

The impact of mangrove degradation and restoration on Total Ecosystem Carbon Stocks

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Abstract

Mangroves play an important role in carbon cycling and are receiving considerable attention to restore degraded areas. Accelerated Natural Regeneration of Mangrove (ANRM) is an approach practiced in Anawilundawa Wetland Ramsar Sanctuary in Sri Lanka since 2019 to restore mangroves in abandoned shrimp ponds. This study was conducted to measure the Total Ecosystem Carbon Stocks in peripheral natural mangroves, areas restored with mangrove seedlings, adjacent landward woody areas and abandoned shrimp ponds which are currently covered with secondary vegetation in Anawilundawa Wetland Ramsar Sanctuary in 2023. Total Ecosystem Carbon Stocks were 216.98 ± 15.00 Mg C/ha (for peripheral natural mangroves), 212.58 ± 33.42 Mg C/ha (restored areas), 280.75 ± 30.37 Mg C/ha (adjacent landward woody area) and 348.12 ± 12.83 Mg C/ha (abandoned shrimp ponds). The highest soil organic carbon (SOC) was found in abandoned shrimp ponds (347.48 ± 12.48 Mg C/ha) while the lowest SOC was reported in the adjacent landward woody area (170.14 ± 18.09 Mg C/ha). The mean total vegetation carbon (aboveground and belowground carbon combined) was highest for woody area of 83.51 ± 12.38 Mg C/ha. The vegetation carbon stocks of peripheral natural mangroves, restored area and abandoned shrimp ponds had 33.67 ± 8.81 Mg C/ha, 1.09 ± 0.24 Mg C/ha and 0.64 ± 0.35 Mg C/ha respectively. This study highlighted higher levels of Total Ecosystem Carbon Stocks in abandoned shrimp ponds (predominantly belowground soil carbon), where currently *Suaeda maritima*, *Suaeda monoica*, and *Tamarix indica* are found naturally as secondary vegetation, perhaps highlighting the potential contribution of secondary vegetation in disturbed areas.

01. Introduction

During 2011–2020, global surface temperature was around 1.1°C higher than 1850–1900 (IPCC 2023). The global temperature increase has occurred alongside an increase in the atmospheric concentration of carbon dioxide (CO_2) from roughly 280 (IPCC 1995) to over 419.3 parts per million (ppm) in 2023 (NOAA research 2024). All scenarios to keep temperature within agreed limits (limiting the increase no more than 1.5°C) (Paris agreement 2015) involve removing CO_2 from the atmosphere and simultaneous reduction in further CO_2 emissions. Therefore, ecosystems that remove CO_2 from the atmosphere and sequester it for long duration as organic carbon are particularly important, and protection and restoration of such ecosystems has received attention as one way to contribute to this (Beers et al. 2020).

Mangroves, seagrasses and salt marshes contribute disproportionately to carbon (C) sequestration and therefore considered important as natural climate solutions. Between 10.45 and 25.07 billion tons of C are stored in the top meter of soil worldwide in these blue carbon ecosystems (Pendelton et al. 2012). Among them, mangroves hold 6.5 billion tons of blue carbon (Choudhary et al. 2024).

While mangroves are found across 121 countries (Beers et al. 2020), their global extent has decreased substantially, because of land use changes (Chen et al. 2022). Valiela et al. (2001) found 35% global mangrove loss towards the end of the 1990s, and Goldberg et al. (2020) calculated an additional 2.1%

decrease between 2000 and 2016. These losses can be attributed to mangrove conversion into agriculture and aquaculture. Leal et al. (2024) found that 43.3% of global mangrove loss between 2000 and 2020 was caused by conversion of mangroves to rice farming, aquaculture, and oil palm plantations. Giri et al. (2015) found a net loss of 11,673 hectares (1.37%) of mangrove between 2000 and 2012 in South Asia. In Sri Lanka, during 1980s and 1990s, 35% of mangrove forest areas – such as Puttalam-Kalpitiya Lagoon – were lost due to conversion into commercial shrimp farms (Bournazel et al. 2015). Approximately 6% (812,000 hectares) of lost mangrove area is deemed restorable globally (Worthington et al. 2019). There are significant efforts to restore degraded areas, often as part of efforts to mitigate climate change through enhancing C sequestration. For reliable accounting of the sequestered C during restoration, it is essential to determine C stocks and understand carbon pathways within the ecosystem – this can be useful even if climate mitigation is not the sole or primary reason for restoration (Howard et al. 2014).

The quantity of C contained in forest ecosystems can be estimated, along with C sequestration, by measuring Total Ecosystem Carbon Stocks, that is the amount of C in above and belowground biomass, woody debris and soil (Momba 2010). Measurements of changes in Total Ecosystem Carbon Stocks through time can also allow inferences about greenhouse gas emissions (Kauffman et al. 2020), and enable estimates of emission factors – that is, the average mass of emissions or removals of greenhouse gases resulting from an activity (Vanderklift et al. 2022). Total Ecosystem Carbon Stocks from mangroves vary considerably among regions (Bhomia et al. 2016), and so local measurements of Total Ecosystem Carbon Stocks are preferred for accurate accounting (Chen et al. 2018). Inventory of a nation's greenhouse gas emissions from wetlands including mangrove requires this information because the loss or gain of C in these wetlands as a result of human activity can comprise a significant source of greenhouse gas emissions or removals of CO₂ from the atmosphere (Chen et al. 2018).

In Sri Lanka, several pilot mangrove restoration efforts have been initiated, mainly to restore abandoned shrimp farms where mangroves occurred previously, using an ecosystem approach known as accelerated/assisted natural regeneration of mangrove (ANRM). This method is based on the principle that natural regeneration of destroyed vegetation is hindered by the absence of enabling physico-chemical and biological factors that favour natural settlement of seedlings and entry of fauna. Hence, natural hydrological processes are first reestablished, and the sites are acclimatized. Later, natural settlement is facilitated with the planting of specific species such as *Rhizophora mucronata* which act as nurse plants, thus accelerating the entry and settlement of other species of mangroves compared to former state. This study was conducted to estimate Total Ecosystem Carbon Stocks at the Anawilundawa ANRM site.

02. Methodology

2.1 Study site

The Anawilundawa Wetland Ramsar Sanctuary lies along the Asian flyway and covers 1,400 hectares (Perera et al. 2005). It is situated in the Puttalam District of the Northwestern Province of Sri Lanka, between the Negombo-Puttalam railway and the coastline (7°42'N, 79°49'E) (Perera et al. 2005). The Anawilundawa Wetland Ramsar Sanctuary was recognized as a Wetland of International Importance by the Ramsar Convention in August 2001 (Information Sheet on-Ramsar wetlands (RIS) 2001). The wetland complex has a combination of freshwater and brackish water ecosystems, such as ancient reservoirs, a brackish water canal constructed around 1802 and popularly known as Dutch canal bordered by remnant mangrove forests, and active shrimp farms on seaward and paddy fields landwards. Thirteen true mangrove species have been recorded from Anawilundawa Wetland Ramsar Sanctuary. Using Accelerated Natural Regeneration of Mangrove, approximately 40 hectares of abandoned shrimp ponds are being restored in Anawilundawa Wetland Ramsar Sanctuary. The restoration area is divided into 23 plots (Fig. 1); in 2024 thirteen (13) were under restoration. Straight palmate (Fig. 3), contoured palmate (Fig. 4) and linear channels (Fig. 5) have been dug to bring brackish water from the Dutch canal and *Rhizophora mucronata*, *Rhizophora apiculata*, *Bruguiera cylindrica*, *Heritiera littoralis*, *Nypa fruticans*, *Xylocarpus granatum*, *Scyphiphora hydrophyllacea* propagules have been planted. Over time *Aegiceras corniculatum*, *Avicennia marina*, *Avicennia officinalis*, *Excoecaria agallocha* and *Lumnitzera racemosa* have recruited naturally into restored areas.

*Figure SEQ Figure * ARABIC 1 Map of sampling plots & Sri Lankan map*

This study was carried out from September 2023 to February 2024. The area was considered in four strata, namely Peripheral Natural Mangroves, Areas Restored with Mangrove seedlings, Adjacent Woody Area and Abandoned Shrimp Pond Areas kept without any restoration and maintained as controls (Fig. 2).

