HIGH SCHOOL EDITION
Journal of Student Research

Volume 13 Issue 2 (2024)

Urban Carbon Dynamics: Estimating Aboveground Biomass and Carbon Sequestration in Daegu's Roadside Trees

Nayoung Kim[1] and Younbin Kim[#]

[1]Daegu Interntional School, Republic of Korea
[#]Advisor

ABSTRACT

Estimating the aboveground biomass (AGB) in roadside trees is essential for quantifying carbon sequestration in urban areas. This study, therefore, aims to develop allometric parameters to estimate AGB, carbon storage, and carbon sequestration for five dominant tree species—Platanus occidentalis, Ginkgo biloba, Zelkova serrata, Quercus palustris, and Chionanthus retusus—in Daegu's Jung-Gu District, Korea. A regression analysis was conducted using two equations: the first equation, the most widely accepted formula for AGB estimation, uses the diameter at breast height (DBH) as the primary variable, and the second one uses measurements of the diameter at breast height (DBH), tree height (H), and tree density (p). The results showed R^2 values exceeding 0.94 for all species examined. According to these parameters, the five dominant roadside tree species in Jung-Gu District, consisting of a total of 5,082 trees, store 50 tons of carbon and sequester 180 tons of carbon dioxide (CO_2) in this District.

Introduction

Recent global initiatives and agreements, such as the 2015 Paris Agreement, have highlighted the urgent need to address the climate crisis and protect the environment. Primary drivers of global warming include urban sprawl and energy production methods such as burning fossil fuels, both contributing to the greenhouse effect and rising temperatures. July 2023 marked a record high for average global monthly temperature, exceeding 17°C [1]. In this challenging scenario, trees serve as primary means for carbon sequestration and are essential for reducing carbon dioxide levels in the atmosphere. In urban areas, roadside trees are particularly significant not only for their role in carbon sequestration but also for their aesthetic value [2]. Estimating how much these roadside trees contribute to carbon sequestration requires a formula for estimating the aboveground biomass of a tree. While belowground biomass also plays a role in carbon storage, aboveground measurements are often more accessible and indicate a tree's total carbon storage capacity. Estimating aboveground biomass advances our scientific understanding and provides a practical approach to counteract climate change. Specifically, the higher the aboveground biomass a tree possesses, the greater its ability becomes to absorb and store atmospheric carbon dioxide. Korea Forest Service [3] recently published significant data on the number of trees and specific species in major Korean cities. As of 2022, there were 10,979,426 roadside trees in 18 major cities and provinces in Korea [3]. Daegu, a basin-type city experiencing elevated temperatures due to the urban heat island effect [4], is home to 226,401 roadside trees. Yet, comprehensive data for estimating the aboveground biomass of roadside trees in specific districts is lacking. This study aims to fill that gap by estimating the carbon sequestration amount of roadside trees in Jung-Gu District, the bustling heart of Daegu.

Material and Methods

Projected Site

The study was conducted in Jung-Gu District, Daegu, Republic of Korea (128.6061745°E, 35.86952722°N; see Figure 1). The district is situated in the heart of Daegu, a city with a total population exceeding 2 million. Jung-Gu District covers a land area of 9.98 km² (only 0.67% of the city), which stretches to 1,497 km². As a result, the district has the highest population density in Daegu Metropolitan City. Jung-Gu, known as the "central district," serves as the primary transit nexus of the city. All three of the city's urban rail lines pass through the district, which also features all three intersection stations. Among the 123 transit bus lanes within the city, more than 50% pass through Jung-Gu District [5]. Despite its urban vibrancy, Jung-Gu District faces a significant challenge: it has the smallest urban park area among the nine districts in Daegu [6]. Due to the highly commercialized environment, immense traffic volume, and limited park space, roadside trees become increasingly important in the district. These trees act as vital environmental buffers, improving air quality, aiding in carbon sequestration, and adding a touch of greenery to an otherwise densely built environment.

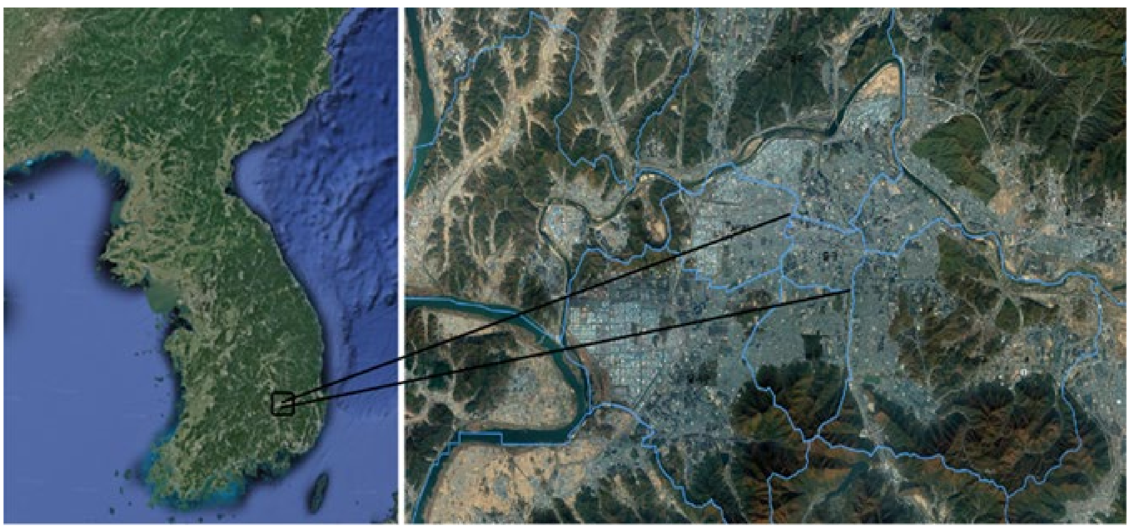

Figure 1a and Figure 1b. Satellite images of Korea and Daegu City. The blue boundaries delineate the different district areas of Daegu City, and the Jung-Gu District is highlighted with two black lines for emphasis.

