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Title	Assessment of forest carbon stocks for REDD+ implementation in the muyong forest system of Ifugao, Philippines
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Citation	Environmental Monitoring and Assessment, 192(9), 571 https://doi.org/10.1007/s10661-020-08531-8
Issue Date	2020-09
Doc URL	https://hdl.handle.net/2115/82597
Rights	This is a post-peer-review, pre-copyedit version of an article published in Environmental Monitoring and Assessment. The final authenticated version is available online at: https://doi.org/10.1007/s10661-020-08531-8
Type	journal article
File Information	Environ.Monit.Assess. v192(9)p.571.pdf

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Assessment of Forest Carbon Stocks for REDD+ Implementation in the Muyong Forest System of Ifugao, Philippines

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Abstract

Forests hold significant potential for carbon sequestration and climate change mitigation. Forest biomass estimation is vital for sustainable forest management, providing critical input data for implementing the United Nations Reducing Emissions from Deforestation and forest Degradation-plus (REDD+) mechanism. This study investigates the total carbon pools—aboveground biomass (AGB), belowground biomass (BGB), forest floor biomass, and soil carbon—using field-based information in the muyong forest management system, which is native to Ifugao in the Philippines. This study reveals that a difference may be observed between the total carbon stock of the private woodlots (muyong) and that of the communal forest (bilid). The results indicate that the bilid forest has trees with small diameter at breast height (DBH) and high tree density in contrast to the muyong, which has trees with high DBH and low tree density. The average carbon stock per unit area is higher in muyong (150.8 tC/ha) than in bilid (126.1 tC/ha). These findings are valuable in determining whether Ifugao's muyong forest system should be included under the REDD+ framework. Human mediation and management helps forests to sequester a greater amount of carbon than they would without human intervention. Implementation of REDD+ should promote Ifugao's ecosystem and biodiversity conservation and agroforestry practices in addition to protecting traditional agricultural practices and livelihoods in relation to rice terraces.

Keywords: Forest carbon stocks, REDD+, muyong, climate change mitigation

1. Introduction

Tropical forests are important carbon reservoirs, storing large quantities of biomass over long periods compared to agriculture and other systems (Ravindranath and Ostwald 2008; Avtar, et al., 2013a). They also fulfill an important role in the global carbon cycle because they act as reservoirs during succession and sources when deforested or degraded by natural or human disturbances (Marin-Spiotta and Sharma, 2013). Continued deforestation and forest degradation pose the threat of releasing large amounts of carbon, which may exacerbate the effects of climate change. The Philippines is one of the world's seventeen countries recognized as megadiverse and is particularly vulnerable to climate change (World Bank, 2010). The total area of forest cover in the Philippines is 8.4 million hectares with 1,160 million tons of aboveground biomass (AGB) in forests and other woodlands (FAO-FRA, 2015). The promotion of restoration initiatives has the potential to increase the country's carbon sink.

Deep in the heart of the Philippine Cordilleras mountain range lies the Ifugao province, which is famous for its rice terraces (UNESCO, 2019). The Ifugao agricultural system is an "agro-cultural complex system," characterized by the interlocking of nature with agricultural practices, social systems, and historical, political, and cultural changes (O'Connor, 1995). The muyong system plays a major role in the survival of the Ifugao rice terraces, providing water and preventing soil erosion (Avtar et al., 2019; Soriano et al., 2019). In the local dialect of the Tuwali tribe, "muyong" translates literally to "forest," although the precise definition may vary depending on the locality. Local people specifically use this term to denote privately-owned and managed woodlots located above rice terraces (*payoh*). Muyong forests differ from other systems with respect to their management and protection (Herath et al., 2015). The Ifugao land classification system designates land categories according to the location, function, and type of agronomic activity that takes place (Butic and Ngidlo, 2003). The muyong system is Ifugao's native forest management system and is vital to the rice terracing system due to its watershed function (Durst et al., 2001). Globally, it has been acclaimed as a comprehensive ecosystem that provides a host of various ecosystem services.

During the last decade, various efforts have been made to accurately quantify forest carbon stock with the aim of understanding global and regional carbon budgets (Lindsell et al., 2013; Ma et al., 2018). Maps of the spatial distribution of biomass can assist in decreasing uncertainty in relation to the global carbon cycle (Duncanson, 2019). The quantification of

global forest biomass relies on AGB estimation. Therefore, most recent studies have focused on the estimation of AGB using ground-based and remote sensing-based methods to improve accuracy. AGB can be estimated from ground-based forest inventory parameters using allometric equations (Brown, 1997; Chave et al., 2014). Geospatial data can also be used to improve AGB estimation using various satellite sensor data. Accuracy in biomass estimation is vital for the implementation of climate change mitigation mechanisms such as Reducing Emissions from Deforestation and forest Degradation-plus (REDD+) as well as for forest management in Asian countries (Andoh and Lee, 2018; Borah et al., 2018).

The Ifugao rice terrace system was first recorded as a World Heritage site in 1995 by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Department of Environment and Natural Resources, 2008). However, the maintenance and conservation of World Heritage sites require financing (Timothy and Nyaupane, 2009). Toorn (2013) found that funding availability is the main issue in the conservation of these cultural landscapes. This study focuses on the assessment of forest biomass stock in the Ifugao system, which will be useful in creating funding opportunities under the existing REDD+ mechanism. Earlier studies have shown that population growth has led to increased demand for firewood and timber products, thereby contributing to deforestation and also affecting ecosystem services (Ravindranath and Ostwald 2008; Avtar et al., 2019). This study explores how REDD+ initiatives can mitigate climate change and value forests to help the traditional cultures of Ifugao communities and livelihoods (UN-REDD 2016). In the Philippines, the Department of Environment and Natural Resources (DENR) is pushing for the nationwide implementation of REDD+ initiatives to reduce the impact of climate change. Lasco et al. (2013) reviewed REDD+ projects in the Philippines and discussed the critical factors for their successful implementation. This study aims to assess the total forest carbon stock of the muyong and bilid forests in Ifugao and its role in climate change mitigation strategies under the REDD+ framework. The REDD+ intervention can also support the area's indigenous people in adopting inventive mechanisms aimed at managing the transformation of the Ifugao economy.

2. Study Area

The Nagacadan barangay is one of the fourteen barangays of the Kiangan municipality of the Ifugao province of the Philippines. It is located about 320km from Metro Manila. The total

population of Nagacadan was 831 as per the 2015 census data. Agriculture and tourism are the main sources of income in the study area. Ifugao is a landlocked mountain province in the epicenter of the Philippine Cordilleras region. The topography of the area is marked by rugged terrain with mountainous forests. The Kiangan is situated in an upland area with an elevation ranges from 500 to 1,300 meters above the mean sea level. The highest point in Ifugao is Mt. Pulag, a popular hiking destination. The Ifugao rice terraces, with an estimated area of 10,323 ha, are listed in the UNESCO World Heritage site as part of the agricultural system used by the Ifugao (Calderon et al., 2009). Figure 1 shows the Ifugao rice terrace system with mountainous areas covered with the muyong and bilid forests. This shows how forest management and rice terraces are complementary to each other.

