Carbon Storage of Leyte Sab-A Basin Peatland, Philippines

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ARTICLE INFO

Received: 13 Jan 2023
Received in revised: 9 Jun 2023
Accepted: 19 Jun 2023
Published online: 11 Sep 2023
DOI: 10.32526/ennrj/21/20230015

Keywords:
Aboveground carbon stocks/ Belowground carbon stocks/ Carbon sequestration/ Land-use change/ Marshland/ Tropical peat swamp forest

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ABSTRACT

Leyte Sab-A Basin peatland (LSBP) is the second largest peatland in the Philippines and comprises 3,088 ha (31 km^2). The study estimated the C storage and carbon sequestration capacity of the peatland's four (4) ecotypes, namely, swamp forest (SF), marshland (ML), agroforestry (AF), and agricultural land (AL) using allometric equations. SF rendered the highest downed wood C-stocks followed by AL and AF. For the litter C-stocks, AF rendered the highest, followed by SF, ML, and AL. SF rendered the highest root C-stocks and CO_2 sequestered, followed by AL and AF. C% is highest in ML with values ranging from 32-43 C% across the soil peat depth, while SF ranges from 29-34 C%, and AL and AF both with 19-37 C%. The LSBP stores 36.6 Tg of C and 134.5 Tg of CO_2 sequestered. This C storage amount can represent 0.04% of tropical peat carbon.

1. INTRODUCTION

Peatlands have been widely accepted to store a massive amount of carbon. Although peatlands account for only 3% of the world's land surface, they are one of the major reservoirs of global soil carbon (C), which is currently estimated to be over 600 Gt carbon (Page et al., 2011; Yu et al., 2010; Yu et al., 2011). Tropical peatlands covering 440,000 km^2 represent about 11% of the world's peatland areas, with the Leyte Sab-A Basin representing 31 km^2 (0.007%) of that area. Page et al. (2011) estimate that 77% of the tropical peat C storage is in Southeast Asia. The tropical peat reservoir is estimated to be 88.6 (81.7-91.0) Gt (Pg) C or 15-19% of the global peat carbon pool.

Aside from sequestering carbon, peat swamp forests provide numerous ecosystem services, including the provision of forest products, hydrological regulation (Dommain et al., 2016), nutrient cycling, and habitat for many endangered and rare species of animals with high biodiversity indices (Nowak, 2013; Cheyne and Macdonald, 2011; Posa et al., 2011). Despite these values, Southeast Asian peatlands are being disturbed by anthropogenic activities such as draining, deforestation, and intensive burning, primarily for agricultural and tree plantation purposes (Margono et al., 2014; Miettinen et al., 2012).

Intense economic and social pressures for timber, land for food crops, and oil palm plantations contribute to Southeast Asia's rapid degradation of peatlands. As a result, massive amounts of carbon gas are transmitted to the atmosphere through the loss of biomass and peat oxidation and burning. One good example is the 1997 widespread wildfires in forested peatlands of Indonesia following a severe El Niño. Extrapolations showed an estimate of 0.81 to 2.57 Gt of carbon were discharged into the atmosphere in 1997 because of burning peat and vegetation in Indonesia - an amount that is equal to 13-40% of the mean yearly worldwide carbon emissions from non-sustainable power sources (Page et al., 2010; Page et al., 2011).

Considering the potential impacts of peatlands degradation at both the regional and global scale, failure to account for these vulnerable C pools can cause biogeochemical and climate models to

Citation: Bobon-Carnice PA, Chanton JP, Migo VP, Faustino-Eslava DV. Carbon storage of Leyte Sab-A Basin Peatland, Philippines. Environ. Nat. Resour. J. 2023;21(5):402-416. (https://doi.org/10.32526/ennrj/21/20230015)

underestimate the future increases in CO_2, which could further enhance anthropogenic-driven climate change. Tragically, the protection of peatlands as a forest isn't under any Kyoto Protocol (KP) Mechanisms or its adaptability systems, for example, Joint Implementation (JI) Program and the Clean Development Mechanism (CDM). In contrast, the C stocks in peatlands are excluded from the United Nations Framework Convention on Climate Change (UNFCC). It could be one of the principal reasons peatlands have been adequately exposed to survival transformation and waste in recent years since strategy-making bodies are not straightforwardly tending to peatland assurance. However, the KP mechanisms and UNFCC are now considering peatlands. The first commitment period was from 2008 to 2012 (Barthelmes et al., 2015; FAO, 2020).

Agusan Marsh and Leyte Sab-A Basin are where important peatland areas were identified in the Philippines. However, there is a lack of targeted research on peatlands in Agusan Marsh despite it being declared a protected wetland under Presidential Proclamation No. 913. Meanwhile, the Protected Areas and Wildlife Bureau (PAWB-DENR, 2009; PAWB-DENR, 2013) nominated the Leyte Sab-A Basin as a Peat Site Profile in Southeast Asia. However, this recognition from the ASEAN is still in process. Aside from this, no other exhaustive scientific study has been conducted on the site. Still, it holds a series of swamps as Leyte's most significant water catchment, which supports wildlife and local communities.

Leyte Sab-A Peatland Basin in the Philippines is categorized as a tropical peatland of Southeast Asia similar to Malaysia (Peninsular; Sabah), Brunei, Thailand, Papua New Guinea, Vietnam, and Indonesia. Leyte Sab-A Basin is the second largest peatland in the Philippines and comprises 3,088 ha. It is an elongated basin from NW to SE on the Philippine Island of Leyte (ADB, 2000). The basin comprises four main ecotypes: swamp forest (SF), marshland (ML), agroforestry (AF), and agricultural land (AL). Massive efforts of the government to convert peatland to agricultural land have not been experienced in the Philippines as it has been in many of these other countries. The conversion of many hectares of peatland in Central Kalimantan, Indonesia, has suffered consequential losses through its Mega Rice Project (Nuthammachot et al., 2019). There are many abandoned lands in Leyte Sab-A Peatland, although a governing body was established (and consequently abolished) to manage it. In contrast to the increased fire incidents in Malaysian and Indonesian peatlands (Tonks et al., 2017; Miettinen et al., 2012), Leyte Sab-A Peatland has experienced subsidence and abandonment of land due to consistently low productivity in agriculture. The remaining untouched grounds of the Leyte Sab-A Peatland Basin have become more vulnerable to conversion as the local people explore more ways to use it since the majority of the land of the community belongs to this resource.

This study characterizes carbon storage in the Leyte Sab-A Peatland Basin's four dominant ecotypes. By doing so, the organic matter allocated to standing trees, downed wood, litter, roots, and soil peat will be described as influencing the aboveground and belowground carbon pool. In addition, abundant species, the presence of water, and the accessibility of the ecotype will also shed light on the existing management and development of the peatland. Lastly, the total carbon content and carbon dioxide sequestered are computed, which will highlight the importance of the Leyte Sab-A Peatland on the extent, distribution, and regional carbon budget of tropical peatlands in Southeast Asia. The study's main objective was to estimate the current C storage of the Leyte Sab-A Basin peatland. Specifically, it determined that the aboveground C storage of the peatland are in the following pools: aboveground carbon comprised of standing trees, downed wood, and litter, and belowground carbon stored in root biomass and the peat soil at different soil depth.

2. METHODOLOGY

2.1 Study sites

The peatland site was identified as Leyte Sab-A Basin Peatland (LSBP), which traverses three municipalities: Santa Fe, Alang-Alang, and San Miguel, Leyte. The peatland is a freshwater-type palustrine wetland system consisting of shallow, slow-moving, and stagnant water. It has a mixture of closed or shaded forest swamps where tall emergent macrophytes grow thick and shade the water from the wind and direct sunlight and an open or unshaded swamp where water lilies and submerged macrophytes dominate. The watershed area is about 18,508 ha (ADB, 2000). Figure 1 shows the location of the LSBP in Leyte Island, Philippines, and the different transects for sampling in the peatland. Figure 2 shows the different ecotypes identified in the peatland with its corresponding vegetation.

