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Assessing Carbon Sequestration and Biodiversity: A Comprehensive Study of Trees at Dhurakij Pundit University

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Abstract

The objectives of this study were: i) to develop a comprehensive tree database for Dhurakij Pundit University (DPU), involving counting and measuring the diameter at breast height *(*DBS*)* of 1.3 meters and had a stem circumference of at least 12 cm at breast height, ii) to evaluate CO_2 sequestration within the university campus by estimating the woody biomass of each tree using allometric equations and calculating carbon storage, CO_2 sequestration potential, and oxygen (O_2) production for each tree. Additionally, the Importance Value Index (IVI) and the Shannon-Weiner Species Diversity (SWSD) Index were calculated to identify the dominant tree species and assess overall species diversity. Data collection was conducted over a two-month period, from September to November 2023. The results indicated that within the 13.23-hectare campus, there were 191 distinct species represented by a total of 2,577 trees, with a tree density of 194.79 trees/ha and a total tree basal area of 107.91 m^2. The estimated carbon storage was 23.41 tC/ha, with CO_2 sequestration reaching 85.82 tCO_2/ha and oxygen production at 62.414 tO_2/ha. DPU's CO_2 sequestration rate of 4.29 tCO_2/ha/year reflected its dense tree population relative to other universities. The SWSD Index (H') of 3.7730 indicated high species diversity. *Pterocarpus indicus* exhibited the highest CO_2 sequestration, while *Ficus annulata* had the highest IVI at 47.3091. This comprehensive database serves as a basis for future assessments of carbon sequestration on campus.

Keywords**:** *carbon storage; CO_2 sequestration; diversity; decarbonization; environment; sustainability*

1. Introduction

National and regional governments worldwide are encouraged to reduce greenhouse gas (GHG) emissions by targeting carbon neutrality and net zero emissions. The Thai government, in alignment with this trend, has announced specific targets, strategies, and roadmaps. Their aim is to achieve carbon neutrality by 2050 and net zero emissions by 2065.

The Kyoto Protocol introduces carbon sinks which remove GHG emissions from the atmosphere. Trees play an important role in mitigating climate change by absorbing carbon dioxide (CO_2) from the atmosphere during photosynthesis, converting CO_2 into organic carbon stored within their biomass. Thus, the potential of trees in their capacity for carbon sequestration and absorption of carbon dioxide from the atmosphere has been recognized. The United Nations Framework Convention on Climate Change (UNFCCC) has implemented the United Nations carbon offset platform, acquiring carbon credits to offset GHG emissions. These carbon credits are derived from diverse projects, including initiatives like forestation to prevent deforestation and degradation (UNFCCC, 2023). Forests, functioning as carbon sinks, play a pivotal role in the global carbon cycle.

For the GHG mitigation mechanism, Thailand Greenhouse Gas Management Organization (TGO) has developed Thailand Voluntary Emission Reduction Program (T-VER) to promote and support all sectors in voluntarily participating in GHG emission reduction program (TGO, 2016). Sustainable forestation is one type of seven T-VER projects. Furthermore, TGO has developed a methodology known as T-VER-S-METH-13-01 for Sustainable Forestation, Sector 14: Afforestation and reforestation (TGO, 2023a), and calculation tools for carbon sequestration in trees including allometric equations (TGO, 2023b). This methodology (TGO, 2023a) aligns with the Clean Development Mechanism (CDM): Afforestation and reforestation project activities implemented on lands other than wetlands (AR-AMS0007), and estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities (AR-TOOL 14 Version 04.2).

Research and studies exploring the carbon sequestration potential of trees have been consistently increasing. Various studies have examined trees on university campuses, including those by De Villiers et al. (2014), Suryawanshi et al. (2014), Junsongduang et al. (2021), Ritchie (2017), and Saral et al. (2017), as shown in Table 1.

In 2014, an investigation into the accumulated CO_2 sequestration by trees on a 68-hectare university campus in New Zealand revealed a total of 5,809.4 tCO_2 from 4,139 trees (De Villiers et al., 2014). This amount constituted approximately 10% of GHG emissions produced by the university (De Villiers et al., 2014). In 2014, a study conducted on carbon sequestration by trees in North Maharashtra University Campus, India, revealed that the carbon sequestration from 462 trees belonging to 10 different species in an area of 0.8 hectares ranged from 1.814-12.272 tC/tree (Suryawanshi et al., 2014). The species with the highest carbon sequestration were *Moringa oleifera* 15.775 tC, *Azadirachta indica* 12.272 tC, *Delonix regia* 12.247 tC. The lowest was *Eucalyptus citriodora* at 1.814 tC (Suryawanshi et al., 2014).

In 2017, a study assessed CO_2 sequestration from five tree species cultivated in VIT University, India (Saral et al., 2017). The range of CO_2 sequestration from these species was between 8.7074 and 52.583 $kgCO_2$/tree. The values for each species were as follows: *Azadirachta indica* (8.7074), *Peltophorum ferrogenium* (23.905), *Cyathea dealbata* (25.675), *Kigelia pinnata* (35.681), and *Millingtonia hortensis* (52.583). *Millingtonia hortensis* exhibited the highest CO_2 sequestration per tree among the studied species (Saral et al., 2017).