Figure 1. Ifugao rice terraces with mountains covered with muyong and bilid forests

The forests in the region are classified as the amalgamation of moss, pine, and dipterocarp forests, respectively (Daniel, 2014). Figure 2 shows the location of Nagacadan and variations of topographic conditions. Shuttle Radar Topographic Mission (SRTM) digital elevation (DEM) data shows the change in the topography in the study area.

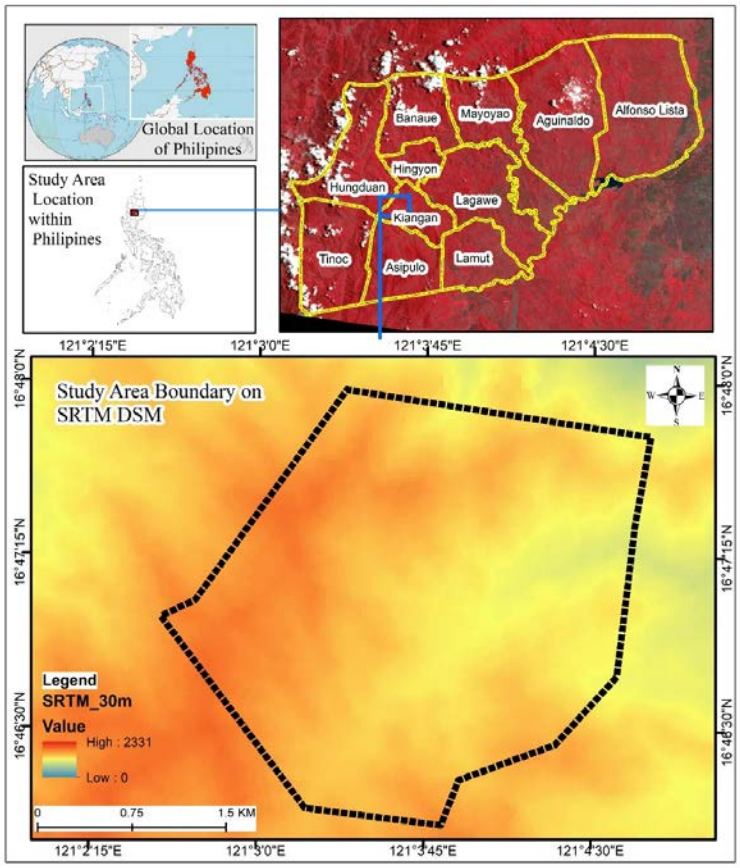


Figure 2. Representation of the study area

There are five land use classes in the study area namely: (1) *muyong*, (2) rice terrace (*payoh)*, (3) *bilid*, (4) *habal*, and (5) fallow/open agricultural land. Table 1 shows the land use types in the study site and their description.

Table 1. Various land-use types in the study area

Land-use type	**Ownership**	**Description**
Muyong	Private	Forest woodlot
Payoh	Private	Rice terrace
Bilid	Communal	Forest area around the mountain
Habal	Private	Swidden farms designated for food production located on a steep incline
Fallow	Private	Drained rice terraces

2.1. Forest Woodlots (Muyong)

The muyong is a privately managed woodlot with diverse plant species, constituting an important part of the agricultural and social system. Within the context of the local culture, the muyong system is a highly functional and efficient mosaic of forest resources and is the product of thousands of years of experimental learning. The local people have observed a link between forest management and food security. Therefore, the protection of muyong is a vital component for the survival of rice terraces (Dugan et al., 2003). As muyong are located at higher elevations relative to the rice terraces, they are considered to regulate the supply of water, which is essential for rice production. Furthermore, the vegetation helps to reduce surface water runoff and erosion, thus also preventing the sediment accumulation in the underlying paddy fields (Matsushima and Tojo, 2010).

2.2. Mountain Forest (Bilid)

The bilid is defined as the forested area around the mountain ridge, which operates under a regime of communal management. Not all of the area on the mountain ridge consists of bilid, as the mountain top is also inhabited by large swaths of tall cane grass and occasional swidden farms (Jang and Salcedo, 2013). The bilid is free for anyone to harvest. Therefore, many farmers take advantage of this when they feel that they have harvested too much from their muyong. The bilid can appear physically similar to a muyong, but it has different management and tenure system.

2.3. Swidden Fields (Habal)

Also known as the *kaingin* in Nagacadan, the habal refers to an area that is explicitly designated for food production. It is one of the most important lands uses in the area and is created through slash-and-burn agriculture. Habal is often established on slopes that are too steep for rice terrace cultivation. As they do not require much maintenance, they are generally located far from the homestead. The habal is a necessary component of the muyong system because local communities rely on it to supplement their diet and it also offers insurance against years with low rice yields (Conklin, 1980).

3. Methodology

This study's methodology was designed to assess forest carbon stocks with the aim of implementing the REDD+ mechanism in Nagacadan, Ifugao. It consists of field- and remote sensing-based biomass estimation. To understand the benefits of the REDD+ mechanism and achieve the objective of this study, forest biomass in the Ifugao system was estimated. Fieldwork was conducted to collect biomass data from February 8–14 2015. We adopted methodologies from Ravindranath and Ostwald (2008) for ground-based biomass calculation using forest inventory data. Avtar et al.'s (2013b) methodologies were used for Phased Array L-band type Synthetic Aperture Radar (PALSAR)-based forest biomass estimation. Figure 3 shows the outline of the methodology for biomass estimation using field-based observation for direct measurement and satellite-based observation for indirect measurement.

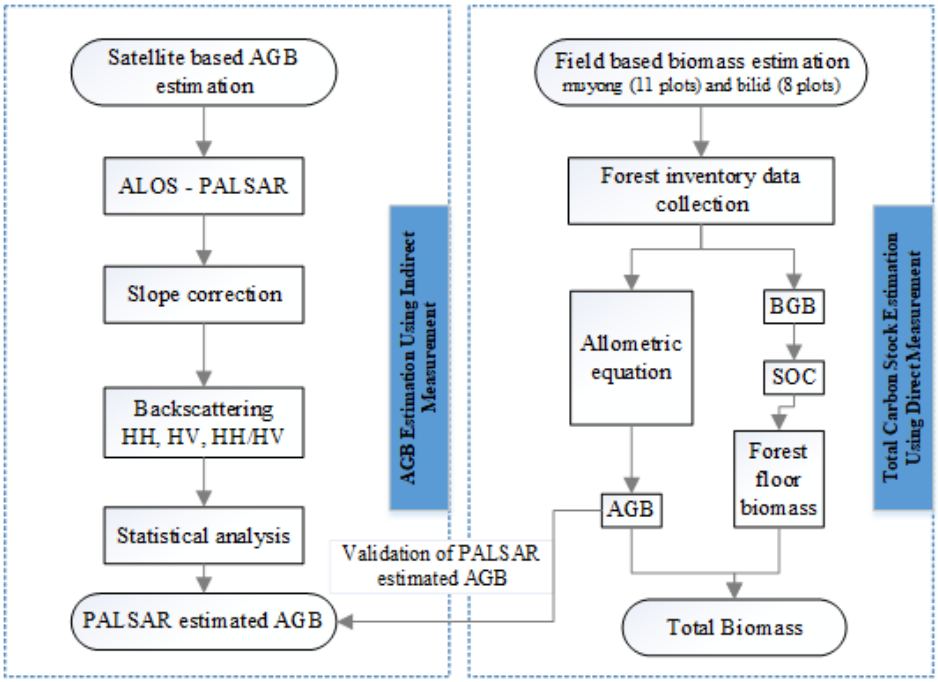


Figure 3. Flow chart of forest biomass estimation using satellite-based and ground-based measurement

