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Carbon Stock Potential of Benguet Pine (*Pinus kesiya* Royle *ex* Gordon) Stands within a Mining Site in Padcal, Benguet Province, Philippines

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ABSTRACT

The study evaluated the climate change mitigation potential of Benguet Pine (Pinus kesiya Royle ex Gordon) forests in a mining site. It measured the amount of biomass, carbon and equivalent CO_2 stored in trees, understorey and herbaceous (UH), necromass and litter (NL), coarse woody debris (CWD), roots and soil organic carbon (SOC) under three stand density types. It adopted a single stratum stratified sampling. A non–destructive sampling was applied to all trees with diameter of 5 cm and above. Total harvesting of UH and NL samples were done in subplots inside the main sample plots. Composite soil samples were collected per soil depth (0–10 cm; 10–20 cm and 20–30 cm) and replicated per elevation type (high, mid and lower elevation). Stand types were classified using Google Earth image and GIS–generated map based on crown stocking density (CSD): high (HDS) = 2/3 CSD, medium (MDS) = > 1/3 – < 2/3 CSD and low (LDS) = >1/3 CSD. Results showed a mean biomass density of 176.83 Mg ha^{-1} with C content of 169.74 Mg ha^{-1}. The C content per stand type is as follows: HDS= 199.06 Mg ha^{-1}; MDS = 188.91 Mg ha^{-1} and LDS = 123.03 Mg ha^{-1}. This amounted to a total 8,277,474.88 Mg of CO_2 in the 12,185–ha Padcal Mine forests.

Key words: biomass assessment, carbon sequestration, mining, Pinus kesiya

INTRODUCTION

The research involved a comprehensive study on the estimation of biomass, C and equivalent CO_2 in different stands of Benguet pine (*Pinus kesiya* Royle ex Gordon) in mining forests at Padcal, Benguet, Philippines. The forests are located within the mining concession areas of the Philex–Padcal Mine. The mining forest project was initiated in response to the call of the government under "Adopt a Tree, Adopt a Mining Forest Movement in 1989 for the "establishment of a mining forest within a specified area by qualified participants" (DAO No. 22).

Philex–Padcal Mine has been operating in the area since 1958 and is involved in the extraction of ore that produces copper concentrates containing copper, gold, and silver through block caving method of underground mining. Along with its mining activities, the company is also protecting 9,620 ha of natural forests. It also maintains and develops additional reforestation sites as part of the project's environmental protection and enhancement program (Philex–Padcal Mine 2015). As of 2014, it was reported that the project had already reforested a total of 2,565 ha of open, denuded and poorly stocked forestlands within the mine tenement. Benguet Pine (*P. kesiya*) is the main reforestation species planted as it is highly adaptable to the site, fire resistant and very common in Benguet province.

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Benguet Pine is a coniferous and fast growing species that thrives in high altitude and on comparatively poor soils. It is one of the most important and widely distributed species in the Cordillera Administrative Region (CAR), characterized as high elevation areas with cold climate (Lumbres *et al.* 2013) suited for this kind of species.

Previous studies on Benguet Pine plantation focused only on its growth characteristics under natural habitat. Studies on the assessment of Benguet Pine's growth performance in terms of biomass accumulation in mined areas are clearly lacking, hence the focus of this study. The study primarily focuses on biomass estimation, which is very important in determining the amount of carbon stock in the stand. Zhao *et al.* (2014) and Lumbres *et al.* (2012) highlighted the importance of accounting carbon budgets in a forest ecosystem which is considered as a major sink in storing carbon in biomass and in the soil (Heimann & Reichstein 2008).

Forest store more C than any other terrestrial ecosystems and contain about 82–86% of all above terrestrial C and the soil of about 73% of the global C stock (Li *et al*. 2015). Tropical forests in particular play a significant role in the global carbon cycle. It was estimated that world's tropical forests through its vegetation and soil contain 428 Gt C, (Lasco *et al.* 2013). It is also a major source of carbon loss through land use, land–use change and forestry (LULUCF) activities mainly in tropical deforestation which IPCC estimated of about 1.6 Gt C y^{-1} of anthropogenic GHGs in the 1990's (Denman *et al.* 2007 as cited by Lasco *et al.* 2013). In Southeast Asia, this sector was the largest contributor of GHG emissions in 2000 (ADB 2009 & Zhuang *et al*. 2010), contributing about 75% in the region's total emissions (Pan *et al*. 2011). Conversion of tropical forest or peatland to agricultural or other commercial uses is driving Southeast Asia to have the highest deforestation rate worldwide (Langner & Siegert 2009). Forest fires caused by both natural and human sources also contribute to the carbon emission by rapidly releasing carbon from vegetation. Between 1997 to 2009, van der Werf *et al.* (2010) estimated that global biomass burning emitted about 2.0 Pg C yr^{-1}.

The Philippines is ranked as one of the top ten countries with the highest deforestation rates (FAO 2006 as cited by Carandang, 2013). Since 1500, the country's deforestation rate is estimated to have contributed about 3.7 Gt of CO_2 emissions and much of this deforestation and land use/cover change occurred in the last century (Lasco & Pulhin 2003, 2009). But LUCF is also the main sector that holds the key to successful emission reduction in the country. It even became a massive sink of carbon in the 2000 Philippine GHG inventory, offsetting about 83% (105 Mt CO^2e sequestered) of the country's emissions mostly coming from the energy sector (PSNC 2014).