Table 1 Research and studies related on carbon sequestration

Year	Reference	Location	Related Findings
2014	De Villiers et al., (2014)	New Zealand	Total 5,809.4 tCO_2 from 4,139 trees in 2014, accounting for 10% of GHG emissions produced by the university
2014	Suryawanshi et al., (2014)	India North Maharashtra University Campus	462 trees, 10 different species, area of 0.8 hectares, 1.814-12.272 tC/tree Three species with highly efficient in accumulated carbon: Moringa oleifera 15.775 tC (highest), Azadirachta indica 12.272 tC (second), Delonix regia 12.247 tC (third), The lowest sequestration: Eucalyptus citriodora 1.814 tC
2017	Saral et al., (2017)	India VIT University campus	CO_2 sequestration per tree ranged from 8.7074 to 52.583 $kgCO_2$/tree: 8.7074 to 52.583 $kgCO_2$/tree. Values for specific species: Azadirachta indica (8.7074), Peltophorum ferrogenium (23.905), Cyathea dealbata (25.675), Kigelia pinnata (35.681), and Millingtonia hortensis (52.583) (highest)
2017	Ritchie (2017)	Canada Dalhousie University, Halifax campus	Three campuses—Studley campus, Sexton campus, and Carleton campus Area of 38 hectares, 1537 trees (40.45 trees/ha), absorbed 60.9 tCO_2/year, accounting 0.071% of the total GHG emissions from Dalhousie University, Halifax campuses (86,077 tCO_2/year, from April 1, 2014, to March 31, 2015)
2021	Junsongduang et al., (2021)	Thailand Khok Thung Ba Forest, Roi Et Rajabhat University	Area of 21.92 hectare, 76 species, with the Shannon-Weiner index of 3.73, stored carbon 80.52 tC/ha.
2003	IPCC (2003)	IPCC	Carbon stored in trees: 0.0033-0.0142 tC/tree/year CO_2 absorption: 0.0521 tCO_2/tree/year

In 2017, an investigation into carbon sequestration from trees on Dalhousie University's campuses in Halifax, Canada was conducted. The study revealed that the total area of the three campuses, Studley campus, Sexton campus, and Carleton campus, was 38 hectares, with a total of 1,537 trees (40.45 trees/ha), absorbed approximately 60.9 tCO_2/year (Ritchie, 2017). This accounted for only 0.071% of the total GHG emissions from Dalhousie University, Halifax campuses which were 86,077 tCO_2-eq during the period from April 1, 2014, to March 31, 2015 (Ritchie, 2017).

In 2021, a study at Khok Thung Ba Forest, Roi Et Rajabhat University, examined tree species diversity and carbon accumulation (Junsongduang et al., 2021). The findings revealed that within the 21.92 hectare Khok Thung Ba forest, there were 76 species, with a Shannon-Weiner index of 3.73. The forest exhibited an accumulated carbon content of 80.52 tC/ha (Junsongduang et al., 2021). The range of default values provided by the IPCC is 0.0033-0.0142 tC/tree/year (IPCC, 2003).

All sectors in Thailand are aligning with national emission targets by setting individual goals in accordance with government directives. Universities, as key institutions of higher education, play a crucial role in reducing GHG emissions. Their carbon management strategies offer valuable models for other organizations and serve as practical examples for emission mitigation. By striving for carbon neutrality, universities also act as leaders and role models within their communities. This study was conducted at Dhurakij Pundit University (DPU), a private university located in the heart of Bangkok, to develop a comprehensive tree database and evaluate CO_2 sequestration within the campus.

2. Objectives

The objectives of this study were as follows:

1) To develop a comprehensive tree database for DPU university by conducting an inventory of all trees. This included counting and measuring diameter at breast height (DBH) and height for each tree that surpassed 1.3 meters in height and had a stem circumference of at least 12 cm at DBH, while excluding smaller trees from the dataset.

2) To evaluate CO_2 sequestration within the university campus by estimating the woody biomass of each tree using allometric equations. This enabled the calculation of carbon storage, CO_2 sequestration potential, and oxygen (O_2) production for each individual tree.

3. Materials and Methods

Trees absorb CO_2 from the atmosphere during photosynthesis, converting CO_2 into organic carbon stored in their biomass, including roots, stems, branches, and leaves, while releasing oxygen (O_2). The quantification of tree carbon storage and CO_2 sequestration in this study complied with TGO protocol (TGO, 2023a; TGO, 2023b). A non-destructive approach was used for estimating tree biomass. The calculation of tree biomass, carbon storage, CO_2 sequestration and O_2 production, important value index (IVI), SWSD index are presented in the following sections.

3.1 Study Area

This study was conducted in a private university, DPU. There were four zones in this university covering 13.23 hectares, as shown in Table 2 and Figure 1. The establishment of the university began with the construction of a few buildings and a small park around Zone Z3, fifty years ago. As the university expanded, additional faculties and more students led to the development of Zones Z2 and Z4, respectively. Eventually, the university continued to expand in sequence, reaching Zone Z1 in recent years. Thus, Zone Z3 possesses many mature and tall trees, featuring valuable native tree species. There were many tall trees surrounding the cultural center and the football field in Zone Z2.