Species Selection

In this study, I focused on the five most dominant tree species in the Jung-Gu District: *Platanus occidentalis, Ginkgo biloba, Zelkova serrata, Quercus palustris, and Chionanthus retusus*. These five species comprise 90% of the district's roadside trees (Table 1). By examining these prevalent species, I aimed to quantify their contributions to carbon sequestration and to ensure that the findings could be generalized to the broader tree population in the district. For a thorough examination, the sampling method must account for the diverse range of tree species and their geographic distribution within Jung-Gu District (Figure 2).

Table 1. Number of trees by species in Jung-Gu District. Note. Analyzing Daegu Metropolitan City's Jung-gu through Big Data [7].

Tree Species	%	Number of Trees
Platanus occidentalis	32.82%	1,842
Ginkgo biloba	23.02%	1,292
Zelkova serrata	14.59%	819
Quercus palustris	11.88%	667
Chionanthus retusus	8.23%	462
Liriodendron tulipifera	4.38%	246
Hibiscus syriacus	2.08%	117
Other species	1.91%	107
Prunus serrulata	1.09%	61
Total	**100%**	**5,613**

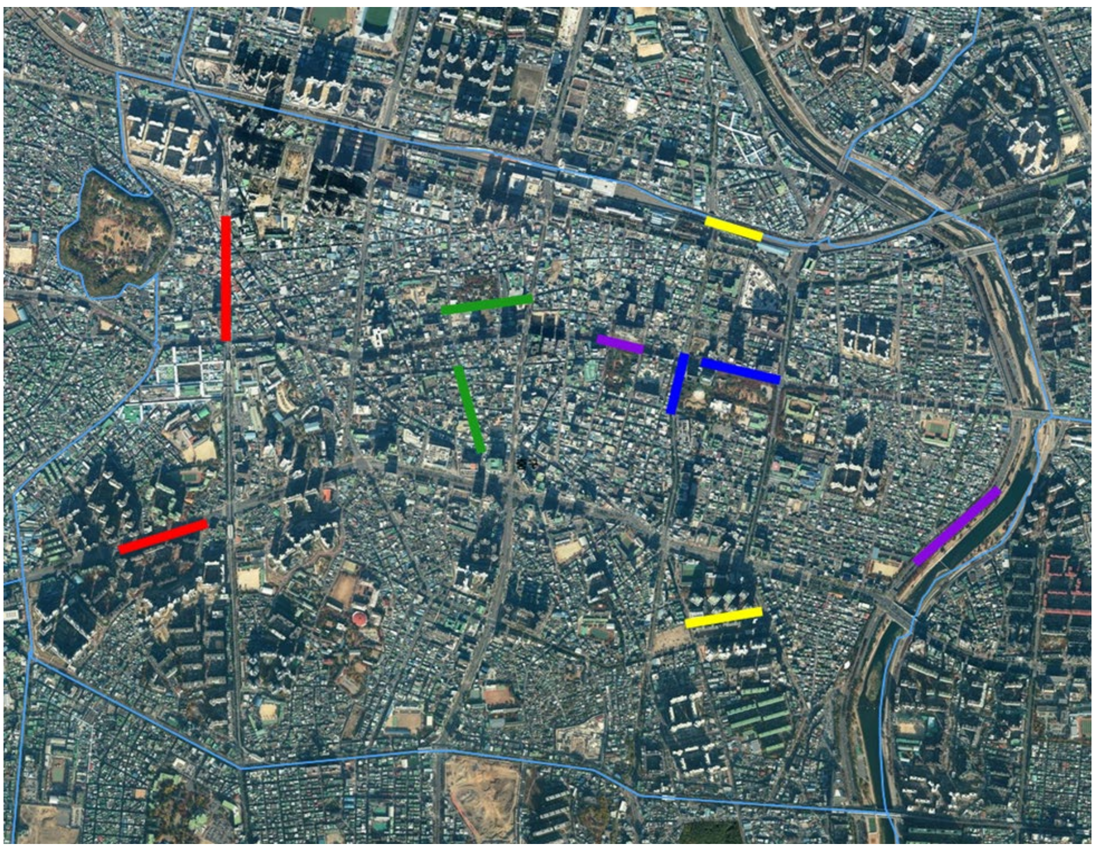

Figure 2. A satellite image of Jung-Gu District.

Considering the unique urban characteristics of each street, I carefully selected two different streets for each of the five studied tree species (Table 2). This strategy allowed me to gather statistically significant samples while minimizing potential biases associated with selecting samples from a single street. As a result, I obtained 20 samples for each of the five studied tree species. Half of the samples were from one street, and the other half were from a different street.

Table 2. Sampling streets for each tree species.