Measurement and analysis of different carbon pools were performed to estimate total carbon stock in the forest. In most forest biomass studies, forest biomass and soil organic carbon (SOC) are the two major carbon pools. Forest biomass pools can be further divided into living AGB and belowground biomass (BGB), which includes litter, roots, litterfall, detritus, dead

organic material, and woody debris (Houghton, 2003). AGB is the major and most evident carbon pool in the terrestrial ecosystem (Ravindranath and Ostwald, 2008). BGB includes live roots that support the carbon cycle by transferring and storing carbon in the soil (Eggleston et al., 2006). Biomass from litter, litterfall, detritus, dead organic material, and woody debris constitutes a small fraction of forest carbon stocks (Ravindranath and Ostwald, 2008). Soil organic matter is also a major contributor to forest carbon stocks and releases CO_2 as a consequence of deforestation (Lal, 2005). Table 2 shows the various methods available for measuring different biomass pools and their suitability for carbon measurement. In this study, the plot-based method was used to estimate AGB.

Non-destructive biomass measurement methods are popular in protected areas because AGB estimation can be achieved without destruction of trees. Data collected from sample plots can be used to estimate the mean carbon stock per unit area of each land-use type, which can then be extrapolated using remote sensing techniques (Avtar, Suzuki, et al., 2013b). This method of AGB estimation was considered the most suitable for the study area. However, the presence of steeply sloping mountainous terrain can cause errors and limit the use of synthetic aperture radar (SAR) data. Furthermore, the region's tropical climate is associated with high amounts of cloud cover, which limits the availability of cloud-free multispectral remote sensing data (Minh et al., 2019). Therefore, the use of field-based measurements (*in-situ*) implementing non-destructive sampling techniques can minimize the uncertainties in AGB estimation.

Table 2. Methods to measure carbon pools (Ravindranath and Ostwald, 2008)

Pools	**Methods**	**Suitability for carbon measurement**
AGB	Plot method	Commonly used and familiar method Cost-effective and suitable
	Harvest method	Not appropriate all the time Time-consuming, labor-intensive and expensive
	Plot-less or transect method	This method is good but it is not suitable in dense forest as well as for periodical monitoring
	Modelling	Need basic input data for building the models It is suitable for projections

		Requires basic input parameters
	Satellite/remote sensing	These methods are suitable for regional and national level monitoring but expensive for small projects.
	Carbon flux measurements	This is an expensive method and requires skilled people.
BGB	Root extraction and weight measurement	Time-consuming, labor-intensive and expensive
	Root to shoot ratio method	This method is commonly used based on AGB data
	Biomass equations	Need data e.g. DBH, tree height, girth etc.
Dead organic matter	Litter	This method needs huge efforts
	Stock measurement	This method is commonly adopted and feasible
Soil carbon	Diffuse reflectance spectroscopy method	This method is expensive and requires skilled human resources
	Modelling	Need basic input data from other methods and suitable for projection
	Laboratory estimation	This is the most suitable method and commonly adopted

3.1. Carbon Stock Estimation using Direct Measurement

Field-based biomass estimation methods were used to collect forest inventory parameters with the assistance of local people in the study area. The random sampling method was used to collect forest inventory parameters to measure forest carbon stock. Figure 4 shows the distribution of sampling plots in the Nagacadan area. In this study, temporary sampling plots were used in light of the limited budget. Moreover, we did not intend to conduct long-term monitoring of the biomass pattern.

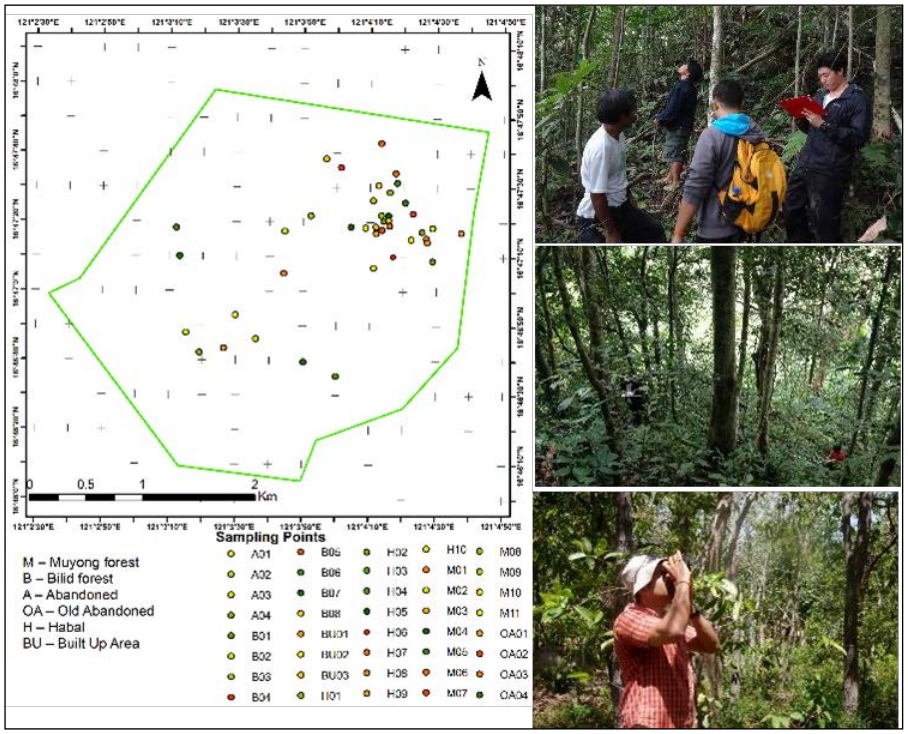


Figure 4. Field data collection and location of sampling plots

Square plots of 10 × 10 m were laid out with measuring tape for AGB estimation. The corners of the plots were located with the help of the Global Positioning System (GPS). The shape and size of the sampling plots constitutes a trade-off between time, accuracy, and cost of measurement. Wondo (2013) suggested that square plots tend to include more heterogeneity and favor more representation than circular plots in the same study area (Wondo, 2013). As suggested by Pearson et al. (2005), based on the consideration of medium-size diameter at breast height (DBH) at the study site, we adopted 10 × 10-m plots to minimize the heterogeneity. This was also due to the steep slope conditions in the mountainous forest. Moreover, the plots were the same size as the pixels of the Advanced Visible and Near-Infrared Radiometer type-2 (AVNIR-2) data.

