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RESEARCH

Plant Diversity, Aboveground Biomass and Carbon Stock in an Isolated Tropical Sub Montane Forest in Sri Lanka

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ABSTRACT

This study was conducted at Rilagala conservation forest, Nawalapitiya to assess and compare the plant diversity, above ground biomass and carbon stock in the periphery and interior of an isolated sub montane forest in Sri Lanka. All trees above 5 cm Diameter at Breast Height (DBH) in eleven randomly demarcated 25 m × 25 m plots were recorded. Distance up to 100 m from the forest boundary considered as the periphery (8 plots) and over 200 m as the core (3 plots). A total of 1,583 trees belonging to 29 species were recorded and aboveground biomass (AGB) and carbon stocks were calculated using allometric equations. The tree diversity of each plot was calculated using the Shannon diversity index (H'). Results were statistically analysed using single factor ANOVA. The species richness and H' were the highest at the periphery (n=23, H'= 2.55) while the lowest at forest interior (n=11, H'= 1.97). The highest tree density was recorded at periphery (2,992 trees ha^{-1}) and it decreased to 1,408 trees ha^{-1} towards the core. The average DBH was 8.5 ± 3.33 cm and it increased towards the forest interior (9.7 ± 4.51 cm) from the periphery (7.2 ± 3.74 cm). Estimated aboveground biomass ranged from 63.99 - 108.13 Mg ha^{-1} with a mean of 82.53 ± 14.39 Mg ha^{-1}. The above ground C stock was estimated from 31.99 - 54.07 Mg ha^{-1} with a mean of 41.26 ± 7.2 Mg ha^{-1}. However, there was no significant difference between forest periphery and core in variables, except species richness ($p<0.05$). The study revealed that the diversity and density of trees decreased towards the forest interior and *vice versa* was recorded for DBH, AGB and carbon stock. The study highlights the importance of conserving isolated tropical sub montane forest patches for carbon sequestration.

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INTRODUCTION

The global attention on tropical forests had increased to mitigate climate change owing to their capacity to store carbon. Terrestrial ecosystems including forests are assumed as net sinks for atmospheric carbon when considering global carbon budget assessments. This reflects the net effect of several land use practices including agricultural abandonment and regrowth, deforestation, degradation and effects of climate change and human activities (Brown, 2002). Reducing emissions from deforestation and forest Degradation (REDD) is an encouraging action plan for countries to initiate forest management projects aiming at mitigating climate change. The carbon stocks in forest ecosystems need to be estimated to qualify for rewards through REDD.

With the high net primary production, tropical forests are more effective in carbon sequestration than other forest ecosystems. Above and below- ground biomass, dead mass, woody debris and soil organic matter are the main carbon pools in a forest ecosystem. Above-ground biomass is an often used parameter in evaluating forest biomass. The use of allometric equations is essential in estimating forest carbon stock by non-destructive methods. Several vegetation characteristics such as Diameter at Breast Height (DBH), height and wood density are used in allometric equations. These regression equations are mathematical functions that relate to oven-dried biomass per tree as a function of a single or a combination of tree dimensions (Brown, 1997). Equations were developed based on the different characters of the vegetation and the ecosystem. The equations developed by Brown (1997) and Chave *et al.* (2005) are often used in above-ground biomass estimation in tropical forests. However, different height-diameter allometric equations estimate aboveground biomass in different confidence levels in varying forest types (Cuni-Sanchez et al., 2017). Thus, several attempts were done to develop region and habitat-specific above-ground biomass estimation allomatric equations (Ketterings et al., 2001, Vieilledent et al., 2012, Mandal and Joshi, 2015).

Several abiotic and biotic factors directly affect the carbon stocks of forest ecosystems. The environmental parameters such as climate, soil and elevation and anthropogenic activities are affecting forest carbon stocks (Marshall et al., 2012, Cuni-Sanchez et al., 2021). Therefore, there is a variation in the carbon stocks in different forest types with varying vegetation characters.

Sri Lanka is rich in floral diversity with high endemism. Owing to the climatic, topographic, soil characters and floral distribution patterns, Sri Lankan forest ecosystems are classified into several forest types including montane, sub-montane, lowland rain forests, moist monsoon forests and dry monsoon forests (Koelmeyer, 1957). Sub-montane forests are transitional forests having mixed characters of both lowland rain forests and montane forests. The extent of the sub-montane forests is declining mainly due to deforestation and habitat fragmentation. However, managing these forest ecosystems is highly important in carbon mitigation plans. Some information is available for ecosystem and habitat specific carbon stocks for Sri Lanka based on field measurements and using satellite images, including, forest plantations (Gunawardena et al., 2006, De Costa and Suranga, 2012), home gardens (Mattsson et al., 2014), moist monsoon forests (Mattsson et al., 2016, Abeysekara et al., 2018), Montane forests (Pathirana and Nissanka, 2014, Mattsson et al., 2016), sub-montane forests (Mattsson et al., 2016), lowland rain forests (Kumarathunge et al., 2011, Mattsson et al., 2016), dry monsoon forests (Mattsson et al., 2016) and open forests (Mattsson et al., 2016).

