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Biomass, Carbon Stock, and Economic Value Assessment of Daclan Communal Forest Parcel IV in Tublay, Benguet

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Abstract

Carbon stock assessment quantifies carbon stored in ecosystems, which is vital for understanding their role in sequestering carbon dioxide, informing sustainable land management crucial for human activities and climate change mitigation. Employing purposive sampling to evaluate the biomass, carbon (C) stock, and carbon dioxide (CO_2) sequestered in Daclan Communal Forest, using non-destructive methods, it informs climate change monitoring, mitigation, and adaptation strategies while promoting proper forest management and sustainable development. Additionally, it underscores the potential economic value derived from the forest's carbon pools. The methodologies used include measuring trees at diameter breast height (DBH) and sampling herbaceous vegetation, litter, and soil for C content determination, using eight (8) 30m by 30m plots to gather the data and samples. The Communal Forest boasted substantial biomass totaling approximately 262 Mg ha^{-1}, comprising 182.17 Mg ha^{-1} of carbon and sequestering 671.26 Mg ha^{-1} of CO_2. This abundance holds a significant economic value estimated at Php3,038,237.09. The figures highlight the considerable role of the Communal Forest in sequestering atmospheric carbon, indicating its potential for carbon crediting and trading. Therefore, collaborative efforts from Local Government Units (LGUs), community residents, and relevant organizations are imperative for the enhancement, sustainability, and conservation of these forests.

Introduction

Increased concentration of greenhouse gases in the atmosphere intensifies the Earth's warming due to its radiative blanketing effect and CO_2 effectively increases this radiative energy (Soon et al., 1999) that triggers the changes in the land carbon (C) cycle, carbon dioxide (CO_2) increases temperatures extending the growing season and increasing humidity (National Aeronautics and Space Administration, 2011). Effects of human-caused atmospheric heating that are happening now are irreversible on the timescale of people alive today and will worsen in the decades to come (Jackson, 2021), as global temperatures continue to rise, climate change will affect our wallets, our health, our safety, and our lives (Cho, 2019).

Furthermore, in this crucial era of global warming, climate change, sea level rise, ocean acidification, and impacts on human health, agricultural and food security, partially triggered due by the increase in CO_2 is the primary greenhouse gas responsible for trapping heat in the Earth's atmosphere, an assessment of C stocks is necessary to prioritize different ecosystems for conservation, C mitigation and adaptation programs that control the effects of CO_2 and its release into the atmosphere. The amount of biomass in a forest directly quantifies the potential amount of C that would be added to the atmosphere or sequestered on the land (Borah et al., 2013; Brown et al., 1999), depending on whether the forests act as sources or sinks. Also, the amount of total biomass stored in a forest indicates the quantity of C that can be sequestered to meet the emission targets (Raha et al., 2020). This kind of information also contributes towards atmospheric C reduction targets as part of international obligations (Mayer et al., 2020; Sahu et al., 2016; UNFCCC, 2014).

C crediting (C offsetting) is a process where individuals, organizations, or countries take actions to reduce their greenhouse gas emissions and earn credits for the amount of CO_2 they have prevented from being released into the atmosphere (Bebbington & Larrinaga-Gonzalez, 2008). Furthermore, C trading is a market-based approach where C credits are bought and sold among participants it involves the exchange of emissions allowances or credits, enabling those with higher emissions specifically the developed countries to purchase credits from those with lower emissions like the Philippines. Determining the potential for C crediting and C trading of forests is crucial for leveraging their ability to mitigate climate change, incentivizing sustainable forest management, and generating economic benefits for local communities (Antonioli, 2021), as well as to help meet the Paris Agreement's aim of halting warming at 1.5°C (Mckay, 2022), 2°C is the tipping point we must never cross, for it marks the boundary between a manageable climate and an irreversible catastrophe (Bosman, 2022).

In the Philippines, forests are among the most valuable natural resources, especially the Communal Forest in the Cordillera Region, for it provides a variety of ecosystem services, ranging from the production of food crops and livestock up to the provision of recreational opportunities (Swinton et al., 2007). Recognizing the C sequestration in the Communal Forest would encourage LGUs and residents to participate in the conservation activity of the natural resources; thus, this study is conducted to assess the biomass, C stock, and CO_2 C sequestered in the forest ecosystem and determine the economic value of Daclan Communal Forest Parcel IV Tublay, Benguet.

Methodology

Study Site

The study was conducted at Daclan Communal Forest Parcel IV, Tublay, Benguet with an area of 14.70ha (Figure 1). The study site was located at the center-west area of the municipality, bounded in the north by Tublay Central, east by Ambassador, south by Caponga, southwest by Shilan (of La Trinidad), and west by barangay Basil, Tublay with an elevation ranging from 1,100m to 1,134.4m. The site's yearly temperature is 25.79ºC and typically receives about 200.64mm of precipitation (Weather and Climate, 2016). Daclan Communal Forest Parcel IV has an approximate elevation of 1386m altitude above sea level (masl).

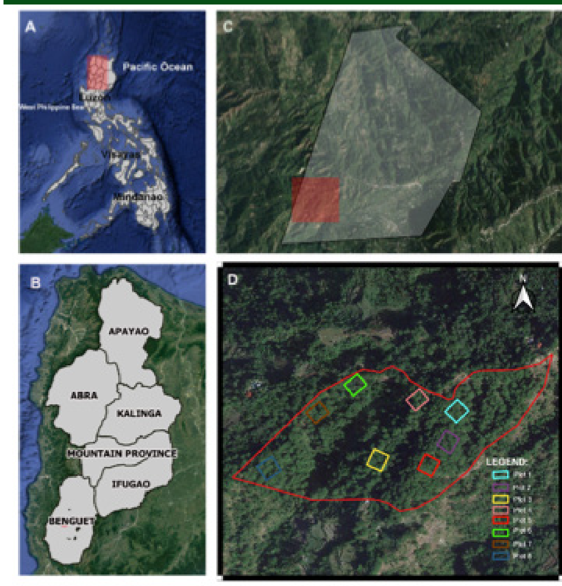
The Communal Forest is a forest ecosystem characterized by the dominance of pine trees (conifers) along with the presence of other broadleaved or deciduous trees, a dominant weed population, and a loamy to clay soil type within the sample plots. It was conserved for communal purposes, such as timber production, conservation, and recreation. According to Corona's classification system, the site has type I climatic type, with distinct wet and dry seasons that begin in May and November respectively, and dry the rest of the year. The study was carried out from August 2022 to May 2023.