Tree Species	Color on the map	Street 1	Street 2
Platanus occidentalis		Dalgubeol-daero	Dalseong-ro
Ginkgo biloba		Daebong-ro	Taepyeong-ro
Zelkova serrata		Sincheon-daero	Gukchaebosang-ro
Quercus palustris		Dongdeok-ro	Gukchaebosang-ro
Chionanthus retusus		Gyeongsang-Gimnyeong-gil	Jong-ro

Data Collection

Three primary parameters were assessed for each tree specimen to evaluate the carbon sequestration capability of roadside trees in Jung-Gu District: trunk DBH, tree height (H), and tree density (p). DBH measures a tree's trunk diameter at 1.3 meters above ground level [8]. A specialized vernier caliper was used to measure the DBH for all 100 samples. The caliper was used to measure DBHs of up to 50 cm (Figure 3).

Historically, estimating a tree's height required using complex techniques or specialized instruments, such as trigonometric computations [9] or scanning laser devices designed specifically for this purpose [10]. However, advancements in smartphones and augmented reality (AR) technology have simplified this task, allowing for easy and accurate height measurements. The heights of the trees were measured using an AR application called AR Ruler App: Tape Measure Cam, which was obtained from the Google Play Store and installed on my smartphone. Nearby streetlights served as control points. The application utilizes the phone's camera to identify both the base and the top of an object—in this case, a tree. This method streamlined the data collection process and reduced the likelihood of manual measurement errors.

The density of the tree trunks was measured using a digital wood density densitometer, which can measure tree densities up to 1.2 g/cm³. The device functions most accurately on flat surfaces. Therefore, measurements were taken on parts of the tree where the surface exhibited minimal curvature and was not obscured by thick bark. Each tree was measured three times to ensure consistent results, and the average value was recorded.

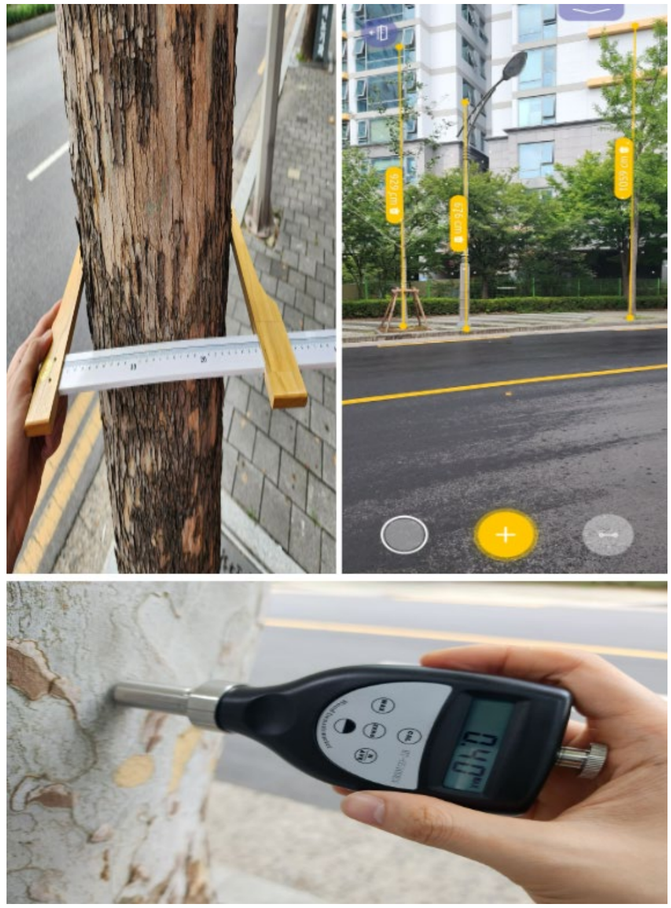

Figure 3a, 3b, and 3c. Photographs of field measurements for the variables using a specialized vernier caliper for measuring trunk DBH, an AR ruler for measuring tree height, and a wood densitometer for measuring tree density.

AGB Estimation

Estimating AGB plays a fundamental role in comprehending the carbon sequestration potential of trees. The most widely accepted formula for AGB estimation is as follows [11]:

$$AGB = a(DBH)^b$$

where DBH represents the tree trunk diameter at breast height, while 'a' and 'b' are species-specific constants, parameters, derived from empirical data. There has been a worldwide effort to accurately estimate the biomass of flora. For example, Jenkins et al. [12] compiled all available diameter-based allometric regression equations in 2003 to estimate biomass for tree species in the United States. More recently, Tang et al. [13] used satellite images from Landsat 8 to estimate aboveground biomass in Yunnan, China. In Korea, researchers such as Jo [14] and Jo and Ahn [15], conducted multiple studies on biomass estimation in Korean cities. Additionally, Park et al. [16] and Yoon et al. [17] formulated volumetric equations for urban trees in Daejeon and Daegu, respectively. In the current study, besides DBH, I utilized the tree height and tree density to derive new parameters for each tree species within the general biomass equation.

Development of Parameters for the Allometric Equation

The selection of an allometric equation is crucial for accurately estimating both biomass and carbon sequestration. It involves capturing the fundamentals of nature into a mathematical formula. I selected an equation recognized for its mathematical framework and empirical robustness. My use of this particular equation in the study stemmed from its strong theoretical foundation and broad relevance:

$$\ln(\mathrm{AGB}) = -1.876 + 2.174\ln(\mathrm{DBH}) + 0.283\ln(\mathrm{H}) + 0.611\ln(\mathrm{p})$$

Ishihara et al. [18] compiled a dataset of 1,203 trees from 102 different species, including 60 deciduous angiosperms, 32 evergreen angiosperms, and 10 evergreen gymnosperms. This dataset serves as a valuable resource for diverse urban settings like the Central District of Daegu. The equation's relevance to this geographic area is emphasized by its basis in data from trees found in temperate, subtropical, and boreal forests, which share climatic and geographical characteristics with Korea. Unlike equations that offer a generalized biomass assessment, this one accounts for specific tree components such as stems, branches, leaves, and roots. This detailed approach provides a thorough understanding of the carbon sequestration dynamics for the deciduous samples in my study. To deepen our understanding, I aim to refine the general allometric equation. I conducted a regression analysis using Jeffery's Amazing Statistics Program (JASP)—a free, open-source statistical analysis tool. In this analysis, I incorporated DBH, height, and tree density into the equation from Ishihara et al. [18] This approach allowed me to determine the values of the parameters "a" and "b" while ensuring my estimates are tailored to distinct tree species and improving the precision of carbon sequestration predictions in my study area.