Figure 3 Photo showing straight palmate in the restored area at Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka. Photograph by Thilina Kumarasiri

2.2 Field Sampling

As the plot layout (Fig. 6) five circular subplots with a 7 m radius, 25 m apart were marked in the four strata (Fig. 2) (Kauffman and Donata 2012). In each sampling area triplicates of the plot layout were taken.

Diameter at breast height (DBH) of woody vegetation was measured (Kauffman and Donata 2012). The biomass of living seedlings was calculated using the average dry mass per seedling (Kauffman and Donata 2012). Seedlings are the plants with a height less than 1.37 m (Kauffman and Donata 2012). Species-specific and common allometric equations were used to estimate aboveground biomass (AGB) and belowground biomass (BGB) (Perera and Amarasinghe 2018; Komiyama et al. 2008; Brown 1997; Mokany et al. 2006; Khanh and Subasinghe 2018; Kangkuso et al. 2018; Howard et al. 2014). A wood density database (Zanne et al. 2009) was used to find out wood densities for species. The carbon conversion factor of biomass for AGB was 0.47 and for BGB was 0.39 (Bhomia et al. 2016). Downed

wood sampling was done by counting the frequency that woody fragments crossed a vertical sampling plane (transect), and the line (or planar) intersect technique was used (Bhomia et al. 2016). For larger downed woods which the diameter is greater than 7.6 cm, the diameter was measured (Kauffman and Donata 2012). Four transects at 45° angle from the main transect were established in each of the five subplots, yielding a total of 20 transects per plot.

A 1 m long open-face auger was used for soil sampling. 5 cm soil subsamples were collected from within four depth intervals: 0–15 cm, 15–30 cm, 30–50 cm, and 50–100 cm (Kauffman & Donata 2012). Loss on Ignition (LOI) was used for soil sample analysis (Howard et al. 2014). Here, 10 g from each oven-dried sub samples were taken and combusted at 450°C for 4 hours. Loss on ignition was converted into Carbon using the equation $0.21 \times \text{LOI}^{1.12}$ (Ouyang and Lee 2020).

Analysis of Covariance (ANOVA) with Tukey's honestly significant difference (HSD) was used to test the hypothesis of equal Total Ecosystem Carbon Stocks in different strata and in interpreting the data.

03. Results

3.1 Above and belowground biomass

Natural mangrove stands contained true mangroves including *Avicennia marina*, *Avicennia officinalis*, *Bruguiera cylindrica*, *Excoecaria agallocha*, *Rhizophora mucronata*, *Lumnitzera racemosa*; mangrove associates including *Thespesia populnea*, *Limonia acidissima*, and salt marsh species *Suaeda monoica* and *S. martina*. Trees had a DBH approximately 9.40 ± 0.37 cm and saplings a mean DBH of 3.31 ± 0.14 cm. The natural mangrove area also contained dead *Avicennia marina* and *Bruguiera cylindrica*.

The restored area mainly contained seedlings and saplings of *Rhizophora mucronate*; 2–3 trees of *Excoecaria agallocha* were also present with mean DBH of 6.83 ± 1.00 cm. This area lacked downed wood.

The adjacent woody area was dominated by true mangroves (*Avicennia officinalis* and *Excoecaria agallocha*) and mangrove associates (*Dolichandrone spathacea* and the liana *Deguelia parviflora*). Some dead trees of *Excoecaria agallocha* were observed as well. The mean DBH of trees was 12.77 ± 0.31 cm while that of saplings was 2.58 ± 0.25 cm.

The abandoned shrimp pond areas contained salt marsh flora *Suaeda monoica*, *Suaeda maritima* and *Tamarix indica* along with *Flueggea leucopyrus* and the mangrove associate *Salvadora persica*. The average DBH of trees was 8.00 ± 0.29 cm while in saplings DBH averaged 2.18 ± 0.31 cm. This area lacked downed wood.

3.2 Total Vegetation Carbon

In the Peripheral Natural Mangrove sites, the mean total vegetation carbon stock (aboveground plus belowground C) was 33.67 ± 8.81 Mg C/ha, and in the area restored with mangrove seedlings it was 1.09

± 0.24 Mg C/ha. The mean total vegetation carbon stock in the adjacent woody area and the abandoned shrimp ponds were 83.51 ± 12.38 Mg C/ha and 0.64 ± 0.35 Mg C/ha, respectively (Fig. 7). The highest total vegetation C stock was found in the adjacent woody area.

3.3 Downed wood Carbon

The mean downed wood carbon with an average biomass of 17.91 ± 6.89 Mg/ha in the peripheral natural mangrove area was 8.96 ± 1.99 Mg C/ha and in the adjacent woody area downed wood with a mean biomass of 54.21 ± 12.15 Mg/ha contained 27.11 ± 3.51 Mg C/ha of carbon (Fig. 8).

3.4 Soil Organic Carbon

The mean Soil Organic Carbon (SOC) stock in the peripheral natural mangrove area was 174.35 ± 12.93 Mg C/ha, while it was 211.49 ± 33.52 Mg C/ha in the area restored with mangrove seedlings. In the adjacent woody area and in abandoned shrimp ponds, the mean SOC stocks were 170.14 ± 18.09 Mg C/ha and 347.48 ± 12.48 Mg C/ha respectively (Fig. 9). The highest SOC was found in the abandoned shrimp pond area which was significantly higher compared to the other three areas ($p < 0.05$).

3.5 Total Ecosystem Carbon Stock

Total Ecosystem Carbon Stocks were 216.98 ± 15.00 Mg C/ha (for peripheral natural mangroves), 212.58 ± 33.42 Mg C/ha (restored areas), 280.75 ± 30.37 Mg C/ha (adjacent woody patch) and 348.12 ± 12.83 Mg C/ha (abandoned shrimp ponds). The highest Total Ecosystem Carbon Stocks was in the abandoned shrimp ponds ($p < 0.05$) (Fig. 14).

The highest contributor to Total Ecosystem Carbon Stock in all strata was SOC (Fig. 15). The contribution of vegetation to the Total Ecosystem Carbon Stock is negligible when compared to SOC at the areas restored with mangrove seedlings and abandoned shrimp ponds.

04. Discussion and Conclusion

This study looks at existing carbon in soil, aboveground, belowground and downed wood compartments in the studied site. The Total Ecosystem Carbon Stocks values for peripheral natural mangroves is 216.98 ± 15.00 Mg C/ha, 212.58 ± 33.42 Mg C/ha for restored areas, 280.75 ± 30.37 Mg C/ha for adjacent woody patch and 348.12 ± 12.83 Mg C/ha for abandoned shrimp ponds. But all types of Carbon were found only in Natural and woody areas.

The Total Ecosystem Carbon Stocks of this study cannot directly be compared with studies such as Cooray et al. (2021), Perera and Amarasinghe (2018) from Sri Lanka, where the carbon stocks are reported without downed wood. However, the Total Ecosystem Carbon Stocks value of natural mangroves in this study, which is 216.98 ± 15.00 Mg C/ha, is lower than the values recorded by Perera and Amarasinghe (2018) in Batticaloa lagoon (506 Mg C/ha) and by Cooray et al. (2021) in Rekawa (1455.4 Mg C/ha) and Batticaloa lagoons (734.7 Mg C/ha). These differences and the differences in

calculation methods highlight the importance of uniform and robust methodologies such as this study to allow composition between studies and sites, both spatially and temporally. This need is further emphasised by the fact that greenhouse gas emission calculations need accurate estimates of all forms of carbon stored in an ecosystem (India State of Forest Report 2021).