The aim of this study was to perform a comprehensive survey of each individual tree within the university. A survey was conducted on all trees in these four zones that have a height exceeding 1.3 meters and a stem circumference, measured at a height of 1.3 meters, of 12 cm or more. The objective was to collect data on both the diameter at breast height (DBH) and the height of these trees. The tools used in this survey included measuring tapes, an altimeter, a Laser Measure GLM 50C (Bosch), data sheets. Data such as circumference, height, number of stems, tree names, location were recorded. The data collection was conducted over a two-month period, from 9 September to 13 November 2023.

Table 2 Study area in DPU

Zone	Area (m2)	Facility
Z1 (West)	16,824	Classrooms, Flight Simulator
Z2 (South)	44,642	President Building, Administer Office, Classrooms, Meeting Rooms, Canteens, Service Areas, Sport Center, Parking Building, Green Area
Z3 (North)	47,013	Classrooms, Computer lab, Laboratories, Offices, Library, Meeting Rooms, Museums, Service Areas, Green Area
Z4 (East)	23,775	Classrooms, Computer lab, Laboratories, Offices, Parking Area
Total	132,254	

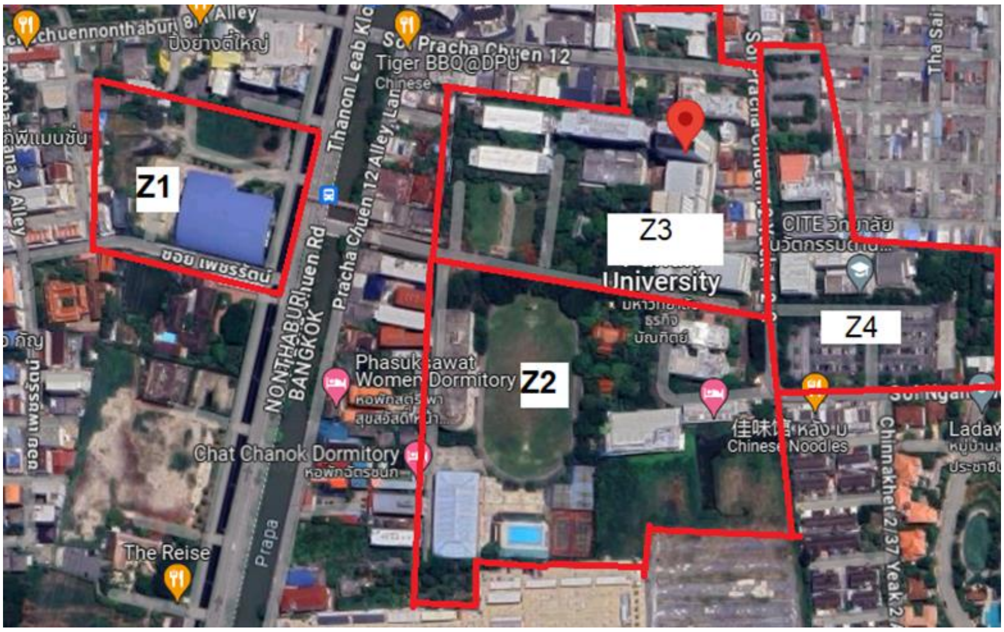

Figure 1 Study Site: Four zones in DPU university
Note: Retrieve 31 January 30, 2024 from Google Maps (Google (n.d.))

3.2 Tree Biomass Estimation

Tree biomass in kilograms is estimated by Allometric equations using two variables: tree diameter (DBH) and tree height (Komiyama et al., 1987; Kutintara et al., 1995; Ogawa et al., 1965; TGO, 2023a; 2023b; Tsutsumi et al., 1983). The aboveground biomass for palm can be calculated from equation (1) using one variable, tree height (H). The aboveground biomass for bamboo and vine can be calculated directly using one variable, tree diameter (DBH) using equation (2)-(4). For the rest of the tree types, the aboveground biomass is the sum of biomass from stem, branch, and leave using equation (5). Allometric equations for stem, branch, and leave depending on each type of forest are shown in Appendix, Table A1. The underground biomass such as roots, is calculated from equation (6). The total tree biomass is the summation of above ground biomass and underground biomass as shown in (7).

Aboveground biomass for palm, vine, bamboo types, and other types can be calculated from equation (1)-(5).

$$W_{ABG}=0.666+12.82(H)^{0.5}\ln(H)\text{, for palm type} \quad (1)$$
$$W_{ABG}=0.8622(DBH)^{2.0210}\text{, for vine group} \quad (2)$$
$$W_{ABG}=0.17446(DBH^2)^{1.0437}\text{, for } \textit{Schizostachyum pergracile} \quad (3)$$
$$W_{ABG}=0.2425(DBH^2)^{1.0751}\text{, for } \textit{Gigantochloa auriculata} \quad (4)$$
$$W_{ABG}=W_S+W_B+W_L\text{, for other types of forest} \quad (5)$$
$$W_{UDG}=0.27W_{ABG}, \quad (6)$$
$$W_T=W_{ABG}+W_{UDG}, \quad (7)$$

where W_S, W_B and W_L for each type of forest are shown in Appendix.