Even though several studies had been conducted to assess the biomass and carbon stock in montane habitats in Sri Lanka, the estimations based on field data for montane and sub- montane forest habitats are limited. The general objective of this study was to assess the tree diversity and estimate carbon stocks in different parts of the Rilagala forest. Specific objectives of the study were to compare the tree diversity, density and above-ground biomass at different locations of the Rilagala forest. The study also focused on assessing the variation of tree diversity with the tree size of a given area and highlighting the importance of conservation of forests for mitigating global climate change.

METHODOLOGY

Study site

The study was conducted at the Rilagala Conservation Forest, Nawalapitiya (6° 57'49.2"- 6° 58'02.9" N 80° 34'24.3"- 80° 35'01.7" E), which is considered a sub-montane forest patch in Sri Lanka. The mean height of the Rilagala forest is 1650m above sea level. This forest reserve is managed by the Department of Forest Conservation, Sri Lanka and the extent of the forest is 209 ha. The annual mean temperature of the area is 17.3 °C and the annual rainfall is 2254.6 mm. Rilagala forest patch is isolated by surrounding tea fields, which is the main crop in the up country. Therefore, human interaction with the forest patch is high. The surrounding tea fields are managed by Dilmah Plantation and a research station had established adjoining the Rilagala forest to facilitate research related to climate change adaptations. A total of 11 sampling plots (P1 to P11) were established covering the total extent of the forest. The extent of a plot is 625 m^2 (25 m × 25 m). Plots were categorized into peripheral or core areas based on the distance from the forest boundary. If the distance to the plot from the forest boundary is less than 100 m, it is considered as a plot in the peripheral area, or if the distance is over 200 m the plot is considered as a core area plot. Plot numbers 1 to 8 were located in the peripheral area of the forest and plot numbers 9 to 11 were located in the deeper areas of the forest (Figure 1).

Data collection and above ground biomass estimation

The Diameter at Breast Height (DBH) of all trees was measured, among the measured trees only trees above 5cm DBH were recorded. The heights of the selected trees were also measured. Field data were collected from January - August 2021. The data were used to calculate the aboveground biomass of the sampling plot.

Allometric equations developed for tropical natural forests were used to calculate the above-ground biomass of the study site. Equations 1-3 were used to calculate the aboveground biomass of sampling plots (Brown, 1997).

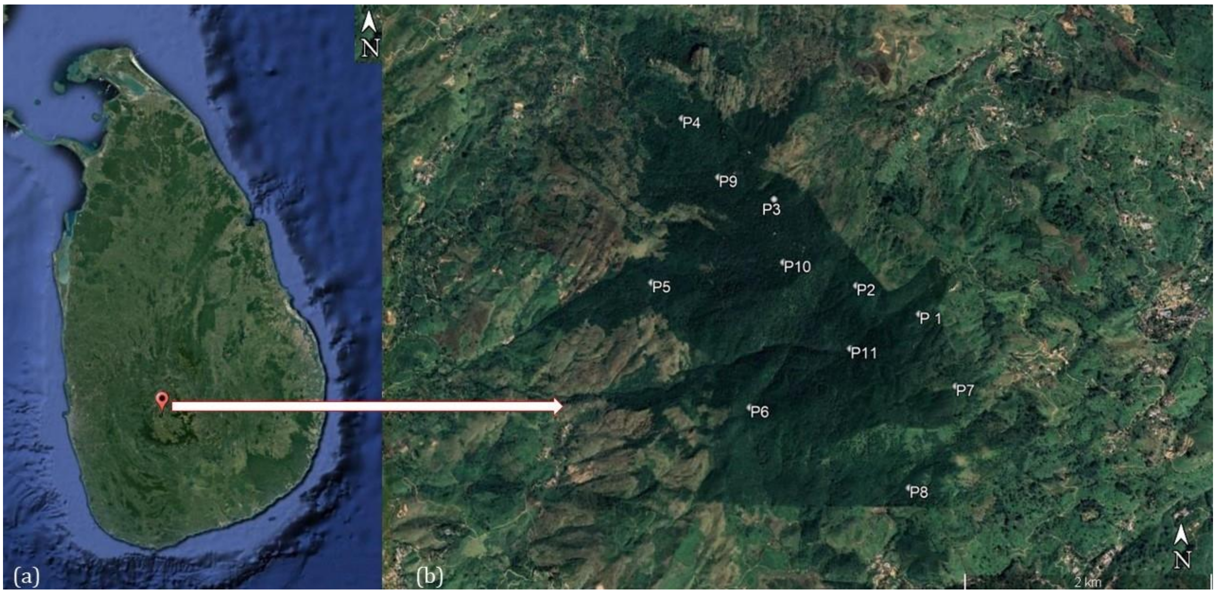

Figure 1. Location of the study site in (a) Sri Lanka and (b) monitoring site in Rilagala forest patch adjoining to Dilmah climate change research centre

$$Y = \exp\{-2.134 + 2.530 \times \ln(\text{DBH})\} \quad \text{Eq. 1}$$

Where, Y= Aboveground tree biomass

$$\text{Tree biomass per hectare} = \frac{\text{Total aboveground tree biomass}}{625} \times 10{,}000$$