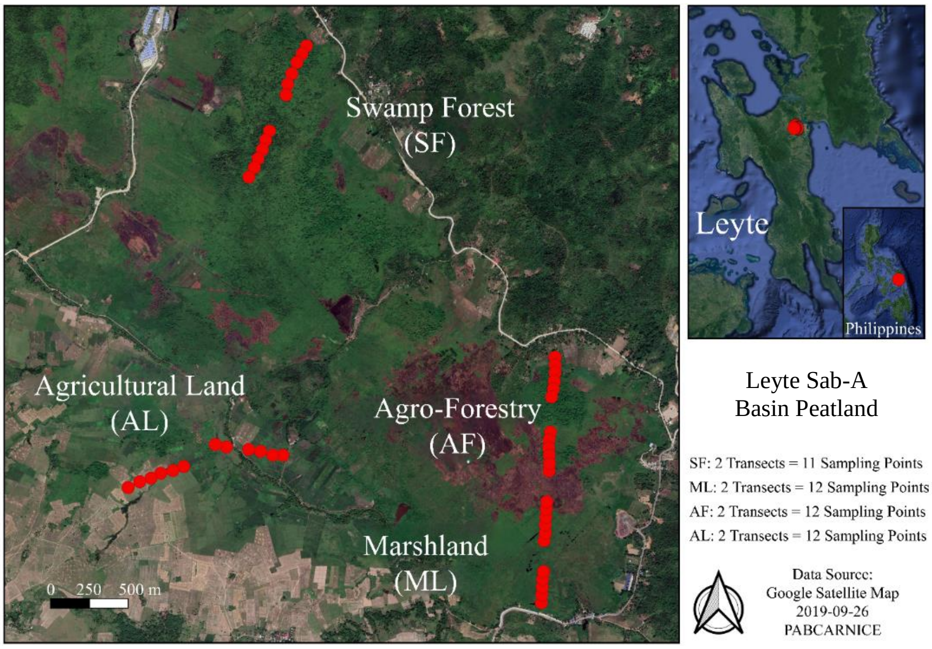

Figure 1. Location of all representative 47 core sampling points in LSBP, Leyte, Philippines

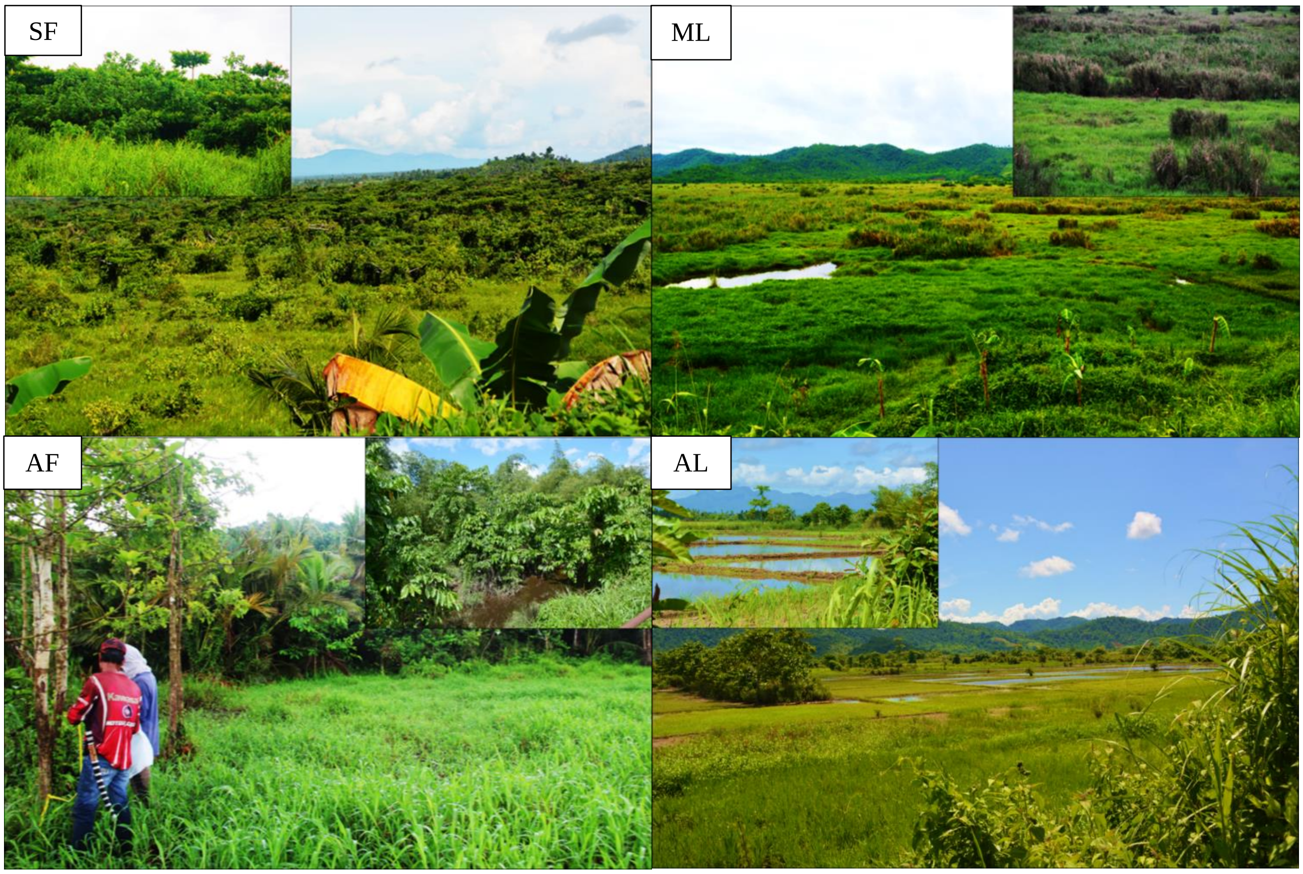

Figure 2. The SF, ML, AF, and AL ecotypes and their vegetation of Leyte Sab-A Basin Peatland

Further, Figure 3 shows the details of the carbon stock assessment scheme in different pools. The standing trees, downed wood, and litter were measured for aboveground C. The root biomass and peat soil at specific depths represent belowground carbon. Downed wood refers to dead or fallen tree branches and woody debris no longer standing and resting on the ground. It includes fallen tree trunks, branches, and woody materials.

2.2 Biomass sampling plots

The study is guided by the protocol used in the ecosystem carbon stocks assessment of tropical peatland forests of Indonesia and Micronesia (Kauffman et al., 2011; Kauffman and Donato, 2012; Kauffman et al., 2016). Figure 4 illustrates the general plot layout to quantify ecosystem C pools following the general carbon assessment scheme in Figure 3. Six plots were established in every ecotype stand along a 250 m transect.