3.3 Calculation of Important Value Index (IVI)

The Importance Value Index (IVI) reflects the importance of tree species in the plant community. IVI can be calculated from (8), which is the summation of three parameters: relative density, frequency, and dominance of each species calculated by equation (9)-(11). However, the relative frequency in equation (10) (Forest Industry Organization Central Region, 2020) is different from the conventional equation, the quantity number of tree for specie *i* is used instead of the number of subplots where species *i* occurs since trees in the university have been planted in planned areas surrounding buildings, parks, pathways and streets. The subplots cannot be arranged.

$$IVI_i = R_{D,i} + R_{F,i} + R_{Do,i} \quad (8)$$

$$R_{D,i} = \frac{D_i}{\sum_{i=1}^{N} D_i} * 100 \quad (9)$$

$$R_{F,i} = \frac{F_i}{\sum_{i=1}^{N} F_i} * 100 \quad (10)$$

$$R_{Do,i} = \frac{D_{o,i}}{\sum_{i=1}^{N} D_{o,i}} * 100 \quad (11)$$

where D_i is the relative density of tree species *i* can be calculated from equation (12) which is number of tree species *i* per square meter, $D_{o,i}$ is the dominance or total basal area of tree species *i* can be calculated from equation (13), where basal area is the cross-sectional area of trees at breast height.

$$D_i = \frac{N_i}{A_T} \quad (12)$$

$$D_{o,i} = \sum_{j=1}^{N_{t,i}} BA_{i,j} \quad (13)$$

3.4 Calculation of Shannon-Weiner Species Diversity Index (SWSD)

Shannon-Weiner Species Diversity Index (SWSD), denoted as H', is calculated by (14) using one parameter p_i which is proportion of number of tree species *i* to total number of trees in that survey area shown in (15). The value of H' index presents the biodiversity in that area. The higher number indicates greater diversity.

$$H' = \sum_{i=1}^{N} [p_i \ln(p_i)] * (-1) \quad (14)$$

$$p_i = \frac{N_{t,i}}{\sum_{i=1}^{N} N_{t,i}} \quad (15)$$

3.5 Carbon Storage, CO_2 Sequestration, and O_2 Production Calculations

While performing photosynthesis, trees draw carbon dioxide out of the air, store carbon and release oxygen. Carbon storage refers to the amount of carbon that trees absorb from the atmosphere during photosynthesis and store in their biomass (trunks, branches, leaves, and roots). This carbon remains locked in the tree as long as it is alive and continues to store carbon in the wood even after the tree is cut down. Thus, carbons are stored as biomass in their stem, branches, leaves, bark and roots. Trees also produce carbon dioxide during respiration; how ever, they are net absorbers of CO_2 because of this carbon store. It is assumed that 47 percent of the wood biomass in trees is carbon. Carbon storage in tree *x* can be calculated from Equation (16). Carbon (12 units) is a component of CO_2 (12+16*2=44 units). Carbon dioxide (CO_2) 44 units are absorbed to obtain carbon 12 units. 44/12 units of carbon dioxide are captured to obtain 1 unit of carbon while oxygen 32/12 units are released. CO_2 sequestration is a natural process in which trees absorb carbon dioxide (CO_2) from the atmosphere and store carbon in their biomass through the process of photosynthesis. CO_2 sequestration by tree *x* can be calculated from Equation (17). O_2 produced from tree *x* can be calculated from equation (18).

$$C_x = 0.47 W_{T,x}, \quad (16)$$

$$(CO_2)_x = C_x * (44/12), \quad (17)$$

$$(O_2)_x = C_x * (32/12) \quad (18)$$

4. Results and Discussion

Survey data and numerical results revealed that there was a total of 2,577 trees and 191 species on the DPU campus resulting in a total carbon storage of 309.54 tonnes of carbon (tC) equivalent to 23.41 tC/ha, CO_2 sequestration 1,134.99 tonnes of CO_2 (tCO_2) equivalent to 85.82 tCO_2/ha, and oxygen production 825.45 tonnes of O_2 (tO_2) equivalent to 62.41 tO_2/ha.

4.1 Basal Area, Carbon storage, CO_2 Sequestration, and O_2 Production

There were 2,577 trees in DPU campus distributed across four zones as shown in Table 3. For more than twenty years, these trees have absorbed CO_2 from the atmosphere converting it into organic carbon, stored in tree biomass. A comparison of the number of trees, tree density, number of species, and total basal area in four zones is shown in Table 3. Zone Z3 and Z2 dominated in number of species, total basal area, and total number of trees, with more trees compared to Zone Z4 and Z1. The areas with the highest tree populations were Zones Z3 and Z2, possessing 772 and 722 trees, respectively, while the tree numbers in Zones Z1 and Z4 are 398 and 685, respectively. Some trees in Zones Z3 and Z2 have been planted since 1979. The trees within these zones are mature, large, and tall, resulting in a higher capacity for cumulative CO_2 sequestration and O_2 production compared to Zone Z1 and Z4. The number of tree species and the total basal area in Zone Z3 and Z2 significantly surpass those in Zone Z1 and Z4. The tree density, representing the number of trees per square meter in each zone, is shown in Table 3. Zone Z4 exhibits the highest tree density per square meter. Nevertheless, the trees within this zone are still in their early stages of growth, appearing small and young. Additionally, bamboo has been planted along the street outside the fence in this area.

