Regular Article
pISSN: 2288-9744, eISSN: 2288-9752
Journal of Forest and Environmental Science
Vol. 39, No. 3, pp. 128-139, September, 2023
https://doi.org/10.7747/JFES.2023.39.3.128

JFES
Journal of Forest and Environmental Science

Effect of Carbon Sequestration and Oxygen Production of Trees on Kangwon National University Campus

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Abstract

Urban forests serve multiple purposes by providing green resting spaces and environmental benefits for city residents. In the old city center, where parks are scarce, the campus of Kangwon National University, Chuncheon, Gangwon-do, South Korea, serves as an urban forest for students, faculty, and citizens. This study aims to quantitatively analyze the environmental functions of green spaces on campus, raising awareness about their importance among campus members. The total carbon storage of campus trees was estimated at 1,653,218 kg, including 1,512,586 kg in forest areas, 131,061 kg in planting spaces around buildings, and 9,571 kg in street spaces. The annual carbon uptake of campus trees was estimated to be 39,391 kg/year, with 30,144 kg/year in forest areas, 8,017 kg/year in planting spaces around buildings, and 1,230 kg/year in horizontal spaces. In addition, annual oxygen production was estimated to be 105,044 kg/year, with 80,385 kg/year in forest areas, 21,378 kg/year in planting spaces around buildings, and 3,281 kg/year in street spaces. Furthermore, we estimated carbon emissions from the use of on-campus facilities to be 4,856,182 kg/year, while oxygen consumption by members was estimated at 53,975 kg/year. However, the campus trees supplied a sufficient amount of oxygen, which was twice the amount required by school members. The carbon uptake amount was approximately 1% of the amount of carbon emissions, resulting in a modest contribution to improving the environmental conditions of the site.

Key Words: urban forest, green campus, carbon storage, carbon sequestration, oxygen production

Introduction

Trees perform a variety of essential environmental functions. For instance, the cumulative carbon uptake of a 25-year-old zelkova tree can offset approximately 5% of per capita carbon emissions from household electricity consumption over the same period (Jo and Park 2017). Furthermore, a zelkova tree with a diameter of 20 cm can collect an annual rainfall volume of 5.1 m^3 (Park et al. 2021). Urban trees and forests also contribute positively to human health by removing gaseous pollutants through their leaf stomata (Nowak et al. 2014). On average, the net annual oxygen production of trees offsets oxygen consumption by 19 people per year (Nowak et al. 2007).

These environmental functions provided by trees are attracting great attention from citizens in modern society. Internationally, there have been notable efforts to quantitatively evaluate and utilize the environmental functions of

Received: July 5, 2023. Revised: August 18, 2023. Accepted: August 18, 2023.

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trees. For example, in Boulder, Colorado and Columbia, Missouri, USA, comprehensive urban forest plans have been established, incorporating quantitative evaluations to determine the target tree crown densities and planting strategies (Kwak 2020). Additionally, in Northampton, Massachusetts, USA, the evaluation results are used to raise public awareness about the importance of urban forests and downtown trees. In Louisiana, the results are used to assess post-disaster damage and develop recovery and restoration plans to improve the environmental functions of trees (Kwak 2020). However, while many studies in Korea have focused on deriving quantitative values for various environmental functions of trees, there is a lack of practical applications or policy integration based on the research outcomes.

Therefore, the purpose of this study was to quantify the carbon storage, absorption capacity, and annual oxygen production of the trees on the campus of Kangwon National University, Chuncheon, Gangwon-do, South Korea. Chuncheon is a small city with a population of 280,000 and has 140 small urban parks with a total area of 3,826,000 m^2. Kangwon National University's Chuncheon Campus has a total area of 963,425 m^2, which is about 1/4 of the total area of urban parks in Chuncheon, where large parks are lacking. A forest area of 199,197 m^2 and a walking trail of more than 3 km on campus function as a large park for citizens. As the campus trees resemble urban forests in terms of their location and environmental characteristics and include forest trees, trees in green spaces, and roadside trees, the study aims to compare the carbon emissions and oxygen consumption of the site to the environmental functions of the trees on campus. This study will be meaningful in quantitatively confirming the net function of carbon reduction and oxygen production of campus trees provided to the local community.

Materials and Methods

Spatial extent

The target area of this study was the Chuncheon Campus of Kangwon National University, South Korea, covering an area of 963,425 m^2 (Fig. 1). To estimate the environmental function of trees across the campus, the tree growth space was divided into the forest area, planting spaces around buildings, and street spaces, considering the cost and time required.