Methods

The study employed purposive sampling to determine plots, focusing on terrain and accessibility. Eight 30m x 30m plots were established within the Communal Forest, divided for vegetation and soil sampling. Non-destructive methods and allometric equations estimate tree biomass, while understory and litter biomass were assessed from 1m x 1m subplots. Soil biomass was determined through core sampling, and soil organic carbon was calculated using relevant formulas. C content of trees, litter, and

Figure 1

Geographical Location of Daclan Communal Forest, Philippines (A) Location of Cordillera Administrative Region in the Philippines, (B) Location of Barangay Daclan Tublay Benguet, and (C) Location of Study Site (D) Study Site with the Laid-out Plots



understory was measured, with CO_2 emissions estimated accordingly. Economic value was projected based on carbon prices.

Determination of the Plot

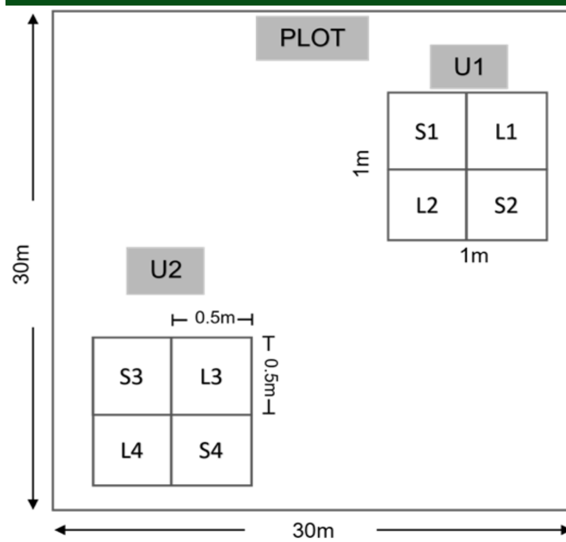
A purposive sampling method with 5% sampling intensity was utilized to collect the necessary data for biomass and C stock of the study site based on terrain characteristics and accessibility. In this sampling method, the researchers purposefully selected individuals or cases that possess specific characteristics or meet predetermined criteria relevant to the research objectives. This sampling approach allowed researchers to target specific information-rich cases that can provide valuable insights into the research topic (Saunders et al., 2012), the sampling method was utilized by several studies (Barcelete et al., 2016; Obonyo et al., 2023; Sudirman e t al., 2020).

Establishment of the Plot

Eight plots, each a 30m x 30m plot, were established in different locations within the Communal Forest using straw and markers. There were two subplots for each plot, with a measurement of 1m x 1m to represent the understory that was utilized for the gathering of understory components. Each subplot was divided into four with a measurement of 0.5m x 0.5m for the gathering of litter and soil samples, which were needed for the computation of data, Figure 2 shows how the plots were established in the Communal Forest of Daclan.

Figure 2

Lay-out of Plots in Daclan Communal Forest



Biomass Estimation of Trees

The aboveground biomass (AGB) was measured using a non-destructive method. Tree biomass density was computed using allometric equations developed by Brown (1997). They are specific for tropical humid regions with an annual rainfall that ranges from 1500-4000mm where the study site belongs.

The plots were utilized to measure pine and broadleaved trees with a DBH larger than 5cm. Diameter tape was utilized in measuring the DBH of trees. The allometric equation by Brown (1997) was utilized to calculate the aboveground biomass of coniferous trees which is shown below:

$$AGB = \exp\{-1.170 + 2.119 * \ln(DBH)\} \quad (1)$$

where: DBH is the diameter at breast height, ln is a natural logarithm, and exp is an exponential function.

Equation 1, particularly for conifers, has also been used by several studies (De Jong et al., 2010; Lasco & Cardinoza, 2007; Lasco & Pulhin, 2009; Lasco et al., 2004; Lumbres & Lee, 2014; Lumbres et al., 2012; Lumbres, 2009), to which the annual rainfall of the Philippines belongs. Furthermore, equation 2 also applied the formula to determine the biomass of different broad-leaf reforestation or plantation species. (Bantas et al., 2011; Fernandez et al., 2015; Lasco & Pulhin, 2009; Patricio & Tulod, 2010).

To calculate the AGB of broadleaved species, the formula was used:

$$AGB= \exp\{-2.134 + 2.53*\ln(DBH)\} \quad (2)$$

To calculate the belowground biomass (BGB) of pine trees and broad-leaved species, the allometric equation of Pearson et al. (2005) was utilized as used in other related studies (Bantas et al., 2011; Helario & Patungao, 2022; Lasco et al., 2017; Ponipon & Nabe, 2017) in determining the BGB of trees, which is:

$$BGB= \exp\{-1.0587 + 0.8836* \ln(AGB)\} \quad (3)$$

Biomass Estimation of Understory and Litter

All herbaceous plants, tree seedlings, grasses, and vegetation with a diameter of less than 5cm were gathered from the 1m × 1m subplot. For the collection of litter samples, each subplot was divided into four portions. The second and third 0.5m x 0.5m sub-subplots were used in the gathering of litter samples. The collected understory and litter samples were separately weighed in a weighing scale to determine the total fresh weight (TFW). A total of 300g from each sample were oven dried and observed within 48 hrs. at 80°C until it obtained its stable weight. Plate 2 shows the establishment of sub-plots and the collection of understory samples.