Kauffman et al. (2020) reported that the global and Asian region mean mangrove Total Ecosystem Carbon Stocks are 856 ± 32 and 772.6 ± 61.6 Mg C/ha – the estimated stocks in natural mangroves in this study is lower than both. Bhomia et al. (2016) recorded lower Total Ecosystem Carbon Stocks in abandoned aquaculture ponds (61 ± 8 Mg C/ha) and restored (planted) mangroves (102 ± 18 Mg C/ha) in Bhitarkanika Conservation Area in Odisha, India, but Total Ecosystem Carbon Stocks in natural mangrove forests was 237 ± 17 Mg C/ha, which is within the range of calculated value for natural mangroves in this study (216.98 ± 15.00 Mg C/ha). Elwin et al. (2019) recorded Total Ecosystem Carbon Stocks of 541.65 ± 79.08 Mg C/ha in abandoned shrimp ponds in Thailand. By measuring the Carbon levels of different varying ages from abandonment, this study also compared the before and after Total Ecosystem Carbon Stocks values and concluded that pond construction resulted in reduction in Total Ecosystem Carbon Stocks. Therefore, the likely reasons for elevated levels of soil carbon in abandoned ponds in this study require further investigations on possible soil transfers, contributions due to feed and faeces accumulation and carbon fluxes along with transformation and exchange.

Globally, restoration of degraded mangroves has gained an accelerated momentum in tropical and subtropical areas (Beers et al. 2020) with substantial focus on carbon sequestration as a solution to global climate change (Donato et al. 2011). However, the results of this study challenge conventional understanding, because significantly higher SOC was recorded in abandoned shrimp ponds (347.48 ± 12.48 Mg C/ha). At the same time results revealed that in the restored area which is approximately 2 years old, the SOC amount is lower compared to the abandoned area (211.49 ± 33.52 Mg C/ha). The difference cannot be explained at present, however an in-depth analysis of carbon fluxes and types including changes to accommodation space may reveal further explanations. The accommodation space is the space available for sediments where organic matter and minerals accumulate (Gore et al. 2024). When a mangrove is converted into a shrimp farm, ploughing and other physical disturbances to the soil alter the accommodation space available for the accumulation of minerals and organic matter. Similarly, during ecosystem restoration, physical modifications such as canal construction might impact this accommodation space. One likely explanation for observed decrease in SOC in the restored area compared to the abandoned area, perhaps could be this.

Soil type may also play a role. The restored and abandoned area had heavy textured clayey soil while the peripheral natural area had sandy soil. A study done at Florida revealed that mangrove soils with a high clay content have correspondingly high organic Carbon percentage (Ahn et al. 2009). Moreover, according to Silver et al. (2000) the soil C in clay is greater than sandy and loam textured soil. In such soil, the depth of anaerobic soil may be important (Cooray et al. 2025; Sathiyamohan et al. 2022). Molecular structure, nutrient availability of incoming organic matter, oxygen availability for microbial activity, flooding and drying frequency etc. may affect soil organic matter breakdown (Lützow et al. 2006;

Melillo et al. 1989; Sollins et al. 1996). Microorganisms break down labile organic compounds, which are usually low molecular weight (such as proteins and carbohydrates), quickly, while high molecular weight refractory or recalcitrant components, like lignin and suberin, take longer to break down due to their complex structure and requirement of high activation energies (Kögel- Knabner et al. 2008; Kristensen et al. 2008). In addition, rainwater accumulates in dug shrimp farm ponds, therefore water-borne items such as deadwood, debris and transported sediment might also settle on the sediment (Suprayogi et al. 2022). Another reason for high levels of C could be saltmarsh vegetation that has been established in abandoned ponds thereby generating autochthonous sediments which are not exposed to tidal fluctuations due to topography. Any flush off under current scenario is partial therefore a significant proportion of autochthonous sediment might remain in abandoned ponds. Salt marsh ecosystems hold onto an average worldwide ecosystem C storage of 334.4 ± 3.5 Mg C/ha (Alongi 2020). The presence of salt marsh flora such as *Suaeda monoica* and *Suaeda maritima*, along with *Tamarix indica*, in the abandoned shrimp ponds also likely contributes to the accumulation of organic matter and subsequent SOC enrichment.

It's also important to note that about 6–11% of the C in the feed is absorbed by shrimp, while the rest is either available for plankton, volatilizes, or remains trapped in the sediments (Funge-Smith and Briggs 1998). Even without any active restoration efforts, abandoned pond areas may become C sinks (Elwin et al. 2019). This may be either with stabilizing the rate of C released as a result of the oxidation of soil organic matter over time, or with increased C burial in the pond sediments as primary production and deposition of organic matter rise with age of the regenerating mangroves (Elwin et al. 2019).

Overall, results of the 1st Total Ecosystem Carbon Stocks study done in Sri Lanka highlight the carbon potential in Sri Lankan mangroves and the need to conserve existing and to restore the degraded. The world average for greenhouse gas emissions is 4.82 tonnes, while Sri Lanka's per capita emissions are just over one tonne (WHO 2023). According to the annual climate risk index, Sri Lanka has been among the top ten countries negatively impacted by climate change, despite having relatively low greenhouse gas emissions (WHO 2023), therefore blue carbon ecosystems are vital.

Recommendation

Even in a disturbed state, it is crucial to measure the initial Total Ecosystem Carbon prior to restoration. Periodic carbon measurements, alongside other success indicators, are essential and with the emerging data, investigations beyond stock estimates to carbon fluxes may assist carrying out restoration with the least disturbance to existing carbon pools. Moreover, a national agreement on a methodology and a calculation process that enables comparison of data is important.

Declarations

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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Author Contributions

Conceptualization was done by Kavindi Dilshara Kandauda and Sevvandi Jayakody. Data curation, Investigation and Visualization was done by Kavindi Dilshara Kandauda. Formal analysis was done by Kavindi Dilshara Kandauda, Rupesh Kumar Bhomia, Susantha Udagedara and Mat Vanderkluft. Field data collection was done by Kavindi Dilshara Kandauda, Waruni Thissera, Thilina Kumarasiri, Manjula Amararathna and Priyal Buddhika Upananda. Methodology was designed by Kavindi Dilshara Kandauda, Richard Mackenzie and Sevvandi Jayakody. Project administration was done by Kavindi Dilshara Kandauda, Hiranya Kelum Wijenayake, Manjula Amararathna and Sevvandi Jayakody. Resources were supplied by Kavindi Dilshara Kandauda, Rupesh Kumar Bhomia, Hiranya Kelum Wijenayake, Richard Mackenzie and Sevvandi Jayakody. Validation by Kavindi Dilshara Kandauda, Rupesh Kumar Bhomia, Susantha Udagedara, Mat Vanderkluft and Sevvandi Jayakody. The first draft of the manuscript was written by Kavindi Dilshara Kandauda. Previous versions of the manuscript were commented and edited by Rupesh Kumar Bhomia, Hiranya Kelum Wijenayake, Richard MacKenzie, Susantha Udagedara, Mat Vanderkluft and Sevvandi Jayakody. All authors read and approved the final manuscript.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