The forest area was determined by selecting lands with a minimum area of 0.5 ha, a minimum width of 30 m, and a canopy cover of at least 10% for trees capable of growing to a height of 5 m or more (Nowak 1994). Within the selected forest area, 30 circular survey areas were randomly selected using ArcGIS Pro's Create Random Points. A circular plot size of 11.3 m was set based on a study by Nowak et al. (2007). Latitude and longitude coordinates were obtained for 30 points using ArcGIS Pro's Calculate Geometry, and a circular survey sphere with a radius of 11.3 m was installed for each of the 30 plots following a site survey based on the latitude and longitude coordinates (Fig. 2). A total of 1,037

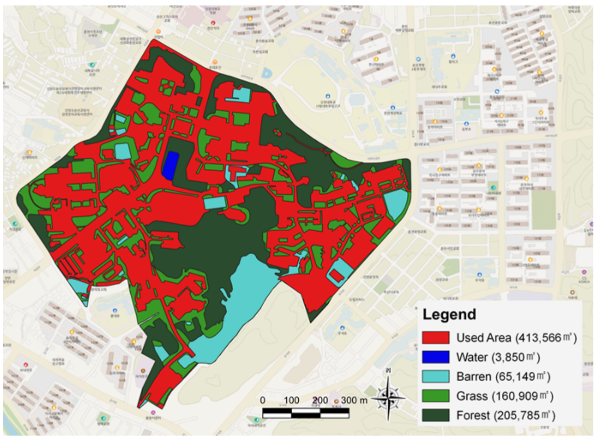

Fig. 1. Land cover map of the site.

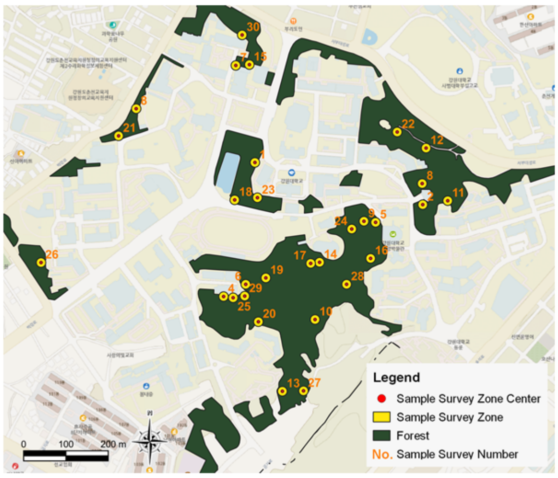

Fig. 2. Map of sampling survey area of forest area.

trees with a height of 30.5 cm or more and a xylem diameter of 2.54 cm or more, which were defined as trees by Nowak et al. (2007), were investigated.

For the planting space around the building, 30 circular survey areas of grass on the land cover map were extracted using the same method as that used for the forest area. The radius of the survey area was set to 11.3 m (Fig. 3). In addition, 359 trees with a height of 30.5 cm or more and a chest diameter of 2.54 cm or more were investigated.

The street space was limited to Kangwon Daehak-gil 1, which spans approximately 1 km. The trees were planted and managed at regular intervals of 6–8 m in or around the road area (Fig. 4). A total of 112 ginkgo, zelkova, and cherry trees were planted along Kangwon Daehak-gil 1 at intervals of approximately 8 m.

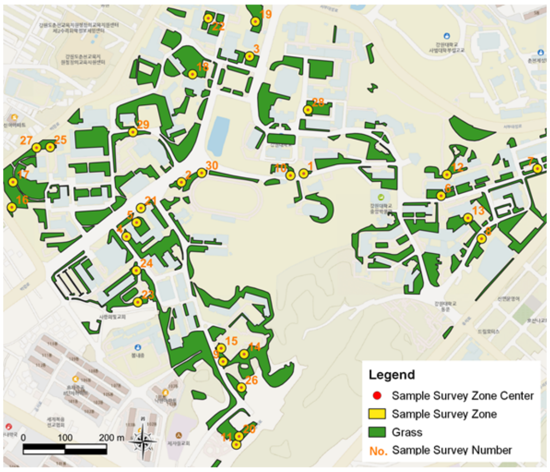

Fig. 3. Map of sampling survey area of planting space around the building.