Determination of the biomass of the understory vegetation and litter was computed using the equation used by Cruz et al. (2005) which is:

$$ODW = \frac{TFW - ((TFW)(SFW-SODW))}{SFW}$$

where: ODW is oven-dry weight
TFW is a total fresh weight
SFW is sampled fresh weight
SODW is sample oven dry weight

Estimation of Soil Biomass

From the first and fourth sub-subplots of each subplot, the coarse litter layer and the top 10cm layer of soil were also removed. Soil bulk density was evaluated using core sampling that represents depths of 0–30cm (Majule & Mwakisunga, 2012). An improvised core sampler was gently put into the soil until it filled up. The soil samples were taken in the 10-20cm depth soil layer to represent the 0-30cm depth.

The soil samples from all sub-subplots per plot were mixed and weighed. For bulk analysis, a 300g soil sample was oven-dried at 105°C within 48 hrs. until a stable weight was obtained by the sample. For the eight 30m x 30m plots, a total of 500g composite soil samples were taken and sent to the Regional Soil Laboratory, Department of Agriculture, Ambuklao Road, Gibraltar, Baguio City, for the soil percent organic matter analysis.

Estimation of Soil Organic Carbon

The bulk density was calculated using the formula:

$$\rho=W/V \quad (5)$$

where: W is the weight,
V is the volume.

The volume of soil was calculated using the formula used in the study of Zaragosa et al. (2016):

$$V=\pi r2L \quad (6)$$

where: V is the volume,
π is the pie,
r is the radius,
L is the length

The percent organic C was calculated by dividing the percent organic matter by 1.724 (Garcia et al., 2011). The 1.724 is the Van Bemmelen factor, which was based on the assumption that organic matter contains 58% organic C (Collins & Kuehl, 2001).

C Determination and CO_2 Estimation

To determine the C content of trees, litter, and understory, multiply the biomass density by 45% (Lasco & Pulhin, 2000). CO_2 was determined by multiplying the calculated C of trees, understory, litter, and soil by 3.67, which is the molecular weight ratio of CO_2. C has an atomic weight of 12, and oxygen has an atomic weight of 16. CO_2 is produced when these two elements combine ($C + O_2 = CO_2$). They have a molecular weight of 44 when combined (1 carbon atom [12] + 2 oxygen atoms [2x16=32]) 12+32=44. The 3.67 was obtained by dividing 44 by 12. This ratio of molecular weight used in calculating CO_2 was used in some studies (Racelis et al., 2019; Racelis et al., 2017)

Estimation of Economic Value

To calculate the current economic value, the estimated C was multiplied by the C price which is 20 USD per Mg (Patnaik & Kennedy, 2021). For the projection of the economic value by 2030, it was multiplied by 50 USD per Mg (Environmental Defense Fund, 2017).

Results and Discussion

Biomass, C, and CO_2 Content of Trees (Above and Belowground)

A total of 396 individual trees composed of 34 species that belonged to 15 families were assessed in the Communal Forest within the 8 plots (Table 1), having a general DBH of 21.35. The Communal Forest was dominated by *P. kesiya,* and it has a bigger DBH based on the average, which was attributed to higher biomass, C, and CO_2, followed by the broadleaved species. The eight plots assessed were dominated by *P. kesiya,* while some plots were composed of mixed species, including broad-leaved.

Plot 1 has a higher number of trees, with a total of 85 individuals compared to 77 for Plot 7 and 69 for Plot 8. Plot 7 has a bigger diameter range of 5cm to 68cm compared to the other two plots, which range from 5.70cm to 67.40cm for plot 8 and 5cm to 64cm for plot 1. Moreover, plot 1 was dominated by *P. kesiya*, and the area has a steeper slope. It was densely stocked because *P. kesiya* trees thrive well in steep topography (Bantas et al., 2011). In contrast, the other two plots were dominated by broadleaves.

Results of the study shown in Table 2, found that plot 1 has the highest AGB with 313.75 Mg ha^{-1}, 141.19 Mg ha^{-1} C, and 518.16 Mg ha^{-1}, which is mostly composed of P. kesiya. This was followed by plots 5 and 3, with 262.53 Mg ha^{-1}, 118.15 Mg ha^{-1} C, 433.62 Mg ha^{-1} CO_2, and 261.01 Mg ha^{-1}, 117.46 Mg ha^{-1} C, and 431.06 Mg ha^{-1} of CO_2, respectively, composed of both *P. kesiya* and broad-leaved species.

In terms of belowground biomass, plot 1 had the highest with a total of 51.42 Mg ha-1 with 23.14 Mg ha^{-1} C and stored 84.93 Mg ha^{-1} CO_2, followed by plots 5 and 3 with 39.39 Mg ha^{-1}, 17.73 Mg ha^{-1} C, 65.06 Mg ha^{-1} of CO_2, and 38.51 Mg ha^{-1}, 17.33 Mg ha^{-1} C, and 63.59 Mg ha^{-1} of CO_2, respectively. This result was associated with the computed higher AGB.

The total mean of the AGB was approximately 220.98 Mg ha^{-1} with 99.44 Mg ha^{-1} of C and 364.95 Mg ha-1 of CO_2, while the BGB was approximately 34.42 Mg ha^{-1} with 15.49 Mg ha^{-1} of C and 56.85 Mg ha^{-1} of CO_2.