Data were collected from four carbon pools: AGB, BGB, forest floor biomass, and soil carbon. To estimate forest carbon stock, forest inventory parameters, including tree height, DBH, tree species, tree density, and forest types were collected. Tree height refers to the total height of trees instead of the height of the merchantable stem, which is used in some allometric equations. DBH of each tree was measured at 130 cm height from the ground by using DBH tapes and markers. All the trees with DBH ≥ 5 cm were measured with a DBH tape. To measure the DBH

in the steep slope, the measurement was conducted on the uphill side of the tree (Ravindranath and Ostwald, 2008).

The following allometric equation was used for the AGB calculation (Brown, 1997). It was developed specifically for forest biomass estimation in moist tropical forests and covered most of the species of tropical forests.

$$AGB = \exp(-2.289 + 2.649 \times \ln(dbh) - 0.021 \times \ln(dbh^2)) \quad (1)$$

Where, ln = natural log, exp = "e to the power of"

To estimate BGB (root biomass) from the AGB, an allometric equation was used as follows (Ravindranath and Ostwald, 2008):

$$BGB = \exp[-1.0587 + 0.8836 * \ln(AGB)] \quad (2)$$

Where, ln = natural log, exp = "e to the power of"

The biomass value obtained from the above equations is converted to carbon stock using a carbon conversion factor of 0.47 (McGroddy et al., 2004).

$$\text{Carbon stock (tC/ha)} = \text{biomass (t/ha)} \times 0.47 \quad (3)$$

Within the sample plot, a smaller plot of 1 × 1 m was established to measure the forest floor layer and soil carbon. The measurement design is presented in Figure 5. A 1 × 1-m plot was used to collect litter, herbaceous (live above ground non-woody with DBH < 2 cm), and soil samples. Deadwood, litter, and dead roots were also collected from the forest floor and separated into fresh and litter types before being dried in the oven. In the same plot, soil samples were randomly collected at a depth of 10 cm and then oven-dried at 70°C for 2 days. Walkley and Black's (1934) methods were used to calculate organic carbon (%). The soil carbon (t/ha) was calculated using the method developed by Nelson and Sommers (1996). Earlier studies have found that the highest percentage of soil carbon is present in the upper soil layer (Racelis et al., 2008 in the Philippines, Ullah et al., 2012 in Bangladesh; Hobley et al., 2016 in Australia).

$$\text{Soil carbon} = [\text{soil bulk density } (gm^{-3}) \times \text{soil depth (cm)} \times \text{soil organic carbon (\%)}] \times 100 \quad (4)$$

The total number of square plots for the collection of forest inventory data for muyong and bilid were 11 and 8, respectively. In contrast to the forest carbon stock and forest floor areas,

the total number of samples for soil carbon was five (three in muyong, two in bilid). Total carbon stock is the summation of carbon stock from AGB, BGB, forest floor, and soil carbon.

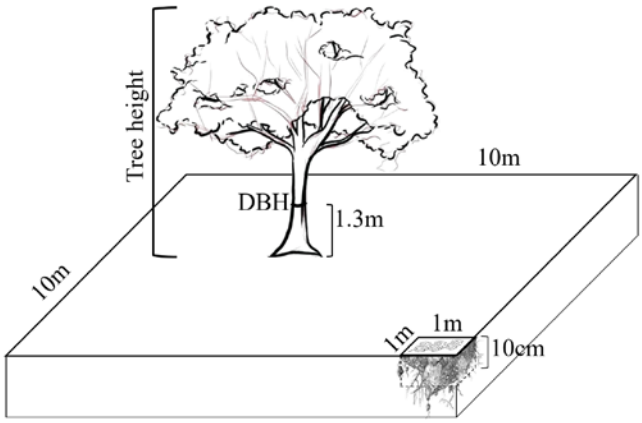


Figure 5. The design of plot samples and carbon measurement in the field

3.2. Carbon Stock Estimation using Indirect Measurement

Conventional allometric-based biomass estimation is one of the most accurate methods used in carbon stock estimation. However, it is expensive, time-consuming, and labor-intensive (Avtar et al., 2012; Avtar et al., 2013c; Avtar et al., 2016). Moreover, it is only applicable in small areas for which forest inventory data are available. Remote sensing can overcome the above-mentioned limitations.

Several studies have modeled forest biomass using various satellite sensors (Anaya et al., 2009; Baccini et al., 2004; Drake et al., 2003; Vashum and Jayakumar, 2012). Avtar et al. (2013b) reported that SAR data are more effective than optical data in measuring AGB in tropical regions due to the limitation of clouds. Other studies have shown that light detection and ranging (LiDAR)-based biomass estimation offers greater accuracy than other remote sensing-based observation methods (Nelson et al., 1988; Vashum and Jayakumar, 2012). However, the use of LiDAR data in developing countries is particularly limited owing to acquisition and processing costs. Therefore, PALSAR data were used to estimate AGB in this study. SAR data with cross-polarization (horizontal and vertical: HV) can detect tree volume and are useful in estimating forest biomass (Avtar et al. 2013b). SAR-based backscattering information is useful for estimating forest biomass and has been used extensively by other researchers (Englhart et al., 2011). Furthermore, due to its penetrative capacity, SAR has the advantage of being insensitive

to weather conditions, such as clouds and rain, which is useful in tropical regions. SAR backscatter information is affected by the topography with steep slopes due to layover and foreshortening effects of SAR data (Avtar et al., 2013b).

The satellite data were acquired from the Advanced Land Observation Satellite (ALOS) mission of the Japan Aerospace Exploration Agency (JAXA) in 2010. AVNIR-2 and PALSAR were used to estimate biomass in the study area. AVNIR-2 is a multispectral image with four bands consisting of blue, green, red, and near-infrared (NIR) bands with a 10-m pixel size. Similarly, PALSAR images have a spatial resolution of approximately 16 m with dual polarization (Tadono et al., 2009). Land use/land cover (LULC) classification of AVNIR-2 data was performed to distinguish various LULC classes in the study area, including bilid, muyong, rice terraces, built-up areas, grassy mountain terrain, open mountain, and water bodies. The maximum likelihood classification algorithm was used to classify AVNIR-2 data (Lillesand and Kiefer, 1999). Forest cover information can be a useful parameter for calculating total carbon stocks in the study area. Samreth et al. (2012) used remote sensing and a ground-based forest inventory approach to estimate carbon stocks in Cambodian forests. The use of forest area and average carbon stock in a particular forest can provide total carbon stock information. We explored similar methodological approaches to calculate average carbon stock in muyong and bilid forests using the following equation.

$$\text{Total carbon stock} = \Sigma\,(\text{forest area}_i \times \text{averaged carbon stock}_i) \qquad (5)$$

Where, $_i$ = forest types (muyong or bilid)

We also used backscattering information from dual-polarization PALSAR data to estimate AGB using the methodology described in Avtar et al. (2013b). Field-calculated AGB was used to validate the PALSAR-estimated biomass.