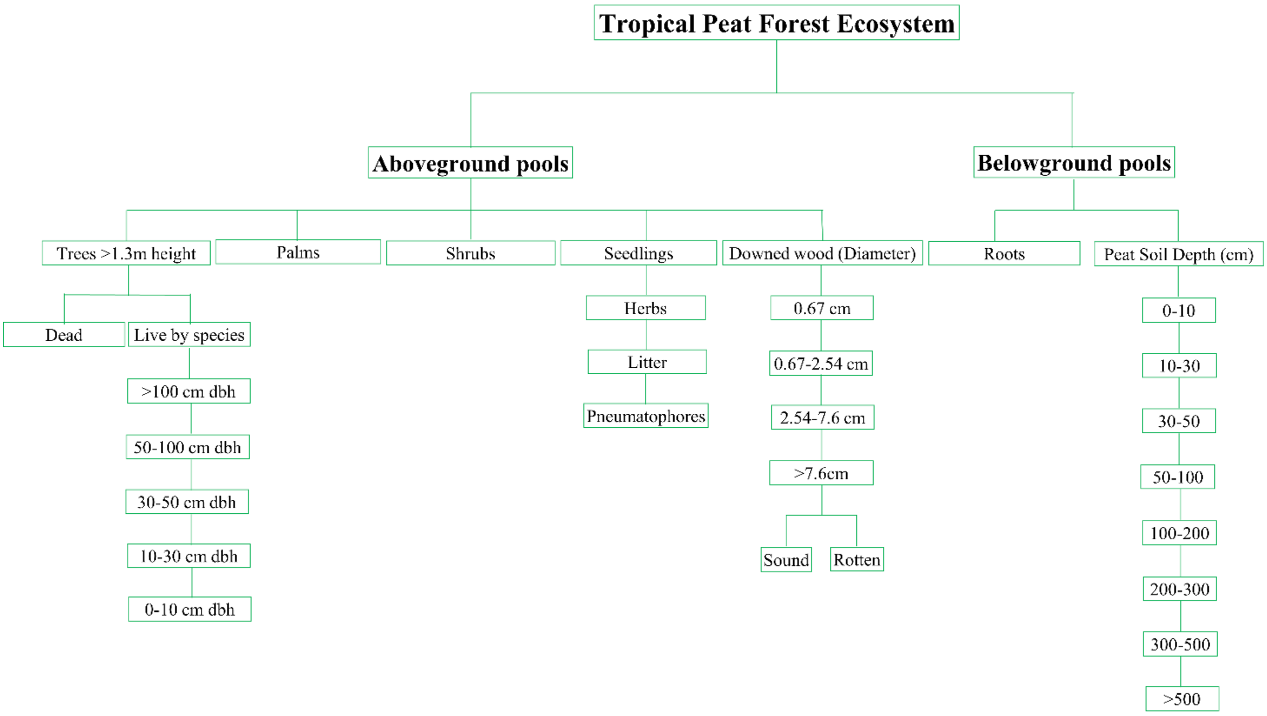

Figure 3. Carbon stock assessment scheme in LSBP

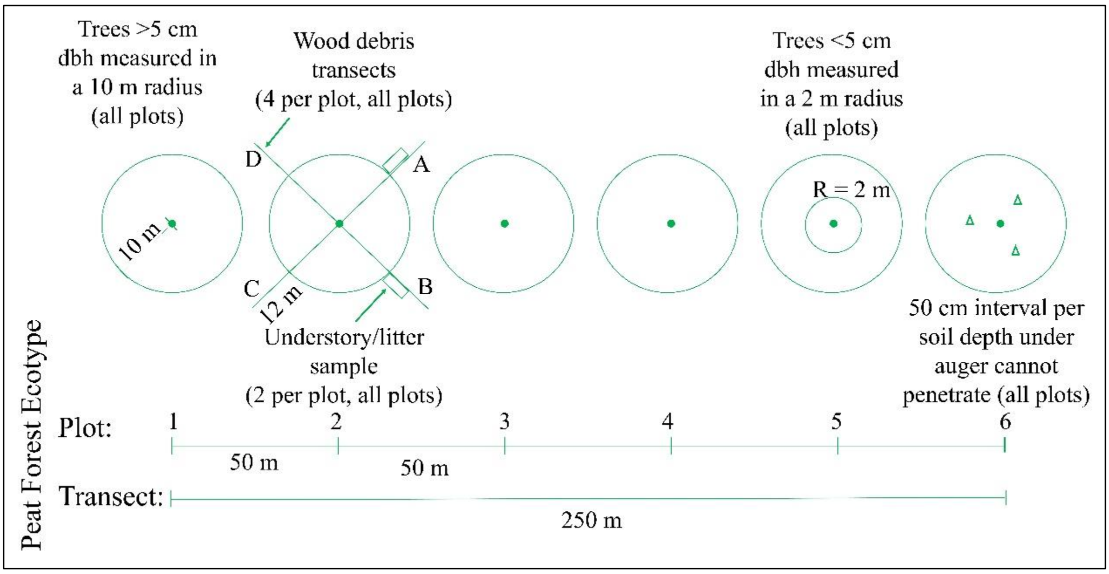

Figure 4. General plot layout to quantify ecosystem C pools of LSBP

2.3 Measuring aboveground carbon pools

2.3.1 Tree biomass: All trees that are >5 cm in diameter were measured in the 10 m radius plot. The smaller trees having <5 cm in diameter were measured in a 2 m radius nested plot.

The biomass equation formula (Bobon-Carnice and Lina, 2017; Bobon-Carnice and Lina, 2021) is as follows:

$$AGB = 21.297 - 6.953 \times (dbh) + 0.740 \times (dbh)^2$$

Where; AGB=aboveground dry matter, kg/tree; and dbh=diameter at breast height, cm.

The total tree biomass multiplied by the average C content of wood (standard value of 45%) is the equivalent value of C stock.

2.3.2 Downed wood: Downed wood was measured using the planar intercept technique (Dibble and Rees, 2005). In each plot, four (4) transects were measured to determine the downed wood mass, which totals 24 transects in each plot.

The equation for calculating the volume of medium to fine (<7.6 cm diameter) downed wood is:

$$\text{Volume } (m^3/ha) = \pi^2 \times (Ni \times \frac{QMDi^2}{8} \times L)$$

Where; Ni=the count of intersecting woody debris pieces in size class i; QMDi=the quadratic mean diameter of size class i (cm); QMD=quadratic mean diameter; and L=transect length (m).

The equation for calculating the volume of large (>7.6 cm diameter) downed wood is:

$$\text{Volume } (m^3/ha) = \pi^2 \times (\frac{d1^2 + d2^2 + d3^2 + \cdots dn^2}{8} \times L)$$

Where; $d_1, \ldots d_n$=diameters of intersecting pieces of large deadwood (cm); and L=the length of the transect line for large size class (m).

Downed wood mass is calculated as the volume multiplied by its mean specific gravity and converted to Mg/ha.

2.3.3 Litter: In each plot, litter sampling was done in 2 micro-plots (50 × 50 cm). Three values were determined based on litter: the fresh weight of the litter sample (FW), the fresh weight of a litter subsample (FWs), and the dry weight of the litter subsample (DWs). In addition, a moisture correction factor (M) was calculated based on the water lost (H_2O, g) from the dried litter subsample. From the formula:

$$\frac{DWs}{FWs} \times FW = DW$$

C stock is estimated as C_{litter}=DW × 0.45 (Bobon-Carnice and Lina, 2017; Bobon-Carnice and Lina, 2021). Litter C stock was then scaled to the standard unit Mg/ha by converting the area of the sampling frame to a hectare and the weight of the sample to Mg.

2.4 Measuring belowground carbon pools

2.4.1 Peat soil: A fabricated Russian peat auger was used in collecting peat samples. Six (6) sub-sampling core points on each transect (2 transects per ecotype) were collected uniformly with a depth interval of 50 cm from the surface (0-50, 50-100 cm) until the auger could not penetrate anymore. All peat soil samples inside the auger core were collected, placed in adequately labeled plastic bags, and brought immediately to the screen house. Each sample was weighed, prepared for initial air drying, and then freeze-dried.

Organic C and N concentrations were analyzed by combustion to CO_2 and N_2 at 1,020°C in an automated CHN elemental analyzer coupled with a Thermo Finnigan Delta XP isotope ratio mass spectrometer for C (δ^{13}C) and N (δ^{15}N) determination, which was done at the National High Magnetic Field Laboratory at Florida State University. Bulk density (Db) will be determined using the core sampling method. Peat C stock was calculated using the equation (Neufeldt, 2005; Donato et al., 2011; Howard et al., 2014):

$$\text{Peat C stocks (Mg C/ha)} = \frac{\%SOC}{100} \times \text{soil depth (m)} \times \text{bulk density} \left(\frac{Mg}{m^3}\right) \times \frac{10{,}000\ m^2}{ha}$$

2.4.2 Root biomass: Belowground biomass for the roots present was also estimated using allometric equations following Cairns et al. (1997):

$$Y = \exp\ [-1.0587 + 0.8836 \times \ln(AGB)]$$

Where; Y=root biomass in Mg/ha of dry matter; ln=natural logarithm; exp="e to the power of"; and ABD=aboveground biomass in Mg/ha of dry matter.

2.5 Data analysis and calculations

All data were subjected to descriptive analysis first and then analyzed using analysis of variance at p<0.05. Factor(s) causing a significant difference between means based on the test statistics values (F-computed) was then subjected to Scheffé's Test at p<0.05. Finally, total carbon density was predicted by testing for the significant interaction between soil depth and ecotype using the Analysis of Covariance (ANCOVA). All statistical analysis was done using SPSS (Student Version 2019, SPSS Inc.,).