Carbon Storage and Sequestration Estimation

Estimating carbon storage and sequestration involves a multistep process that converts tree measurements into biomass and carbon content. The methodology of this study adheres to established protocols in forestry and environmental science to ensure accuracy and relevance. I used root-to-shoot ratios (RS) to convert ABG to whole tree biomass (WTB). Specifically, the ratios of 0.24 for the tropical zone and 0.26 for the temperate zone are often used, as recommended by Michael et al. [11]. In addition, Cannell [19] suggested RS values of 0.26 for coniferous trees and 0.25 for deciduous trees. Given that the trees in my sample are coniferous and located in a temperate zone, an RS ratio of 0.26 was deemed most appropriate.

$$\mathrm{AGB} \times 1.26 = \mathrm{WTB}$$

The total estimated biomass includes the moisture content of the trees. Nowak [20] recommended using 0.48 for conifers and 0.56 for hardwoods to estimate dry weight biomass (DWB) in terms of dry weight proportion.

$$WTB \times 0.56 = DWB$$

This value is then multiplied by the constant 0.5 to estimate the carbon storage (CS) of the tree [20].

$$DWB \times 0.5 = CS$$

To convert this into potential carbon dioxide sequestration (CDS), I applied a conversion factor of $\frac{44}{12}$ [21]. This factor translates carbon storage into potential carbon dioxide sequestration capacity, reflecting the molecular weight ratio between carbon dioxide and carbon.

$$CS \times \frac{44}{12} = CDS$$

Discussion

Table 3 presents the allometric parameters for each of the five tree species. Each species exhibited high R^2 values, ranging from 0.942 to 0.997, indicating a strong fit of the model to the data for estimating aboveground biomass. Root mean square error (RMSE) values varied between 0.04 and 0.079. The high R^2 values were expected, given the characteristics of the formula I used. The formula from Ishihara [18], the main selection for this study, has a coefficient of 2.174 for ln(DBH), which is heavily weighted compared to those of ln(H) and ln(p).

The average value of 2.271 for Parameter B aligns with findings from other studies. For example, Pillsbury [9] reported Parameter B values ranging from 2.129 to 2.809, averaging at 2.541. Chojnacky [22] published biomass equations for 675 North American tree species, and the values that contributed to the Parameter B average of 2.446 ranged from 2.106 to 2.647. In Korea, the Parameter B value becomes close to that of the present study. Specifically, Lee [23] derived a general Parameter B of 2.460 for deciduous trees, while Park [16] calculated an average Parameter B value of 2.233 for four species that also appear in my study. Correlation coefficients between DBH and height were positive across all species, averaging at 0.465 [24].

Among the species studied, *Platanus occidentalis* and *Chionanthus retusus* exhibited the weakest correlation, suggesting that while height generally increases with DBH, the relationship is not as pronounced for these species. The average correlation coefficient between DBH and tree density was 0.111. Typically, a correlation coefficient close to 0 indicates a very weak linear relationship between these variables. In this context, it means that changes in DBH have little impact on tree density, and vice versa. While my data suggests a weak correlation between tree density and DBH, existing literature offers mixed findings. Abetu [25] found an inverse relationship between tree density and DBH, while Siliprandi [26] observed a positive correlation for trees in Apuí, located near the southern edge of the Amazon Forest. Given these contrasting findings, it is challenging to make definitive conclusions about the relationship between tree density and DBH based solely on my dataset.

Table 3. Allometric Parameters for aboveground biomass estimation of roadside trees in Jung-Gu District. N = number of trees; DBH = diameter at breast height; AGB = aboveground biomass; RMSE = root mean square error.

Tree	N	DBH	Height	Density	$AGB = a(DBH)^b$	R^2	RMSE	p	DBH vs. Height	DBH vs. Density

HIGH SCHOOL EDITION
Journal of Student Research

Species		(cm)	(m)	(g/cm^3)	a	b				R	R
Platanus occidentalis	20	18.8–46.8	8.4–16.1	0.38–0.52	0.119	2.298	0.981	0.077	< 0.001	0.161	0.0715
Ginkgo biloba	20	10.1–32.1	7.0–13.5	0.39–0.50	0.154	2.219	0.997	0.049	< 0.001	0.889	0.0219
Zelkova serrata	20	20.4–37.1	7.5–12.1	0.70–0.85	0.172	2.289	0.992	0.04	< 0.001	0.634	0.312
Quercus palustris	20	21.7–37.6	9.0–13.5	0.51–0.70	0.142	2.298	0.942	0.079	< 0.001	0.500	0.0558
Chionanthus retusus	20	9.8–22.1	6.1–9.7	0.63–0.79	0.181	2.253	0.987	0.059	< 0.001	0.143	0.0960

For *Platanus occidentalis*, I compared my findings with those of Yoon et al. [17], who also conducted research in Daegu (Figure 4). A key difference between the two studies lies in my specific focus on trees specifically in the Jung-Gu District and the inclusion of tree density as a parameter, in contrast to the crown area used by Yoon et al.

