Analysis of Tree Biomass and Carbon Sequestration: A Case Study of the Navaminda Kasatriyadhiraj Royal Air Force Academy

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Abstract

This study aims to analyze the aboveground biomass and carbon sequestration potential of trees within the Navaminda Kasatriyadhiraj Royal Air Force Academy (NKRAFA). Field data were collected from five designated zones, including tree species, diameter at breast height (DBH), and tree height. Standard allometric equations were used to estimate aboveground biomass, which was then converted into carbon stock and expressed as carbon dioxide equivalent (CO_2e). The results show that the total carbon sequestration potential of trees within the academy is approximately 590.30 metric tons CO_2e. Spatial analysis indicates that a higher number of trees does not necessarily lead to greater carbon sequestration. Areas with fewer but larger trees demonstrate higher biomass accumulation and greater carbon storage per unit area than areas with dense populations of smaller trees. These findings emphasize the importance of considering both tree size and biomass characteristics, rather than tree density alone, when assessing carbon sequestration potential. The results provide practical insights to support sustainable green space management and contribute to low-carbon development planning.

Keywords: Tree Biomass, Carbon sequestration, Navaminda Kasatriyadhiraj Royal Air Force Academy

1. Introduction

From the past to the present, human societies have relied extensively on natural resources to support basic living needs and economic development. Consequently, forest resources, one of the most vital natural systems sustaining human life, have been increasingly exploited, leading to a substantial decline in forest areas worldwide. This decline has resulted in ecosystem degradation, biodiversity loss, and disruption of environmental balance, which are difficult to restore once lost (Marod, 2012). Beyond their ecological importance, forests also play a critical role as major carbon sinks by absorbing atmospheric carbon dioxide (CO_2), a key greenhouse gas driving global climate change.

The rapid rise in atmospheric CO_2 concentrations is primarily associated with human activities such as industrial production, transportation, and agriculture. These emissions have intensified global warming and contributed to severe climate impacts, including rising temperatures, extreme weather events, forest fires, and polar ice melting. In response, the United Nations Framework Convention on Climate Change (UNFCCC) entered into force in 1994 as a global agreement aimed at mitigating climate change and reducing its impacts on ecosystems and natural systems. As a signatory to the UNFCCC, Thailand has committed to reducing greenhouse gas emissions by 20–25 percent by 2030 under its national climate mitigation roadmap (Office of Natural Resources and Environmental Policy and Planning, 2022). One important mechanism supporting emission reduction efforts is the carbon credit system, which enables countries and organizations to reduce or sequester greenhouse gas emissions beyond assigned limits to trade these reductions in carbon markets. The global carbon market has expanded rapidly, reaching an estimated value of USD 851 billion in 2021 (World Bank, 2022), highlighting the growing economic potential of forest conservation and restoration. Despite national conservation efforts, however, Thailand's forest cover continues to decline, accounting for only 31.59 percent of the country's land area in 2020 (Royal Forest Department, 2024). This trend not only increases CO_2 emissions but also reduces the nation's capacity to absorb atmospheric carbon.

Afforestation and forest restoration are widely recognized as practical and effective strategies for enhancing carbon sequestration. Trees absorb CO_2 through photosynthesis and store carbon in the form of biomass, including aboveground biomass, such as stems, branches, and leaves, and belowground biomass in roots. Carbon remains sequestered in tree biomass until it is released through harvesting or burning (Makphan et al., 2018; Duakkaew et al., 2018). Among these components, aboveground biomass is commonly used as a key indicator for carbon stock estimation due to its ease of measurement and compatibility with standard allometric equations.

In this context, the Navaminda Kasatriyadhiraj Royal Air Force Academy (NKRAFA) provides a unique and relevant case study. Following its relocation from Don Mueang, Bangkok, to a new site in Muak Lek District, Saraburi Province in 2023, the academy now occupies an extensive area of more than 850 rai in a hilly landscape. The institution has actively promoted green space development through the "Nakhrafa Ruamjai Planting Trees to Increase Green Areas" initiative, established in honor of His Majesty the King and aligned with the Sufficiency Economy Philosophy. This initiative forms part of the Saraburi Sandbox Project, which aims to establish Saraburi as Thailand's first low-carbon model province through collaboration among government agencies, academic institutions, and the private sector.