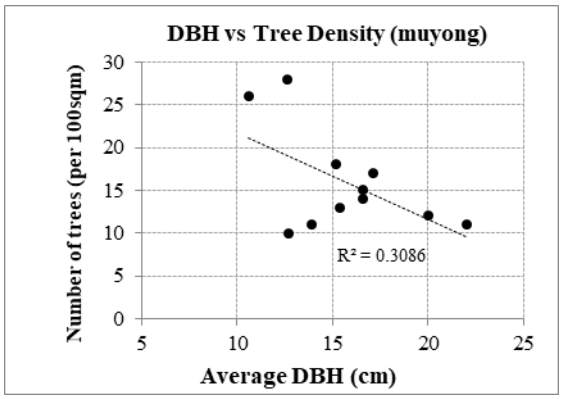
4. Results and Discussion

This study aimed to assess the forest carbon stocks in the Ifugao system using direct and indirect measurement methods to obtain information from four carbon pools: (1) AGB, (2) BGB, (3) forest floor layer, and (4) SOC. We also attempted to generate a land-use map of the area using AVNIR-2 data and biomass estimation using equation 5. PALSAR-based methods were also used to estimate forest biomass.

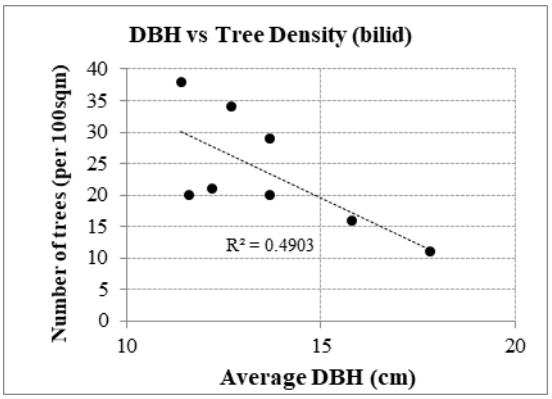
4.1. Carbon Stock Estimation using Direct Measurement

4.1.1. Forest Carbon Stock (AGB + BGB)

To quantify forest carbon stocks, we collected forest inventory parameters (tree height, DBH, species, tree density, and forest types) in muyong and bilid forests. This study evaluated total forest biomass in the Ifugao forest management system. Appendices A1 and A2 show the forest inventory parameters and calculation of forest biomass stocks in the muyong and bilid forests, respectively. Statistical analysis was conducted to compare the various forest inventory parameters. Figure 6 shows the linear regression between tree density and average DBH of the sampling plots. A moderate relationship was observed between tree density and average DBH in muyong with a correlation value of 0.56 (R^2 = 0.31), while a strong relationship was observed in bilid with a correlation value of 0.7 (R^2 = 0.49). As tree density increases, the trees' DBH values tend to be smaller. The relationship between average DBH and tree density demonstrates that in dense forests, tree growth rate can be restricted due to the limited space and greater competition among trees for growth determinants such as nutrients, space, and access to sunlight. Similarly, Takahashi et al. (2018) also noticed a large DBH and a low tree density for evergreen conifers in the Shizumo forest reserve. Comparison of average DBH between the muyong and bilid revealed that the muyong features trees with a high average DBH and low tree density in contrast to the bilid forest. Furthermore, the findings show that tree density per hectare is higher in the bilid, which supports the theory that lack of maintenance allows the natural regrowth of plants in the bilid.



(a)



(b)

Figure 6. Linear regression between DBH and tree density in (a) muyong and (b) bilid forests

Figure 7 shows a histogram of the DBH frequency distribution with respect to tree density. The histogram shows the normal distribution of DBH in the muyong and bilid. The average and standard deviation of DBH were 15.79 cm and 11.63 cm in muyong, while the values were 13.14 cm and 6.29 cm in bilid. The muyong showed a greater difference in DBH than bilid. Despite the uneven number of sample plots, the data support the view that the muyong management system enables the growth of larger trees. This is evidenced by the measurement of the largest tree in the bilid at 36 cm DBH while 10 trees larger than 36 cm and one larger than 70 cm (accounting for 0.6%) were observed in the muyong. The histogram illustrates the muyong's association with the growth of larger trees owing to the maintenance and protection activities implemented by private forest holders.

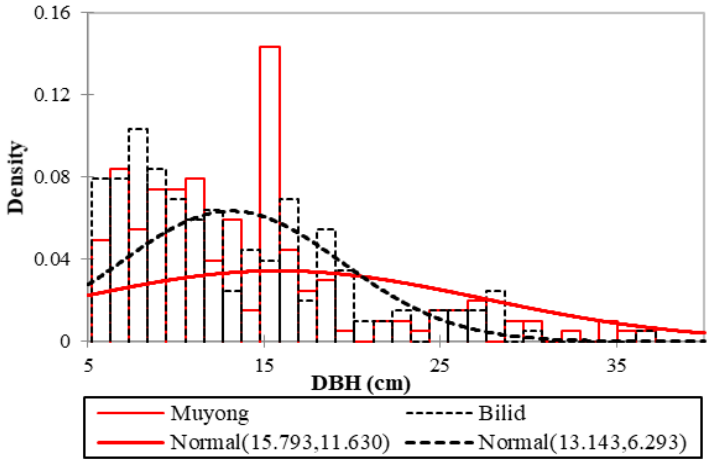


Figure 7. Histogram of tree density and DBH in muyong and bilid forests

In this study, Brown's (1997) allometric equation was used to determine the AGB based on DBH information. In tropical forests, the biomass of trees with DBH greater than 70 cm can account for 40% of the total forest biomass density, and these trees represent less than 5% of all trees (Brown and Lugo, 1992). Appendices A1 and A2 show the mean AGB (215 t/ha), BGB (38.9 t/ha) and total biomass (254.7 t/ha) recorded in the muyong forest, and the mean AGB (166.3 t/ha), BGB (33.5 t/ha) and total biomass (199.7 t/ha) recorded for bilid forest. The muyong forest had high average carbon stocks with 119.7 ± 76 tons of carbon per hectare (tC/ha)

compared to the bilid which had 93.9 ± 27.6 tC/ha. Although the plots in the bilid showed high tree density compared to the muyong, the muyong showed higher total forest carbon stock values.

4.1.2. Forest Floor Biomass

Table 3 shows the amount of fresh and litter samples in the 1-m^2 sampling plots within the 10-m^2 plots. The bilid forest showed higher coverage of fresh and litter samples than the muyong forest. After the fresh samples were collected, they were oven-dried to determine the dry mass.