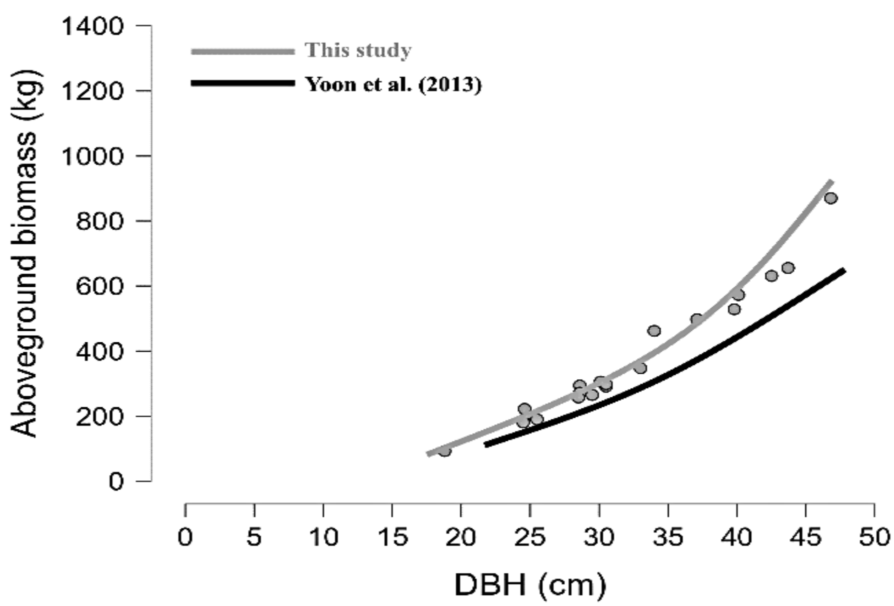

Figure 4. Relationship between DBH and AGB for *Platanus occidentalis* and comparison to results from another relevant study.

In the case of *Ginkgo biloba*, my results were set against those of Ha et al. [27], who analyzed five samples of *Ginkgo biloba* from Jinju, a city approximately 80 km from Daegu. They employed a destructive method that segmented the tree into five parts: foliage, branches, stem bark, stem wood, and roots. In comparing aboveground biomass (excluding root mass) between the two studies, *Ginkgo biloba* showed the closest similarity among the five tree species I examined.

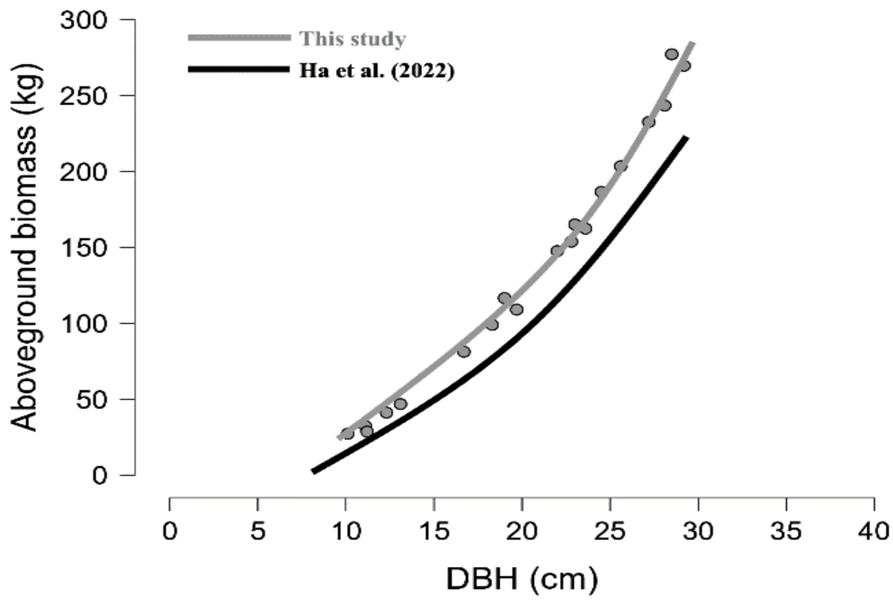

Figure 5. Relationship between DBH and AGB for *Ginkgo biloba* and comparison to results from another relevant study.

For *Zelkova serrata*, our findings were juxtaposed with the research conducted by Pillsbury et al. (1998). Pillsbury and his team employed a method where they measured the biomass of each tree segment to calculate the total aboveground biomass. A potential source of variation between our results and theirs could stem from regional differences, given that their study was based in California while ours was in Daegu.