To abate further loss of forest, the concept on REDD+ is being promoted by reducing emissions from deforestation and forest degradation and has been expanded to include conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks. As required by the UNFCCC, member countries have to regularly report their forest status and assess the carbon stocks present in their forest (Basuki *et al*. 2009). The same statement was earlier proposed by Lasco *et al*. (2004) that carbon stocks assessment must be done in different forest areas in the Philippines to have a more comprehensive and accurate information on carbon density of the country's forest. These will also help experts to determine the potential of these forests in climate change mitigation.

In the case of Padcal Mine as a mining project, carbon emission primarily comes from the use of fossil fuels to run its massive machineries and equipment. It is recommended that aside from the use of energy efficient technologies, natural or green mitigation measures like reforestation, agroforestry and conservation of existing forests could be pursued to reduce its emissions. Hence, the study would help determine the potential of these vegetation particularly Benguet Pine to offset its carbon emissions. It also identified more areas or adding more sinks which means establishing or maintaining more forest vegetation to compensate and help abate the project's emissions.

MATERIALS AND METHODS

Study site

The Padcal Mine is located in the Province of Benguet under the Cordillera Administrative Region (CAR). Figure 1, shows the location of the study site. The topography is generally rugged with moderate to very steep mountain slopes of about 35 to 75%. Elevation ranges from 1,600 to 1,886 masl. It belongs to Climatic Type I which has two pronounced seasons: dry from November to April and wet during the rest of the year. Maximum rain period is from June to September with an average annual rainfall that ranges from 2,500–3,600 mm and a

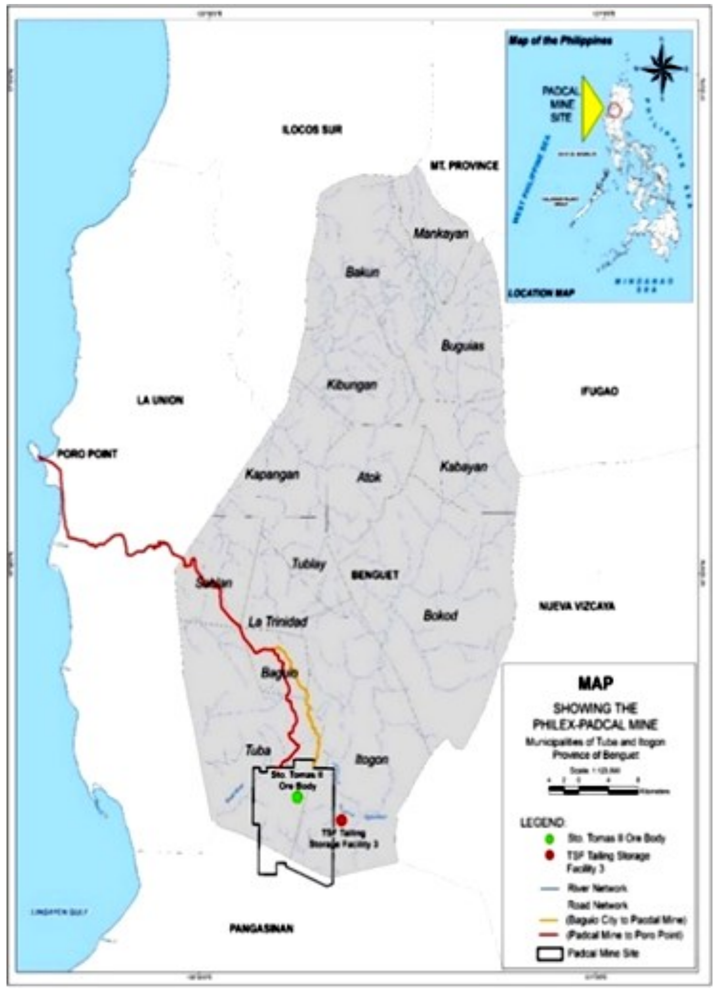

Figure 1. Location map of the Philex–Padcal Mine project.

typhoon frequency of 2–2.5 times a year (Bareja 2011). The temperature in the area ranges from 6ºC to 26ºC with December to February as the coldest months of the year.

The forest vegetation is under the supervision of the Padcal Mine primarily established, protected and managed under its reforestation program. It covers a total area of 12,185.00 ha based on GIS–generated data. The study site was classified into high (HDS), medium (MDS) and low (LDS) density stand based on crown stocking density (CSD) range of: 2/3 CSD for HDS, > 1/3 – < 2/3 CSD for MDS and >1/3 CSD for LDS. Stand classification and assessment were done using the Google Earth image of the area and processed through ArcGIS to produce the map (Figure 2). The data was validated on the ground through vegetation sampling.

Sampling Method

The study adopted a single stratum stratified sampling in the biomass inventory of the stands. A total of 45 sampling plots were established with 15 plots per stand type scattered within the project's reforestation sites (Figure 3). Biomass were measured both from the above–ground (live and dead biomass) and below–ground biomass (roots and soil organic matter). It was further categorized into six (6) major C pools: trees, UH, CWD, NL, roots and soil C. Estimating the C concentration in each component has improved the accuracy of the carbon content assessments of the stands (Li *et al*. 2011).