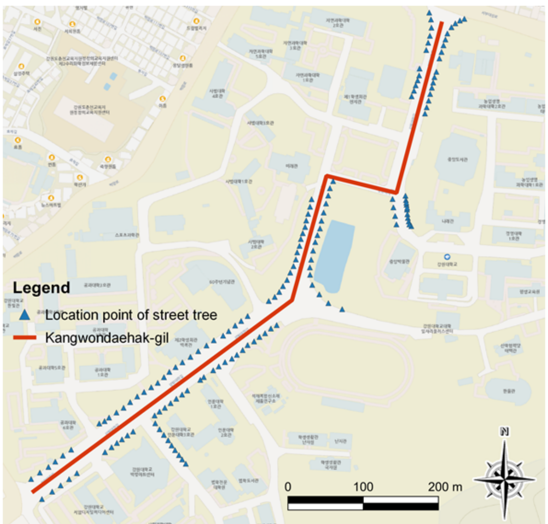

Fig. 4. Trees of street spaces.

Investigation items and period

In this study, we focused on quantifying the environmental factors of trees, specifically carbon storage and uptake and annual oxygen production. For quantification purposes, we selected tree species name and chest diameter as common input values. The forest area was surveyed on July 8, 10, and 16, 2022, and the planting space around the building was surveyed on September 24 and 25, 2022. Street spaces were investigated during the daytime on May 1, 2022.

The estimation method of carbon storage

The carbon storage amount defined in this study refers to the amount of carbon accumulated in trees over a long period, while the carbon uptake represents the difference between the carbon storage amount of a tree in the reference year and that in the following year (reference year±1) (Jo et al. 2019). The carbon storage in the forest area was calculated by multiplying the tree biomass with the carbon conversion factor (0.51 for conifers and 0.48 for broad-leaved trees) (Eggelston et al. 2006). Two methods for estimating tree biomass relative growth were used. The first method utilized the equation presented in the Carbon Emission Factors by Major Tree Species for Forest Greenhouse Gas Inventory (Korea Forest Research Institute 2010) (Table 1).

The second method involved a tree biomass relative growth model developed by dividing tree parts into stems,

Table 1. Allometric equation1 for estimating forest tree biomass

Species of trees	Allometric equation*	R^2
Pinus densiflora	$Y=204.303D^{2.21887}$	0.9839
Pinus rigida	$Y=298.996D^{2.18435}$	0.9316
Pinus koraiensis	$Y=107.308D^{2.46030}$	0.9822
Larix kaempferi (Lamb.) Carrieère	$Y=149.903D^{2.40737}$	0.9504
Quercus acutissima Carruth	$Y=421.731D^{2.19347}$	0.8931
Quercus mongolica	$Y=834.069D^{1.91565}$	0.9240

*Y, dry weight (g); D, diameter at breast height (cm); R^2, coefficient of determination.
Source: Korea Forest Research Institute (2010), Author Rewriting.

branches, leaves, and roots for each major tree species in Korea (Korea Forest Research Institute 2014). The formulas used for each species based on breast diameter is presented in Table 2.

By applying both relative growth equations and the carbon conversion coefficient, we calculated the carbon storage