Table 3. Amounts of fresh and litter samples collected per square meter

Forest types	Fresh (herbaceous) (g)	Litter (g)	Total Sample (g)
Muyong	419±188	1,075±446	1,494±481
Bilid	673±447	1,776±412	2,449±608

Table 4 shows the average dry mass and carbon content in the fresh and litter samples of the forest floor. The bilid showed higher average levels of dry mass in both fresh and litter samples than the muyong. The presence of high fresh and litter carbon in the bilid is due to the natural growth of herbaceous vegetation on the forest floor.

Table 4. Average dry mass and carbon content in the fresh and litter samples of the forest floor

Forest types	Average Dry Mass			Average Carbon		
	Fresh (t/ha)	Litter (t/ha)	Total (t/ha)	Fresh (tC/ha)	Litter (tC/ha)	Total (tC/ha)
Muyong	2.99	7.93	10.92	1.41	3.73	5.13
Bilid	4.86	13.15	18.01	2.28	6.18	8.46

4.1.3. Soil Carbon

Soil carbon is the main contributor to forest carbon stocks next to AGB (Lal, 2005). Soil samples were collected from the 10-cm topsoil layer to estimate SOC. The soil samples were oven-dried

at 70°C for 48 h in the laboratory. They were then subjected to carbon content analysis under laboratory conditions. Table 5 shows the average soil organic carbon stock in muyong and bilid forests. The average SOC was 26.02 and 23.78 tC/ha in the muyong and bilid forests, respectively, to a soil depth of 10 cm. The 0–10-cm level of the soil is expected to be rich in carbon owing to the presence of humus or organic matter accumulated from the decomposed litter (Ullah et al., 2012; Hobley et al., 2016). The soil carbon results revealed a higher SOC value in muyong than in bilid. This may be attributed to the bilid's greater exposure to sunlight and its greater susceptibility to soil erosion. Furthermore, the practices of weeding, regular thinning, and treatment can play a beneficial role in carbon sequestration in muyong. Finkral and Evas (2008) also reported that thinning treatments can re-establish ecological processes and help in ecosystem restoration and function.

Table 5. Average soil organic carbon stock

Forest types	**Average Soil Bulk Density**	**Mean Soil Organic Carbon (%)**	**Avg. Soil Organic Carbon Stock (tC/ha)**
Muyong	0.72+0.19	3.88±0.09	26.02±4.81
Bilid	0.73±0.03	3.26±0.90	23.78±0.98

4.1.4. Total Carbon Stock

Table 6 shows the total carbon stocks in the muyong and bilid. The results show that the carbon stock in the muyong was higher than that in the bilid. The average carbon stock in the muyong was estimated to be 150.86 tC/ha compared to the 126.14 tC/ha found in the bilid. The presence of large DBH trees in muyong forests can contribute to the majority of forest biomass, as has been confirmed by other studies (Brown & Lugo, 1992; Brown et al., 1995; Culmsee, et al., 2010). Among the all-carbon pools, most of the carbon stock was in the AGB pool. Forest carbon stock information is important for planning, management, and carbon sequestration in the Ifugao system. Information of this nature is essential to understanding carbon stock potential in the forest system at a micro-level. Climate, soil type, topographic factors, and biotic factors are the main determinants of forest biomass and its spatial distribution (Xu et al., 2015). Biomass

accumulation in forests also varies according to microclimate and anthropogenic disturbances (Brown and Lugo, 1990).

Table 6. Total carbon stocks based on field data

Forest types	AGB (tC/ha)	BGB (tC/ha)	Forest Floor		Soil carbon (0-10cm)	Total Carbon Stock
			Fresh	Litter	(tC/ha)	(tC/ha)
Muyong	101.4	18.3	1.41	3.73	26.02	150.86
Bilid	78.2	15.7	2.28	6.18	23.78	126.14

4.2. Carbon Stock Estimation using Indirect Measurement (remote sensing-based analysis)

Geospatial data can be used to study forest biomass, which is fortunate, as conventional field-based methods are expensive and time-consuming. Moreover, conventional field-based methods are only applicable to small-scale analysis. Therefore, remote sensing-based methods can be applied to a larger area (Vashum et al., 2012). In this study, the maximum likelihood classification algorithm was used to classify AVNIR-2 data with the help of field data. Figure 8 shows the LULC map of the study area. The area was classified into seven classes: muyong, bilid, rice terraces, built-up areas, grassy mountain area, open mountain, and water bodies. The classified image attempts to distinguish muyong (sea-green) forests from the bilid (green). Some misclassification with respect to bilid or muyong occurred owing to the presence of steep topography in the area. Most of the area is covered by bilid (32.5%), followed by rice terraces (30.4%) and muyong (29.5%).