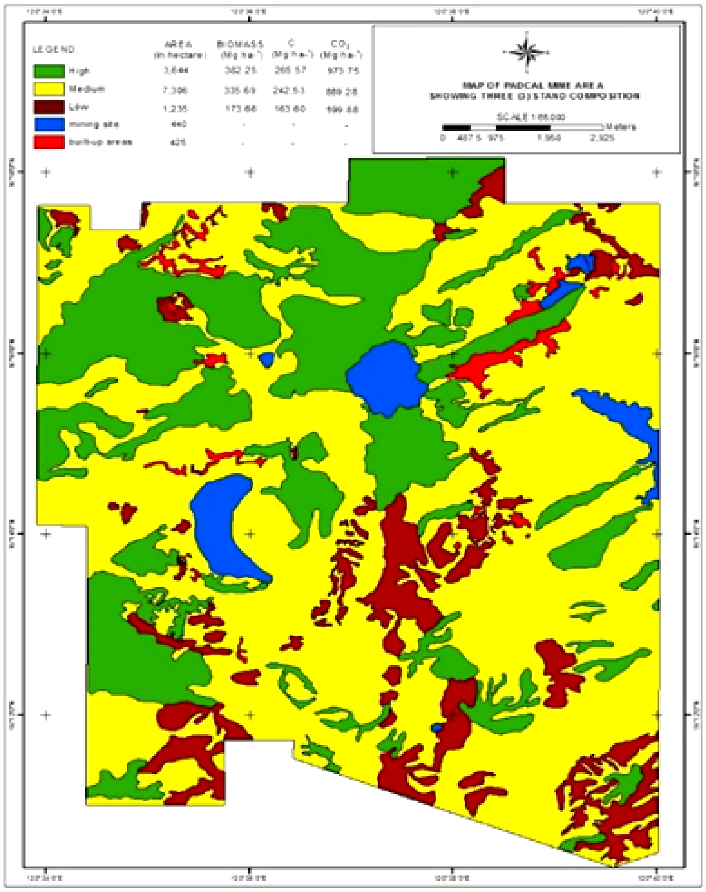

Figure 2. Stand density classification within the Padcal Mine

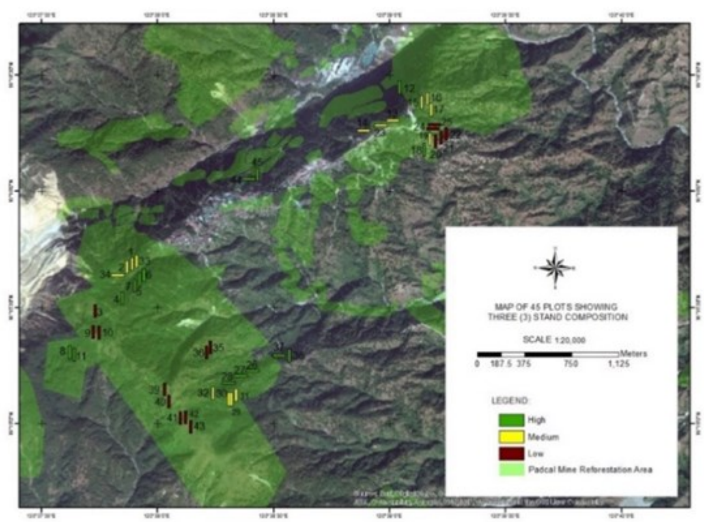

Figure 3. Distribution of sampling plots on the ground plotted on the Google Earth image

It employed the nested plot sampling method developed by Hairiah *et al*. (2011), Figure 4. It employs a distinct sub–plot size for a particular tree DBH range or type of vegetation applicable to stands with a wide range of tree diameters or stands with changing diameters and stem densities (Pearson *et al*. 2005).

The study used the non–destructive sampling to measure trees with DBH ≥ 30 cm found in the 20m x 100m plot (bigger plot) while a 5m x 40m subplot lay–outed inside the bigger plot was used to quantify trees with 5–30 cm DBH. The DBH and height including the common name and scientific name were tallied for each tree inventoried. A separate 0.5m x 0.5m sub–plot inside the bigger plot was used to sample UH (trees < 5 cm diameter) and other vegetation including the NL samples through destructive sampling. Fresh and oven–dry weight of samples were taken for carbon density determination.

Similar with live trees, a non–destructive sampling was applied to dead standing trees, fallen logs and stumps or CWD inside the 20 m x 100 m bigger plot. Standing dead trees and fallen logs found in the plot with ≥ 5 cm diameter and 0.5 m length were measured by its DBH (both at the top and ground level) and total height. Biomass estimation of standing dead wood follows certain classes based on the wholeness of a tree. Downed dead woods were classified according to density classes: sound, intermediate, and rotten. Representative wood samples per species and per decomposition class of fallen dead wood were collected for wood density determination.

Soil C was measured by getting a composite sample from each of the three (3) soil layers with the following depth: 0–10 cm; 10–20 cm and 20–30 cm and replicated per elevation type: high, mid and lower elevation from each plot. A separate sampling for soil bulk density using a soil sampler was done on an undisturbed spot. Each core sample was carefully put in labeled plastic bags and brought to a soils laboratory for analysis.