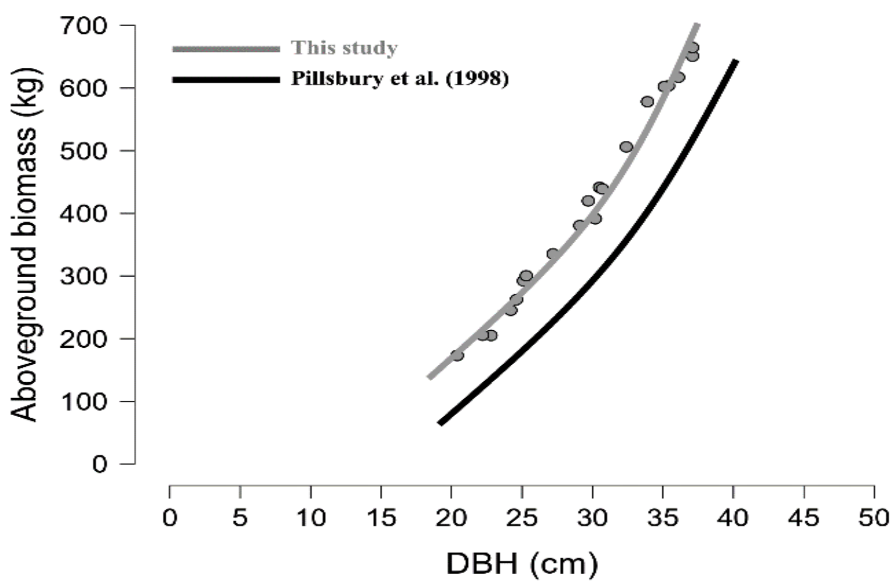

Figure 6. Relationship between DBH and AGB for *Zelkova serrata* and comparison to results from another relevant study.

In the case of Quercus palustris, my results were contrasted with the findings of Jenkins et al. (2003). Their study was notable as it presented results that were lower than most other studies on the same species. Due to the limited research available on estimating biomass for Quercus palustris, we used Jenkins's generalized equation for Quercus (oak) as a reference.

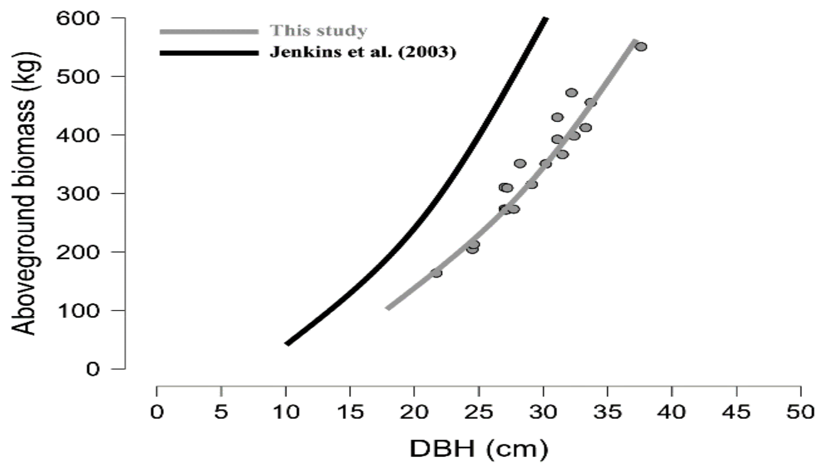

Figure 7. Relationship between DBH and AGB for *Quercus palustris* and comparison to results from another relevant study.

For *Chionanthus retusus*, my findings were compared with two other studies. Jo et al. [28] are among the few researchers who have explored aboveground biomass for this species in Korea. However, the tree trunk diameters in their study ranged from 3.1 to 10.5 cm, significantly different from the 9.8 to 22.1 cm range in my study. Additionally, I referenced the work of Park et al. [16], who examined 195 *Chionanthus retusus* trees in Daejeon, a city located 120 km from Daegu. Park et al. [16] reported aboveground biomass in square meters, which I converted to align with the units in my study, using an average tree density of 0.71g/cm^3 or 710kg/m^3. Variations in my findings compared to those of Park et al. [16] could be attributed to differences in tree density. Another contributing factor might be Park et al.'s [16] application of a 0.8 multiplier to their biomass estimates to account for potential overestimations in urban settings, as suggested by Nowak [20].

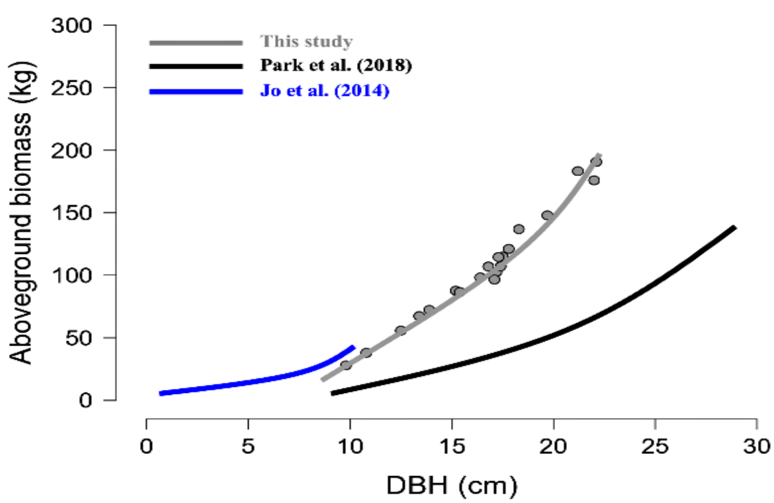

Figure 8. Relationship between DBH and AGB for *Chionanthus retusus* and comparison to results from other relevant studies.

Conclusion

Carbon sequestration is often quantified as a rate (i.e.,tons/year), making growth rates significant for accurate estimates. However, average DBH growth rates differ among studies. Smith [29] and Nowak [20] reported an average growth rate of 0.61 cm/year for urban tree species. Nowak [20] also used different constants to account for tree condition: 1 for trees in excellent condition, 0.76 for trees in poor condition, and 0.42 for trees in critical condition. In Korea, Park [30] estimated that the average DBH growth rates for three common street trees in Gyeonggi-do, the most populous province in Korea, were 1.25 cm/year for *Ginkgo biloba*, 1.23 cm/year for *Zelkova serrata*, and 1.41 cm/year for *Platanus occidentalis*. Given this variability in DBH growth rates across studies, I exercised caution in estimating carbon dioxide sequestration rates. Instead, my focus was on quantifying the total amount of carbon dioxide sequestered (Table 4).