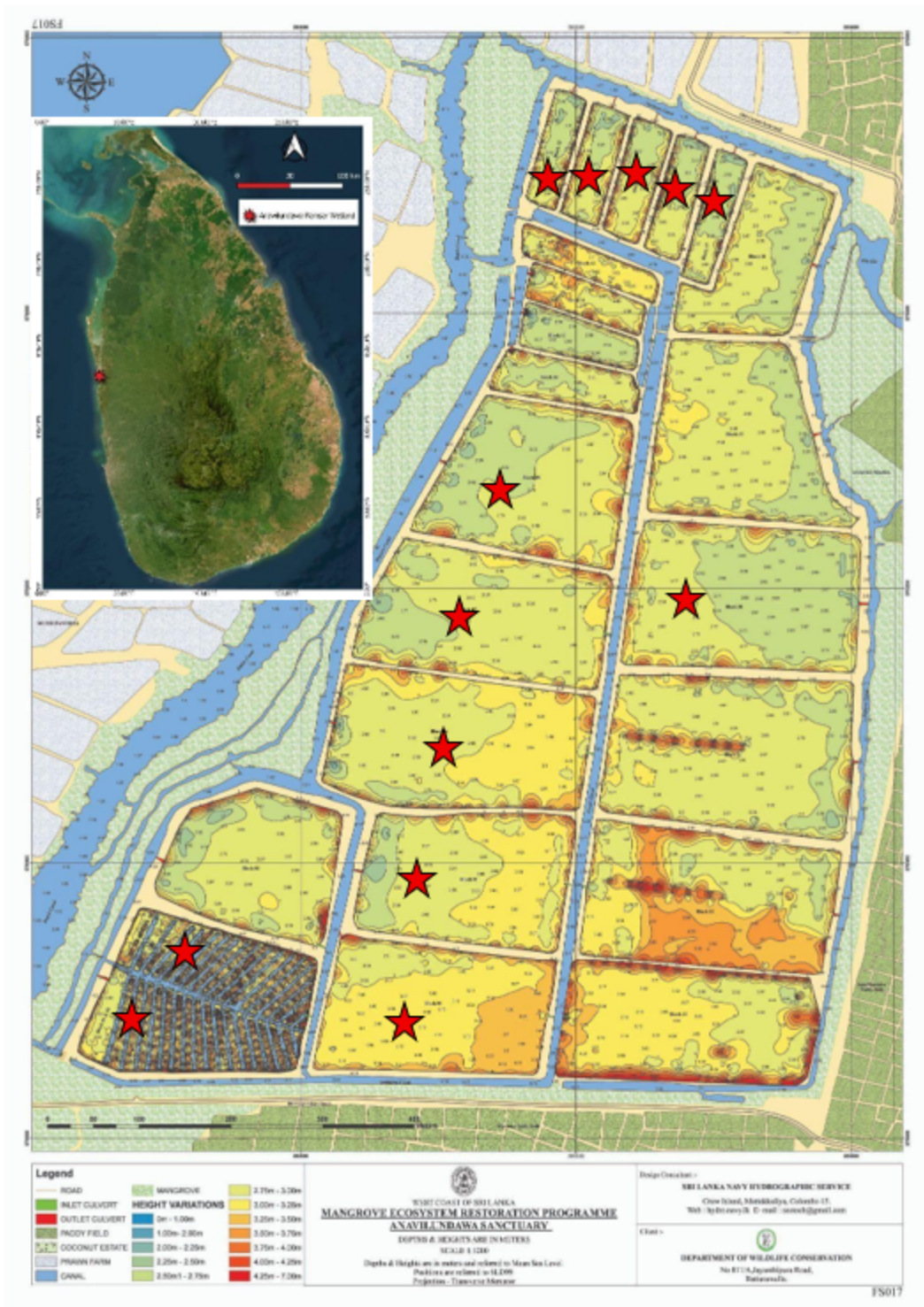


Figure 1

Study area: Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka. There are 23 plots within this study area undergoing restoration. The plots under current restoration are marked with a star

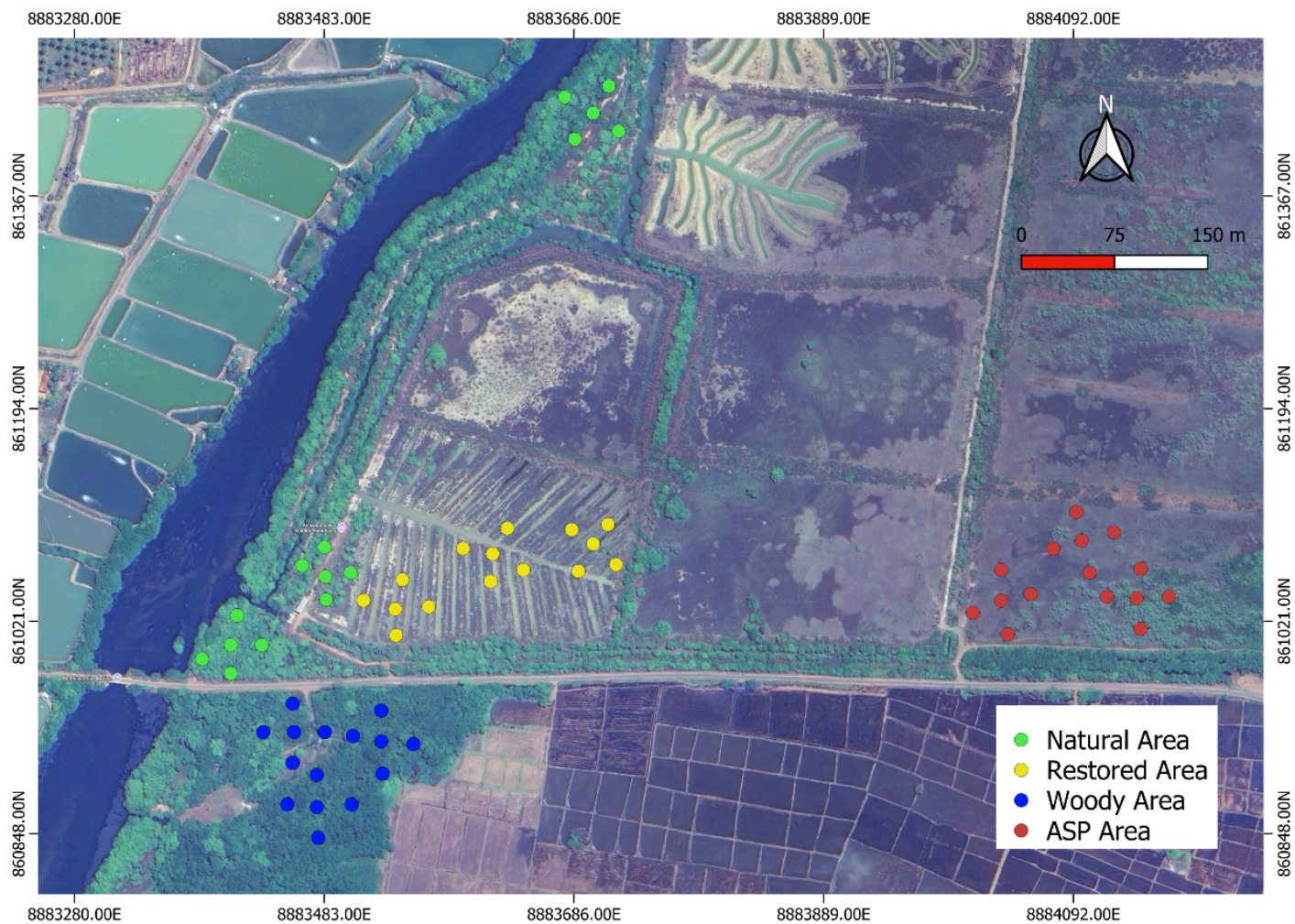


Figure 2

Field sampling plots: Showing five circular subplots in triplicates at each natural, restored, woody and ASP (abandoned shrimp pond) area at Anawilundawa Accelerated Regeneration of Mangroves, Sri Lanka



Figure 3

Photo showing straight palmate in the restored area at Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka. Photograph by Thilina Kumarasiri



Figure 4

Arial photo showing contoured palmate in the restored area at Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka. Photograph by Shevyn Marshall



Figure 5

Arial photo showing linear channel in the restored area at Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka. Photograph by Shevyn Marshall