Data Computation and Analysis

Biomass

A) Tree

Tree biomass density were computed using allometric equations developed by Brown (1997) catered to trees at certain DBH limits. They are specific for tropical humid regions with an annual rainfall that ranges from 1500 – 4000 mm where the study site belongs. The equation particularly for conifers had also been used by several studies (Lasco *et al.* 2004; Lasco & Cardinoza 2007; Lasco & Pulhin 2009; Lumbres 2009; de Jong *et al.* 2010; Lumbres *et al.* 2012; Lumbres & Lee 2014). Lasco and Pulhin (2009) and Patricio and Tulod (2010) also applied the formula in determining the biomass of different broad–leaf reforestation or plantation species. The equations are as follows:

For coniferous species DBH ≥ 2–52 cm:

Equation 1

$$\textbf{TB (kg)} = \exp\{-1.170 + 2.119 \cdot \ln(\text{DBH})\} \quad (R^2: 0.98)$$

For broad–leaf species with DBH < 60 cm:

Equation 2

$$\textbf{TB (kg)} = \text{EXP}(-2.134 + 2.530 \cdot \text{LN}(\text{DBH})) \quad (R^2: 0.97)$$

For broad–leaf trees with DBH ≥ 60–148 cm:

Equation 3

$$\textbf{TB (kg)} = 42.69 - 12.800 \cdot \text{DBH} + 1.242 \cdot (\text{DBH})^2 \quad (R^2: 0.84)$$

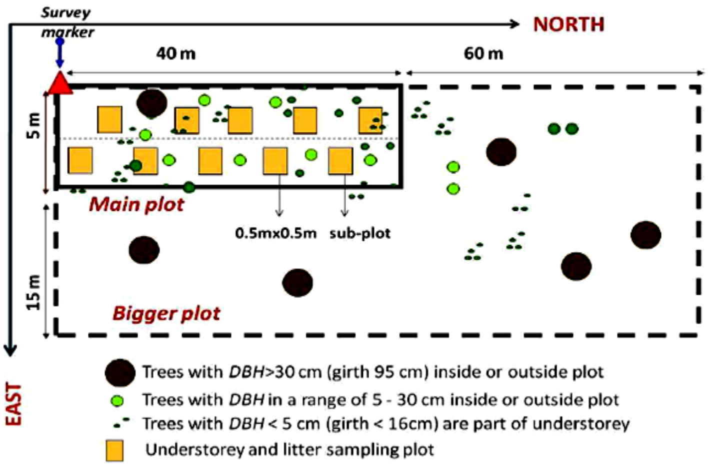

Figure 4. Diagram of nested plot design for vegetation sampling by Hairiah *et al.* (2011)

Where:
TB = tree biomass density in kg; DBH = in cm

Biomass per tree was converted to ton or Mg measurement unit; 1 ton = 1 Mg

Equation 4

$$T_{TB} = \frac{\sum \text{Biomass of all trees in a transect (ton)}}{\text{Area of the transect } (m^2)} \times \frac{10{,}000 \text{ m}^2}{1 \text{ ha}}$$

Where:
T_{TB} = total tree biomass in Mg ha^{-1}

B) Understory/Herbaceous and Necromass and litter

Equation 5

$$\text{UH \& NL density } (t\ ha^{-1}) = \frac{ODW\ (g)}{Area\ of\ plot\ (m^2)} \times \frac{10{,}000 \text{ m}^2}{1 \text{ ha}} \times \frac{1\ ton}{10^6\ g}$$

Where:
ODW = oven–dry weight of sample

C) Coarse Woody Debris
The study used the biomass computation proposed by Pearson *et al.* (2005) depending on the type of dead wood or classes, as prescribed below:

Standing dead wood. Class 1 used the allometric formula for biomass estimation of live trees with 2–3% allowance for leaf biomass for broadleaf and 5–6% for softwood or conifer species deducted from the total tree biomass. Classes 2, 3 and 4 were computed by converting tree volume into dry biomass based on the average wood density of each sample gathered. The tree volume and biomass were computed using the formula:

Equation 6

$$\text{Volume } (m^3) = \frac{\pi h\,(r_1 + r_2)^2}{2^2} = \frac{\pi h\,(r1^2 + r2^2 + 2r1r2)}{4}$$

Where: h = ht. in meters, r_1 = radius at the base, r_2 = radius at the top

Equation 7
Biomass = Volume x Wood density (from samples)

D) Downed Dead Wood. Biomass density of the lying dead wood is based on the computed wood density of each wood density class; sound, intermediate and rotten taken from the wood samples collected. It is computed using the following formula:

Equation 8
Density (g cm^{-3}) = mass (g)/ volume (cm^3)

Equation 9
mass = the mass of the oven dried sample

Equation 10
Volume = π x (ave. DBH/2)^2 x ave. width of the fresh sample

Equation 11
Biomass (t ha^{-1}) = Volume x Density

E) Roots. Computation for the root biomass was based on the biomass of individual tree using Pearson *et al.* (2005) formula as presented below:

Equation 12
Root Biomass = EXP (–1.0587+0.8836*LN (TB))

Where TB = Tree Biomass in t/Mg

F) Soil Organic Carbon (SOC). The following formula are used to compute for the SOC.

Equation 13
BD (g cm^3) = Dry wt. of soil (g)/ Vol. of cylinder (cm^3)

Where BD= Bulk density

The dry weight of soil and the equivalent SOC was computed using the following formula:

Equation 14
Volume of 1 ha soil = 100m x 100m x 0.3 m (or 0.1 m/soil level/depth)

Equation 15
Weight of soil (t) = Bulk Density x Soil Volume

Equation 16
SOC = Weight of soil (t) x % C

Carbon Content. Biomass density in Mg is converted into its carbon content valued at 45% (Lasco & Pulhin 2011) as presented in the formula below:

Equation 17
Total C stored = Biomass density (t ha^{-1}) x % C content

Where: % C = 45%

Carbon Dioxide (CO_2) Equivalent. The CO_2 density in Mg ha^{-1} per carbon sink was derived using the formula below:
Equation 18
Total CO_2 = Total C stored in Mg ha^{-1} x 44/12

RESULTS AND DISCUSSIONS

Biomass Content

Among the three stand types, HDS had the highest total biomass density of 234.45 Mg ha^{-1} followed by MDS of 216.32 Mg ha^{-1} and the least was LDS which is 83.50 Mg ha^{-1}. Overall, the study has an average biomass density of 178.09 Mg ha^{-1} (Table 1).