3. RESULTS AND DISCUSSION

3.1 Aboveground pools

3.1.1 Standing trees: The different ecotypes are a significant factor in C-stocks' difference (P-value=2.05E-06) for standing trees. SF rendered the highest mean of C-stocks of (mean±SE) 14.0±1.7 Mg C/ha, followed by AL with 4.7±1.0 Mg C/ha and AF with 2.2±0.5 Mg C/ha (Figure 5(a)). Pairwise comparison through Scheffé's Method test showed that SF had significantly higher C-stocks than AL and AF. On the other hand, C-stocks of AL and AF are found to be not significantly different from each other. Therefore, untouched ecotypes such as an SF have significantly higher C-stocks for standing trees than ecotypes with frequent human activities.

The exact sequence of results was also observed in CO_2 sequestered by the standing trees of the SF. SF ecotype is superior with 51.4±6.4 Mg CO_2/ha, followed by AL (17.2±3.8 Mg CO_2/ha) and AF (8.0±1.7 Mg CO_2/ha) (Figure 5(f)). Such results are due to the diameter at breast height (dbh) values and the number of trees in each ecotype. SF's standing trees C-stock results are comparable to the intermediate forest (IF) standing tree C-stocks of Caimpugan Peatland in Agusan Marsh, Philippines, with 14.42 Mg C/ha (Alibo and Lasco, 2012). The C stock of standing trees of SF is lower than the live standing trees in the Peruvian cloud montane peat forest (69.3±13.4 Mg C/ha) (Román-Cuesta et al., 2011), but much higher than an open peatland mosaic live vegetation (1.9±0.2 Mg C/ha) in Minnesota, USA (Weishampel et al., 2009).

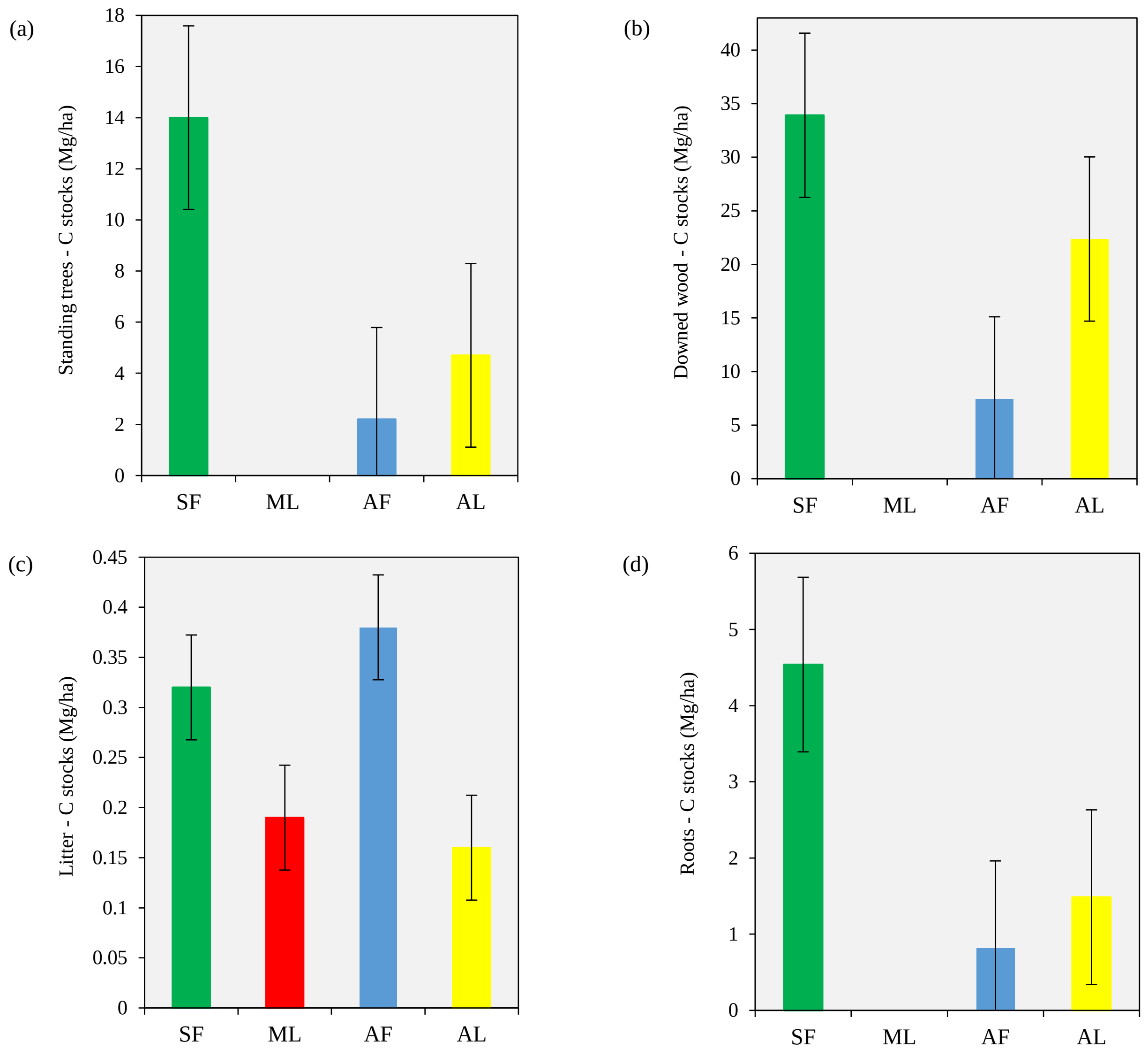

Figure 5. Mean C-stocks (a to e) and CO_2 sequestered (f to j) of standing trees, downed wood, litter, roots, and peat soil C-stocks across all four ecotypes