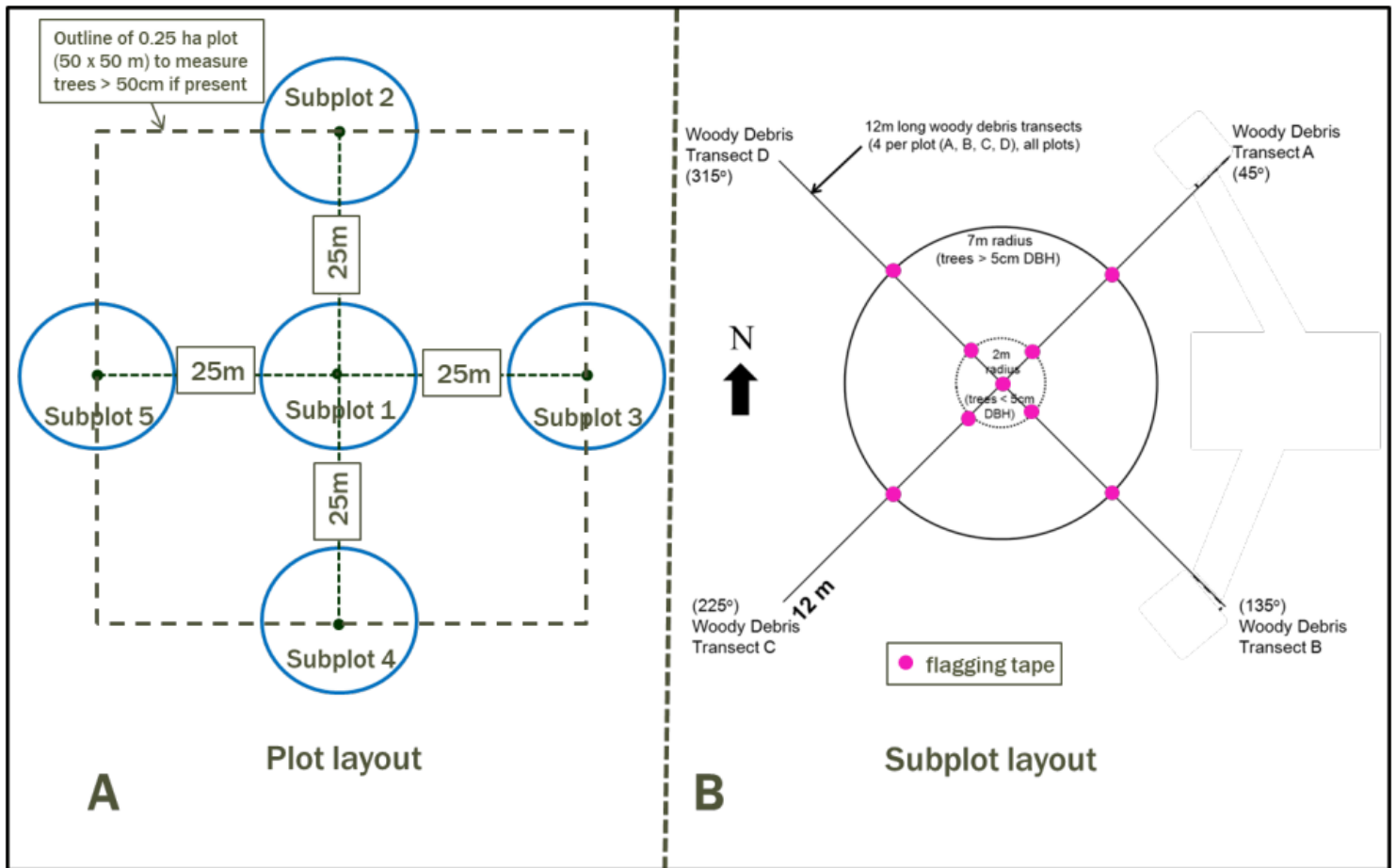


Figure 6

Plot layout and subplot layout carried out within four strata. A) 7 m radius subplots for measuring DBH of trees (DBH>5 cm and height>1.37 m). B) 12 m long field tapes laid in four directions to measure and count downed wood, 2 m radius circles marked within 7 m radius subplot to measure DBH of saplings (DBH<5 cm and height> 1.37 m) and to count seedlings (height<1.37 m) Source: Mackenzie,nd

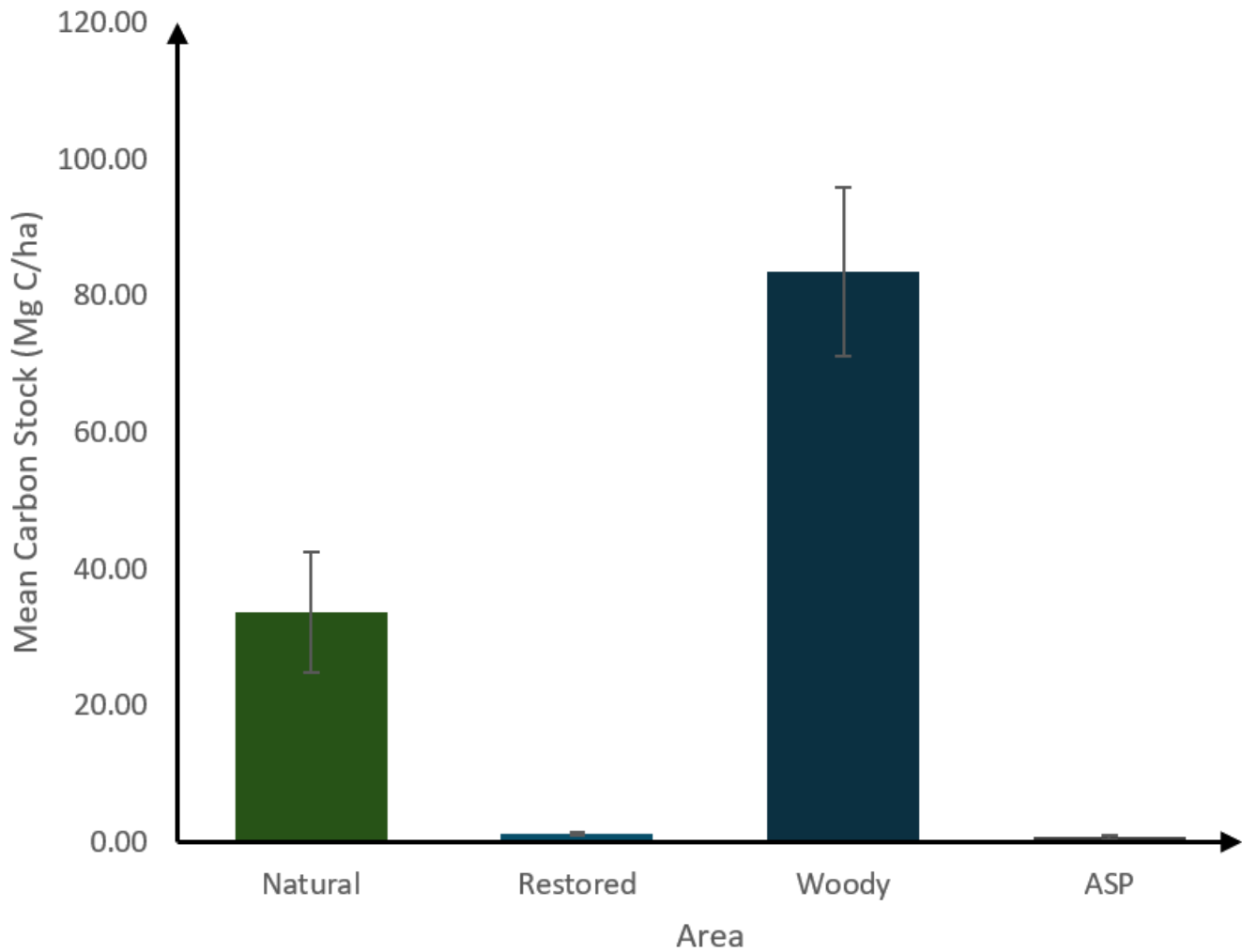


Figure 7

Comparison of mean total vegetation carbon stocks (sum of aboveground and belowground) $\pm$ standard error (Mg C/ha) in natural, restored, woody, and ASP (abandoned shrimp pond) areas in Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