The result is slightly lower than the estimated biomass density for a pine forest in Pantabangan–Caranglan, 181.22 Mg ha^{-1} (Lasco *et al*. 2005), protected pine forest in Baguio City, 184.60 Mg ha^{-1} (Lasco *et al*. 2004) and much lower in Mindanao area, 230.05 Mg ha^{-1} primarily contributed by older stands (Patricio & Tulod 2010). However, the study registered a higher tree biomass content (139.72 Mg ha^{-1}) compared with other pine forests within Luzon area like in Nueva Ecija (mixed with broad–leaved species), 83.20 Mg ha^{-1}, from a pure stand, 107.80 Mg ha^{-1} (Sakurai *et al*. 1994), a pine stand in Baguio City with only 16.51Mg ha^{-1} (Lumbres *et al*. 2014). These results only prove the significant contribution of Pinus kesiya stands particularly in Padcal, Benguet in storing carbon emphasizing the importance of its protection from deforestation to avert carbon emissions.

Total biomass production of HDS is about 9% and 64% higher from medium and sparsely vegetative stands, respectively. On the other hand, biomass production of MDS is 61% higher than LDS. The above results are further presented in a graphical form (Figure 5). Results indicate that there is a general downward trend in terms of biomass accumulation among and between stand types.

Comparing further the sequestration potential among C pools within stand type and between and among stand types, Figure 6 shows a decreasing trend in biomass stored. The HDS exhibited the highest tree biomass stored than MDS and LDS. The downward trend was also significant in NL and roots. Only a slight difference can be observed between UH and CWD. On the other hand, an opposite trend can be observed in the UH C sink, MDS and LDS are 1 Mg higher than HDS.

Carbon Stored Estimation

The Padcal Mine forests have an overall mean C content of 170.33 Mg ha^{-1} (Table 2). The result is comparable with the study of *Pinus densiflora* forest in Korea under high stand densities with a mean C content of 162.0 Mg ha^{-1} (Noh *et al*. 2013). Locally, the result is higher than the study of Patricio & Tulod (2010) for *P. kesiya* plantations in Mindanao which has a mean C of 158.98 Mg ha^{-1}. Though the Mindanao pine forests did not include the CWD in the computation, adding 1% CWD share of C content as reflected in this study would total to about 160.57 Mg ha^{-1} of soil C, which is still below than the values obtained in this study.

Table 1. Summary of total biomass production per vegetation type.

Carbon pools	Stand Density Mean ± Standard Error HDS (Mg ha^{-1})	MDS (Mg ha^{-1})	LDS (Mg ha^{-1})	Total Mean Biomass (Mg ha^{-1})	%
Trees	184.41 ±10.32	171.97 ±18.99	62.80 ±14.33	139.72 ±11.80	78
UH	2.23 ±0.31	3.17 ±0.65	3.19 ±0.41	2.86 ±0.28	2
NL	14.19 ±2.49	11.34 ±1.95	6.84 ±1.12	10.79 ±1.18	6
CWD	3.12 ±1.07	1.68 ±0.58	0.81 ±0.37	1.87 ±0.44	1
Roots	30.50 ±1.98	28.16 ±3.19	9.86 ±2.10	22.84 ±1.97	13
TOTAL	**234.45 ±32.24**	**216.32 ±30.14**	**83.50 ±10.84**	**178.09±24.40**	**100**

