.0155*(DBH^2*MH)	Codilan et al., 2009
Banana	AGB = 0.030*($DBH^{2.13}$)	Arifin, 2001; Noordwijk et al., 2002
Bamboo	AGB = 0.131*($BDC^{2.28}$)	Priyadarsini, 2000
Oil palm	AGB = 0.0976 *(TH) + 0.0706	ICRAF, 2009
Palm	AGB = 4.5 + 7.7*(TH)	Frangi and Lugo, 1985
Nipa	AGB = 0.3999 + (7.907*TH)*0.2 Note: 0.2 added in the equation since nipa does not have aboveground stem	Modified from Teopolo et al., 2002
Coffee	AGB = 0.281 $D^{2.06}$	Arifin, 2001
Root Biomass	RB = EXP(-1.0587 + 0.8836*LN[AGB])	Cairns et al., 1997

Note: AGB = estimated aboveground biomass (kg/tree); RB = estimated root biomass; DBH = diameter at breast height (cm); BDC = basal diameter of cluster (cm); TH = total height (m); ρ = wood specific gravity (Mg/m^3); EXP = exponent; LN = natural logarithm

For this study, a conservative estimate of 45% tons of C per 100% tons of oven-dried biomass was adopted since the carbon content of biomass dry weight based on the studies conducted in and out of the country ranges from 40% to 55% (Lasco and Pulhin, 2000 as cited by Lasco et al., 2005).

Conversely, a simple formula on oven dried weight was used to compute for the biomass of understorey plants, weeds, rice, corn, and floor litter.

$$ODW = TFW- (TFW*(SFW-SODW))/SFW$$

Where ODW is total oven dry weight, TFW total fresh weight, SFW sample fresh weight and SODW sample oven dry weight

The carbon content of each pool was calculated by getting the 45% of the total biomass, except for soil carbon which was computed by obtaining the product of soil weight and % organic carbon. The total carbon was calculated as the summation of all carbon content in all pools.

RESULTS AND DISCUSSION

Biomass and Carbon Stock Assessment

Plantation: Among the major land uses considered in the study, plantation had the largest above- and belowground biomass which was estimated to be 630.64 tons ha^{-1} and 102.45 tons ha^{-1}, respectively. Its soil carbon was also computed at 3.64 tons ha^{-1}. Forty five percent of its combined biomass inclusive of soil carbon amounted to 333.53 tons of carbon per hectare (Table 2). Such quantity of carbon is almost 300 tons larger than the average of the total stored carbon in selected Philippine plantations amounting to only 55.6 tons ha^{-1} (Lasco and Pulhin, 2000 as cited by Lasco et al., 2005). Though the typical condition of most of the tree plantations in the watershed is not ideal (crooked, and mostly thinner and shorter (stunted) relative to the trees age), their density (close spacing) has contributed much to their current biomass.

Conversely, Lasco and Pulhin (2003) reported that carbon stocks of plantations in Mt. Makiling ranged from 125.6 to 285.7 tons ha^{-1} and even way lower in other parts of the country. A separate study conducted earlier by Racelis (2000), however conformed with the result of this study and revealed that mahogany plantation in Mt. Makiling, due to its age, dense stocking and large girth, had a computed carbon stock of 542.05 tons ha^{-1}. These results also added that the dipterocarp stand in the same study area, sharing similar features, had even higher stored carbon of about 639.81 tons ha^{-1}.

Secondary forest including apitong stand: The second type of land use in Wahig-Inabanga watershed having considerable quantity of biomass and, thus, carbon was the secondary forest. Its above- and belowground biomass were 209.51 tons ha^{-1} and 38.13 tons ha^{-1}, respectively. Its soil carbon of 3.78 tons ha^{-1} was the largest among the computed soil carbon in all land uses. These gave a total carbon stock of 115.22 tons ha^{-1} (Table 2). The computed total stored carbon of secondary forest in Wahig-Inabanga watershed was comparable with that of the secondary forest in Kaliwa watershed. The latter, according to Lasco et al. (2005), has a total carbon stock of 121.21 tons ha^{-1}. Lasco and Pulhin (2009) stated an average of 111.10 tons ha^{-1} of stored carbon for several surveyed secondary forests in the country.