Table 2. Allometric equation 2 for estimating forest tree biomass

Species of trees	Allometric equation*		Equation range of use diameter at breast height	R^2
Pinus densiflora	Stem	$Y=0.209D^{2.087}$	6-70 cm	0.960
	Branch	$Y=0.067D^{1.995}$		0.867
	Leaf	$Y=0.100D^{1.635}$		0.632
	Root	$Y=0.231D^{1.753}$		0.875
Pinus rigida	Stem	$Y=0.220D^{2.116}$	6-40 cm	0.940
	Branch	$Y=0.004D^{2.814}$		0.711
	Leaf	$Y=0.035D^{1.743}$		0.708
	Root	$Y=0.063D^{2.285}$		0.791
Pinus koraiensis	Stem	$Y=0.064D^{2.377}$	6-40 cm	0.929
	Branch	$Y=0.621D^{1.395}$		0.345
	Leaf	$Y=0.025D^{2.237}$		0.773
	Root	$Y=0.056D^{2.175}$		0.903
Larix kaempferi (Lamb.) Carrière	Stem	$Y=0.016D^{2.888}$	6-50 cm	0.954
	Branch	$Y=0.005D^{2.774}$		0.633
	Leaf	$Y=0.215D^{1.864}$		0.541
	Root	$Y=0.009D^{2.806}$		0.796
Quercus acutissima Carruth	Stem	$Y=0.051D^{2.724}$	6-30 cm	0.851
	Branch	$Y=0.012D^{2.854}$		0.822
	Leaf	$Y=0.006D^{2.478}$		0.568
	Root	$Y=0.460D^{1.669}$		0.658
Quercus mongolica	Stem	$Y=0.595D^{1.766}$	6-40 cm	0.828
	Branch	$Y=0.007D^{2.970}$		0.845
	Leaf	$Y=0.005D^{2.362}$		0.625
	Root	$Y=0.691D^{1.526}$		0.711
Quercus serrata	Stem	$Y=0.177D^{2.195}$	6-30 cm	0.941
	Branch	$Y=0.003D^{3.265}$		0.896
	Leaf	$Y=0.002D^{2.713}$		0.849
	Root	$Y=0.400D^{1.676}$		0.604
Robinia pseudoacacia	Stem	$Y=0.173D^{2.178}$	6-30 cm	0.994
	Branch	$Y=0.041D^{2.358}$		0.993
	Leaf	$Y=0.027D^{2.040}$		0.988
	Root	$Y=0.006D^{3.131}$		0.990
Liriodendron tulipifera	Stem	$Y=0.121D^{2.288}$	6-50 cm	0.908
	Branch	$Y=0.020D^{2.228}$		0.686
	Leaf	$Y=0.090D^{1.263}$		0.484
	Root	$Y=0.0001D^{3.913}$		0.919
Castanea crenata	Stem	$Y=0.0003D^{4.217}$	6-30 cm	0.863
	Branch	$Y=0.010D^{3.006}$		0.949
	Leaf	$Y=0.261D^{1.199}$		0.891
	Root	$Y=0.130D^{2.159}$		0.917

*Y, dry weight (kg); D, diameter at breast height (cm); R^2, coefficient of determination.
Source: Korea Forest Research Institute (2010), Author Rewriting.

amount for each tree by calculating the mean value. When applying the aboveground biomass calculation formula derived from forest trees to trees growing in two open environments under management, previous studies have shown that they tend to underestimate the biomass, even when trees have the same diameter at breast height. Therefore, two models developed specifically for landscape trees were considered and applied to calculate the carbon storage amount of trees in the planting space around the building (Nowak 1994).

Landscape trees differ from forest trees in terms of variations in management activities, competition with adjacent trees, growth density, tree type, and health (Park et al. 2021). Therefore, in this study, a quantitative model for each tree type developed for landscaping purposes growing in open environments within cities was applied as the first regression equation (Table 3). For the second regression formula for calculating the carbon storage of trees growing in the planting space around a building, we modified an existing equation from the study by Lee (2003), which estimated the amount of carbon dioxide storage and absorption. This regression formula simplified tree species into broad-leaved and coniferous trees (Table 4). The regression formula was developed by combining relevant prior studies to classify the trees at the target site into broad-leaved and coniferous trees, calculating the average of each total diameter at breast height and applying the value. Similar to that of the forest, two carbon storage units per tree were derived using the two regression equations, and their arithmetic averages were calculated.

Regarding street spaces, street trees were considered landscaping trees, and the regression equation for calculating the carbon storage amount for these was similar to that for trees in the planting space around the building. However, the regression equation for calculating carbon storage in single trees by landscape tree2 (Table 4) was developed based on the number of trees occupying a certain area and the average diameter at breast height. We de-

Table 3. Regression equation 1 for calculation of carbon storage in single tree by landscape tree species

Species of trees	Regression equation*	Equation range of use diameter at breast height	R^2
Acer palmatum	$Y=-23.2064+4.8538D$	5-20 cm	0.9666
Zelkova serrata	$\ln Y=-2.4708+2.3862\ln D$	5-28 cm	0.9951
Prunus yedoensis Matsum	$\ln Y=-2.8265+2.4181\ln D$	5-23 cm	0.9916
Ginkgo biloba	$\ln Y=-2.8428+2.3787\ln D$	5-25 cm	0.9855
Pinus densiflora	$\ln Y=-3.1140+2.4430\ln D$	5-25 cm	0.9821
Pinus koraiensis	$\ln Y=-4.4489+2.8942\ln D$	5-31 cm	0.9857
Abies holophylla Max	$\ln Y=-2.2126+2.0814\ln D$	5-19 cm	0.9818
Chionanthus retusa	$\ln Y=-2.7512+2.4952\ln D$	3-11 cm	0.9851
Cornus officinalis	$\ln Y=-3.3110+2.4057\ln Dg$	3-15 cm	0.9790
Prunus armeniaca var. ansu Maxim	$\ln Y=-2.4307+2.2999\ln D$	4-14 cm	0.9883
Taxus cuspidata	$\ln Y=-3.7842+2.4407\ln Dg$	2-15 cm	0.9552