The accumulation from CO_2 absorption resulted in total carbon storage of 309.54 tC, CO_2 sequestration 1,134.99 tCO_2 equivalent to 8.58 $kgCO_2/m^2$, and oxygen production 825.45 tO_2, as shown in Table 4. The average age of the trees ranged from 15 to 20 years, resulting in a total of 15.48 tC/year, with carbon storage rate of 0.006 tC/tree/year falling within the range of values provided by IPCC (IPCC, 2003), 0.0033 – 0.0142 tC/tree/year. This translates to an annual sequestration of 56.75 tCO_2/year, equivalent to 0.022 tCO_2/tree/year slightly lower than the IPCC reference value of 0.0521 tCO_2/tree/year (IPCC, 2003), and 4.29 tCO_2/ha/year. Zone Z3 and Z2 exhibited the highest CO_2 sequestration per square meter, followed by Zone Z4 as indicated in Table 4. In contrast, the CO_2 sequestration in Zone Z1 was relatively low, given that this zone was constructed more recently. Zone Z3 and Z2 exhibited dominance in carbon storage accounting for 40.54% and 38.42%, respectively, with larger areas constituting 35.55% and 33.75%, respectively. In contrast, Zones Z4 and Z1 accounted for carbon storage 15.60% and 5.44% of the total, with areas of 17.98% and 12.72%, respectively, as shown in Figure 2.

A comparison in percentage of zone area, CO_2 sequestration, and number of trees in four zones is shown in Figure 2. Zone Z3 and Z2 covered approximately 70% of the area, contribute to around 80% of CO_2 sequestration, and host roughly 60% of the total number of trees. Consequently, Zone Z3 and Z2 can be identified as the green zones within the university.

Table 3 Area and tree characteristics in each zone

Zone	Area (m^2)	Number of Trees	Tree Density (Trees/m^2)	Number of Species	Total Basal Area (m^2)
Z1 (West)	16,824	398	0.0237	25	7.96
Z2 (South)	44,642	722	0.0162	115	36.06
Z3 (North)	47,013	772	0.0164	119	42.44
Z4 (East)	23,775	685	0.0288	45	21.46
Total	132,254	2577	0.0195	191	107.91

Table 4 The value of Carbon storage, CO_2 Sequestration, O_2 production in each zone

Zone	Carbon Storage (kgC)	CO_2 Sequestration ($kgCO_2$)	CO_2 Sequestration ($kgCO_2/m^2$)	O_2 Production (kgO_2)
Z1 (West)	16,847.42	61,773.87	3.6718	44,926.45
Z2 (South)	118,916.36	436,026.66	9.7672	317,110.30
Z3 (North)	125,490.12	460,130.45	9.7873	334,640.33
Z4 (East)	48,289.41	177,061.19	7.4474	128,771.77
Total	309,543.32	1,134,992.17	8.5819	825,448.85

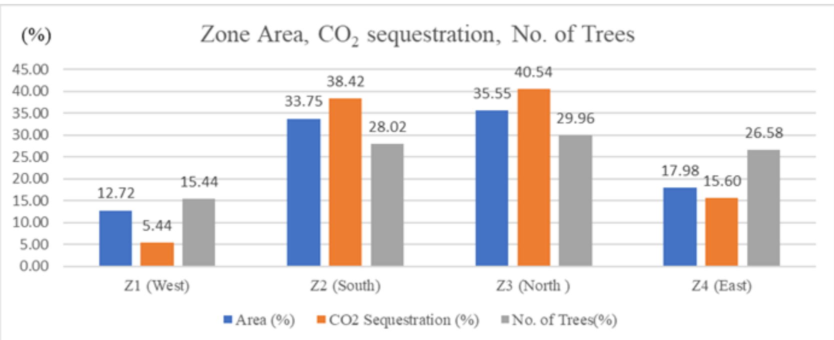

Figure 2 Comparison of zone area (%), CO_2 sequestration (%), and number of trees (%) in four zones

4.2 Dominance Tree and SWSD Index

The top ten major tree species with the highest CO_2 sequestration are shown in Table 5. The first species, *Pterocarpus indicus*, with a count of 109 trees and a basal area of 12.51 m², exhibited the highest accumulated CO_2 sequestration, reaching 123,459.27 $kgCO_2$ equivalent to 1.13 tCO_2/tree. Additionally, it accumulated carbon storage of 33,670.71 kgC and produced an accumulated amount of oxygen as high as 89,788.56 kgO_2. The second and third species were *Peltophorum pterocarpum* and *Millingtonia hortensis*, which captured 102,588.61 $kgCO_2$ equivalent to 2.01 tCO_2/tree, and 95,368.66 $kgCO_2$ equivalent to 1.44 tCO_2/tree, respectively. It was noteworthy that *Alstonia scholaris*, with a count of 21 trees, ranks fifth in terms of CO_2 sequestration. Despite having a lower count, it occupied a substantial basal area and closely follows the fourth-ranking *Ficus benjamina* with 45 trees. This was attributed to the large and tall nature of *Alstonia scholaris*. The sixth-ranking was *Tamarindus indica* with 62 trees. However, *Ficus annulata*, *Polyalthia longifolia*, and *Pterocarpus indicus* stand out with 588, 170, and 109 trees, respectively.