Agroforestry: Same with the first two land uses, agroforestry had an estimated total carbon stock of more than 100 tons ha^{-1}. Its estimated total stored carbon was 104.05 tons ha^{-1} (Table 2). This value is twice as high as the estimate presented by Lasco and Pulhin (2000) as cited by Lasco et al. (2005) disclosing an average of 50.3 tons ha^{-1} for agrorestry sites in the country. The bloated values in the present study were attributed to the dominance of coconuts and other tree crops in the surveyed areas. However, such amount of carbon is still below the carbon stocks of Taungya agroforestry and mixed multistorey systems in Bukidnon with 174 tons ha^{-1} and 162 tons ha^{-1}, respectively (Labata et al., 2012).

Shrub/brushland: The computed above- and belowground biomass per hectare in shrub/brushland amounting to 172.56 tons ha^{-1} and 32.77 tons ha^{-1}, and a soil carbon of 3.50 tons ha^{-1} provided an equivalent carbon stock of 95.90 tons ha^{-1} (Table 2). This value is comparatively higher than the estimates of Lasco and Pulhin (2000) as cited by Lasco et al. (2005), in several watersheds in the country which ranged from 29.0 tons ha^{-1} to 74.27 tons ha^{-1}. This could be due to the presence of few invasive timber species such as yemane (*Gmelina arborea*), mahogany (*Swietenia macrophylla*) and ipi-ipil (*Leucaena leucocephala*) which have been naturally dispersed from adjacent plantations and have grown with small-sized native shrubs and trees.

Mangrove: Among the major land uses, mangrove is generally noted as the most represented in terms of number of individuals. However, the density alone is not the only requisite for a particular land use to acquire high biomass. The foremost requirement is the availability of considerable number of huge diameter trees which, unfortunately, is not a good trait of the surveyed mangrove areas. Based on records, more than half of the measured plants (mostly young *Rhizophoras*) had diameters of less than 5 cm. For this reason, the computed biomass densities were only 87.98 tons ha^{-1} for aboveground and 17.72 tons ha^{-1} for belowground, with a corresponding carbon stock of not more than 50 tons ha^{-1} (Table 2). These values are over 3 times smaller than the country's average mangrove biomass and carbon stock of about 401.8 and 176.8 tons ha^{-1}, respectively (Lasco and Pulhin, 2000 as cited by Gevana et al., 2008). Gevana et al., (2008) reported that mangroves' biomass density may reach up to more than 500 tons ha^{-1} especially if it is dominated by large-sized *Rhizophoras*. One good example is the study of Fujimoto (2000) as cited by Gevana et al., (2008) in Matang, Malaysia which revealed that above-ground biomass alone was computed to reach 558 tons ha^{-1}. *Rhizophora*-dominated mangrove stands are noted to have large biomass and carbon density (Tanouchi et al., 2000 as cited by Gevana et al., 2008). The presence of their unique physiognomic characteristics such as the presence of stilt roots, dense stem and branches, and relatively large canopy contributes much to the total biomass.

Grass: The result of the above-ground biomass density computation for the surveyed grasslands, together with its carbon stock, coincides with the estimates of Lasco and Pulhin (2000) as cited by Lasco et al., (2005). The carbon stock of 5.48 tons ha^{-1} is comparable with the country's average carbon stock for grasslands of about 5 tons ha^{-1} (Table 2).

Rice: Farms planted to rice are among the land uses with little amount of biomass and consequently carbon content. This is due to seasonal harvests leaving almost no traces of biomass especially after land preparation. The rice farms' computed above-ground biomass density and total carbon stock were 4.11 tons ha^{-1} and 5.3 tons ha^{-1}, respectively (Table 2). Same with grass, more than half of the total carbon stock for rice came from the soil carbon.