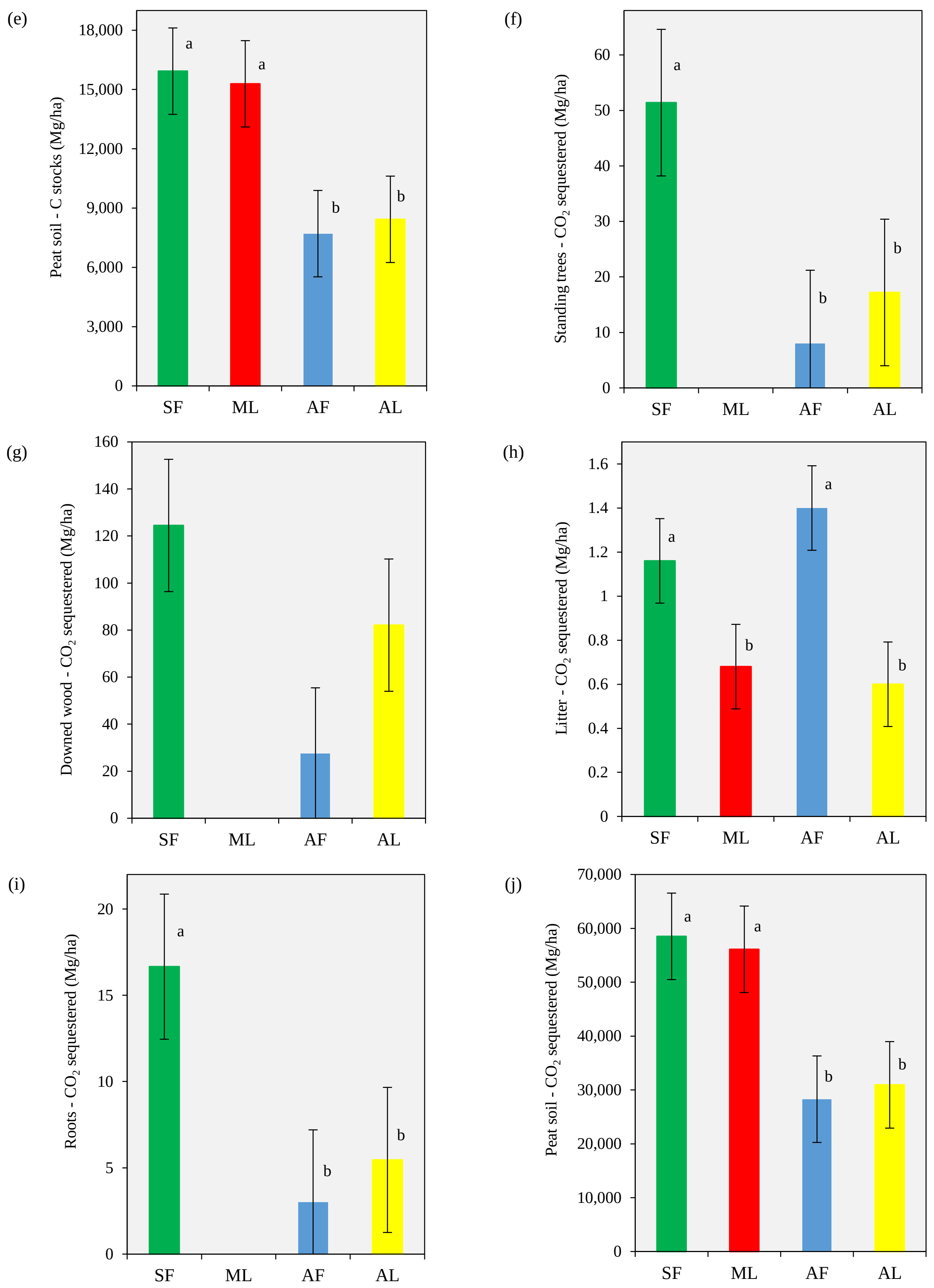

Figure 5. Mean C-stocks (a to e) and CO_2 sequestered (f to j) of standing trees, downed wood, litter, roots, and peat soil C-stocks across all four ecotypes (cont.)

3.1.2 Downed wood: Results showed that C-stocks from downed wood were significantly different across ecotypes (P-value=0.029). SF rendered the highest downed wood C-stocks (33.92±5.38 Mg C/ha), followed by AL (22.37±7.34 Mg C/ha), and AF as the least (7.45±3.63 Mg C/ha) (Figure 5(b)). Such results are higher than the fallen deadwood in Andean cloud peat montane forest with only 6.7±3.2 Mg C/ha (Román-Cuesta et al., 2011), and in the peat swamp wetlands of Chiapas, Mexico, with 12.5±2.8 Mg C/ha (Adame et al., 2015).

For the amount of CO_2 sequestered in downed wood, the value reached 124.5±19.7 Mg C/ha in the SL ecotype, followed by AL (82.10±13.33 Mg C/ha) and AF (27.3±13.3 Mg C/ha) as depicted in Figure 5(g). Also, it must be noted that no standing trees were found inside the representative sampling plots of the ML ecotype because grasses and sedges dominate it.

3.1.3 Litter: Results show in LSBP that the mean litter C-stocks between ecotypes are significantly different from each other (P-value=6.7571E-09). AF rendered the highest litter C stock (0.39±0.02 Mg C/ha), which is not statistically different from SF C stock (0.32±0.03 Mg C/ha). On the other hand, carbon stocks of ML (0.19±0.01 Mg C/ha) and AL (0.16±0.02 Mg C/ha) are not significantly different (Figure 5(c)), and the C stocks of AF and SF are significantly higher than them. Consequently, the same pattern can be observed in the CO_2 sequestered across all ecotypes (Figure 5(h)).

Although there are avenues where litter can store more C, the computed values are low compared to the litter C stock of the three vegetation zones in Caimpugan Peatland in Agusan Marsh, Philippines, which ranged from 4.16 ton/ha to 34.49 ton/ha (Alibo and Lasco, 2012). The characteristic basin topography of LSBP, with the lowest registered elevation of 11.5 above sea level, mainly contributes to the water level in the peatland such that water is almost always present in all parts of the land. Therefore, it can influence the lower density of standing trees that can tolerate persistent waterlogged conditions leading to less litterfall across all ecotypes.

3.1.4 Total aboveground C-stocks and CO_2 sequestered

SF had the highest total aboveground C stock (48.24 Mg C/ha), followed by AL (27.23 Mg C/ha), AF (10.03 Mg C/ha), and lastly, ML (0.19 Mg C/ha) with a mean total aboveground C of 21.42 Mg C/ha (Figure 6). LSBP has lower calculated aboveground C-stocks than the 150-250 ton/ha estimated average aboveground C stock of tropical peatlands (Rieley and Page, 2008). However, it is comparable to the intermediate forest (31.16-43.40 ton/ha) and pygmy forest (8.45-16.56 ton/ha) mean aboveground C-stocks of Caimpugan Peatland, Philippines (Alibo and Lasco, 2012). Consequently, aboveground C stocks in the Philippines, both LSBP and Caimpugan Peatland, are quite low compared to the primary and secondary forest in Central Kalimantan, Indonesia, with 204±32 and 172±17 Mg C/ha but at par with its oil palm plantation with 29±0.3 Mg C/ha (Novita et al., 2021). It further implies that LSBP vegetation is quite degraded. Nonetheless, downed wood contributed most to the aboveground C storage across all ecotypes, followed by standing trees and litter.

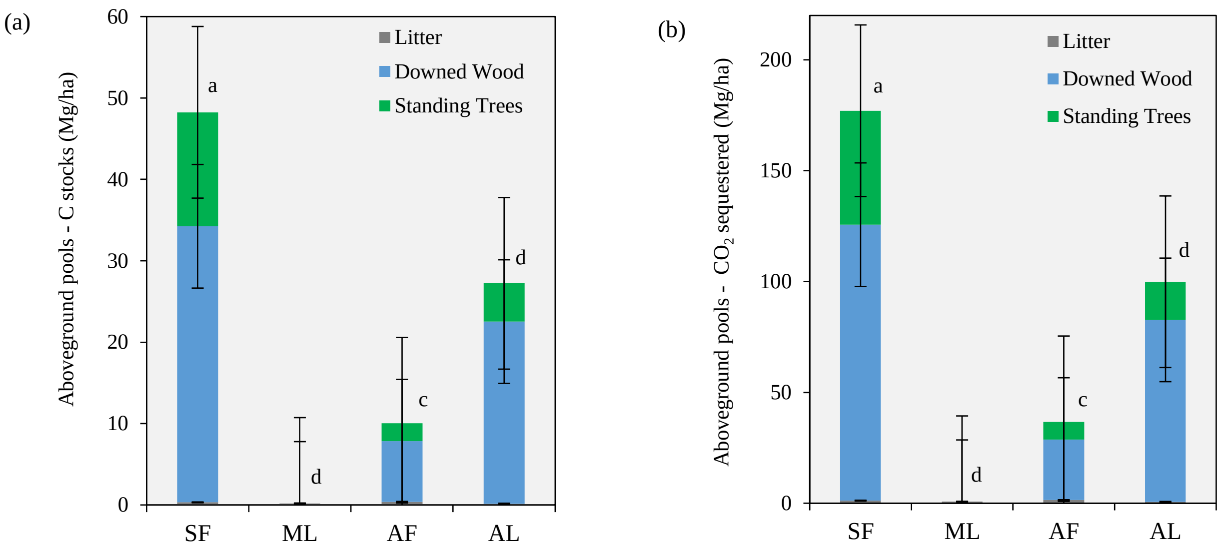

Figure 6. Total C-stocks and CO_2 sequestered of aboveground (a, b) and belowground biomass (c, d)