Eq. 2

$$\text{Above ground C stock per ha (kg ha} - 1) = \text{Tree biomass per ha (kg ha} - 1) \times 0.5$$

Eq. 3

Tree diversity

The Shannon diversity index was used to calculate the floral diversity of the vegetation. Shannon diversity index was calculated using Equation 4.

$$H' = -\Sigma P_i \times \ln(P_i)$$

Eq. 4

Where; H'= Shannon diversity index, Pi= Proportional abundance of the i^{th} species

Tree density

Collected data were used to calculate tree density for each plot using Equation 5,

$$\text{Tree density (trees ha} - 1) = \frac{\text{Number of trees recorded in the plot}}{625} \times 10{,}000$$

Eq. 5

Where, 10,000= extent of a hectare in m^2, 625= extent of a sampling plot in m^2

Statistical analysis

The stratified random sampling method was used to select sampling plots in the Rilagala Conservation Forest. Above-ground Biomass, Carbon stock, Species richness, Tree diversity and Tree density were assessed in each plot in forest interior and forest periphery. The ANOVA test was conducted to statistically evaluate the difference in two forest strata in each parameter.

RESULTS AND DISCUSSION

Tree diversity of Rilagala Conservation forest

A total of 1,583 trees belonged to 29 plant species of 17 families. The composition of the sampling area was dominated by a few tree species. Only four species had recorded over 100 individuals and those encountered over 50% of the plant community (67.47%, n= 1,068). The most common tree species is *Syzygium aqueum* (n=564), followed by *Litsea glaberrima* (n=251), *Cinnamoum ovalifolium* (n=134) and *Symplocus cordifolia* (n=119) (Appendix 1).

The Shannon diversity index was calculated for each plot to compare the floral diversity within the selected areas of the Rilagala conservation forest. The highest plant diversity was recorded at the periphery plot P4 (H'= 2.55), while the lowest was at the interior plot P9 (H'= 1.97). Furthermore, collected data were used to calculate the tree density of each sampling plot. The highest tree density was recorded at the P1 (2,992 trees ha^{-1}) and it was the lowest at the P10 (1,408 trees ha^{-1}). The highest species richness (Number of species) was recorded in P3 and P4 (23) and the lowest in P9(11). The highest values for all measured vegetation parameters (Species richness, Tree diversity and Tree density) were recorded in peripheral area plots (Table 1).

Variation in tree diameter at breast height

Recorded trees were classified according to the DBH value classes. Most of the trees (76.44%, n=1210) had a DBH value of less than 10 cm (Figure 2). Human interaction was high in the peripheral area of the forest compared to the interior of the forest. Timber harvesting, and firewood collection were the most abundant disturbances caused by the human to the natural vegetation. Therefore, the peripheral area of the forest reserve was in the early stage of forest succession while the vegetation of the core area had the vegetation characteristics of a mature forest.

Table 1. Calculated Shannon diversity index and Tree density for 11 sampling plots at different locations of Rilagala conservation forest

	Plot										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
S	19	22	23	23	20	20	13	12	11	15	13
H’	2.41	2.21	2.20	2.55	2.22	2.19	2.19	2.19	1.97	2.25	2.26
D	2992	2976	2800	2448	2656	2752	1728	1424	2896	1408	1248

S- Species richness, H’- Tree diversity, D- Tree density, P1 – P8- Peripheral area plots, P9 – P11- Forest interior plots