The value derived from this study was greater than those derived by Lasco and Pulhin (2009) in terms of biomass densities of *P. kesiya* in Baguio City and Nueva Ecija, which is 200 Mg ha^{-1} and 107.83 Mg ha^{-1}, respectively. Also, the estimated total biomass of *P. kesiya* in the Pantabangan-Caranglan watershed was 181. 22 Mg ha^{-1} (Lasco et al., 2005) while in Bukidnon, the estimated biomass of *P. kesiya* plantations was 230.05 Mg ha^{-1}, this was due to the study site having higher tree densities (Patricio & Tulod, 2010), and the unique characteristics of *P. kesiya's* that can stock high C that lies on their growth patterns and physiological characteristics.

Furthermore, the study of Polon et al. (2022) discovered that the urban forest in the Baguio Botanical Garden had a very low total C stock density of 55.29 Mg ha^{-1} and a total biomass density of 122.66 Mg ha^{-1}. According to Erickson-Davis (2018), urban areas only make up a small portion of the total contribution because of their constrained spatial extent and the presence of development, such as buildings, roads, and other infrastructure.

In addition, the results of the study are comparable to other forest types by Lasco et al. (2017) wherein they assessed the Mossy Forest,

Table 1

Tree Species Composition Within the Plot of Daclan Communal Forest

Common Name	Family Name	Scientific Name	Count	Class	Ave. DBH (cm)
Benguet Pine	Pinaceae	*Pinus kesiya*	139	Coniferous	36.04
Calliandra	Fabaceae	*Calliandra calothyrsus*	36	Broad-leaved	7.30
Gmelina	Lamiaceae	*Gmelina arborea*	25	Broad-leaved	18.31
Asaan	---	---	23	Broad-leaved	12.28
Anitap	Euphorbiaceae	*Macaranga cumingii*	20	Broad-leaved	11.04
Kamiding	Anacardiaceae	*Semecarpus philippinenses*	19	Broad-leaved	15.04
Tabangaoen	---	---	13	Broad-leaved	16.59
Darow	Rubiaceae	*Wendlandia brachyantha*	12	Broad-leaved	9.45
Sagumisim	---	---	10	Broad-leaved	81.00
Anidog	Rosaceae	*Photinia glabra*	9	Broad-leaved	11.63
Diwdiw	Moraceae	*Ficus septica*	9	Broad-leaved	10.79
Keri	Melastiastomataceae	*Astronia cumingii*	8	Broad-leaved	11.03
Kuday	Apocynaceae	*Wrightia pubescens*	8	Broad-leaved	10.76
Kinadaring	---	---	7	Broad-leaved	9.74
Bangbanget	Asteraceae	*Centratherum punctatum*	6	Broad-leaved	21.47
Sekka	---	---	6	Broad-leaved	21.47
Tebbel	Moraceae	*Ficus nota*	6	Broad-leaved	11.62
Utimpi	---	---	6	Broad-leaved	13.57
Anuding	Nyctaginaceae	*Pisonia umbellifera*	4	Broad-leaved	19.20
Bayog	Sterculiaceae	*Pterospermum acerifolium*	4	Broad-leaved	9.23
Pasvek	Podocarpaceae	*Podocarpus amarus*	4	Broad-leaved	9.35
Sabdang	Fabaceae	*Erythrina subumbrans*	3	Broad-leaved	37.77
Sawidi	---	---	3	Broad-leaved	11.00
Alumit	Moraceae	*Ficus minahassae*	2	Broad-leaved	20.50
Balete	Moraceae	*Ficus balete*	2	Broad-leaved	10.00
Depping	---	---	2	Broad-leaved	23.50
Salakan	---	---	2	Broad-leaved	29.85
Tihem	Rubiaceae	*Neonauclea vidalii*	2	Broad-leaved	10.50
Anitel	---	---	1	Broad-leaved	7.30
Calacal	Vitaceae	*Leea congesta*	1	Broad-leaved	6.20
Narra	Fabaceae	*Pterocarpus indicus*	1	Broad-leaved	8.30
Otempeak	---	---	1	Broad-leaved	8.30
Species A	---	---	1	Broad-leaved	7.20
Species B	---	---	1	Broad-leaved	27.30
		TOTAL	**396**		

Table 2

Computed Biomass, C, CO_2 Content of Trees

Plot	AGB (Mg ha^{-1})	C AGB (Mg ha^{-1})	CO2 AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	C BGB (Mg ha^{-1})	CO2 BGB (Mg ha^{-1})
1	313.75	141.19	518.16	51.42	23.14	84.93
2	198.13	89.16	327.20	30.31	13.64	50.06
3	261.01	117.46	431.06	38.51	17.33	63.59
4	220.24	99.11	363.72	32.31	14.54	53.36
5	262.56	118.15	433.62	39.39	17.73	65.06
6	153.52	69.09	253.54	25.38	11.42	41.92
7	221.33	99.51	365.19	35.34	15.90	58.36
8	137.52	61.88	227.12	22.72	10.23	37.53
Ave.	220.98	99.44	364.95	34.42	15.49	56.85

P. kesiya forest, and secondary forest. *P. kesiya* ranks first in terms of C density with a total of 146.17 Mg ha^{-1} and a biomass density of 324.82 Mg ha^{-1}. It was attributed to the relatively large trees compared to those of secondary forest. Followed by secondary forest in terms of biomass density with a total of 146.17 Mg ha^{-1} with 65.78 Mg ha^{-1} C. With a total biomass density of 128.84 Mg ha^{-1} and 57.98 Mg ha^{-1} for C, Mossy Forest has the lowest biomass density among the three forest groups. This can be attributed to the site having more growing space for larger trees for their roots to properly absorb nutrients and water from the soil (Anstett et al., 2021). With this, the trees have greater access to sunlight, which helps increase their diameter. The presence of large trees was maintained, as biomass is commonly found in long-lived, bigger trees. Also, the diameter growth increment was significantly affected by the interaction effect of exposure and the diameter class of *P. kesiya* (Noble, 2012).