2. Research Objective

To analyze the aboveground biomass and carbon sequestration potential of trees within the Navaminda Kasatriyadhiraj Royal Air Force Academy.

3. Literature Review

3.1 Climate Change and Greenhouse Gas Concepts

Climate change is primarily driven by human activities that increase the concentration of greenhouse gases (GHGs) in the atmosphere. Major GHGs include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), all of which trap heat and contribute to global warming. The combustion of fossil fuels for industrial production, transportation, and electricity generation remains the largest source of greenhouse gas emissions. In addition, deforestation significantly reduces natural carbon sinks while releasing stored carbon back into the atmosphere, thereby accelerating climate change. Agricultural activities and land-use changes also play a substantial role, particularly through methane emissions from livestock production and monoculture farming systems. Industrial processes, such as cement and steel manufacturing, together with the use of fluorinated gases in refrigeration and industrial applications, further contribute to long-term greenhouse gas accumulation. Collectively, these factors have intensified climate change and increased their severity over time.

The impacts of climate change are widespread and include rising global average temperatures, altered precipitation patterns, increased frequency of droughts and floods, sea-level rise, and more frequent extreme weather events such as heatwaves and tropical storms. These changes pose serious threats to ecosystems, biodiversity, food security, and human livelihoods. Scientific assessments indicate that, without urgent mitigation measures, global temperatures could exceed 1.5°C above pre-industrial levels, resulting in severe and potentially irreversible consequences (Masson-Delmotte et al., 2018). Among all greenhouse gases, carbon dioxide plays the most significant role due to its high concentration and long atmospheric lifetime. CO_2 accounts for approximately 76% of global greenhouse gas emissions, primarily from fossil fuel combustion, land-use change, and deforestation. Atmospheric CO_2 concentrations have increased from about 280 ppm in the pre-industrial era to more than 410 ppm in recent years (Friedlingstein et al., 2020). Because natural systems can absorb only a limited proportion of emitted CO_2, excess emissions continue to accumulate in the atmosphere.

In response to the global climate crisis, several international frameworks have been established, including the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement. These agreements aim to stabilize greenhouse gas concentrations and limit global temperature rise. Thailand, as a signatory to the UNFCCC and the Paris Agreement, has committed to reducing greenhouse gas emissions by 20–25% by 2030 under its national climate mitigation roadmap. These international and national commitments underscore the importance of effective carbon management strategies, particularly forest conservation, afforestation, and systematic carbon sequestration assessment.

3.2 Carbon Cycle Theory in Forest Ecosystems

The carbon cycle in forest ecosystems explains the continuous movement of carbon among the atmosphere, vegetation, and soil. This cycle plays a critical role in maintaining atmospheric carbon balance and regulating global temperature. Forest ecosystems act as major carbon sinks by absorbing atmospheric carbon dioxide (CO_2) and storing it in plant biomass and soil, thereby helping to mitigate climate change.

3.2.1 Photosynthesis and Carbon Sequestration in Plants

Photosynthesis is the primary process through which plants capture atmospheric carbon and convert it into organic matter for growth and energy storage. This process occurs mainly in green plant tissues containing chlorophyll and involves two key stages: the light reactions, which capture solar energy, and the Calvin cycle, which uses that energy to convert CO_2 into glucose. The produced carbohydrates are then used for plant growth and are stored in various plant components, including stems, branches, leaves, and roots. Through this process, plants serve as the foundation of carbon storage and energy transfer within forest ecosystems.