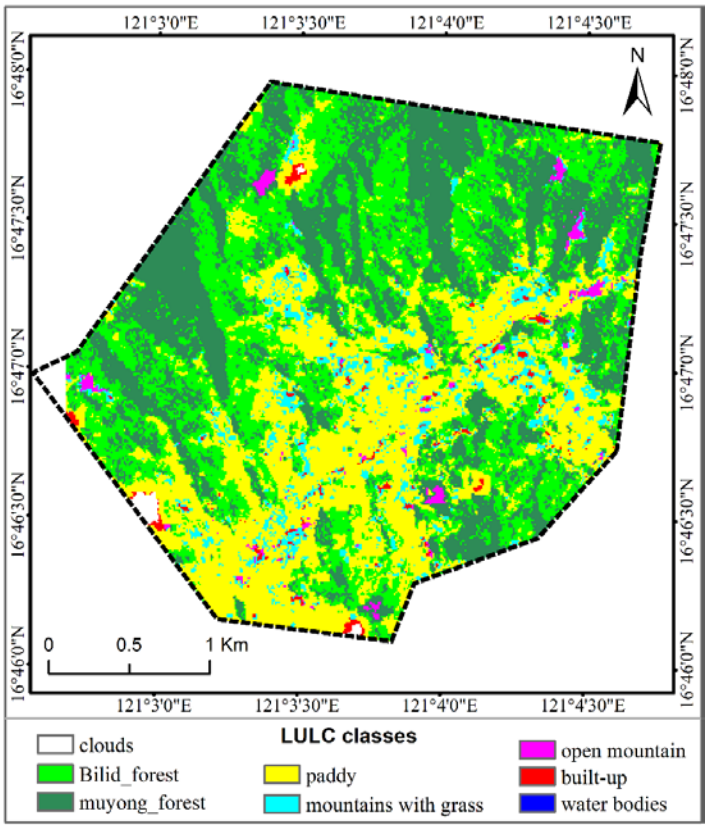


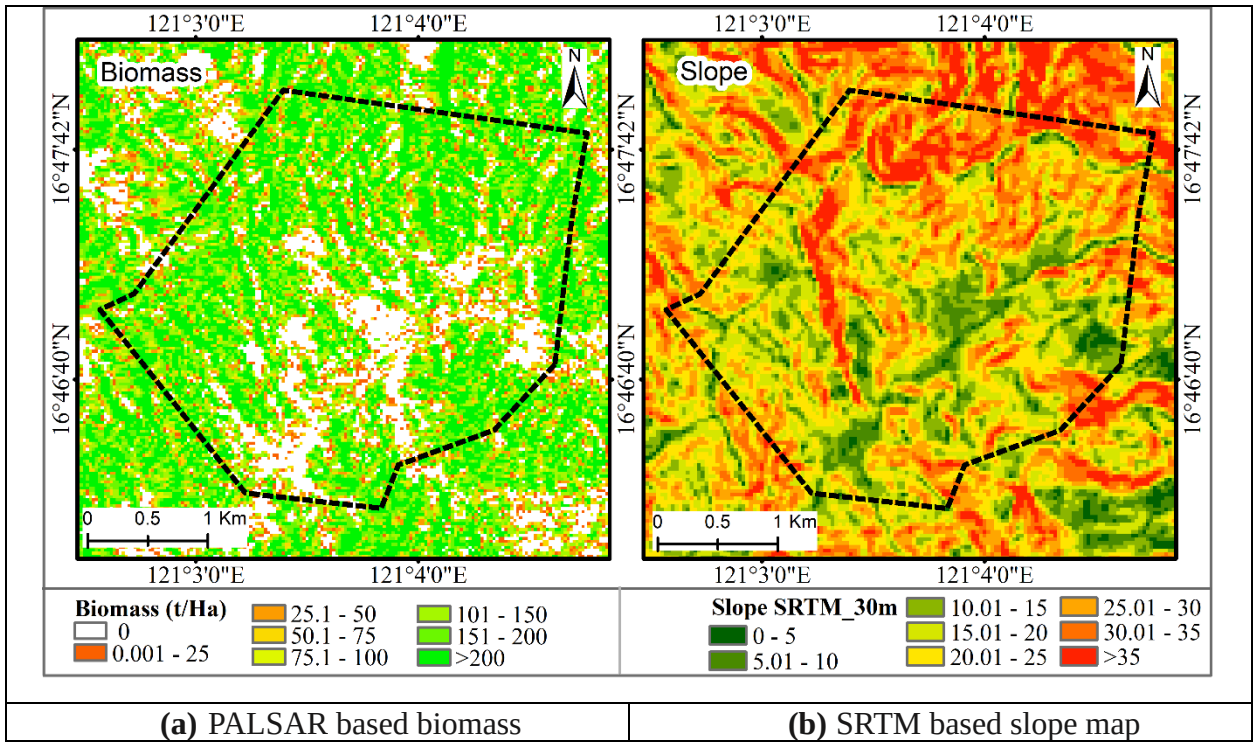
Figure 8. Land use/land cover map of the study area

AVNIR-2-based forest area information and average carbon stocks in bilid and muyong forests were used to estimate total carbon stocks. Table 7 shows the estimated average carbon stocks in the muyong and bilid forests using field-based and remote sensing-based information. The total carbon stocks were 401,061.3 and 369,804.6 tC in muyong and bilid forests, respectively. This information will be useful for policy-makers in designing REDD+ policies for the study area. Some uncertainties in the biomass estimation may potentially arise because soil carbon up to soil depth of 10 cm is considered in this study.

Table 7. Total carbon stocks in muyong and bilid based on remote sensing and field data

Forest Types	Forest area (ha) (2010)	Average carbon stock (tC/ha)	Total carbon stock (tC)
Muyong	2658.5	150.86	401061.3
Bilid	2931.7	126.14	369804.6

Avtar et al.'s (2013b) methodology was used to estimate AGB using PALSAR data. Figures 9a and 9b show the biomass map using PALSAR data and the slope map using SRTM-DEM data from the study area. The slope map of the study area (Fig. 10b) clearly shows that most of the area had a slope greater than 20 degrees with the exception of the paddy fields. Therefore, the biomass estimation using PALSAR data may have low accuracy due to the topographic effects on SAR data. Attarchi and Gloaguen (2014) also noticed the effect of topography on PALSAR-based biomass estimation in a mountain forest in Iran and proposed the use of multi-satellite data to overcome topographic effects.



(a) PALSAR based biomass | **(b)** SRTM based slope map

Figure (9a) PALSAR-based biomass of the study area (9b) SRTM-based slope map

Figure 10 shows a weak correlation (R^2 = 0.029) between PALSAR-estimated biomass and field-measured biomass. No significant relationship was observed with PALSAR-estimated biomass because most of the plots were on a steep slope and SAR data are not effective in steep areas owing to the topographic effects. Lone et al. (2017) also used PALSAR data to study the influence of slope and aspect in AGB estimation in India and found that topography influences the saturation of backscattering. The high slope areas have a high saturation limit of backscattering with 50–60 t/ha uncertainty. The key limitation to the PALSAR-based biomass estimation was the topographic effect of SAR data in the study area, which limits the

applications of remote sensing techniques. To overcome the topographic limitations, LiDAR data can be useful for more precise biomass estimation in mountainous areas. Further studies on forests in other areas of Ifugao would be useful in addressing the lack of information available for remote sensing analysis. However, the potential for remote sensing opportunities in the area remains limited due to the cloud cover and topography.

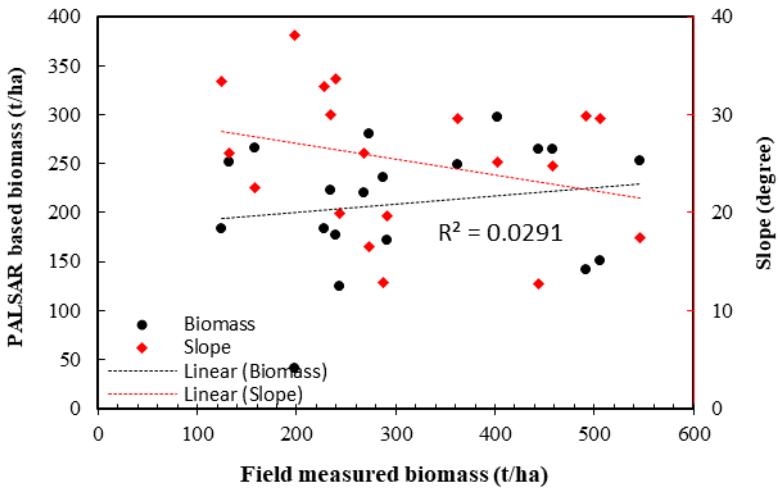


Figure 10. Correlation between PALSAR-estimated biomass and field-measured biomass

The estimation of total carbon stock is an important input for several current and future initiatives. The results can improve our understanding of how the muyong forest contributes potential carbon stock and the role of a landscape. The muyong forest showed higher total biomass than the bilid forest, and a greater difference in DBH was found in the muyong than in the bilid. Tree density is higher in the bilid forest than in the muyong, and this supports the hypothesis that the selective cutting and facilitated growth practices in the muyong are beneficial for carbon sequestration. Interestingly, the maintenance of muyong forests not only promotes carbon sequestration but also provides water for the rice fields during the dry season.