In contrast to Belo and Mendes's (2018) study at Talingguroy Forest in Wangal, the results were relatively lower, with an average of 320.21 Mg ha^{-1} biomass, a C stock value of 150.50 Mg ha^{-1}, and a CO_2 of 552.34 Mg ha^{-1}. This was because certain species that were present have smaller DBHs, whereas biomass is primarily found in species with larger DBHs. According to Yang et al. (2022), their results showed that large plants, species diversity, and stand density all increased aboveground biomass. As also observed, some vines that climb up trees to gain more sunlight become structural parasites of trees, slowing down the growth of trees as they reach the tree's crown (Holbrook & Putz, 1996).

Biomass, C, and CO_2 Content of Understory Vegetation

The understory vegetation at the study site had an average biomass, C, and CO_2 content of 1.65 Mg ha^{-1}, 0.74 Mg ha^{-1}, and 2.72 Mg ha^{-1}, respectively (Table 3). Observations indicate that the understory vegetation at the location consists of only a few species, with one species often predominating in most of the sampled plots. This lack of variety in seedlings, grasses, shrubs, and herbs can impact the total biomass of understory vegetation. Plot 6 has a biomass density of 2.63 Mg ha^{-1}, followed by Plot 4 having 1.99 Mg ha^{-1}, and Plot 8 with 1.77 Mg ha^{-1}, Plot 3 and Plot 7 have the least amount of biomass with 1.06 Mg ha^{-1} (Table 3). This result is linked to the understory vegetation's growth limitation caused by the tree composition, where photon energy from light is made less available since it cannot pass through higher canopy levels (BD Editors, 2016). Additionally, it was attributed to the work that was done in some plots, such as Plot 6, where Gmelina trees were cut down to provide space for light. However, Plot 8's shrubs and other plants were cut resulting in poor understory vegetation. In terms of understory vegetation, broadleaved areas have more biomass content in their understory vegetation than areas where pine trees dominate.

Based on the findings, plot 6 has the most stored C with 1.19 Mg ha^{-1} and 4.37 Mg ha^{-1} of sequestered CO_2. Plot 4 comes in second, storing 0.90 Mg ha^{-1} C and 3.30 Mg ha^{-1} CO_2, whereas Plot 3 and Plot 7 obtained the least C of 0.48 Mg ha^{-1}. The total average of C stored is 0.74 Mg ha^{-1} and it has 2.72 Mg ha^{-1} of sequestered CO_2.

Plot 6 has the highest concentration of deposited C due to the presence of various herbaceous plants that aid in sequestering C, as compared to the other plot, which was dominated by a few plant species, and due to the development compositions of the understory vegetation, particularly in the pine tree areas. In contrast to other plots that only have a few types of trees and dense areas, it was noted that the diversity of trees and their population in the vicinity of Plot 6, Plot 4, and Plot 8 were reasonable. This explains why the plots had high C stock.

The findings of the study are relatively high compared to the study of Ponipon and Nabe (2017) that was conducted at Alapang Communal Forest in La Trinidad, Benguet having a C stock of 0.34 Mg ha^{-1} and 1.25 Mg ha^{-1} of sequestered CO_2. Moreover, the outcome was higher than the average estimated biomass density, C, and CO_2 of agroforestry systems in Bukidnon, Philippines from Labata et al. (2012) study which was composed of three different systems: Mixed multistory system, Taungya agroforestry system and Falcata-coffee multistory system, which had 1.14 Mg ha^{-1} of understory biomass, 0.36 Mg ha^{-1} of C, and 1.32 Mg ha^{-1} CO_2. The relatively low biomass density values obtained from the study can be attributed to the small size of *P. falcataria* trees in the falcata-coffee multistorey system (Labata et al., 2012). However, the result of the study was lower than the conducted study by Fernandez et al., (2015) at the BSU forest reservation in Wangal, La Trinidad, Benguet with a biomass of 11.63 Mg ha^{-1}, C stock of 5.23 Mg ha^{-1} and it has 19.21 Mg ha^{-1} of sequestered CO_2. Also, the result is relatively lower than what Medina et al. (2020) found in their study of the human-disturbed forest of Mt. Kiamo in Bukidnon, Philippines, which had a mean biomass of 16.80 Mg ha^{-1}, 8.56 Mg ha^{-1} C stored and 31.42 Mg ha^{-1} sequestered CO_2. In the case of the study, Mt. Kiamo is observed to show evidence of human disturbance as it is currently threatened by ongoing slash-and-burn agriculture in several of its patches of forest (Medina et al., 2020). However, their result was higher than the result of the study because vegetation burning causes the release of nutrients stored in the biomass into the soil, which promotes the growth of understory plants, leading to increased biomass and C stocks (Wu et al., 2020), and reduced competition can lead to increased growth and biomass accumulation in the understory (Gao et al., 2021). Although it is important to note that while ongoing slash-and-burn agriculture may initially result in higher biomass and carbon in the understory, this effect is often temporary because of its negative long-term effect (Hauser & Norgrove, 2013); thus, the activity must be limited and monitored.