3.2.2 Carbon Storage in Aboveground and Belowground Biomass

Carbon absorbed through photosynthesis is stored in plant biomass, which is commonly classified into aboveground and belowground components. Aboveground biomass comprises plant structures above the soil surface, including stems, branches, and leaves, whereas belowground biomass consists mainly of root systems. Both components play important but distinct roles in carbon sequestration. Aboveground biomass is widely used as a key indicator for carbon stock assessment because it can be reliably estimated from tree measurements using standardized allometric equations. Large and long-lived trees are particularly effective in sequestering carbon, as they are stored in stable organic compounds such as cellulose and lignin, allowing carbon to remain immobilized for decades or even centuries. Although leaves have relatively short lifespans, leaf litter contributes to soil organic matter, indirectly supporting long-term carbon storage. Belowground biomass contributes to long-term carbon sequestration by storing carbon within root systems and soil organic matter. Roots enhance soil stability and promote the retention of carbon, while decomposing plant residues further increases soil carbon pools. Together, aboveground and belowground biomass form an integrated carbon storage system that plays a crucial role in reducing atmospheric CO_2 concentrations and maintaining ecosystem stability.

3.3 Carbon Credit and Carbon Market Concepts

Carbon credit is a market-based instrument used to manage and reduce greenhouse gas emissions, particularly carbon dioxide (CO_2). One carbon credit represents the reduction or sequestration of one metric ton of CO_2e equivalent. The carbon credit mechanism allows organizations or countries that achieve emission reductions beyond their targets to sell excess credits to others that exceed their emission limits, thereby enabling emission offsetting through market transactions (Hashmi, 2008). This system creates economic incentives for reducing greenhouse gas emissions and encourages investments in low-carbon projects.

Carbon credits are traded within carbon markets, which can be broadly categorized into two types: compliance markets and voluntary markets. Compliance markets are regulated by legal and international frameworks, such as emissions trading systems and agreements under the Kyoto Protocol, where entities are required to meet mandatory emission reduction targets. In contrast, voluntary carbon markets allow organizations and individuals to purchase carbon credits on a voluntary basis to offset emissions, improve environmental performance, or demonstrate corporate social responsibility. Voluntary markets are particularly popular among private companies seeking to achieve sustainability or carbon neutrality goals.

In the forestry sector, carbon credit generation relies on standardized methodologies to ensure accuracy, transparency, and credibility. Internationally recognized standards, such as the Verified Carbon Standard (VCS), Gold Standard, and Climate, Community & Biodiversity (CCB) Standards, are commonly applied to validate forest-based carbon sequestration projects. These standards emphasize measurable carbon benefits, long-term environmental integrity, and, in some cases, positive social and biodiversity outcomes. Together, carbon credit mechanisms and market systems play a significant role in supporting forest conservation, afforestation, and climate change mitigation efforts.

3.4 Methods for Biomass and Carbon Sequestration Assessment in Forests

The assessment of biomass and carbon sequestration in forest ecosystems commonly relies on tree measurements combined with allometric equations. Tree diameter at breast height (DBH) and total tree height are measured in the field and used to estimate biomass through established relationships between tree size and biomass (Chave et al., 2014). Aboveground biomass is calculated using allometric equations that estimate biomass components of stems, branches, and leaves based on DBH and tree height (Ogawa et al., 1965). Total aboveground biomass is obtained by summing these components. Belowground biomass is then estimated as a proportion of aboveground biomass, using a root-to-shoot ratio of 0.27, as recommended by the IPCC (2006).

Carbon stock is calculated by multiplying total biomass by a carbon fraction of 0.47, which represents the average carbon content of dry biomass. The amount of carbon dioxide equivalent (CO_2e) sequestered is subsequently derived by converting carbon stock using the molecular weight ratio of CO_2 to carbon (44/12 or 3.66), following IPCC guidelines. The economic value of carbon sequestration is estimated by multiplying the amount of CO_2e sequestered by the prevailing carbon credit market price. Future carbon credit values can be estimated by considering market trends and policy developments.