Corn: Among the land uses assessed in this study, it was corn which had the least estimated biomass and carbon stock. This was because of having only 3-4 individual plants which were harvested for biomass calculation in a standard one square-meter plot. In addition, regular care and maintenance like harrowing and weeding limit the growth of herbaceous weeds and grasses. For these reasons, the computed above-ground biomass was only 2.97 tons ha^{-1} and its carbon stock was 4.74 tons ha^{-1}. It is also noticeable that a big chunk, roughly 3.4 tons, of carbon per hectare was derived from soil carbon (Table 2).

Table 2 Computed above and belowground biomass and carbon in major land uses in Wahig-Inabanga Watershed, Bohol, Philippines

Land Use	AGB (ton ha^{-1})	BGB (ton ha^{-1})	Soil Carbon (ton ha^{-1})	Total Carbon (ton ha^{-1})
Plantation	630.64	102.45	3.64	333.53
Secondary forest with Apitong stand	209.51	38.13	3.78	115.22
Agroforestry	188.28	34.71	2.21	104.05
Shrub/Scrubland	172.56	32.77	3.50	95.90
Mangrove with nipa	87.98	17.72	2.21	49.77
Grassland	4.52	-	0.96	5.48
Rice	4.11	-	3.45	5.30
Corn	2.97	-	3.40	4.74

Note: AGB = aboveground biomass; BGB = belowground biomass

Table 3 Carbon storage of different land uses in Wahig-Inabanga Watershed, Bohol, Philippines

Land Use	Area of Coverage (ha)	Carbon Stock (tons ha^{-1})	Total Carbon Stock (tons)
Secondary forest	1,247.75	113.29	141,357.60
Shrubland	5,910.05	92.12	544,443.81
Cultivated perennials*	23,878.82		
a. Coconut/tree-based agroforestry farm	(90%)	104.05	2,236,132.10
b. Tree plantation	(10%)	333.53	796,430.28
Mangrove with nipa	537.63	49.78	26,763.22
Rice	14,146.65	5.30	74,977.25
Corn	9,401.21	4.74	44,561.74
Grassland	4,073.16	5.48	22,320.92
		Total	**3,886,976.90**

*Note: *"Cultivated perennials" is assumed composed of 90% coconut/tree-based agroforestry farms and 10% plantations.*

Total Carbon Budget

Table 3 provides a rough estimate of the carbon budget of the whole watershed. A total of 3,886,976.90 tons or 3.89 megatons of carbon was computed based on the land uses' areas of coverage and computed carbon stocks. The biggest share comes from cultivated perennial crops which had the largest area of coverage within the watershed and the highest estimated carbon stocks.

Shrub/brushland and secondary forest also had significant contributions on the watershed's carbon budget due to the substantial number of trees and shrubs which were appraised in these types of land use compared to those with extensive area of coverage however dominated by low stature annual plants.

CONCLUSION AND RECOMMENDATION

The Wahig-Inabanga watershed's estimated overall carbon stock of 3.89 megatons presents the finest contribution of the watershed to the global carbon budget. Around 83.38% of these are presented in cultivated perennial crops, while the rests are stored other land uses. The possibility of increasing its potential to store more carbon could only be harnessed if appropriate management interventions were implemented.

Open areas like grasslands, for instance, offer immense potential of sequestering carbon through tree planting and agroforestry. If in case tree planting and agroforestry, as immediate interventions, are inappropriate, natural or artificial regeneration may be the best alternative option.

Among the land uses assessed in the watershed, it was only mangrove which had lower carbon density estimate relative to previously reported values. This indicates substantial degradation of mangroves vegetation through time. For this type of land use, provision of alternative livelihood, protection and conservation, apart from reforestation activities are the best options to undertake. Any management intervention would only be wasted if alternative livelihood options are not available and conservation and protection measures are not properly enforced.

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