There were a total 191 species with a total 2,577 trees. The SWSD Index, H', at DPU campus was 3.773 indicating a high level of biodiversity among tree species within the university campus. This index surpassed those recorded in the Khok Thung Ba forest (3.73) (Junsongduang et al., 2021).

4.3 Important Value Index and Growth Distribution

The top five tree species with highest important value index (IVI) are shown in Table 6. Relative density (R_D) and relative frequency (R_F) were quite similar, as R_D was the number of trees of a given species per square meter, while R_F represented the number of trees of that species across the entire campus. *Ficus annulata* with 588 trees exhibited the highest IVI, 47.3091. Growth distribution of trees in DPU campus is shown in Figure 3. Most of the trees' DBH were in the range of 0.31-13.66 cm. Most trees were of medium growth, whereas there were 66 large old trees with DBH more than 53.67 cm. There were two extremely large trees, *Samanea saman*, due to their natural growth.

Table 5 Top ten major tree species with highest CO_2 sequestration within this university

Sequence Order	Species	Number of trees	Basal Area (m^2)	Carbon Storage (kgC)	O_2 Production (kgO_2)	CO_2 Sequestration ($kgCO_2$)
1	*Pterocarpus indicus*	109	12.51	33,670.71	89,788.56	123,459.27
2	*Peltophorum pterocarpum*	51	8.52	27,978.71	74,609.90	102,588.61
3	*Millingtonia hortensis*	66	4.13	26,009.63	69,359.02	95,368.66
4	*Ficus benjamina*	45	6.20	18,382.30	49,019.47	67,401.78
5	*Alstonia scholaris*	21	4.86	17,959.50	47,891.99	65,851.49
6	*Tamarindus indica*	62	5.39	16,563.89	44,170.38	60,734.27
7	*Delonix regia*	26	4.80	13,713.17	36,568.46	50,281.64
8	*Dolichandrone serrulata*	26	4.05	13,055.23	34,813.94	47,869.17
9	*Ficus religiosa*	18	3.06	9,465 .02	25,240.04	34,705.06
10	*Polyalthia longifolia*	170	3.32	9,212.51	24,566.68	33,779.19

Table 6 Top five trees species with highest IVI

Sequence Order	Species	Relative density (R_D)	Relative frequency (R_F)	Relative dominance (R_{DO})	IVI
1	*Ficus annulata*	22.8172	22.8172	1.6746	47.3091
2	*Pterocarpus indicus*	4.2297	4.2297	11.5947	20.0542
3	*Polyalthia longifolia*	6.5968	6.5968	3.0794	16.2730
4	*Peltophorum pterocarpum*	1.9790	1.9790	7.8994	11.8575
5	*Tamarindus indica*	2.4059	2.4059	4.9969	9.8087

Table 7 Comparison number of trees, carbon storage and CO_2 sequestration with other universities

University	Tree Numbers	Carbon Storage (tonnes)	CO_2 Sequestration (tonnes)
KIWI University (De Villiers et al., 2014)	4,137	1,585	5,809
California State University (De Villiers et al., 2014)	3,900	862	3,170
Eastern Illinois University (De Villiers et al., 2014)	4,051	1,591	5,828
DPU University	2,577	309.5	1,135

Table 8 Comparison number of trees, area, and CO_2 sequestration with other universities

University	Area (ha)	Tree Numbers	Tree/ha	tCO_2/year	tCO_2/ha/year	tCO_2/tree/year	Species
University of Pennsylvania (Ritchie, 2017)	64.7	4,086	63.15	125	1.93	0.031	
California State University De Villiers et al. (2014), (Ritchie, 2017)	142	3,900	27.47	154	1.085	0.040	
University of Windsor (Ritchie, 2017)	51	1,634	32.04	68.7	1.35	0.042	
Dalhousie University [Canada] (Ritchie, 2017)	38	1,537	40.45	60.9	1.6	0.040	71
DPU University	13.23	2,577	194.79	56.75	4.29	0.022	191