Table 4. Total carbon storage and sequestration summary for the five dominant trees in Jung-Gu District.

Tree Species	The Average of DBH (cm)	N	Total Carbon Storage (ton)	Total Carbon Dioxide Sequestration (ton)
Platanus occidentalis	32.1	1842	20.86	76.49
Ginkgo biloba	20.9	1292	9.53	34.93
Zelkova serrata	29.5	819	8.52	31.25
Quercus palustris	29.1	667	6.85	25.11
Chionanthus retusus	16.6	462	2.71	9.92
Total		**5082**	**48.46**	**177.70**

Allometric parameters for the five predominant roadside trees were derived using DBH, height, and tree density. These parameters enabled me to estimate the total carbon storage and sequestration capacities of these trees. Collectively, these five species make up over 90% of the roadside trees and are responsible for storing 50 tons of carbon and sequestering 180 tons of CO_2 in the Jung-Gu District. During field measurements, I observed that many trees were planted in concrete. This setting might lead to an underestimation of the trees' actual carbon sequestration capabilities. For several trees, the trunk base was encased in concrete (Figure 9), and in some cases, the roots were visibly protruding.

Figure 9. Photograph of a tree in poor condition along a concrete roadside in Jung-Gu District

In the densely urbanized Jung-Gu District, these roadside trees serve as vital air purifiers. Given their importance, they warrant meticulous care and attention. The findings of this study show that non-destructive methods can effectively estimate a district's carbon storage and sequestration. Collaborative efforts with like-minded researchers could refine these equations further, making them applicable to specific districts or even entire cities.

Acknowledgment

I thank Korea Forest Service and the Daegu Jung-Gu District for their invaluable contribution to this study. Their statistics for roadside trees were instrumental in the completion of this research. I would also like to acknowledge the pioneering efforts of researchers who have devoted their careers to estimating the biomass of trees. Their studies have paved the way for further exploration in the field.

Reference

[1] Earth Observatory, *July 2023 Was the Hottest Month on Record.* [Online]. Available: https://earthobservatory.nasa.gov/images/151699/july-2023-was-the-hottest-month-on-record (accessed: Sep. 1 2023)

[2] W. Fan, B. Yang, F. Liang, and Z. Dong, "*Using Mobile Laser Scanning Point Clouds to Extract Urban Roadside Trees for Ecological Benefits Estimation*," International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B2-2020, pp. 211–216, 2020, doi: 10.5194/isprs-archives-XLIII-B2-2020-211-2020.

[3] Korea Forest Service, *2022 Street Tree Planting and Management Project Performance.* [Korean, Online]. Available: https://www.forest.go.kr/kfsweb/cop/bbs/selectBoardArticle.do?nttId=3181819&bbsId=BBSMSTR_1069&pageIndex=13&pageUnit=10&searchtitle=title&searchcont=&searchkey=&searchwriter=&searchdept=&searchWrd=&ctgryLrcls=&ctgryMdcls=&ctgrySmcls=&ntcStartDt=&ntcEndDt=&orgId=&mn=NKFS_06_09_01&component= (accessed: Sep. 1 2023).

[4] S.-H. Kim, C.-B. Cho, and H.-D. Kim, *"Investigation of Urban High Temperature Phenomenon in Summer Using the High Density Ground Monitoring System in Daegu Metropolitan Area,"* Journal of Environmental Science International, vol. 23, no. 9, pp. 1619–1626, 2014, doi: 10.5322/JESI.2014.23.9.1619.

[5] Daegu Transportation Corporation, *DTRO.* [Korean, Online]. Available: https://www.dtro.or.kr/ (accessed: Sep. 1 2023).

[6] S. Lee and K. Shim, *A study on park evaluation model for establishment of urban park policy*. Architecture and Urban Space Research Institute, Seoul, 2013.

[7] Daegu Metropolitan City, Jung-Gu, *Analyzing Daegu Metropolitan City's Jung-gu through Big Data.* [Korean, Online]. Available: https://www.jung.daegu.kr/bigdata/tree/TreeAnaly01.do (accessed: Sep. 1 2023).

[8] T. F. Miller, D. J. Mladenoff, and M. K. Clayton, *"Old-Growth Northern Hardwood Forests: Spatial Autocorrelation and Patterns of Understory Vegetation,"* Ecological Monographs, vol. 72, no. 4, pp. 487–503, 2002, doi: 10.1890/0012-9615(2002)072[0487:OGNHFS]2.0.CO;2.

[9] N. H. Phillsbury, J. L. Reimer, and R. P. Thompson, "*Tree Volume Equations for Fifteen Urban Species in California,"*. California Department of Forestry and Fire Protection, Los Angeles, 1998.

[10] J. Kalliovirta and T. Tokola, *"Functions for Estimating Stem Diameter and Tree Age Using Tree Height, Crown Width and Existing Stand Database Information,"* Silva Fenn., vol. 39, no. 2, 2005, doi: 10.14214/sf.386.

[11] M. T. Ter-Mikaelian and M.D. Korzukhin, *"Biomass Equation for Sixty-Five North American Tree Species,"* Forest Ecology and Management, vol. 97, Issue 1, pp. 1 - 24, 1997, doi:10.1016/S0378-1127(97)00019-4.