3.5 Related Studies

Previous studies have demonstrated the significant role of urban and forest ecosystems in carbon sequestration and climate change mitigation. McHale (2007) showed that urban tree planting can be economically viable within carbon credit markets under appropriate management and site selection conditions. Adhikari (2019) found that effective community forest management increased soil organic carbon storage, particularly on north-facing slopes, highlighting the importance of site characteristics. McPherson (2001) demonstrated that urban vegetation can indirectly reduce carbon emissions by lowering building energy consumption through shading, evapotranspiration, and wind reduction. Similarly, Nowak (2013) reported substantial carbon storage and sequestration by urban and community trees across the United States, providing improved estimates for climate policy planning. Downey (2021) further confirmed that urban afforestation significantly enhances soil carbon storage compared to degraded land, emphasizing the potential of urban tree planting as a practical strategy for long-term carbon sequestration.

4. Methodology

This study employed a quantitative research design combined with spatial analysis to analyze the aboveground biomass and carbon sequestration potential of trees within the Navaminda Kasatriyadhiraj Royal Air Force Academy (NKRAFA), Thailand. Field data were collected from trees located within the area, dividing into 5 zones (A, B, C, D, and E) as shown in Figure 1.

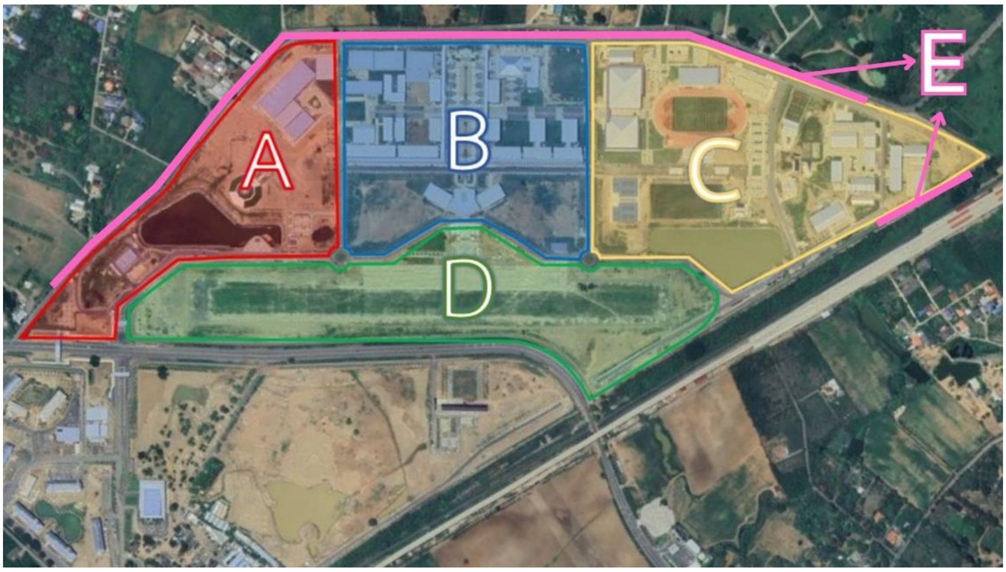

Figure 1: Map showing the five study zones (A–E) within the NKRAFA

Tree measurements included girth at breast height (GBH) and total tree height. GBH was used to calculate diameter at breast height (DBH), and both DBH and tree height were used to estimate biomass. Aboveground biomass was estimated using established allometric equations for mixed deciduous forests (Ogawa et al., 1965), based on DBH and tree height. Carbon stock was calculated by applying a carbon fraction of 0.47 to the estimated biomass, following IPCC guidelines. The amount of carbon sequestration was expressed as carbon dioxide equivalent (CO_2e) using a conversion factor of 3.66.