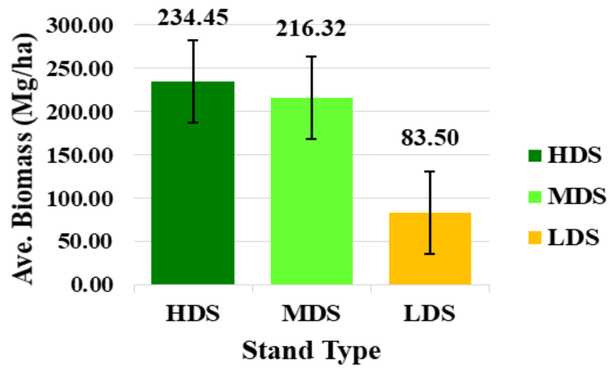

Figure 5. Comparing the mean biomass stored per stand type

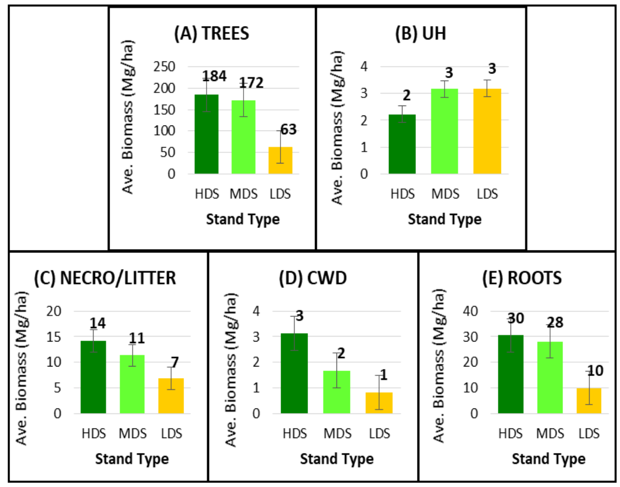

Figure 6. Graph showing the mean biomass content of C pools among stand types

Comparing between and among stand types, HDS has the highest carbon density in its biomass and soil, totaling to 199.06 Mg ha^{-1}. This is followed by MDS with a total carbon content of 188.91 Mg ha^{-1} and 123.03 Mg C ha^{-1} in LDS. The amount of carbon stored between the HDS and MDS is less differentiated as compared to LDS versus HDS and MDS. The change between HDS and MDS is about 12 Mg C ha^{-1}. The difference between HDS or MDS versus LDS is about 76 Mg C ha^{-1} or (38% higher) and 64 Mg C ha^{-1} (or 34% higher), respectively. Figure 7 presents the decreasing trend of C accumulation from HDS to LDS.

Statistical analysis on the relationship of C stored among and between stand types using ANOVA (analysis of variance) and multiple comparisons show that there is a marked dissimilarity between different stand types. Using multiple comparisons (Tukey's test) at 5% significance level, stored C of HDS is highly differentiated from LDS and MDS versus LDS. However, there is no significant difference in C or CO_2 accumulation between HDS and MDS.

Comparing further the potential of C pools between stand types in terms of biomass and C stored, results

Table 2. Summary of C stored in different carbon pools within the stands.

Carbon Pools	Stand Density (Mean ± Standard Error) HDS ($C\ Mg\ ha^{-1}$)	MDS ($C\ Mg\ ha^{-1}$)	LDS ($C\ Mg\ ha^{-1}$)	Total Ave. C ($Mg\ ha^{-1}$)
Tree	82.98 ± 4.64	77.38 ± 8.54	28.26 ± 6.45	62.88 ± 5.31
UH	1.00 ± 0.14	1.42 ± 0.29	1.44 ± 0.19	1.29 ± 0.13
Necro/ Litter	6.39 ± 1.12	5.10 ± 0.88	3.08 ± 0.50	4.86 ± 0.53
CWD	1.40 ± 0.48	0.76 ± 0.26	0.36 ± 0.17	0.84 ± 0.20
Roots	13.72 ± 0.89	12.67 ± 1.43	4.44 ± 0.95	10.28 ± 0.89
Soil	93.56 ± 8.08	91.57 ± 8.29	85.46 ± 7.39	90.19 ± 4.50
Total C stored	**199.06 ± 9.22**	**188.91 ± 12.37**	**123.03 ± 9.07**	**170.33 ± 7.73**
CO_2 stored	**729.87 ± 33.81**	**692.67 ± 45.37**	**451.12 ± 33.24**	**624.56 ± 28.35**

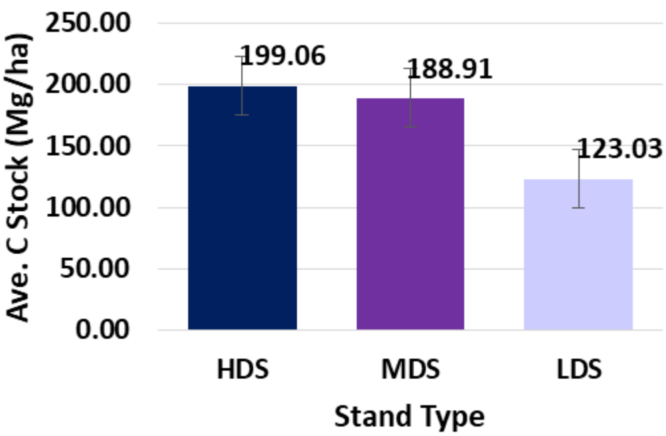

Figure 7. Graph showing average C stock among the three (3) stand types

show that the tree and root components are strongly differentiated (1% level of confidence) versus two stand types and among stand types.

Necromass and litter is positively significant at 5% level of confidence while CWD is only noteworthy at 10% confidence level. Soil and UH vegetation have the same biomass and C assimilation capacity for all stand types with no major difference. Generally, the accumulation potential of each carbon pool per stand type decreases from HDS to LDS except for UH vegetation as shown in Figure 8.

Figure 9 shows the storing capacity of each carbon pool in terms of mean C density in the order of: soils > trees > roots > necro & litter > UH, and > CWD. Similar trend was also observed in pine stands in Mindanao particularly from younger plantations between one to six years old (Patricio & Tulod 2010) and from pine forests of Central Java, Indonesia (Basuki & Wahyuningrum 2013) from age 9 to 34 years old. But as the stand gets older especially stands of more than 50 years old for Mindanao pine and 36 years old in Indonesia pine, the order changed where trees C surpassed soil C. Loaiza (2010) found that the ratio of SOC at 50 cm depth to carbon stock in tree biomass was 169% in tropical pine forest in Brazil. Li *et al.* (2011) citing other studies of pine forest in Korea reported that more C stock is found in trees among the aboveground biomass, but the biomass of shrubs and herbs, tree root biomass, forest floor, and mineral soil also provide large C pools.

It is common for broad leaf species in lowland areas that trees exhibit the highest C content followed by soil and it is either litter or U/H being the least in the rank. This is primarily true in those stands with larger trees with DBH³ 60cm and whose biomass is greater than four tons. Lasco & Pulhin (2006) reported that trees contribute about 97% of the total biomass for Kaatoan bangkal (*Neolamarckia cadamba* (Roxb.) Bosser) plantation while 94% for Alibangbang (*Bauhinia malabarica* Roxb.). On the other hand, about 4–6% of the total biomass is supplied by understory/litter of Auriculiformis (*Acacia auriculiformis*) and Ipil–ipil (*Leucaena leococephala* (Lam.) de Wit) plantations.