Table 3

Computed Biomass, C, CO_2 Content of Understory

Plot	Biomass (Mg ha^{-1})	C (Mg ha^{-1})	CO_2 (Mg ha^{-1})
1	1.55	0.70	2.56
2	1.76	0.79	2.89
3	1.06	0.48	1.76
4	1.99	0.90	3.30
5	1.35	0.61	2.24
6	2.63	1.19	4.37
7	1.06	0.48	1.76
8	1.77	0.79	2.90
Ave.	1.65	0.74	2.72

Biomass, C, and CO_2 Content of Litters

The average biomass, C, and CO_2 content of the litter were 5.76 Mg ha^{-1}, 2.59 Mg ha^{-1}, and 9.51 Mg ha^{-1} respectively (Table 4). On the study site, the forest litter was composed of different dead and withered plants. As observed, most of the litters were dominated by the thick pine needles of *P. kesiya*, together with other leaves coming from different broad-leaved species and other withered weeds and plants within the plots. Plot 5 obtained the highest biomass (9.35 Mg ha^{-1}), C (4.21 Mg ha^{-1}), and CO_2 (15.45 Mg ha^{-1}) among the plots. This highest number obtained in the data was associated with a species within the plot that was a pure stand of *P. kesiya*. This higher calculated biomass, C, CO_2 were similar to the findings of Bantas et al.

(2011), who discovered that the thick layer of Benguet pine needles and twigs had the highest value of the foregoing. On the other hand, plot 6 acquired the lowest biomass with 3.58 Mg ha^{-1}, 1.61 Mg ha^{-1} C, and 5.92 Mg ha^{-1} of CO_2, this was due to the lower number of broadleaved species in the plot and the absence of coniferous species. The study of Patricio and Tulod (2010) indicated that the rate of litter layer formation and decomposition is dependent on the number of trees and the area of the understory vegetation. Additionally, the process of decomposition is faster during warmer days, resulting in the release of C sequestered in the litter layer (Patricio & Tulod, 2010).

In relation to it, the result was higher than the average litter biomass calculated by Verma and Jain (2017), whose study reveals that the litter biomass varied from 1.66 to 2.97 t ha^{-1}. Also, the result was relatively higher than the mean biomass density and C obtained by Ebasan et al. (2016) in their study with 0.02 Mg ha^{-1} litter biomass, and 0.05 Mg ha^{-1} C. This can be attributed to the number of species on the study site as well as the fact that the study site is disturbed, as mentioned in the previous paper, because it serves a variety of purposes for the residents nearby, such as recreation which affects the litter layer through the generation of additional litter cause by picnickers, campers, hikers, and other visitors to forested areas may generate waste in the form of food packaging, plastic bottles, and other discarded items. Agriculture had an impact on the litter through land-use changes, and domestic purposes Domestic activities, such as firewood collection or gathering forest products, can directly affect the biomass and carbon of the litter layer (Goncalves et al., 2021).

In contrast with Dimalen and Rojo's (2019) study, the results were relatively lower, with a mean average of 39.15 Mg ha^{-1} litter biomass and an 18.05 Mg ha^{-1} mean average for C litters. This is due to the cleaning operation that was taking place in the forest where the plots are located to remove some of the broad-leaved vegetation to make space for the newly planted *P. kesiya* seedlings, which is relatively similar to the study of Ebasan et al. (2016), where the low litter layer was because the forest sampling sites have been kept clean through regular sweeping of litter around the area. The CO_2 was attributed to the biomass, for they are directly proportional.

Table 4

Computed Biomass, C, CO_2 Content of Litters

Plot	Biomass (Mg ha^{-1})	C (Mg ha^{-1})	CO_2 (Mg ha^{-1})
1	4.89	2.20	8.08
2	4.79	2.15	7.91
3	6.37	2.87	10.53
4	6.03	2.71	9.96
5	9.35	4.21	15.45
6	3.58	1.61	5.92
7	5.00	2.25	8.26
8	6.06	2.73	10.00
Ave.	5.76	2.59	9.51

Furthermore, the rate of formation and decomposition of litter layers is determined by the volume of growing tree stock and the extent of ground vegetation. Litter is broken down by bacteria and fungi in the soil, which use their enzymes to convert them into forms that are useful to them (Liski, 2004). This factor can explain the low calculated biomass, C, and CO_2 of the study site in litter layers, as observed in other studies (Labata et al., 2012; Lasco et al., 2005; Patricio & Tulod, 2010). During the decomposition process of the litter layer, the C stored in the little layer is eventually transferred to the soil, reducing the C stock in the litter layer and increasing the C stock in the soil pool (Ebasan et al., 2016).

Biomass, C, and CO_2 Content of Soil

In the Communal Forest soil was the second largest C pool (Avtar et al., 2020) and is the main contributor to forest C stocks next to AGB (Lal, 2005). The site has an overall mean C soil of 64.64 Mg ha^{-1} and CO_2 of 237.22 Mg ha^{-1}. The results derived from this study were relatively higher than those of Patricio and Tulod (2010) a Benguet pine plantation that has 57.07 Mg ha^{-1} C another is the study of Avtar et al. (2020) in Ifugao, Bilid (Communal Forest) has 23.78 Mg ha^{-1} C and 126.14 Mg ha^{-1} CO_2. Also, the result of soil C in this study was higher than the results of Medina et al. (2020), which revealed a mean soil C of 28.90 Mg ha^{-1}. This was because the forest's undisturbed state preserves the litter and organic matter content in the soil, both of which are essential for the soil's ability to sequester C (Bantas et al., 2011). Also, the litter will gradually accumulate on the forest floor, and C will eventually be transferred to the soil via decomposition (Ebasan et al., 2016); besides that, natural ecosystems, such as forests and grasslands, generally have higher C storage capacity compared to agricultural or urban areas (Sha et al., 2022). Therefore, the amount of C sequestered increases with the amount of organic matter present in the soil.