Implementation of the REDD+ mechanism can provide opportunities for the local people to conserve and manage the muyong system more sustainably in addition to reaping the financial benefits associated with carbon sequestration in the muyong system. Furthermore, the implementation of REDD+ can help protect the environment and biodiversity. It can conserve carbon stocks and provide a better adaptation mechanism to climate change in the Philippines, which is one of the climate change mitigation policies (Center et al., n.d.; Roe, 2012).

Climate change and other anthropogenic factors are affecting the rice terraces, and local people are struggling to sustain their livelihoods. Consequently, people have begun to leave the muyong area in search of employment elsewhere (Avtar et al., 2019). As part of the effort to reduce the outward migration of local people, REDD+ can make a positive impact with respect to long-term maintenance of the muyong forest. As a means of generating more income, REDD+ supports coffee tree growth in the muyong forest and taps into the organic food market rather than wood collection. Thus, REDD+ is still considered a promising means of creating incentives and other livelihood options to reduce deforestation and sustain the economic transformations of the Ifugao economy.

This preliminary study had several limitations, including the limited number of sampling plots and the relative spacing of sampling plots due to steep topography. Systematic sampling with a sufficient number of plots may be the optimal approach to accurately estimate total carbon stocks. The use of species-specific allometric equations may be more effective than generic allometric equations in reducing uncertainties (Kiyono et al., 2010; Samreth et al., 2012). We measured soil carbon only at a soil depth of 10 cm, although earlier studies used soil carbon data from a soil depth of 1 m. The number of sampling plots was also limited and should be increased to improve measurement accuracy. The use of permanent sampling plots (PSPs) may help to enhance the accuracy of carbon estimation (Samreth et al., 2012). Continuous monitoring is required to determine the rate of sequestration with the establishment of PSPs.

The use of remote sensing techniques for biomass estimation in this study was limited by cloud cover and topographic conditions (i.e., slope). However, this could be improved through the application of advanced topographic correction techniques (Umarhadi and Danoedoro, 2019) as well as the use of high-resolution satellite data with object-based classification methods, such as GEOBIA (Weih Jr. and Riggan Jr., 2010) and the use of advanced modeling methods to estimate biomass, such as random forest (RF), stepwise regression (SR), and support vector regression (SVR) (Liu et al., 2017). The use of multi-sensor remote sensing data can improve the accuracy of image classification and biomass estimation. Improvement of biomass estimation is essential for an effective measurement, reporting, and verification (MRV) system. The incentives from REDD+ can help muyong forests with high carbon stock. The biomass products will also

be useful for Sustainable Development Goals (SDG) Goal 15, which includes the improvement of carbon management.

5. Conclusions

This study has demonstrated the effective use of direct and indirect methods to assess forest carbon stocks. The results reveal that carbon stock differs among muyong and bilid forests of the Ifugao system, and most of the carbon stock is found in AGB. Field-based methods are useful for calculating average carbon stocks in muyong (150.86 tC/ha) and bilid (126.14 tC/ha) forests. Owing to the positive role of human interventions, muyong forests happen to sequester a larger amount of carbon (than the natural capacity). This makes the muyong an appropriate forest management system for the implementation of the REDD+ framework. These data can play an important role in filling the gaps in the existing national forest biomass estimation. It is essential that high-quality carbon stock data be generated to facilitate the monitoring of forest carbon and understanding resilience under the REDD+ mechanism. Remote sensing data have limited applications in the study area due to cloud cover and topographic effects. Accurate and reliable biomass estimation models are necessary for the non-destructive estimation of carbon stocks. Furthermore, carbon sequestration safeguards against deforestation and also helps to develop symbiotic linkages between agroforestry and biodiversity conservation. REDD+ mediation is expected to support the Ifugao economy by providing additional incentives and opportunities that will assist local communities in maintaining their traditional rice terraces system.

Acknowledgment

The authors extend their thanks to the Asia-Pacific Network for Global Change Research (ARCP2011-13NMY-Herath) for supporting the field research and Japan Aerospace Exploration Agency (JAXA) for providing satellite data (PER2A2N133). We are also thankful to people of Ifugao who helped during the fieldwork. We are also thankful to Dr. Dixon Tuzon Gevana and Dr. Diwa Johanna Paula for their supports and suggestions.

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Appendix

Table A1. Muyong Forest Carbon Stock

Muyong	AGB		BGB		AGB+BGB		C Stock	
	kg	tons/ha	kg	tons/ha	kg	tons/ha	kg	tons/ha
M01	666.22	70.1	133.30	14.0	799.52	84.1	375.8	39.5
M02	2345.49	246.6	417.87	43.9	2763.36	290.6	1298.8	136.6
M03	3167.92	333.1	535.70	56.3	3703.62	389.4	1740.7	183.0
M04	1066.22	112.1	209.00	22.0	1275.21	134.1	599.3	63.0
M05	2465.64	259.3	515.15	54.2	2980.79	313.4	1401.0	147.3
M06	1008.68	106.1	191.53	20.1	1200.21	126.2	564.1	59.3
M07	1500.47	157.8	291.27	30.6	1791.74	188.4	842.1	88.5
M08	1965.55	206.7	375.16	39.4	2340.72	246.1	1100.1	115.7
M09	5421.45	570.0	834.79	87.8	6256.24	657.8	2940.4	309.2
M10	1248.71	131.3	240.64	25.3	1489.35	156.6	700.0	73.6
M11	1723.20	181.2	322.56	33.9	2045.76	215.1	961.5	101.1
Average	**2052.7**	**215.8**	**369.7**	**38.9**	**2422.41**	**254.7**	**1138.5**	**119.7**
Std. Dev	**1338.0**	**140.7**	**201.5**	**21.2**	**1537.1**	**161.6**	**722.5**	**76.0**

Table A2. Bilid Forest Carbon Stock

Bilid	AGB		BGB		AGB+BGB		C Stock	
	kg	tons/ha	kg	tons/ha	kg	tons/ha	kg	tons/ha
B01	1383.0	145.4	264.6	27.8	1647.6	173.2	774.4	81.4
B02	1243.6	130.8	252.9	26.6	1496.5	157.3	703.4	73.9
B03	1324.9	139.3	273.2	28.7	1598.1	168.0	751.1	79.0
B04	915.9	96.3	196.6	20.7	1112.5	117.0	522.9	55.0
B05	1542.0	162.1	303.1	31.9	1845.1	194.0	867.2	91.2
B06	2389.5	251.2	464.9	48.9	2854.4	300.1	1341.6	141.0

B07	1589.8	167.2	346.3	36.4	1936.2	203.6	910.0	95.7
B08	2262.8	237.9	443.6	46.6	2706.3	284.6	1272.0	133.8
Average	**1581.4**	**166.3**	**318.2**	**33.5**	**1899.6**	**199.7**	**892.8**	**93.9**
Std. Dev	**471.8**	**49.6**	**88.2**	**9.3**	**559.4**	**58.8**	**262.9**	**27.6**