Soils significantly contribute in the carbon accumulation of all stand types among carbon pools (Figure 10). Its role is even highlighted by LDS whose part was more than half (69%) of the total carbon stored within the stand. Trees and roots follow next which obtained 37% and 6% share, respectively. NL also gave a good contribution of carbon stored in this study (4.86 t ha^{-1}) as compared to Patricio & Tulod (2010) which is minimal and as

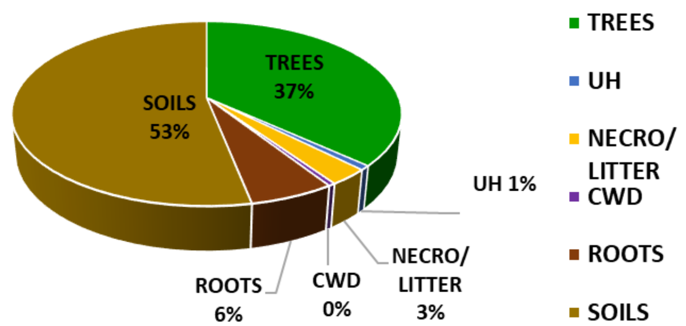

Figure 9. Mean percentage contribution of different carbon pools to the total C stock of Padcal Mine forest vegetation

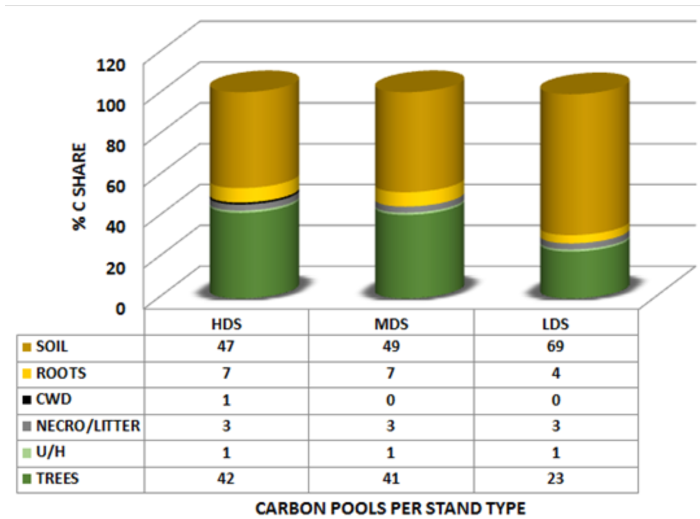

Figure 10. Percentage share of C content in different C pools across three vegetation types

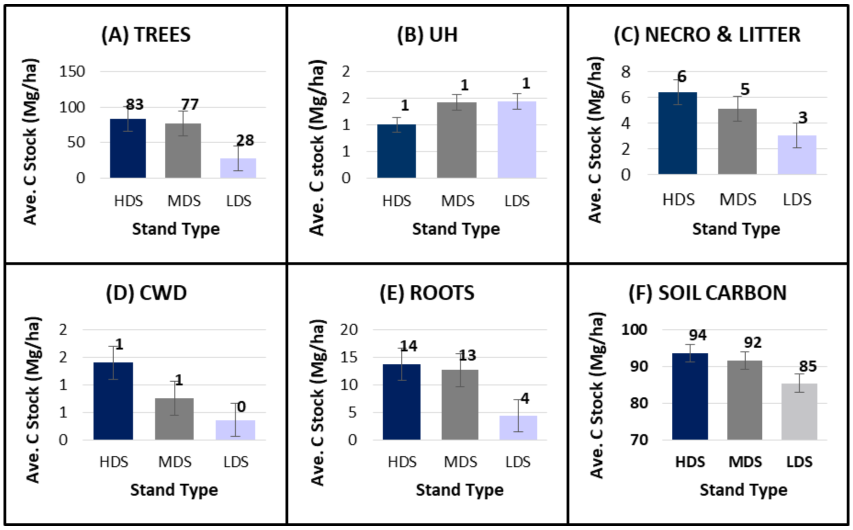

Figure 8. Comparing the stocking potential of each C pool between and among stand types

low as half a ton ha^{-1} of C content. Trees, NL and slightly on roots followed a decreasing trend of C sequestered among the three stand types. CWD consistently has the lowest carbon content in all stand types and even insignificant to other stands sampled.

The study site has an overall mean soil C of 90.19 Mg ha^{-1} primarily shared by the HDS. This value shows that soil in Padcal Mine area is more fertile (with high OM content) than in Mindanao based on the study of Patricio & Tulod (2010) whose soil C is 36% lower (57.7 Mg ha^{-1} of C). It was reported that soil under coniferous forest can store up to 76% of organic carbon (Lorenz 2011). The result could be attributed to the influence of precipitation on primary production controlling SOC content and the strong influence of temperature on microbial activity affecting SOC degradation especially during early rates of litter decomposition (Hobley *et al*. 2015). In a temperate forest, decomposition is slow duxe to unfavorable microclimatic condition like low temperature that limits microbial activity affecting SOC degradation (Hobley *et al*. 2015). Cooler climate zone has lower decomposition rate (Li *et al*. 2015) which generally favors the accumulation of organic matter. Due to slow decomposition, organic matter existing in various stages of decomposition remains at the surface of the mineral soil forming the so–called forest floor.