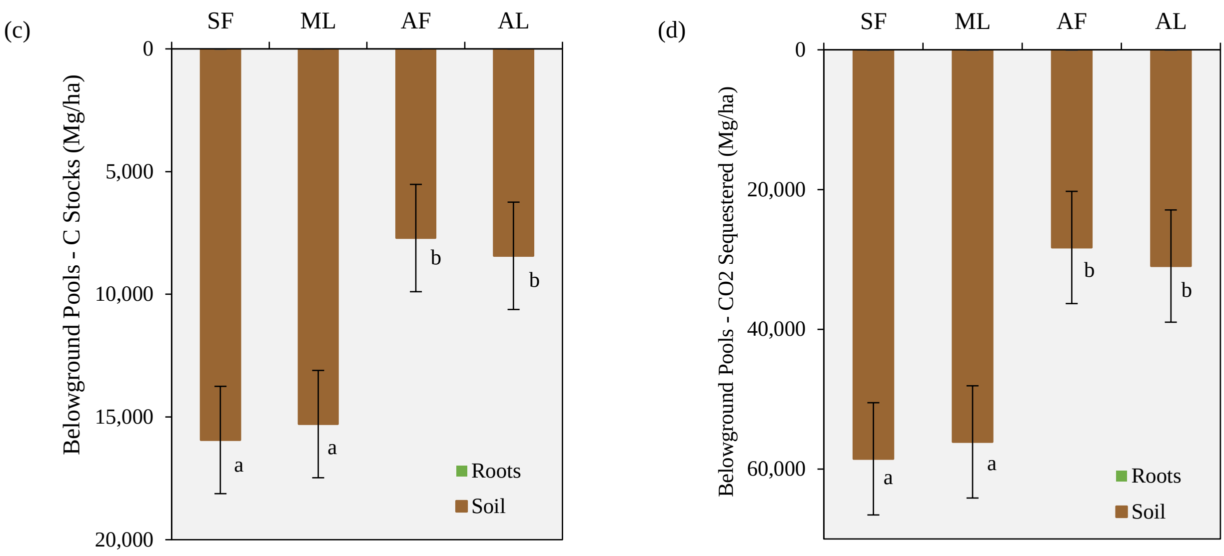

Figure 6. Total C-stocks and CO_2 sequestered of aboveground (a, b) and belowground biomass (c, d) (cont.)

Estimating aboveground C-stocks is critical in each ecotype so that it is easy to determine which pools should be prioritized in terms of protection, preservation, and increasing C storage. It must be noted that compared with the belowground counterpart, aboveground C pools are more susceptible to anthropogenic disturbances. AF and AL are the ecotypes frequently visited by the residents at the study site. Each total is lower than that of the lesser disturbed SF. Even for the specifics of an aboveground pool (standing trees, downed wood, litter), AF and AL tend to behave similarly, with values of C-stocks not significantly different from one another but consistently lower than SF.

3.2 Belowground pools

3.2.1 Root biomass: SF rendered the highest root C-stocks (4.54±0.59 Mg C/ha) and CO_2 sequestered (16.66±2.16 Mg/ha), which are both significantly different from AL (1.49±0.31 Mg C/ha; 5.46±1.12 Mg/ha CO_2 sequestered) and AF (0.82±0.16 Mg C/ha; 3.00±0.58 Mg/ha CO_2 sequestered), but AL and AF are not significantly different from each other (Figure 5(d) and Figure 5(i)). However, root biomass C-stocks are meager compared to the other C pools. It could be due to the type of roots and varying root concentration as it goes down into soil layers.

3.2.2 Soil peat and bulk density: The highest mean bulk density across all depths is 0.074 g/cm^3 (AF), and mean values across ecotypes are statistically significant with each other except SF (0.062 g/cm^3), which is quite similar to AL (0.066 g/cm^3) and ML (0.059 g/cm^3) values. All ecotypes tend to have a similar range of bulk density of 0.055-0.064 g/cm^3 at the topsoil (0-50 cm) and entirely stayed in that range, but AL increased at 100-150 cm to 0.088 g/cm^3, as well as AF at 150-200 cm to 0.104 g/cm^3 (Figure 8(a)). Very high bulk density (0.088-0.99 g/cm^3 range for SF, ML, and AF) was recorded at the last soil depth penetrated by the peat sampler, suggesting the layer is compacted.

The mean values for dry bulk density across all ecotypes are low (SF=0.062 g/cm^3; ML=0.059 g/cm^3; AF=0.074 g/cm^3; AL=0.066 g/cm^3) compared with the 0.09 g/cm^3 peat bulk density of sites across Southeast Asia (Page et al., 2010). The results are closer to Northern Island's mean bulk density (0.069 g/cm^3) of non-forested raised bogs (Tomlinson and Davidson, 2000). AF mean bulk density is significantly higher than its ecotype counterparts, suggesting that this land use is more compacted than the rest. It can be observed in the field that AF is more accessible to the people and lies closer to the local trails, which have many activities that can lead to compaction.

3.2.3 Soil peat and C%: Figure 7(b) shows that C% is highest in ML with values ranging from 31.8-43.3 C% across the soil peat depth while SF ranges from 29.2-34.0 C%, AL with 19.1-37.4 C% and AF with 19.1-37.4 C%. ML and AL have close values of 41.9 C% and 41.4 C%, respectively, at the peat's top 0-50 cm layer. However, the value decreased for AL in the 100-150 cm layer.

The mean value of ML (40.5 C%) is higher than the other three ecotypes and is significantly different from other means. This value is unsurprising because of the many vital grasses and sedges dominating the ML. In the field, it can be observed that grasses have piled up over the years that can be used as a walking trail to access the innermost portion of the peatland basin while maintaining buoyancy over the standing water below. C% in ML has only substantially decreased from the mean when it reached the 650-700 cm soil depth, which is already impenetrable in AL and AF ecotypes. Notably, this ML value of 35.7 C% is close to the 33.0 C% in SF at the same depth. Hence, it implies the influence of water presence on the carbon content and even the impenetrability of that layer.

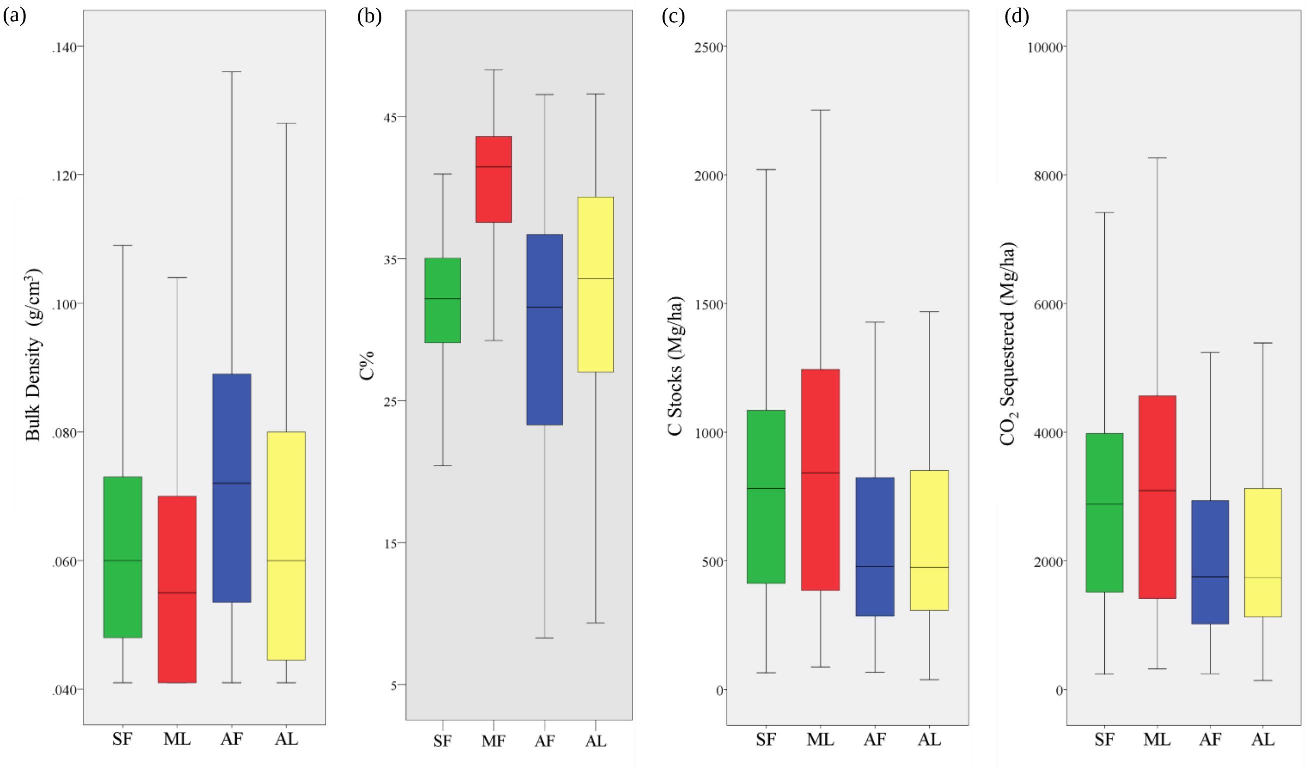

Figure 7. Box plot of (a) means bulk density (g/cm^3), (b) C%, (c) C-stocks (Mg/ha), and (d) CO_2 sequestered (Mg/ha) across four ecotypes

It also explains why the 0-50 cm upper layer of ML and AL have values close to each other (41.9 C% and 41.39 C%, respectively). However, the mean of AL (32.6 C%) has become significantly different and lower than that of ML because of the many years of cultivating the peatland for planting rice and some root crops. When the soil is opened, it is exposed to various transformations of its organic matter. It is subjected to a series of plowing and harrowing and other activities that lower its C content through time. At the same time, many C has been removed as harvestable plant parts leaving or returning only a fraction into the soil.