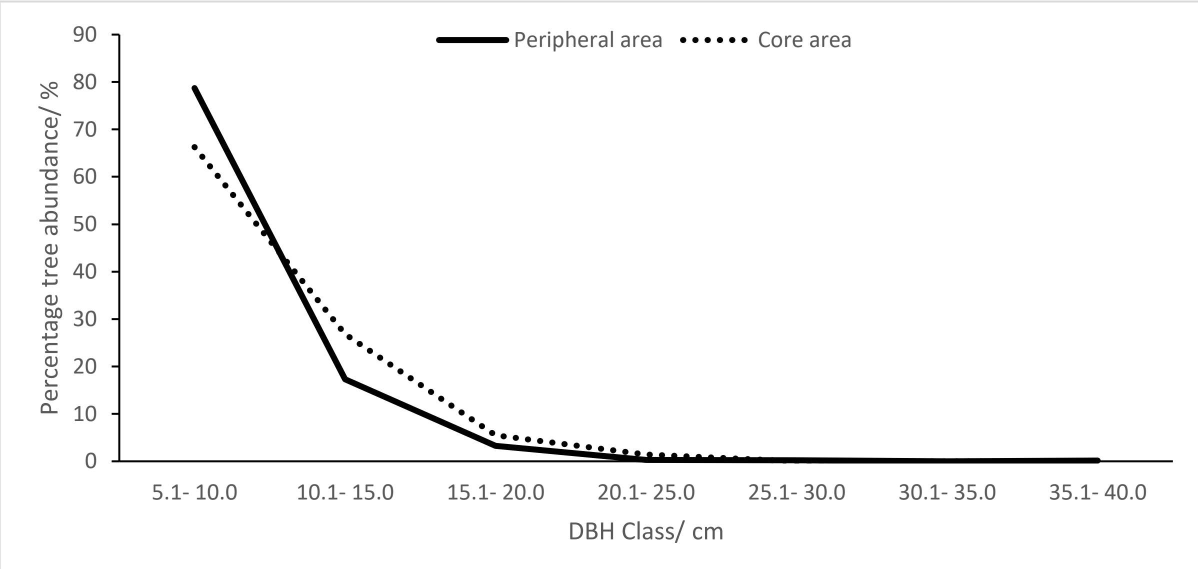

Figure 2. DBH class distribution of selected trees at the sampling plot in Rilagala forest

Above-ground biomass and Carbon stocks

The 1,583 tree individuals were selected with above 5 cm DBH to calculate the above-ground biomass and carbon stocks. The estimated above-ground biomass of the sampled trees ranged from 63.99- 108.13 Mg ha^{-1} with a mean of 82.53 ± 14.39 Mg ha^{-1}. The estimated carbon stock for the plots was ranged from 31.99 - 54.07 Mg ha^{-1} with a mean of 41.26 ± 7.2 Mg ha^{-1}. The lowest estimations for both above-ground biomass and carbon stocks were recorded in the peripheral area plot (P4), and the highest estimation was recorded for a forest interior plot (P9) (Table 2).

There was no statistically significant difference ($p>0.05$) for calculated values between forest interior and periphery for tree diversity, tree density, above-ground biomass and carbon stock. However, a statistically significant difference was recorded for tree species richness ($p<0.05$) between forest interior and periphery (Table 3).

Even though the tree abundance decreased drastically with the DBH class, the biomass for DBH class did not decrease in the same gradient. The highest percentage of biomass was recorded at the DBH class 8.1- 9.0 cm (8.52%) (Figure 3). Therefore, it is proven that larger DBH classes contain a high amount of biomass even at the forest’s early successional stages.

Table 2. Above-ground Biomass (AGB) and Carbon (C) stock for 11 sampling plots at different locations of Rilagala conservation forest

	Plot										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
AGB	64.83	92.35	83.55	63.99	89.05	86.67	99.66	78.17	108.13	72.65	68.74
C stock	32.41	46.17	41.77	31.99	44.52	43.33	49.83	39.08	54.07	36.32	34.37

Table 3. Statistical difference of ANOVA test for measured parameters for forest interior and periphery

	SS	*df*	*MS*	*F*	*P-value*	*F crit*
Above-ground biomass	1.7266	1	1.7266	0.007514	0.93282	5.117355
carbon stock	0.440183	1	0.440183	0.007659	0.932179	5.117355
species richness	78.54545	1	78.54545	5.197861	0.048572	5.117355
tree diversity	0.026022	1	0.026022	1.297912	0.284008	5.117355
tree density	842302.1	1	842302.1	1.872451	0.204379	5.117355

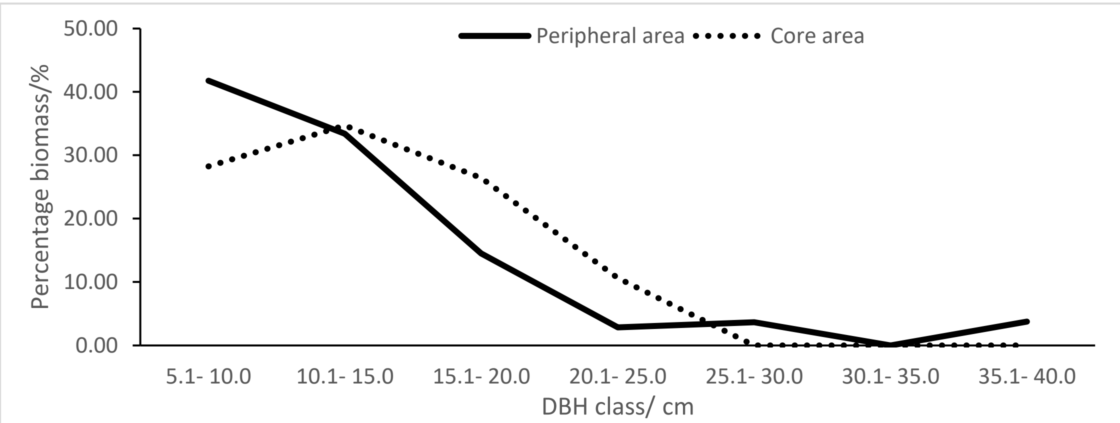

Figure 3. Variation of aboveground biomass of trees in each DBH class in Rilagala forest