Additionally, the study's findings differed from those of Fernandez et al. (2015), who found that the old-growth Benguet pine stand stored 80.09 Mg ha^{-1} C and CO_2 of 293.93 Mg ha^{-1} which is a result of the stand's 40–80-year-old pine trees. This is because old-growth forests have been actively accumulating organic matter, including plant debris and litter, for many decades or even centuries. This accumulated organic matter contributes to the soil C stock (Luyssaert et al., 2008). Furthermore, old-growth Benguet pine stands typically have extensive root systems that penetrate deep into the soil. These roots contribute to the accumulation of soil organic C through the input of root biomass and turnover of fine roots, and they may have higher organic matter content, better soil structure, and higher microbial activity, which contribute to increased C storage.

In comparison to other forest types, the Communal Forest has a lesser amount of C sequestered. The study of Labata et al. (2012) was higher; it evaluated three different agroforestry systems in Bukidnon, including the taungya agroforestry, mixed multistorey, and falcata coffee multistorey system, which store, respectively, 160.42 Mg ha^{-1} C, 124.29 Mg ha^{-1} C and 84.69 Mg ha^{-1} C. This was due to the management practices benefits in the agroforestry that influence the greater soil C stored in it. The proper use of fertilizers and nutrient management practices can enhance plant growth and productivity, increasing C input into the soil through root residues and organic matter (Xu et al., 2020), although some management practices can be observed on the site in terms of reforestation like the planting of trees and the planting of fire lines that have a relatively low impact on the soil C stored in the forest.

Total Biomass, C, CO_2 of Daclan Communal Forest

The estimated total biomass of the Communal Forest is approximately 262.81 Mg ha^{-1}, with a total C of 182.91 Mg ha^{-1} and CO_2 total of 671.26 Mg ha^{-1} (Table 5). Trees have the highest potential C pools which stock approximately 114.94 Mg ha^{-1}, followed by the soil (64.64 Mg ha^{-1}), litter (2.59 Mg ha^{-1}), and l understory (0.74 Mg ha^{-1}) which contributed a smaller amount of C stocks. The result implies that Daclan Communal Forest has an average potential in sequestering C for the computed C stocks compared to other studies which is relatively moderate.

The study by Medina et al. (2020) in Bukidnon has higher biomass and C stocks, which are 277.81 Mg ha^{-1} and 143.14 Mg ha^{-1}, respectively. This higher amount was due to the mean total of two forests. On the other hand, the result of Ponipon and Nabe (2017) in the Alapang Communal Forest was relatively lower, with a total biomass of 144.77 Mg ha^{-1} C and 493.38 Mg ha^{-1} of CO_2. This lower calculated C and CO_2 of the two studies was associated with the low densities of tree species, for higher tree densities generally lead to greater carbon uptake due to the increased leaf area and biomass in the forest (Liu et al., 2018) and management practices. Also, the conversion of forests to other land uses, such as agriculture or urbanization, can have significant consequences for carbon storage (Plassmann, 2018).

Table 5

Summary of Average Total Biomass, C, and CO_2 of Daclan Communal Forest

Carbon Pools	Biomass (Mg ha^{-1})	C (Mg ha^{-1})	CO_2 (Mg ha^{-1})
Trees	255.40	114.94	421.80
Understory	1.65	0.74	2.72
Litter	5.76	2.59	9.51
Soil		64.64	237.23
TOTAL	262.81	182.91	671.26

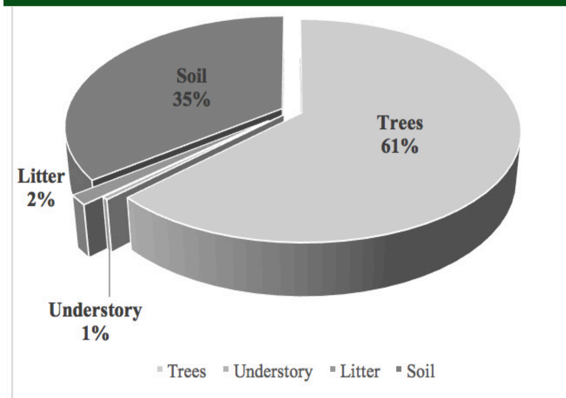
The result compared to other forest types was relatively low, as per the study of Dimalen and Rojo (2019) in Mahogany Forest in Cotabato City, with a mean total biomass density of about 605 Mg ha^{-1} and a mean total C stored of about 491 Mg ha^{-1}, due to the characteristics it consists; mangroves exhibit high rates of net primary productivity, which is the amount of C fixed through photosynthesis (Gu et al., 2022), mangrove soils can accumulate C over thousands of years, creating what is known as "blue carbon-(refers C stored in coastal ecosystems such as mangroves, seagrasses, and salt marshes)" (Chatting et al., 2022), the dense foliage of mangrove trees and the complex root systems that enable them to capture significant amounts of sunlight and nutrients, promoting rapid growth, thus the high productivity of mangroves leads to substantial C accumulation in both above-ground biomass and below-ground biomass (Jones et al., 2020), etc. compare to the other forest types.

Also, the result was higher than the result of the study of Lasco et al. (1999) in brush land forest in Leyte Geothermal Forest Reserve with 63.8 Mg ha^{-1} of biomass and 29 Mg ha^{-1} of C, merely because it was characterized by low-statured vegetation with sparse tree cover, and the low productivity and slow growth rate of brush land vegetation that restrict the amount of biomass that can accumulate over time (Sternberg, 2003).

Figure 3 shows the four C pools and their percentage of C stored wherein trees have the bigger C percentage (61%), followed by soil (36%), litter (2%), and understory (1%). The results were relatively similar to those of Patricio and Tulod (2010), where trees (53%) had the highest potential for sequestering C, followed by the soil (39%), while the understory (2.67%) and litter (1%) contributed less. This was due to the characteristics of *P. kesiya* compared to a mixed one. Some of these are their large trunks, branches, and extensive foliage, which contribute to substantial C storage in the form of woody biomass, which allows them to accumulate and store more C than smaller or slower-growing tree species. Furthermore, the long life span of *P. kesiya* allows them to continue accumulating C over an extended period, possess dense wood with a high concentration of C, and are well-adapted to various environmental

Figure 3

C Percentage per C Pool in the Communal Forest



conditions and disturbances (Köhl et al., 2017). Climate, relief, and land use influence the quantity and heterogeneity of SOC stocks in these soils (Rastrero & Martos, 2022).