[12] J. C. Jenkins, D. C. Chojnacky, L. S. Heath, and R. A. Birdsey, *"National-Scale Biomass Estimators for United States Tree Species,"* Forest Science, vol. 49, no. 1, pp. 12–35, 2003.

[13] J. Tang *et al., "Enhancing Aboveground Biomass Estimation for Three Pinus Forests in Yunnan, SW China, Using Landsat 8,"* Remote Sensing, vol. 14, no. 18, p. 4589, 2022, doi: 10.3390/rs14184589.

[14] H. K. Jo, *Development of Model and Technology for Establishment, Management and Evaluation of Urban Forests in Living Zone to Improve Carbon Sequestration Sources and Multi-Dimensional Benefits Against New Climate Change Regime*. Korea Forest Service, Seoul, 2020.

[15] H.-K. Jo and T.-W. Ahn, *"Carbon Storage and Uptake by Deciduous Tree Species for Urban Landscape,"* Journal of the Korean Institute of Landscape Architecture, vol. 40, no. 5, pp. 160–168, 2012, doi: 10.9715/KILA.2012.40.5.160.

[16] J. H. Park, S. G. Baek, M. Y. Kwon, S. M. Je, and S. Y. Woo, *"Volumetric Equation Development and Carbon Storage Estimation of Urban Forest in Daejeon, Korea,"* Forest Science and Technology, vol. 14, no. 2, pp. 97–104, 2018, doi: 10.1080/21580103.2018.1452799.

[17] T. K. Yoon *et al., "Allometric Equations for Estimating the Aboveground Volume of Five Common Urban Street Tree Species in Daegu, Korea,"* Urban Forestry & Urban Greening, vol. 12, no. 3, pp. 344–349, 2013, doi: 10.1016/j.ufug.2013.03.006.

[18] M. I. Ishihara *et al., "Efficacy of Generic Allometric Equations for Estimating Biomass: A Test in Japanese Natural Forests,"* Ecological Applications, vol. 25, no. 5, pp. 1433–1446, 2015, doi: 10.1890/14-0175.1.

[19] M.G.R. Cannell, *World Forest Biomass and Primary Production Data*. Academic Press, London, UK, 1982.

[20] D. J. Nowak and D. E. Crane, *"Carbon Storage and Sequestration by Urban Trees in the USA,"* Environmental pollution, vol. 116, no. 3, pp. 381–389, 2002, doi: 10.1016/S0269-7491(01)00214-7.

[21] Intergovernmental Panel Climate Change 2003, *Good Practice Guidance for Land Use, Land-Use Change and Forestry.*
[Online]. Available: https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf (accessed: Sep. 1 2023).

[22] D. C. Chojnacky, L. S. Heath, and J. C. Jenkins, *"Updated Generalized Biomass Equations for North American Tree Species,"* Forestry, vol. 87, no. 1, pp. 129–151, 2014, doi: 10.1093/forestry/cpt053.

[23] G. G. Lee, *"Sustainability Indicators of Greenspace in Apartment Sites,"* Doctoral dissertation, The Graduate School Seoul National University, 2003.

[24] A. Sumida, T. Miyaura, and H. Torii, *"Relationships of Tree Height and Diameter at Breast Height Revisited: Analyses of Stem Growth Using 20-Year Data of an Even-Aged Chamaecyparis Obtusa Stand,"* Tree Physiology, vol. 33, no. 1, pp. 106–118, 2013, doi: 10.1093/treephys/tps127.

[25] D. Abetu and T. Bekele, *"Carbon Stock in the Dirki Woodland Vegetation of Central Ethiopia: A Case Study in Ilu Gelan District, West Shewa Zone, Oromia Regional State,"* Tropical Plant Research, vol. 6, no. 3, pp. 438–451, 2019, doi: 10.22271/tpr.2019.v6.i3.054.

[26] N. C. Siliprandi, E. M. Nogueira, J. J. Toledo, P. M. Fearnside, and H. E. M. Nascimento, *"Inter-Site Variation in Allometry and Wood Density of Goupia Glabra Aubl. In Amazonia,"* Brazilian Journal of Biology, vol. 76, no. 1, pp. 268–276, 2016, doi: 10.1590/1519-6984.22514.

[27] J. Ha, G. Baek, B. Choi, J. Lee, Y. Son, and C. Kim, *"Development of Allometric Equations for Carbon Storage of Ginkgo Biloba Linn., Zelkova Serrata (Thunb.) Makino. And Prunus × Yedoense Matsum. Planted in Jinju-City,"* KSCCR, vol. 13, no. 2, pp. 135–145, 2022, doi: 10.15531/KSCCR.2022.13.2.135.

[28] H.-K. Jo, J.-Y. Kim, and H.-M. Park, *"Carbon Reduction Effects of Urban Landscape Trees and Development of Quantitative Models - for Five Native Species -,"* Journal of the Korean Institute of Landscape Architecture, vol. 42, no. 5, pp. 13–21, 2014, doi: 10.9715/KILA.2014.42.5.013.

[29] W. B. Smith and S. R. Shifley, *"Diameter Growth, Survival, and Volume Estimates for Trees in Indiana and Illinois,"* St. Paul, MN, 1984.

[30] E. Park and K. Kang, *"Estimation of C Storage and Annual CO2 Uptake by Street Trees in Gyeonggi-Do,"* Korean Journal of Environment and Ecology, vol. 24, no. 5, pp. 591–600, 2010.