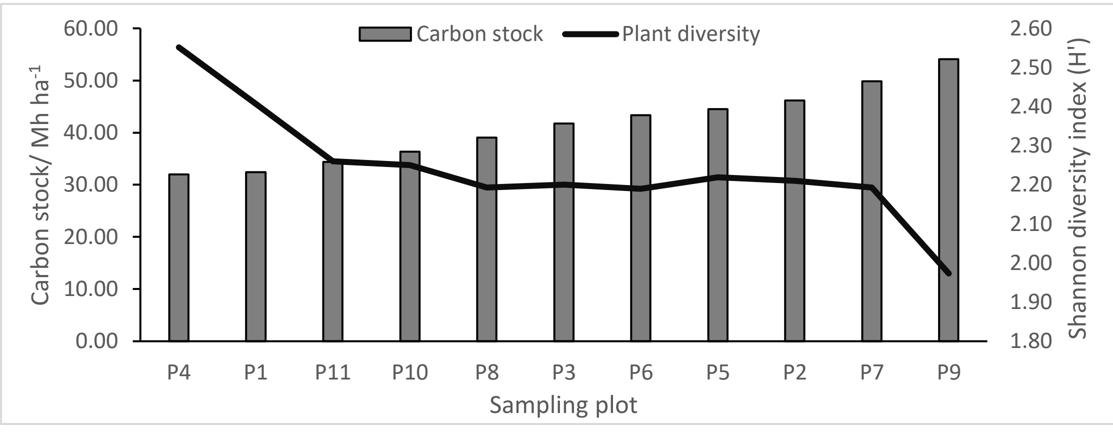

Figure 4. Variation of the floral diversity and estimated carbon stocks in each sampling plot moving towards the central area of the forest from the boundary

As presented in the Tables 2 and 3, a variation in the calculated Shannon diversity index and estimated carbon stock had been recorded towards the central area of the plot. When considering the distances from the forest boundary to the sampling plot, floral diversity decreased and estimated carbon stock was increased (Figure 4).

Estimation of tree biomass is important since it provides more accurate information on forest biomass and carbon sequestration. Using allometric equations is the most applicable methodology of estimate plant biomass for all regions. Several equations had developed depending on different vegetation characters and variables. To generate a precise allometric equation for multi species forests, a sufficient number of trees should be sampled with represent size and species distribution. But this process is time consuming and costly. To resolve this drawback, generic equations have been developed for broad ecological zones and species groups (Brown, 2002). Using these generic equations will estimate the forest biomass for the specified region. However, there are some limitations in the applicability and accuracy of estimations of these allometric equations. When considering the large scale biomass estimations, a difference in estimated biomass was recorded in bigger raster size (1000 m) in local scales (1: 10,000). But no differences were recorded in smaller raster sizes (1, 10, 100m) in local scale and regional scale (1: 100,000) biomass estimations (Pechanec et al., 2022). Attention needs to be given to these factors before selecting the equation. To overcome these limitations, modifications to generic equations and the development of more habitat specific equations had done (Ketterings et al., 2001, Vieilledent et al., 2012, Mandal and Joshi, 2015).

Several attempts were conducted to calculate carbon stocks for different Sri Lankan habitats previously. Mattsson *et al.* (2016) evaluated the aboveground carbon stock in different forest types in Sri Lanka. For the sub montane forest category, they stated that the aboveground carbon stock was varying from 13- 243 Mg ha^{-1}. The mean aboveground carbon stock was considered as 138 ± 100 Mg ha^{-1}. Apart from sub montane forests, little published information is available for other ecosystems also. A study conducted by Abeysekara *et al.* (2018) in Udawattakele, Kandy in Sri Lanka had recorded the carbon stock as 81.61 t ha^{-1}, which is considered as a moist monsoon forest. They have accounted aboveground biomass of trees, liana, seedlings, saplings, deadwood and below ground biomass as the total biomass. Mattsson *et al.* (2016) recorded that the aboveground carbon stock for moist monsoon forests in Sri Lanka is varying from 38- 132 Mg ha^{-1}. A similar study conducted by De Costa and Suranga (2012) estimated the above-ground biomass and carbon stock for monoculture forest plantations and mixed plantations. The highlight of the study was mixed plantations had comparatively high per hectare carbon stock (226- 279 t ha^{-1}) than monoculture plantations (164- 205 t ha^{-1}). Furthermore, Mattsson *et al.* (2014) assessed the mean above-ground carbon stock of home gardens in the dry zone of the country as 13 Mg ha^{-1} with a range of 1- 56 Mg ha^{-1}. The high variation was due to the tree diversity, composition and size variation between home gardens (Mattsson et al., 2014).