On the other hand, the result was contradictory to the results of Racelis et al. (2017) and Labata et al. (2012), wherein their results revealed that soil had the highest percentage of C stocks with 53% and 77%, respectively, followed by trees and other C pools. Forest ecosystems in soil were distinguished by the continuous input of organic matter, which includes plant litter, fallen leaves, branches, and dead organisms; their slower decomposition rates allow for organic matter accumulation, resulting in higher C stocks in the soil. In addition, tree roots significantly contribute to soil C stocks. Trees have extensive root systems that reach deep into the soil, contributing significant root biomass. In contrast to aboveground biomass, which is vulnerable to disturbances such as fire, wind throw, or logging, C stored in soil has the potential for long-term storage. The shade provided by the forest canopy reduces temperature extremes, making the environment more suitable for soil organisms and encouraging organic matter preservation.

The result implies that the different forest management practices. Specific C storage potential of pine tree stands can also be influenced by local environmental conditions, site characteristics, management practices, and the age and structure of the forest. Additionally, while pine trees can store substantial C, maintaining a diverse mix of tree species in forests is crucial for promoting biodiversity and ecosystem resilience. Furthermore, the C stocks of soils may vary because disturbances like land-use change, intensive agricultural practices, or excessive soil erosion can lead to C losses from the soil, emphasizing the significance of sustainable land management and forest conservation for maintaining high soil C stocks. Nevertheless, despite the small amount of C stocks in the litter and understory, they are still significantly helpful in reducing the emission of greenhouse gases.

In addition, the estimated average biomass, C, and CO_2 of the Communal Forest study is a positive indicator of good forest health for the higher biomass and carbon often exhibit greater productivity and ecosystem functioning for the increased biomass indicates a higher level of primary production and energy capture within the forest ecosystem, resulting in enhanced nutrient cycling, increased habitat availability, and improved overall ecosystem services (Luyssaert et al., 2008), and the larger and healthier the trees, the more capable they are of withstanding disturbances and recovering from them that contributes to the long-term sustainability and health of the forest ecosystem (Gora & Esquivel-Muelbert, 2021).

Potential for C Crediting and C Trading of Daclan Communal Forest

The Daclan Communal Forest not only has significant economic value today, estimated at Php3,038,237.09 but its value is expected to grow significantly by 2030, reaching around Php7,595,592.72, owing to C sequestration. As public concern about climate change grows, it will the demand for C-offset projects and initiatives. This high potential economic value of Daclan Communal Forest is likely to attract investments and partnerships focused on C sequestration. As global C markets mature and gain traction, the forest's capacity to sequester C will become even more valuable by 2030, providing an opportunity for the local community to participate in C credit trading and generate additional income. This increased economic value emphasizes the forest's importance as an environmental and economic asset. Furthermore, by engaging in carbon trading, the Daclan Communal Forest project demonstrates how environmental stewardship can be economically viable, serving as a model for other communities seeking to combat climate change while improving livelihoods. C trading's success is dependent on effective implementation, strong governance, and continuous evaluation to address the complex challenge of climate change, a comprehensive approach combining multiple strategies and policies is required. This forward-looking approach integrates environmental conservation and economic prosperity, ensuring that the forest remains a valuable asset for both the planet and the people who rely on it.

Conclusions

As we learn more about the ecological process driving C accumulation, sequestration, and emissions in the forest ecosystem, we were not only able to improve the estimates of forest C stocks and stock changes but also better quantify the uncertainty associated with these estimates. From the results of this present study, it is concluded that plots with a high number of tree species and dominated by *P. kesiya* have the highest C stocks, the bigger the BDH the higher the stocks stored especially the *P. kesiya* that can stock high C based on their growth patterns and physiological characteristics. C stock of understory was influenced by several factors that have direct implications on C gain such as herbaceous diversity and composition, and tree densities within the plots. Different plant species contribute varying amounts of litter, with leafy species generally providing higher C inputs compared to needle-like or grassy species that were abundant in the study site. Factors like the state of the forest (undisturbed or not), decomposition of litter, forest management practices, and characteristics of trees within the forest have a significant effect on the C stock in soils. The potential C credit and C trading of the communal forests can preserve their ecosystems, advance local economies, and support the coordinated national and international effort to battle climate change.

Recommendations

Following the results, the following measures are recommended (1) *P. kesiya* has great potential for sequestering C, so it is highly recommended to plant more of these species. Concerned agencies like the DENR and LGUs of the municipality should be informed to enhance recent policies or guidelines for the conservation and protection of this existing species soon; (2) Stand improvement practices such as pruning and thinning to reduce competition, improve growing conditions, and promote the growth of desirable tree species to promote the overall health, productivity, biodiversity, and ecosystem services within the Communal Forest.; (3) Conservation of the tree species within the Communal Forest is recommended while integrating enrichment planting into the forest to improve its composition, function, or productivity.; (4)The concerned agencies on the Communal Forest must maintain their forest management practices, which are the National Greening Program and selective cutting, but can promote other practices like agroforestry, community-based management, and soil conservation practices, for these practices have such a great impact on the soil as one of the C pools, that it must be preserved from degradation and land-use conversion.; and (5) to harness the potential of Communal Forests for C crediting and trading, it is recommended to prioritize ecosystem preservation through sustainable forest management practices, while simultaneously fostering local economic development through capacity building and market access, thereby aligning with the collective global endeavor to combat climate change.

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