Note: Tree age in DPU university is approximately 15-20 years

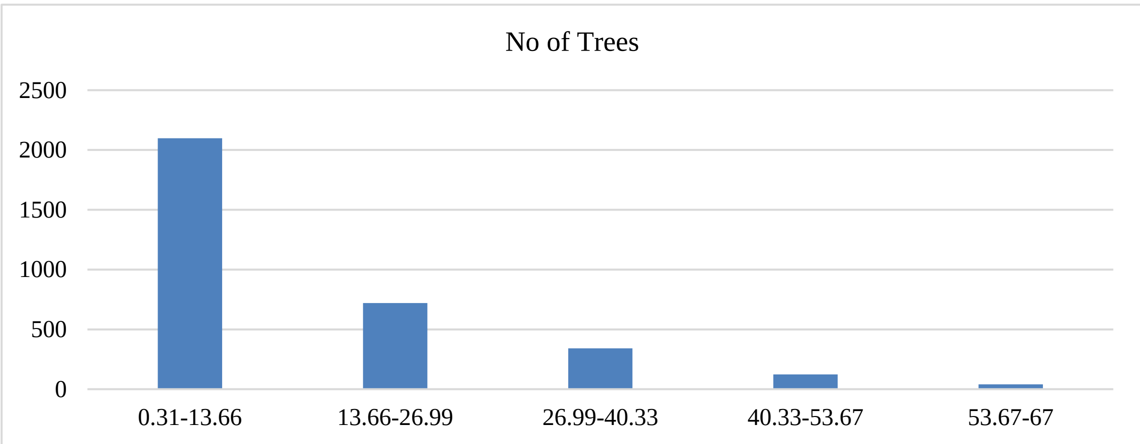

Figure 3 Growth distribution of trees in DPU campus

4.4 Discussion

The study revealed that the primary tree species of dominance was *Pterocarpus indicus*, demonstrating the highest levels of CO_2 sequestration, carbon storage, and oxygen production, contributing to 10.88% of the overall values. Furthermore, *Pterocarpus indicus* exhibited the largest basal area, accounting for 11.59% of the total, with 109 trees representing 4.23% of the overall tree count. Another noteworthy species was *Peltophorum pterocarpum*, contributing 9.04% to the overall values of CO_2 sequestration, carbon storage, and oxygen production, and representing 7.90% of the total basal area with 51 trees, equivalent to 1.97% of the total tree count within the university. On the other hand, *Ficus annulata*, despite having the maximum number of trees (588 trees or 22.82% of the total tree count within DPU campus), attained the highest Importance Value Index (IVI).

The accumulated carbon storage in DPU was 309.5 tC with CO_2 sequestration reaching 1,135 tCO_2 as shown in Table 7. These amounts were quite low compared to other universities due to the smaller area.

As shown in Table 8, DPU achieved the highest tree density (194.79 trees/ha) and CO_2 sequestration rate (4.29 tCO_2/ha/year), highlighting its dense tree population despite its smaller area, reflecting its commitment to sustainable development. Strategic tree planting enhances shade, carbon absorption, and oxygen production, fostering a healthier environment for students and staff. However, the CO_2 sequestration per tree was lower due to the predominance of thinner species, like *Ficus annulata, Polyalthia indicus*, and *bamboo*, planted along the campus perimeter, with larger trees concentrated in central green zones.

Universities have implemented tree care plans with sustainability goals tailored to their unique needs. California State University emphasized student engagement and education on trees' role in carbon sequestration (California State University, Bakersfield, 2022), while Eastern Illinois University focused on proper planting, maintenance, and disease management (Eastern Illinois University, 2019). The University of Pennsylvania prioritized urban forest preservation to support community well-being and educational opportunities (University of Pennsylvania, 2017), and the University of Windsor emphasized tree risk management, routine pruning, young tree training, and strategic planting to enhance aesthetics and environmental services (University of Windsor, 2011). Dalhousie University highlighted the ecological, social, health, and economic benefits of natural spaces (Dalhousie University, 2022). However, comparisons between universities may be limited due to differences in climate zones and tree species. DPU, situated in a tropical forest zone with abundant water and year-round greenery, contrasts with universities in cooler coniferous forests, such as those in Canada or the United States.

DPU's vision, "DPU will be a major driving force in new business transformation for sustainable economic growth," is integrated across all curricula, particularly core subjects linked to Capstone Projects addressing SDGs, with a focus on climate action. The university has planted thousands of trees and actively promotes environmental initiatives, waste management, and green space development, securing a top-three position among Thai private universities in the UI Green Metric World University Ranking for nine consecutive years. DPU has provided support and funding for numerous research and development projects aimed at promoting sustainability across various domains, including electric vehicles and environment (Nirukkanaporn, & Petcharaks, 2019), health risks from air pollution (Thanvisitthpon et al., 2021), energy storage owner in an electricity structure (Petcharaks et al., 2023), first step to carbon neutrality in higher education (Petchchedchoo et al., 2023), carbon footprint of academic gowns (Petchchedchoo et al., 2024) etc.

The high SWSD Index (H') of 3.7730 reflected high biodiversity on DPU Campus, demonstrating sustainable performance despite limited green space. Compared to Bangkok's public parks, which feature 419–9,710 trees, 256 trees/ha, and 543 species, with CO_2 sequestration ranging from 4.9 to 975.9 tCO_2/ha (excluding palms) (Singkran, 2022). Campus trees provide carbon sequestration, climate regulation, air quality improvement, and energy savings, while enhancing well-being and aesthetics. A data-driven management strategy is essential to support decarbonization efforts and guide DPU toward carbon neutrality.

Additional research is crucial to evaluate the annual growth rates for obtaining accurate data. Furthermore, it should analyze the management costs associated with maintaining trees on the university campus. Additionally, the study should focus on identifying tree species exhibiting sustainable growth and resilience to climate change. Planting trees that are well-suited to their environment, including considerations of soil type and humidity, is essential. Specifically, allocating more trees for zones Z1 and Z4 should be prioritized. Urban campuses can use this study as a model to enhance sustainability by maximizing tree density, biodiversity, and carbon sequestration, even in limited spaces. Establishing tree databases and prioritizing high-sequestration, climate-resilient species can support carbon neutrality goals. Campuses should optimize green spaces, monitor tree growth, and align efforts with decarbonization strategies to mitigate climate impacts while improving air quality and fostering environmental responsibility among students.