Several studies were conducted in Sri Lankan forest habitats to estimate forest biomass using GIS techniques and modelling. Pathirana and Nissanka (2014) estimated the total carbon stock in the Knuckles forest area considering both above-ground and below-ground biomass using satellite images. They had estimated the total carbon stock as 215.95 Mg ha^{-1}. In an estimation conducted by Gunawardena *et al.* (2015) for the Horton plain national park, the mean above-ground biomass was estimated at 50.17 Mg ha^{-1} from the field data and 32.5- 62.72 Mg ha^{-1} using satellite images by different models. Dayathilake *et al.* (2020) estimated the above-ground carbon stock for wetlands in Colombo from 8.13- 66.49 Mg ha^{-1}. However, there is a difference in estimations based on the field data and satellite data. Gunawardena *et al.* (2016) suggested that remote sensing methods would result in an overestimation of above-ground biomass by 17%, especially when the three height is more than 5m, based

on a study conducted at the wetlands of Negombo in Sri Lanka.
With increasing elevation, aboveground biomass is increasing slightly from sub-montane forests to montane forests. The main reason for this variation is the wood specific gravity, which is high in montane forests due to the low tree and canopy heights (Culmsee et al., 2010). The wood density in Sri Lankan montane forests is also higher than sub-montane forests, but the highest wood density was recorded in lowland rain forests (Mattsson et al., 2016). Similarly, the above-ground carbon stock is low in tropical montane forests compared to the tropical lowland forests due to the climate and soil characteristics with increasing elevation (Singh et al., 2019, Cuni-Sanchez et al., 2021).

The vegetation characters and tree composition of a forest change with time. It is obvious a significant change in the forest carbon stock with this forest succession. Mature forests can sequestrate more carbon compare to early secondary forests. A study conducted in Singapore by Ngo *et al*. (2013) primary forests contain more carbon stock (337 Mg ha^{-1}) than 60-year-old secondary forests (274 Mg ha^{-1}). Further, they highlighted that 50% of the C stock in the primary forest was contributed from the above-ground biomass, while the value decreased to 38% in the regenerating forest. Therefore, forest succession is an important factor in forest biomass estimations. Forest structure is the main visible character of a forest that changes with the succession. The dominating tree species, DBH, tree height, tree diversity and tree density are the main forest characteristics that change with the succession. Alia *et al.* (2020) highlighted that the forest structure promotes forest biomass directly and indirectly in a study conducted in Sri Lanka.

The average plant DBH for all the sampling plots is 8.5 cm, and 75.99% of the total abundance are smaller trees with a DBH of less than 10 cm. Only 0.88% of the recorded trees had a DBH over 20 cm, which can consider as big trees. Bigger trees are restricted to the central part of the forest. These bigger trees can store more carbon compared to smaller trees. These large trees contribute nearly half or more to above-ground biomass in worldwide forests (Ali and Wang, 2021). Based on that it is often considered that the contribution of smaller trees (DBH less than 10 cm) to the total biomass of the forest is less and tends not to be measured. But this is depending on the successional stage of the forest (Brown, 2002). The vegetation is dominated by smaller trees in early the stages of the regenerating forest, while larger trees dominated the mature forests. Nalaka *et al.* (2013) had quantify the contribution of the small diameter trees that are omitted from the calculations to the total biomass of the forests. They highlighted that trees with a diameter of less than 10 cm contained 12% (in medium yield forests) to 49% (in non-productive forests) of the total biomass in dry zone forests in Sri Lanka.

The estimated carbon stock from the current study also falls into the estimated carbon stock range by Mattsson *et al.* (2016). However, the average estimation and the highest estimation are far behind the estimations of Mattsson *et al*. (2016). The reason may be the stage of a succession of the Rilagala forest. As it is an isolated small forest patch, with high disturbances, still most of the forest passes through the early stages of the forest succession. Furthermore, with the extent and isolation, the extent of available mature forests is comparatively low. Therefore, the estimated carbon stock for this forest patch is comparatively low. Simultaneously, the findings of this study highlight the importance and contribution of smaller trees to the forest carbon stocks.

The tree density ranged from 1408 to 2992 trees ha^{-1} and was the highest in the plots in the peripheral area where the species richness was highest. Since the rainfall and the elevation of all plots belongs to the same category, this variation is due to different stages of succession. Forest edges follow early stages of forest succession and act as ecotones, which have mixed characteristics of bordering habitats. Floristic diversity, species richness and abundance were high in forest edges (Couto-Santos et al., 2015). A forest vegetation experience a rapid and dynamic process of species substitution and structural changes during succession. A faster demographic rate record in young forests while a larger spatial turnover of species was recorded in mature forests (Dalmaso et al., 2020). This spatial heterogeneity is directly affecting on the forest biomass. Both biotic such as plant height and abiotic factors such as annual precipitation influences the spatial variation of forest biomass (Zhang et al., 2022).