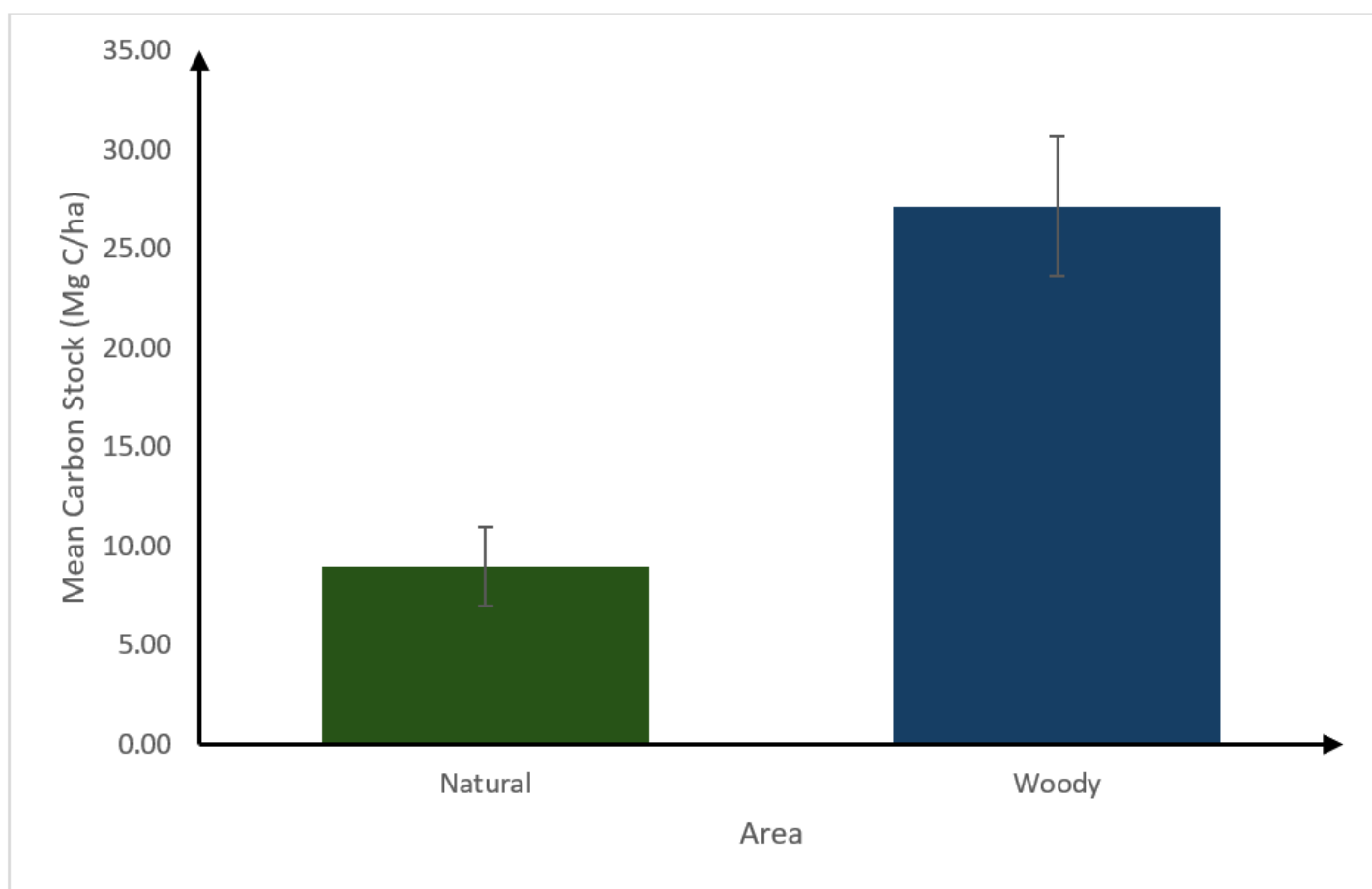


Figure 8

Comparison of mean downed wood carbon stocks $\pm$ standard error (Mg C/ha) in natural, and woody areas in Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

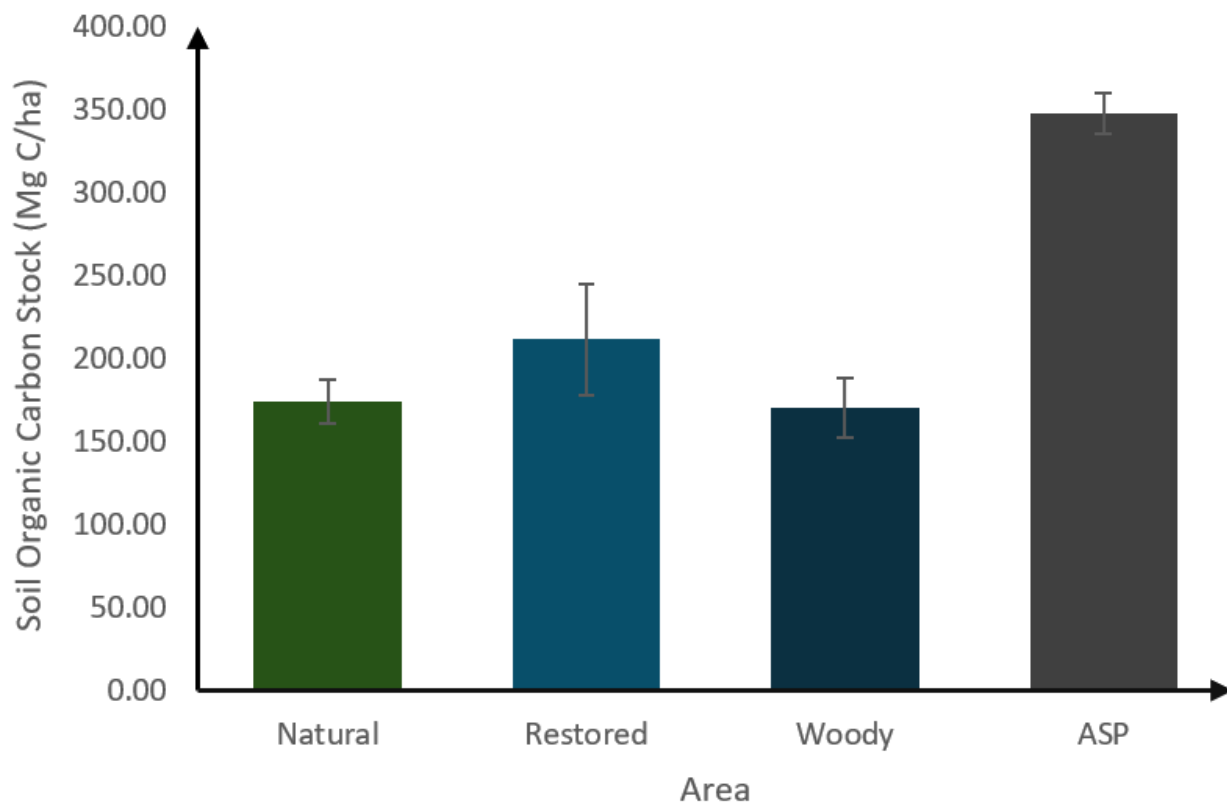


Figure 9

Comparison of mean Soil Organic Carbon stocks $\pm$ standard error (Mg C/ha) in natural, restored, woody, and ASP (abandoned shrimp pond) areas in Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

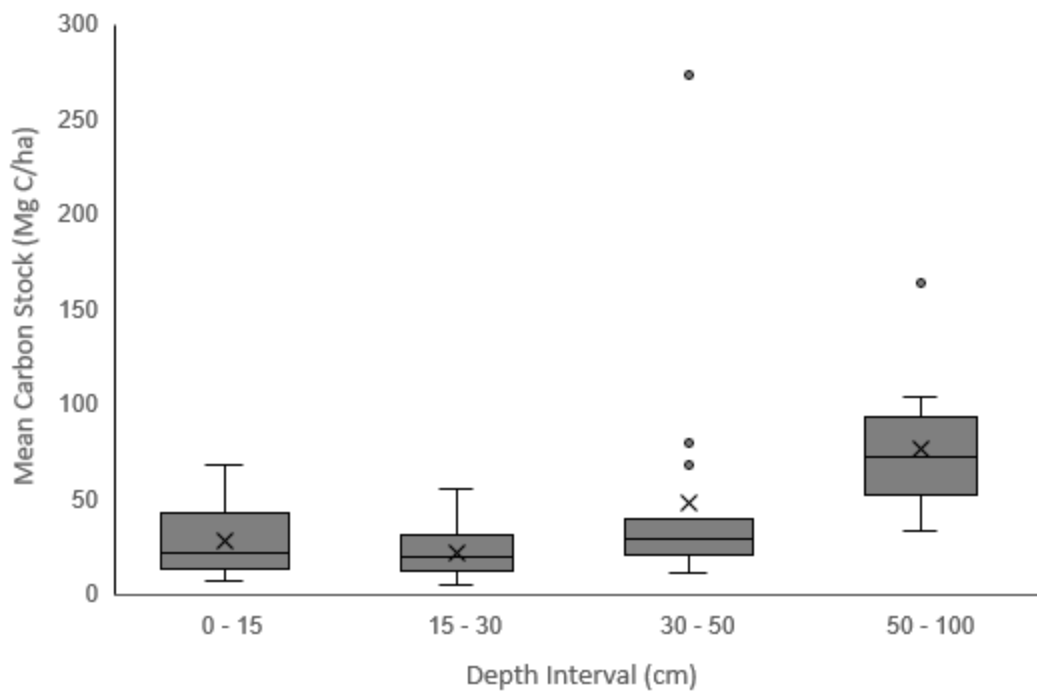


Figure 10

Comparison of mean Soil Organic Carbon (Mg C/ha) in different depth intervals at the natural area of Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