5. Conclusion

This study established a comprehensive tree database for Dhurakij Pundit University (DPU) and assessed key environmental contributions, including carbon storage, CO_2 sequestration, and oxygen production. Despite its relatively small area (13.23 hectares), DPU demonstrated a high tree density (194.79 trees/ha) and biodiversity, with 2,577 trees across 191 species. The dominant species, *Pterocarpus indicus*, played a significant role in CO_2 sequestration, carbon storage, and oxygen production, while *Ficus annulata* exhibited the highest Importance Value Index (IVI).

The results highlight the university's commitment to sustainability, with a CO_2 sequestration rate of 4.29 tCO_2/ha/year, reflecting the strategic distribution of trees. However, the presence of predominantly thinner species, such as *Ficus annulata* and *Polyalthia longifolia*, limited the per-tree sequestration capacity. Future tree management strategies should prioritize planting high-carbon sequestration and climate-resilient species in underutilized areas (e.g., zones Z1 and Z4) to enhance environmental benefits.

The tree database developed in this study serves as a foundation for future assessments of growth trends and carbon sequestration potential. These findings provide valuable insights for urban campus sustainability initiatives, reinforcing the importance of data-driven tree management in achieving carbon neutrality. Moving forward, additional research should focus on long-term monitoring of tree growth rates, maintenance costs, and the effectiveness of different planting strategies to maximize carbon sequestration in urban green spaces.

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Abbreviations

COP : Conference of the Parties
DBH : Diameter at Breast Height
DPU : Dhurakij Pundit University
IPCC : Intergovernmental Panel on Climate Change
GHG : Greenhouse GAS
IVI : Importance Value Index
SWSD : Shannon-Weiner Species Diversity
TGO : Thailand greenhouse Gas Management Organization
UNFCCC : United Nations Framework Convention on Climate Change

Nomenclatures

A_T : Total area including four zones (m^2)
$BA_{i,j}$: Basal area of tree species *i* tree *j*
C_x : Accumulated carbon storage in tree *x* (kgC)
CO_2 : Accumulated carbon dioxide by tree *x* ($kgCO_2$)
DBH : Diameter at breast height 1.3 m
D_i : Relative density of tree species *i*
$D_{o,i}$: Dominant of tree species *i*
F_i : Frequency of tree species *i* (number of tree species *i*)
H : Tree height
H' : Shannon-Weiner Species Diversity Index
N : Number of species
N_t : Number of trees
$N_{t,i}$: Number of trees species *i*
O_2 : Accumulated oxygen released by tree *x* (kgO_2)
p_i : Ratio of number of tree species i to total number of trees in survey area
$R_{D,i}$: Relative density of tree species *i*
$R_{F,i}$: Relative frequency of tree species *i*
$R_{Do,i}$: Relative dominance of tree species *i*
W_{ABG} : Aboveground biomass in kg
W_S : Stem biomass in kg and calculated from formula in Appendix
W_B : Branch biomass in kg and calculated from formula in Appendix
W_L : Leaf biomass in kg and calculated from formula in Appendix
W_{UDG} : Underground biomass in kg
W_T : Total biomass in kg

Appendix

Table A1 Stem, branch, and leaf biomass

Forest Type	Biomass (kg)	Reference
Dry Evergreen Forest	$W_S=0.0509(D^2H)^{0.919}$ $W_B=0.00893(D^2H)^{0.977}$ $W_L=0.0140(D^2H)^{0.669}$ $W_T=W_S+W_B+W_L$	Tsutsumi et al., (1983)
Tropical Evergreen Rain Forest	$W_S=0.0396(D^2H)^{0.9326}$ $W_B=0.006003(D^2H)^{1.027}$ $W_L=(\frac{28}{W_S+W_B}+0.025)^{-1}$ $W_T=W_S+W_B+W_L$	Ogawa et al., (1965)
Dry Dipterocarp Forest, Mixed Deciduous Forest	$W_S=0.0396(D^2H)^{0.933}$ $W_B=0.00349(D^2H)^{1.030}$ $W_L=(\frac{28}{W_S+W_B}+0.025)^{-1}$ $W_T=W_S+W_B+W_L$	Ogawa et al., (1965)
General Plant Group	$W_S=0.0396(D^2H)^{0.933}$ $W_B=0.00349(D^2H)^{1.030}$ $W_L=(\frac{28}{W_S+W_B}+0.025)^{-1}$ $W_T=W_S+W_B+W_L$	Ogawa et al., (1965)
Mangrove Forest	$W_S=0.05466(D^2H)^{0.945}$ $W_B=0.01579(D^2H)^{0.9124}$ $W_L=0.0678(D^2H)^{0.5806}$ $W_T=W_S+W_B+W_L$	Komiyama et al., (1987)
Palm	$W_T=0.666+12.82(H)^{0.5}(\ln H)$	Pearson et al., (2005)
Vine	$W_T=0.8622(D)^{2.0210}$	Viriyabancha et al., (2012)
Bamboo: *Schizostachyum pergracile*	$W_T=0.17446(D^2)^{1.0437}$	Kutintara et al., (1995)
Bamboo: *Thyrsotachys siamensis*	$W_T=0.2425(D^2)^{1.0751}$	Kutintara et al., (1995)