The major drivers of deforestation and forest degradation in Sri Lanka are land encroachments, infrastructure development projects and private agriculture ventures. Further, land encroachments and agricultural practices are the main causes of the fragmentation and shrinking of sub-montane forest ecosystems. It is essential to conserve and manage remaining forest habitats in the country to mitigate climate change and get benefits from global action plans such as REDD. The findings of the present study will spotlight and attract the attention of policymakers and authorities to the significant importance and contribution of isolated forest patches to achieve national goals.

CONCLUSIONS

Forests play a significant role in carbon sequestration, with higher above-ground biomass and carbon stocks found in areas with larger trees. Conversely, there was a negative correlation between tree diversity and density and carbon stocks, as areas with smaller trees exhibited greater tree diversity and density. Interestingly, this relationship held true across all plots, irrespective of their location within the forest. Hence, tree size appears to be a crucial factors influencing both carbon stocks and tree diversity. Although no significant difference was observed, the forest periphery recorded the highest plant diversity and density, while the forest core had the highest biomass. The limited extent of the forest may contribute to the absence of significant differences in carbon stocks throughout the area. Nevertheless, the study underscores the importance of safeguarding these isolated habitats for biodiversity conservation and climate change mitigation.

Sub-montane forest habitats in Sri Lanka face threats from anthropogenic activities, leading to a reduction in their extent. Many of these habitats are situated in marginal areas adjacent to upcountry crop plantations. As a result, a transect from the boundary to the forest center reveals different forest successional stages. This variation affects forest characteristics, biomass, and carbon stock within the same forest. The plant community is dominated by a few species, with higher plant diversity and tree density observed in the peripheral areas of the Rilagala conservation forest. Conversely, the central area of the same forest exhibits higher average DBH (diameter at breast height), aboveground biomass, and carbon stock. Thus, this study's findings emphasize the significance of managing forest habitats for carbon sequestration and climate change mitigation.

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REFERENCES

Abeysekara, A. M. S. K., Yatigammana, S. K., & Premakantha, K. T. (2018). Biomass and carbon stock estimation of Udawattakele forest reserve in Kandy district of Sri Lanka. *Journal of Tropical Forestry and Environment,* 8(2), 13-28.

Alia, A., Mattsson, E., Nissanka, S.P., & Wang, L. (2020). Topmost trees and foremost species underlie tropical forest structure, diversity and biomass through opposing mechanisms. *Forest Ecology and Management*, 473, 118299. doi.org/10.1016/j.foreco.2020.118299

Ali, A., & Wang, L. (2021). Big-sized trees and forest functioning: Current knowledge and future perspectives. *Ecological Indicators*, 127, 107760. doi.org/10.1016/j.ecolind.2021.107760

Brown, S. (1997). Estimating biomass and biomass change of tropical forests, a primer. *A Forest Resources Assessment Publication*, FAO Forestry Paper 134. Food and Agriculture Organization of the United Nations, Rome.

Brown, S. (2002). Measuring carbon in forests: current status and future challenges. *Environmental Pollution*, 116, 363–372.

Chave, J., et al. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia,* 145, 87–99.

Couto-Santos A. P. L. D., Conceicao, A. A., & Funch, L. S. (2015). The role of temporal scale in linear edge effects on a submontane Atlantic forest arboreal community. *Acta Botanica Brasilica,* 29(2), 190-197.doi: 10.1590/0102-33062014abb3732

Culmsee, H., Leuschner, C., Moser, G., & Pitopang, R. (2010). Forest aboveground biomass along an elevational transect in Sulawesi, Indonesia, and the role of Fagaceae in tropical montane rain forests. *Journal of Biogeography*, 37, 960–974. doi:10.1111/j.1365-2699.2009.02269.x

Cuni-Sanchez, A., Pfeifer, M., Marchant, R., Calders, K., Sorensen, C. L., Pompeu, P. A., Lewis, S. L. & Burgess, N. D. (2017). New insights on above ground biomass and forest attributes in tropical montane forests. *Forest ecology and management*, 399, 235- 246.

Cuni-Sanchez, A., et al., (2021). High aboveground carbon stock of African tropical montane forests. *Nature*, 596, 536- 542.

Dalmaso, C. A., Marques, M. C. M, Higuchi, P., Zwiener, V. P., Marques, R. (2020). Spatial and temporal structure of diversity and demographic dynamics along a successional gradient of tropical forests in southern Brazil. *Ecol Evol*. 10, 3164–3177. Doi:10.1002/ece3.5816

De Costa, W. A. J. M. & Suranga,. H R. (2012). Estimation of carbon stocks in the forest plantations of Sri Lanka. *J.Natn.Sci.Foundation Sri Lanka,* 40 (1), 9-41.