Peat soil organic C-stocks of LSBP contributed significantly to the belowground C-stocks of the whole peatland. SF rendered the highest peat soil C-stocks with 15,932±1,247 Mg C/ha and 58,515±4,586 Mg CO_2/ha sequestered, followed by ML with 15,288±1,013 Mg C/ha and 56,110±3,718 Mg CO_2/ha sequestered, which are not significantly different with each other; however, they are both significantly different from AL with 8,431±908 Mg C/ha, and 30,941±3,335 Mg CO_2/ha sequestered and AF with 7,706±582 Mg C/ha, and 28,282±2,136 Mg CO_2/ha sequestered (Figure 5(e) and Figure 5(j)). Such results are attributed to the soil profile depth in each ecotype where SF and ML reached 900 cm and 850 cm, respectively, while AL is down to 650 cm and AF to 600 cm.

Figure 7 and Figure 8 also show that C%, C-stocks, and CO_2 sequestered significantly increase as depth increases. The C-stocks in the SF peat soil of LSBP are higher than the 6,838 Mg/ha C-stocks of combined swamp forests in a vast dome-shaped Changuinola peatland in San San Pond Sak wetland complex in Panama (Upton et al., 2018). Sjögersten et al. (2018) described the Changuinola peatland as consistent with a surface water pool of 18.2 cm (highest) in the hardwood forest type and the lowest,

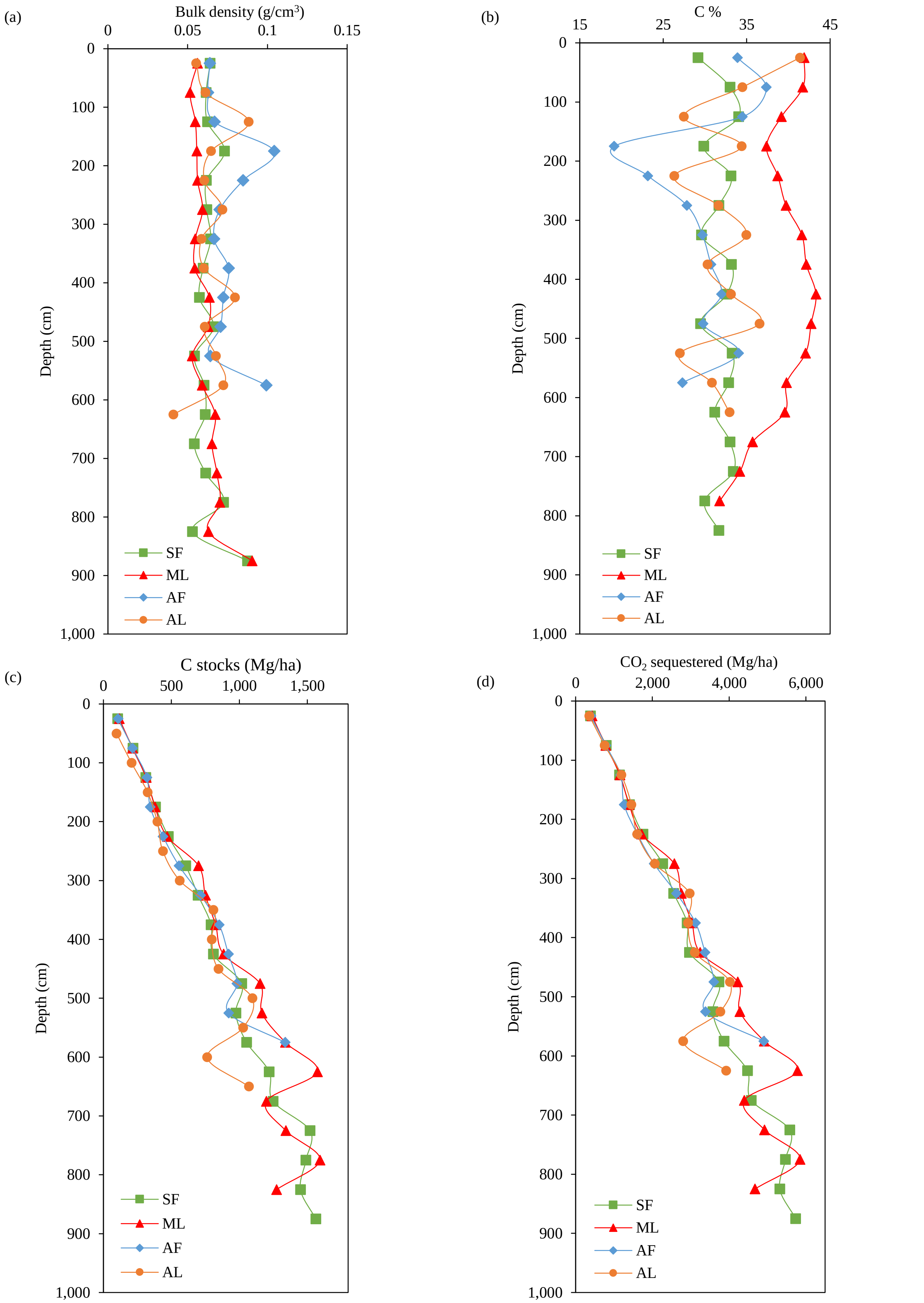

Figure 8. Depth function of (a) mean bulk density (g/cm³), (b) C%, (c) C-stocks (Mg/ha), and (d) CO_2 sequestered (Mg/ha) across four ecotypes

8.1 cm in the stunted forest. In LSBP, water is almost always present in the ML, which registered higher C-stocks owing to the deeper extent of its soil peat (8.5 m) in contrast to the shallower Changuinola peatland (2.2-4.0 m depth range for the forest types).

3.2.4 Total belowground C-stocks and CO_2 sequestered: SF rendered the highest belowground C-stocks of LSBP with 15,936.59 Mg C/ha, the same results with the aboveground C-stocks (Figure 5(a) to Figure 5(c)). It is attributed to its peat depth that reaches up to 900 cm belowground. Previously, the sampled ML of peatland had the lowest aboveground C stock because of the few amounts of litter, and no standing trees and downed wood found. ML registered a high value of 15,288.94 Mg C/ha for the belowground C stock, second to SF. It is all attributed to the deep layers of soil peat. ML followed SF with 15,288.94 Mg C/ha even without the root biomass, which is not significantly different from each other (Figure 5(c)); but is significantly different from AL 8,432.51 Mg C/ha and AF 7,707.26 Mg C/ha.

The mean values of AF (549.1 Mg C/ha) and AL (569.7 Mg C/ha) C-stocks across all depths are not statistically different from each other but are statistically different with SF (849 Mg C/ha) and ML (778 Mg C/ha). However, such calculations neglect soil depths on each ecotype, and results showed that SF is still superior, followed by ML, AL, and AF. Further, SF and ML could sequester CO_2 (58,515 Mg/ha and 56,110 Mg/ha, respectively, Figure 5(d)) but are not statistically different.