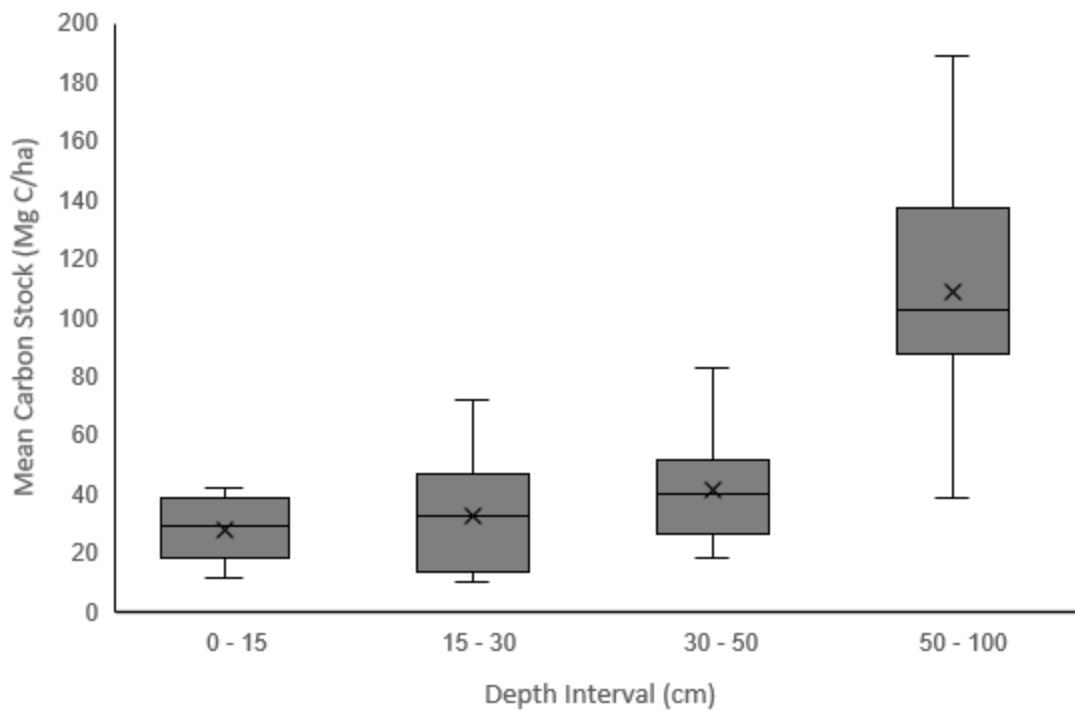


Figure 11

Comparison of mean Soil Organic Carbon (Mg C/ha) in different depth intervals at the restored area of Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

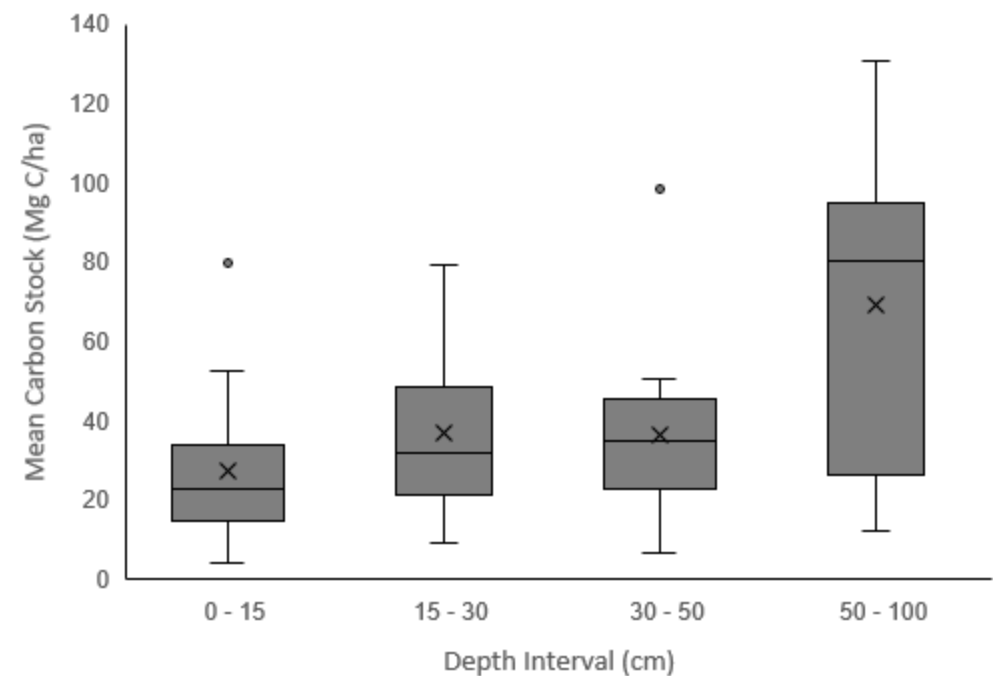


Figure 12

Comparison of mean Soil Organic Carbon (Mg C/ha) in different depth intervals at the woody area of Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

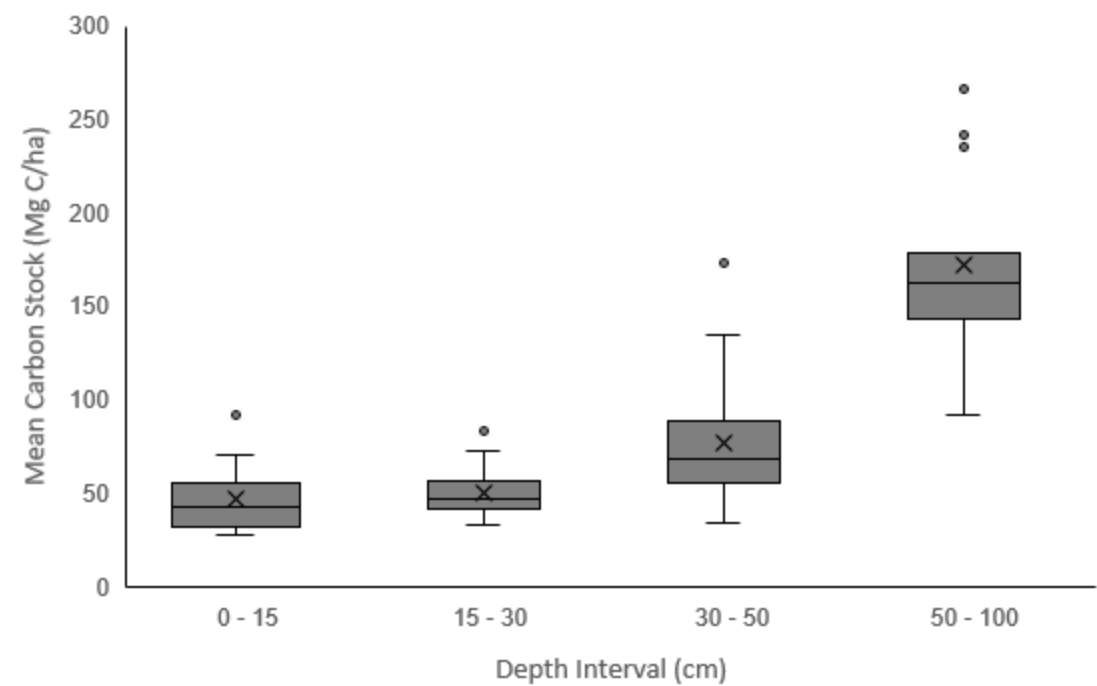


Figure 13

Comparison of mean Soil Organic Carbon (Mg C/ha) in different depth intervals at the abandoned shrimp pond area of Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