Gunawardena, A. R., Nissanka, S. P., & Dayawansa, N. D. K., (2006). Relationship between above ground live biomass and satellite image spectral responses (Landsat EMT+) of *Pinus caribaea* morelet at lower Hantana region in Sri Lanka. Tropical Agricultural Research, 18, 334-345

Gunawardena, A. R., Nissanka, S. P., Dayawansa, N. K. D., & Fernando, T. T. (2015). Estimation of Above Ground Biomass in Horton Plains National Park, Sri Lanka Using Optical, Thermal and RADAR Remote Sensing Data. *Tropical Agricultural Research*, 26(4), 608- 623.

Gunawardena, A.R., Nissanka, S.P., Dayawansa, N.D.K., & Fernando, T.T. (2016). Above Ground Biomass Estimation of Mangroves Located in Negombo - Muthurajawela Wetland in Sri Lanka using ALOS PALSAR Images. *Tropical Agricultural Research*, 27 (2), 137– 146

Ketterings, Q. M., Coe, R., van Noordwijk, M., Ambagau, Y. & Palm, C. A. (2001). Reducing uncertainty in the use of allometric biomass equations for predicting above ground tree biomass in mixed secondary forests. *Forest Ecology and Management*, 146, 199- 209.

Koelmeyer, K. O. (1957). Climatic classification and the distribution of vegetation in Ceylon. *Ceylon Forester*, N. S., 3, 144-63.

Kumarathunge, D.P., Thattil, R.O., & Nissanka, S.P (2011). Evaluation of the plotless sampling method to Estimate aboveground biomass and other stand Parameters in tropical rain forests. *Applied ecology and environmental research*, 9(4), 425-431.

Mandal, G., & Joshi, S. P. (2015). Estimation of above-ground biomass and carbon stock of and invasive woody shrub in the subtropical deciduous forests of Doon Valley, western Himalaya, India. *J. For. Res*. doi: 10.1007/s11676-015-0038-8.

Mattsson, E., Ostwald, M., Nissanka, S. P., & Pushpakumara, D. K. N. G. (2014). Quantification of carbon stock and tree diversity of home gardens in a dry zone area of Monaragala district, Sri Lanka. *Agroforest Syst*. doi: 10.1007/s10457-014-9780-8

Mattsson, E., Ostwald, M., Wallin, G., & Nissanka, S. P. (2016). Heterogeneity and assessment uncertainties in forest characteristics and biomass carbon stocks: Important considerations for climate mitigation policies. *Land use policy*, 59, 84-94.

Nalaka, G.D.A., Sivanathawerl, T., & Iqbal, M.C.M. (2013). Scaling Aboveground Biomass from Small Diameter Trees. Tropical Agricultural Research, 24 (2), 150 – 162

Ngo, K. M., Turner, B. L., Muller-Landau, H. C., Davies, S. J., Larjavaara, M., Hassan, N. F. B. N. & Lum, S. (2013). Carbon stock in primary and secondary tropical forests in Singapore. *Forest ecology and management*, 296, 81- 99.

Pathirana, P.S., & Nissanka, S.P. (2014). Estimation of carbon stock of knuckles conservation area using optical remote sensing data. *In* Proceedings of the Peradeniya Univ. International Research Sessions, Sri Lanka, Vol. 18, 4th & 5th July, 2014, p 549

Pechanec, V., Štˇerbová, L., Purkyt, J., Prokopová, M., Vˇceláková, R., Cudlín, O., Vyvleˇcka, P., Cienciala, E. & Cudlín, P. (2022). Selected Aspects of Carbon Stock Assessment in Aboveground Biomass. *Land*, 11, 66. doi: 10.3390/ land11010066

Singh, R., Bhardwaj, D. R., Pala N. A., & Rajput, B. S, (2019). Biomass production and carbon stock potential of natural vegetation, agroforestry and cultivated land use systems along altitudinal gradient in north western Himalaya. *Range Mgmt. & Agroforestry*, 40, (1), 94-103

Vieilledent, G., Vaudry, R., Andriamanohisoa, S. F. D., Rakotonarivo, O. S., Randrianasolo, H. Z., Razafindrabe, H. N., Rakotoarivony, C. B., Ebeling, J., & Rasamoelina, M. (2012). A universal approach to estimate biomass and carbon stock in tropical forests using generic allometric models, *Ecological Applications*, 22(2), pp. 572–583

Zhang, T., Ding, G.; Zhang, J.; Qi, Y. (2022). Contributions of Biotic and Abiotic Factors to the Spatial Heterogeneity of Aboveground Biomass in Subtropical Forests: A Case Study of Guizhou Province. *Sustainability*, 14, 10771. doi.org/10.3390/su141710771