Biomass content in the litter on the forest floor and the soil C is perhaps the least understood and least appreciated component. Variations in the rate of SOCs accumulation can be attributed to the differences in species, environmental factors and stand age (Zhao *et al.* 2014), season, climate, forest type, fire history and disturbance dynamics (Noh *et al*. 2013). Some species produce more litter and roots than others, thus producing more organic inputs which eventually influence SOC. This is true with the conifer species, like *P. kesiya* as it produces considerable amount of litter specially pine needles which are very abundant in the forest floor. In the case of Padcal pine forest, forest litter accumulated as high as 14.19 Mg ha^{-1} or equivalent to 6.39 Mg ha^{-1} of carbon which falls in the upper range of Chinese pine forests litter C (Zhao *et al*. 2014). The litters decompose slowly as manifested by the high piles of litter on the forest floor. The slow decomposition process helps in the gradual but continuous build–up of soil C in the forest floor. Soil organic matter does not easily leach since the fresh litter on top of the old one serves as trapping mechanism for the decomposed litter. Hence, it is regarded as a long–term storage compartment for atmospheric carbon. It can continue to accumulate soil C over hundreds of years. It was also found out that the amount of SOC increases over time. So, as the vegetation matures, naturally its soil carbon content also increases. Soil C continues to pile up and eventually percolate to the lower depth or layer of the soil. These observations are well supported by the results of this study. The discrepancy was not so significant in terms of soil organic matter from the 0–10 cm depth of soil sampled down to 30 cm depth. Some samples even exhibited an increase in soil C in the lower depth but generally with a very slight difference.

Necromass also plays an important role in the C sequestration potential of the study site which had some bearing on the increased soil C. Necromass is regarded as a long–term carbon sink in the forest. Some studies refer to it as forest floor mass (Zhao *et al.* 2014; Osman 2013). It constitutes the litter and wood debris found on the forest floor. Several authors have already documented the importance of necromass to carbon storage particularly for pine species in temperate forests. In China, the latest study by Zhao *et al.* (2014) of a Chinese pine forest observed that litter biomass C ranges from 5.1 to 7.9 Mg ha^{-1} in a young to a mature stand. Other pine species in China has litter C content as low as 0.8 to 16.6 t ha^{-1}. This condition was observed to be unique to a conifer forest located in high elevation areas as compared to most broad–leaf dominated species in lowland areas where necro/litter C value is usually insignificant and even null. The reason is due to the warmer environment in the lowland areas that favors faster decomposition process.

Aside from fine litter, coarse woody debris (CWD) is one major component of necromass retained in the stand. They are composed of dead wood or fallen and decaying trees that remained in the stand. It was observed that wood decomposition in the tropics can be slower than the growth of new wood in a disturbed stand. So, with the retention of CWD in the stand, the stand gains additional biomass. The contribution of CWD to forest carbon is reported to be poorly quantified. Some authors accounted this for an amount equivalent to 10% to 40% of the aboveground biomass of a forest depending upon forest age and climatic regime (Noh *et al*. 2013). A study in red pine forest (*Pinus densiflora* S. et Z) registered a CWD C of 4.84 Mg ha^{-1} (Noh *et al*. 2017). It was observed that in many stands CWD input can be sudden and massive, a situation that further enhances net carbon storage because conditions for decomposition change (more light, less humidity, extreme temperatures) and population of decomposers cannot keep up with the inputs.

Total C and CO_2 Estimate of the Entire Padcal Mining Forests

The total C and CO_2 stock of the Padcal Mine forest is computed based on the mean C stock per stand type multiplied by the total area covered by each type. GIS generated map of the Padcal Mine forests reflected a total area of 12,185.00. This

Table 3. Summary of total C and CO_2 stock of the entire mining forests.

Stand Density Type	Total Area (ha)	Mean C Stored (Mg ha^{-1})	Total C Stored (Mg)	Total CO_2 Stored (Mg)
HDS	3,644.00	199.06	725,374.64	2,659,707.01
MDS	7,306.00	188.91	1,380,176.46	5,060,647.02
LDS	1,235.00	123.03	151,942.05	557,120.85
Total	12,185.00	170.33	2,257,493.15	8,277,474.88

results to a total CO_2 stored of 8,277,474.88 Mg which is equivalent to amount of emissions being captured by the Padcal Mine forests (Table 3).

CONCLUSION

The study shows the potential of Benguet Pine forests to offset carbon emissions in a mining project. This is achieved by protecting and maintaining the existing natural stands in the project site and reforesting its mined–out areas. By protecting and maintaining the natural forest stands, the company is able to conserve carbon stored in the vegetation and soil. As shown in the study, high density stands, as expected, have higher carbon storage capacity than medium and low density stands. Thus, the carbon storing capacity of the latter two types of stands can be enhanced through the implementation of silvicultural strategies and enrichment planting. Moreover, establishment and maintenance of additional tree plantations through reforestation could help expand the carbon storage and sequestration potential of the mining forest.

The study further demonstrated that while mining is seen as destructive to the environment, adoption of effective mitigation measures could minimize its adverse impacts and even contribute to the protection of the environment. Specifically, developing, maintaining and protecting mining forests not only mitigate climate by absorbing and storing carbon but also help minimize if not totally prevent climate change–induced soil erosion and landslide. Hence, the study complements the DENR's move to regulate the mining industry in the country by allowing only those companies that practice responsible mining. It involves, among others, the implementation of effective environmental protection measures and climate mitigation strategies.

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