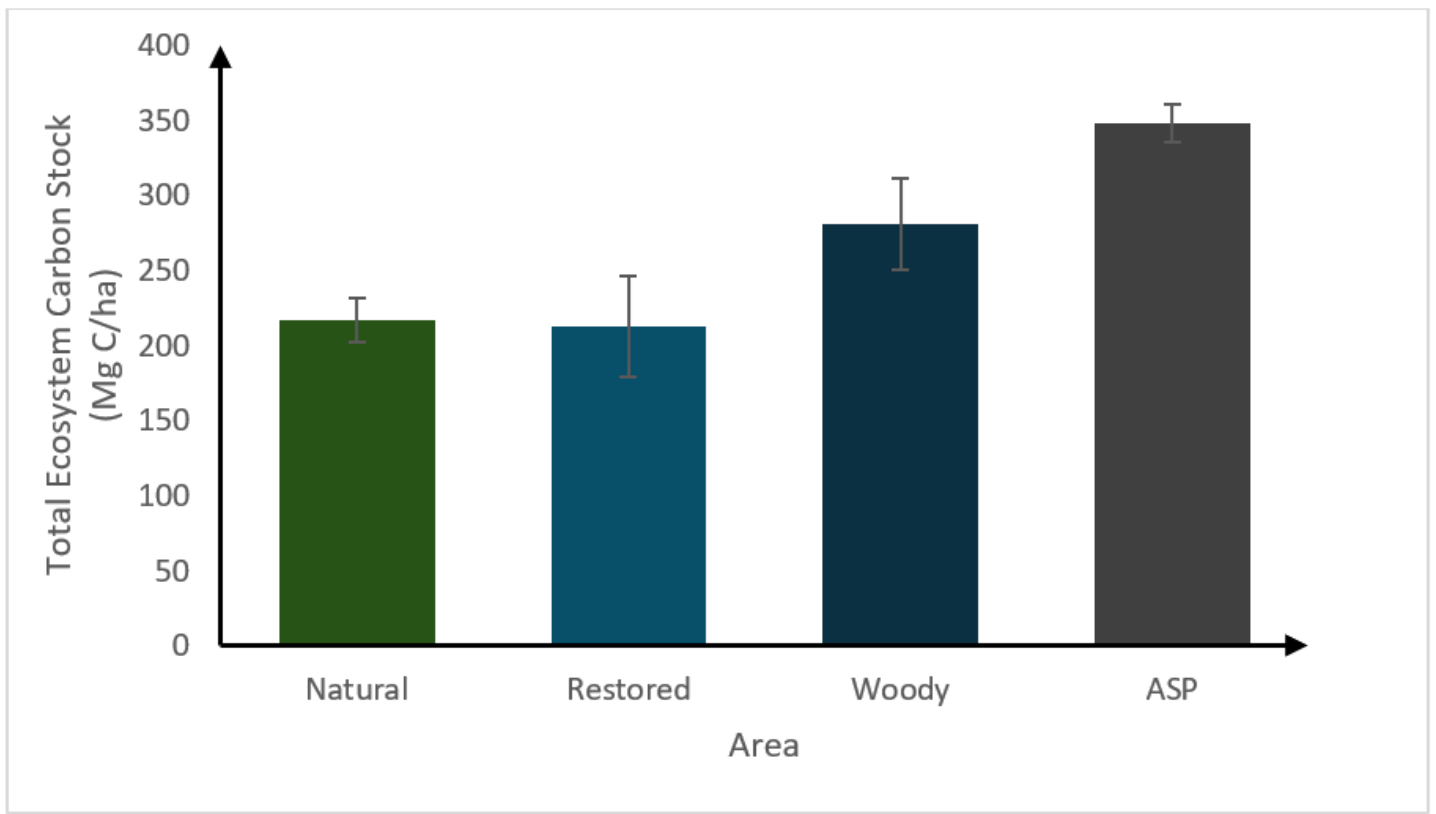


Figure 14

Comparison of mean Total Ecosystem Carbon Stocks $\pm$ standard error (Mg C/ha) in natural, restored, woody, and ASP (abandoned shrimp pond) areas in Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka

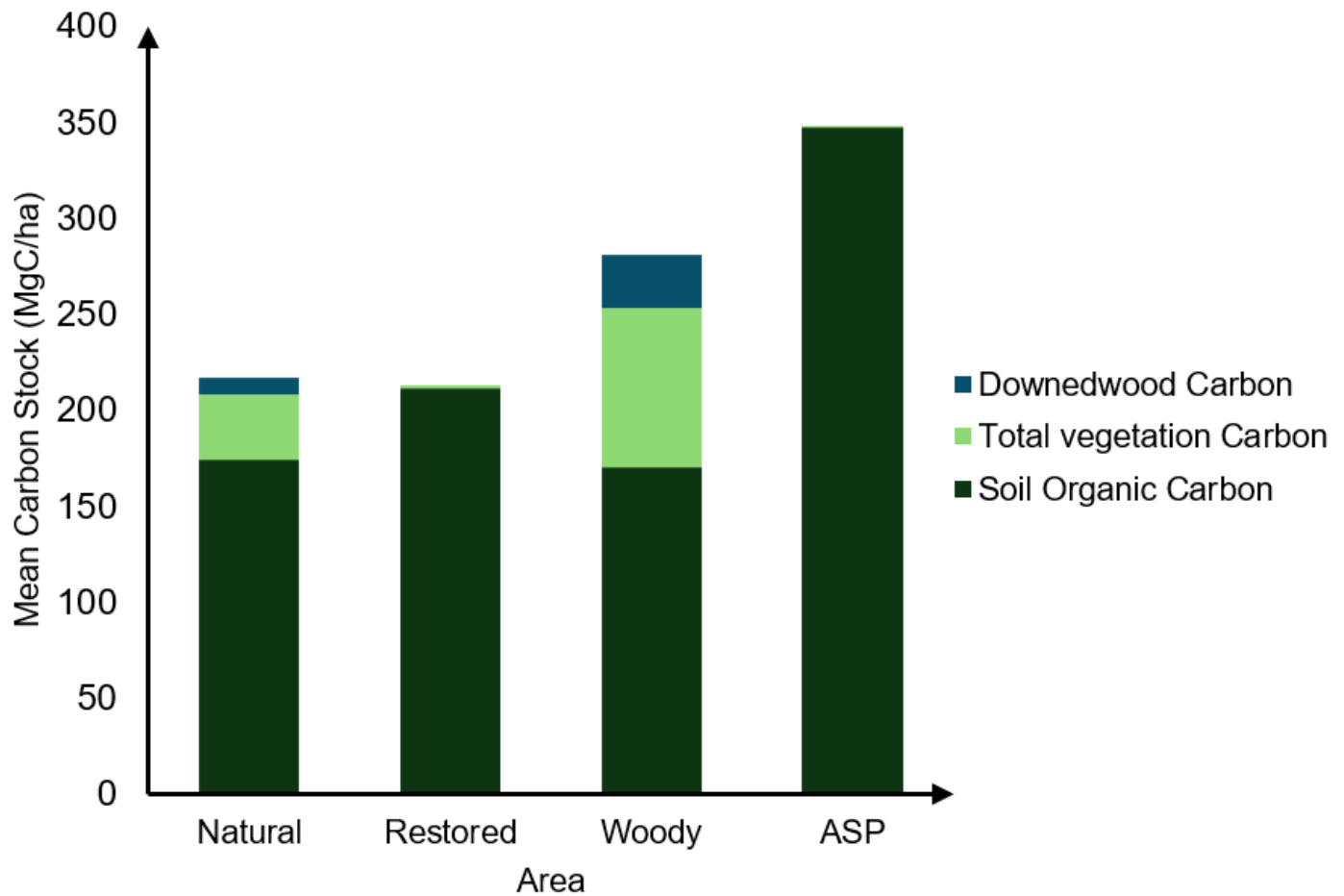


Figure 15

Comparison of mean soil, total vegetation and downed wood carbon stocks (Mg C/ha) in natural, restored, woody, and ASP (abandoned shrimp pond) areas in Anawilundawa Accelerated Natural Regeneration of Mangroves, Sri Lanka