5. Result

This study analyzed the aboveground biomass and carbon sequestration potential of trees within the Navaminda Kasatriyadhiraj Royal Air Force Academy (NKRAFA) using field measurements and established allometric equations. A total of 2,040 trees were surveyed across five designated zones, revealing clear spatial variation in tree structure, density, and carbon storage capacity. Across the study area, average diameter at breast height (DBH) ranged from approximately 14 to 25 cm, while average tree height ranged from 6 to 12 m. These structural variations contributed to differences in aboveground biomass and carbon sequestration among the study zones. Table 1 summarizes the estimated average aboveground biomass per tree, average carbon stock (kg C) per tree, average CO_2e sequestration per tree, and total CO_2e sequestration for each zone, enabling comparison between per-tree carbon storage efficiency and cumulative carbon storage at the area level.

As shown in Table 1, Zone D recorded the highest average aboveground biomass and average CO_2e sequestration per tree, with values of 873.11 kg/tree and 1,501.92 kg CO_2e/tree, respectively, reflecting the presence of larger and structurally mature trees. However, despite these high per-tree values, Zone D contributed the lowest total CO_2e sequestration (21,026.92 kg CO_2e), primarily due to the very limited number of trees in this zone (14 trees).

In contrast, Zone B, characterized by a high tree density (591 trees), recorded the highest total CO_2e sequestration at 224,568.63 kg CO_2e, despite having lower average biomass and CO_2e sequestration per tree (220.89 kg/tree and 379.98 kg CO_2e/tree, respectively). This indicates that areas dominated by a large number of medium-sized trees can store more total carbon than areas with fewer, larger trees. Zones A, C, and E exhibited intermediate values of average biomass and CO_2e sequestration, reflecting a combination of moderate tree size and density.

Table 1: Estimated Aboveground Biomass, Carbon Stock (kg C), and CO_2e Sequestration per Tree and Total CO_2e Sequestration per Zone

Zone	Avg Aboveground Biomass (kg/tree)	Avg Carbon Stock (kg C/tree)	Avg CO_2e Sequestration (kg CO_2e/tree)	Total Carbon Stock (kg C)	Total CO_2e Sequestration (kg CO_2e)
A	140.67	66.11	241.96	16,792.79	61,461.61
B	220.89	103.82	379.98	61,357.55	224,568.63

Zone	Avg Aboveground Biomass (kg/tree)	Avg Carbon Stock (kg C/tree)	Avg CO_2e Sequestration (kg CO_2e/tree)	Total Carbon Stock (kg C)	Total CO_2e Sequestration (kg CO_2e)
C	133.79	62.88	230.14	42,881.28	156,945.48
D	873.11	410.36	1,501.92	5,745.06	21,026.92
E	147.13	69.15	253.09	34,507.25	126,296.54

Note: Carbon stock (kg C) = Aboveground biomass × 0.47 (IPCC carbon fraction). CO_2e = Carbon stock × 3.66 (molecular weight ratio of CO_2/C, following IPCC guidelines).

Figure 2 illustrates the variation in average aboveground biomass and average carbon stock per tree across the five zones. A pronounced peak is observed in Zone D, while Zones A, C, and E show relatively similar mid-range values. This pattern highlights heterogeneity in tree size distribution and carbon sequestration potential within the study area.