3.3 Total C-stocks and CO_2 sequestered of LSBP

SF rendered the highest total C-stocks among the four ecotypes with 15,984.83 Mg/ha and sequestered 58,709.17 Mg/ha of CO_2 (Figure 9(a) and 9(b)). Such results are not statistically different from ML which rendered 15,289.13 Mg/ha and could sequester 56,111.12 Mg/ha of CO_2. However, AL and AF are statistically different from both ML and SF. AL rendered 8,459.72 Mg/ha C-stocks and sequestered 31,047.19 Mg/ha of CO_2, while AF rendered 7,717.28 Mg/ha C-stocks and 28,322.40 Mg/ha of CO_2 sequestered. The mean C-stocks of the four (4) ecotypes are 11,862.74 Mg/ha, which is comparable to >5,000 Mg C/ha of tropical peatlands (Rieley et al., 2008; Moore et al., 2013), and the whole LSBP with 3,088 ha has 36.63 Tg (0.037 Pg) of C, which could also sequester 134.47 Tg/ha of CO_2.

In the review by Page et al. (2010), the Philippines has a minimum of 60-2,400 km^2 out of 196,404-332,152 km^2 of tropical peatlands. Based on these minimum area values and assumptions of 1-2 m soil peat thickness and using the 60 kg/m^3 volumetric carbon density, estimates for the total C content of South East Asia is 11.8 Gt up to 39.8 Gt (Pg). The lower estimate for the Philippines alone is 0.004 Gt (Pg), while the upper estimate is 0.288 Gt (Pg) C storage. With the findings of the current study on LSBP, its C storage value can shift the carbon budget in the region (Table 1).

Compared to tropical forests, the total C-stocks of the peatland SF is much higher than the 393 Mg C/ha of C from the natural forests of a 20,438-ha watershed inside the Philippine National Oil Company geothermal plant, also in Leyte Island. It is also higher than the 418 Mg/ha C content of the secondary forests in Mt. Makiling Forest Reserve in Laguna, where the biomass contributed 43% C and the soil organic C 40% (Lasco et al., 2004).

Compared to other peatlands, the SF ecotype is higher than the 975±51 Mg/ha C-stocks from the secondary peat swamp forest of North Selangor Peat Swamp Forest situated on the west coast of Peninsular Malaysia (Tonks et al., 2017). In all ecotypes of LSBP, more than 99% of the carbon storage is contributed by peat soil. As per a review of other literature, as seen in Table 1, most peat depths are 300 to 500 cm (Sjögersten et al., 2021; Novita et al., 2021; Anshari et al., 2022; Tonks et al., 2017; Orella et al., 2022). In this study, peat depth reached up to 900 cm, as all peat samples from the surface until the peat auger could not penetrate anymore were sampled and analyzed to get the overall C-stock estimation of the LSBP ecosystem. In contrast with the study of Decena et al. (2022) in the same area, the study only considered the 1 m depth, which could be an underestimation.

Subsequently, the results further emphasize the importance of regulating activities that may impact the natural process in the peat soil and threaten the longer residence time of C in the soil. One significant threat to this was explained by a three-year study by Hirano et al. (2007), who concluded that the lowering of groundwater level because of the drainage disturbance to the tropical peat swamp forest in Central Kalimantan, Indonesia has resulted in the peatland becoming a carbon source and released CO_2 into the atmosphere. As a result, portions of LSBP have also been converted into AF. However, the C-stocks of this converted peatland are still higher than the forest plantations with a combined value of 315 ton/ha located at the Leyte geothermal field (Lasco et al., 2002), hence, emphasizing the carbon sequestration of a peatland, whether intact or converted. Nevertheless, the conversion of peatland into other land use must be examined thoroughly because of its implications on the amount of carbon that can be held into the peatland ecosystem.

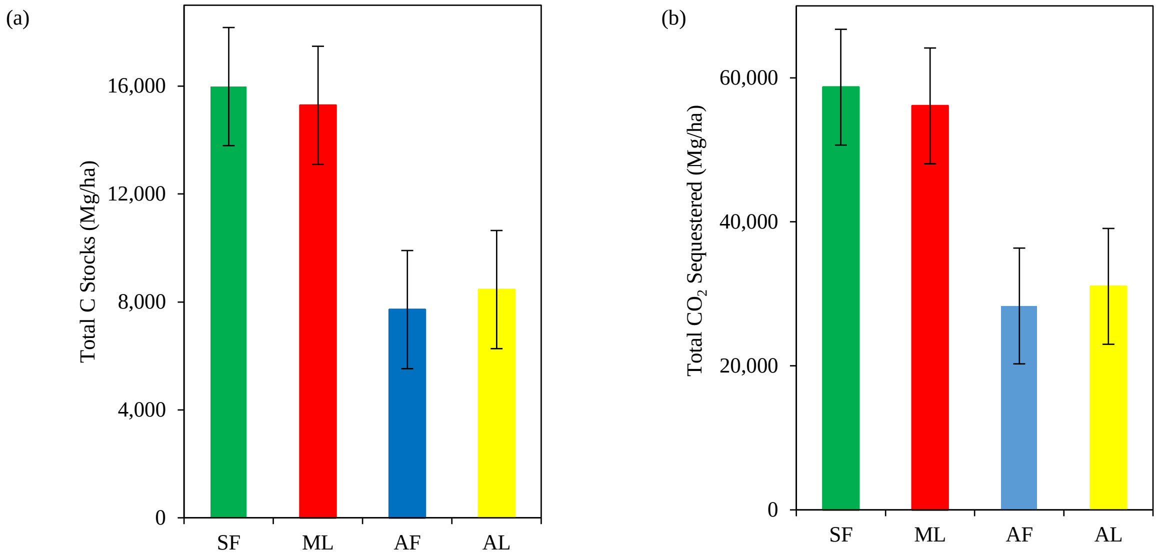

Figure 9. Total C-stocks and CO_2 sequestered (Mg/ha) of LSBP

Table 1. Summary of ecosystem C-stocks of peat swamp forest and natural forest

Location	Peat depth (cm)	Ecotypes	Ecosystem C (Mg C/ha)	Sources
Tropical area	-	Tropical Peatlands	~250 to >5,000	Rieley et al. (2008); Moore et al. (2013)
Campeche and Tabasco, Mexico	350	Peat Swamp Forests	3,130	Sjögersten et al. (2021)
Central Kalimantan, Indonesia	290	Primary Peat Swamp Forest	1,526±316	Novita et al. (2021)
West Kalimantan Province, Indonesia	500	Bush Fern, Secondary Forest, Oil Palm Plantation	1,253	Anshari et al. (2022)
North Selangor, Malaysia	125-273	Secondary Peat Swamp Forest	975±151	Tonks et al. (2017)
Agusan del Sur, Philippines	100	Undisturbed Peat Swamp Forest	750	Orella et al. (2022)
Oriental Mindoro, Philippines	100	Disturbed Peat Swamp Forest	595	Orella et al. (2022)
Makiling Forest Reserve, Philippines	-	Natural Secondary Forest	418	Lasco et al. (2004)
Leyte Geothermal Reserve, Philippines	-	Natural Forest	393	Lasco et al. (2002)
Leyte Sab-A Basin Peatland, Philippines	900	Peat Swamp Forest, Marshland, Agroforestry, and Agricultural Land	11,863	This study

4. CONCLUSION

The study found significant differences in the C storage of different components of the aboveground and belowground C-stocks among the four ecotypes in the peatland. The results indicate that all ecotypes had higher C-stocks in the belowground pool, likely due to the deep soil peat reaching 900 cm. The mean C-stocks of the four ecotypes were 11,862 Mg/ha. Furthermore, the marshland ecotype, dominated by grasses and with lesser biomass on the surface, was similar to the SF ecotype but had higher C-stocks in its soil peat layers. The study's objective of assessing the C-stocks in the peatland was achieved. The whole LSBP, with an area of 3,088 ha, was found to have a computed value of 36.6 Tg of C-stocks. It can sequester 134.5 Tg/ha of CO_2, a staggering amount of C storage. These findings have significant implications for regional C budget projections in Southeast Asia, highlighting the long-term importance of the peatland basin in the face of numerous threats to its function.

ACKNOWLEDGEMENTS

The first author would like to acknowledge the crucial contribution of Dr. Ma. Victoria O. Espaldon and Dr. Nina M. Cadiz in polishing the dissertation. Dr. Jeremy D. Owens and Mr. Burt H. Wolff for assessing all the analyses conducted in National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL, USA. Commission on Higher Education-Faculty Development Program II for giving the first author a Ph.D. graduate scholarship and the Fulbright Scholarship Program for granting a Ph.D. Exchange Scholarship and funding the study.

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