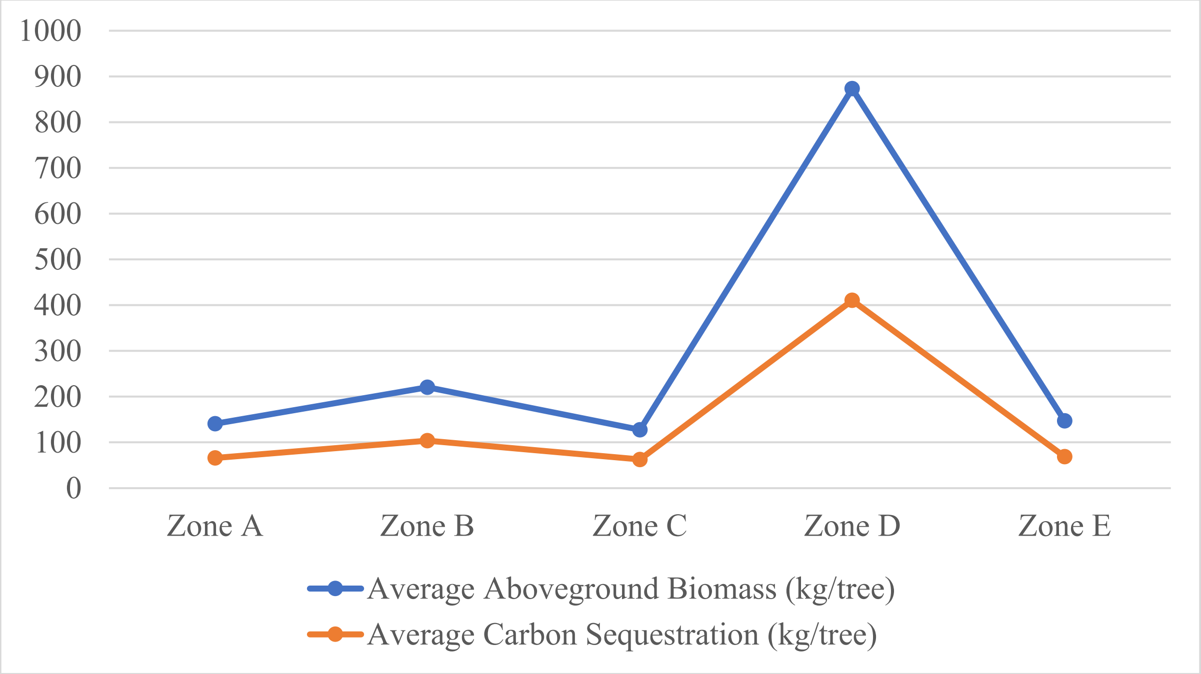

Figure 2: Comparison of Average Aboveground Biomass and Carbon Stock of Trees

Overall, the total CO_2e sequestered within the Navaminda Kasatriyadhiraj Royal Air Force Academy was estimated at 590,299.18 kg CO_2e, or approximately 590.30 metric tons CO_2e. The results clearly demonstrate that total carbon sequestration is influenced by both tree size and tree density. Larger trees contribute more carbon on a per-tree basis, whereas areas with higher tree density contribute more substantially to total carbon storage. These findings emphasize the importance of considering both structural and spatial characteristics when evaluating aboveground biomass and carbon sequestration potential.

6. Conclusion

This study analyzed the aboveground biomass and carbon sequestration potential of trees within the Navaminda Kasatriyadhiraj Royal Air Force Academy using field-based measurements and established allometric equations. Tree species, diameter at breast height (DBH), and height were used to estimate aboveground biomass and associated carbon storage following IPCC guidelines. The results indicate that trees within the study area possess a substantial capacity for carbon sequestration, with a total estimated storage of approximately 590.30 metric tons CO_2e. Clear spatial variation was observed among the five study zones, reflecting differences in tree size, structure, and density. Zones characterized by larger trees exhibited higher average aboveground biomass and CO_2e sequestration per tree, while zones with higher tree density contributed more to total carbon storage.

In particular, the comparison between Zones B and D demonstrates that carbon sequestration potential is not determined by tree quantity alone. Despite having significantly fewer trees (14 trees), Zone D exhibited a disproportionately high carbon stock per tree (410.36 kg C/tree; 1,501.92 kg CO_2e/tree) due to larger trunk diameters and more developed tree structures. Zone B, by contrast, achieved the highest total CO_2e sequestration (224,568.63 kg CO_2e) through its high density of 591 medium-sized trees (379.98 kg CO_2e/tree). This finding highlights the critical role of tree morphological characteristics such as trunk size, height, and overall growth in determining aboveground biomass and carbon sequestration potential. In conclusion, the findings confirm that both tree size and tree distribution patterns are key determinants of aboveground biomass and carbon sequestration capacity. These results provide a clear empirical basis for understanding how structural characteristics of trees influence carbon storage within institutional green spaces.

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