*Y, carbon storage (kg/tree); D, diameter at breast height (cm); Dg, diameter of root (cm); R^2, coefficient of determination.
Source: Jo and Ahn (2012); Jo et al. (2013, 2014), Author Rewriting.

Table 4. Regression equation 2 for calculation of carbon storage in single trees by landscape tree species

Item	Formula*	Range of diameter at breast height
Broad-leaved tree carbon storage	$\ln Y=-1.3582+2.4595\ln DBH_{aver}$	5-40 cm
Coniferous tree carbon storage	$\ln Y=-1.0470+2.1436\ln DBH_{aver}$	5-40 cm

*Y, carbon storage (kg/tree); DBH_{aver}, average diameter of basal height (cm).
Source: Lee (2003).

termined that the equation would be difficult to apply to trees growing in the street space of this study. Therefore, only the regression equation for calculating carbon storage in single trees by landscape tree1, developed to calculate the carbon storage amount of a single tree, was used to calculate the carbon storage of trees in the street space (Table 3).

The total area of carbon storage was estimated for the surveyed forest as part of a sample survey, as well as for the planting space around the building. In the survey area unit, the total amount of carbon stored by trees was calculated by adding all the carbon storage of each tree and the amount of tree carbon storage per unit area of each survey area (kg/m^2; calculated by dividing the calculated total amount by the survey area [400 m^2]). Subsequently, the standard error between values was calculated. Finally, the average carbon storage by trees per unit area of the obtained forest area and the planting space around the building was multiplied by the total forest area (205,785 m^2) and the area of the planting space around the building (160,909 m^2). In addition, by adding the amount of carbon stored by street space trees to this value, the total carbon stored by trees was estimated for all tree growth spaces at the target site.

The estimation method of annual carbon uptake

The values derived from two methods were averaged to calculate the annual carbon uptake of trees in the forest areas. The first method involved using a formula based on the IPCC guidelines to calculate the standard carbon uptake of major forest species (Formula 1).

$$\text{Carbon uptake by tree type } (tCO_2/ha/year) = Vol \times WD \times BEF \times (1+R) \times CF \times 44/12 \text{ (Formula1)}$$

where Vol is the regular average growth volume by tree species (m^3/ha), WD is the basic wood density (t $d.m/m^3$), BEF is the biomass expansion factor, R is the root content ratio, CF is the carbon conversion coefficient, and 44/12 is the carbon-carbon dioxide ratio.

The average growth volume by tree species (Vol) was determined using wooden load biomass and forestry yield table (Korea Forest Research Institute; Korea Forest Service 2021) of the real forest forestry yield table. To derive Vol, the status index was assessed based on the stand age and height of the dominant tree. The stand age was selected by referring to the forest floor map of the target site provided by the Forest Space Information Service of the Korea Forest Service, and the height of the dominant tree was selected based on actual measurements. After selecting the status index, Vol was derived based on the average diameter. Fourteen species from target sites that could be derived from the real forest forestry yield table were identified. Considering that the unit of Vol is m^3/ha and the area of the forest survey area in this study was 0.04 ha, the value presented in the real forest forestry yield table was multiplied

Table 5. National specificity coefficient and carbon conversion coefficient by major tree species in forest

Species of trees coefficient	Basic wood density	Biomass expansion factor	Root content ratio	Carbon conversion coefficient
Pinus densiflora	0.419	1.483	0.258	0.51
Pinus koraiensis	0.408	1.742	0.276	
Larix kaempferi (Lamb.) Carrière	0.453	1.335	0.291	
Pinus rigida	0.504	1.325	0.362	
Quercus acutissima Carruth	0.721	1.450	0.313	0.48
Quercus mongolica	0.663	1.603	0.388	
Castanea crenata	0.510	2.630	0.50	
Quercus serrata	0.660	1.550	0.430	
Quercus variabilis Blume	0.720	1.340	0.320	
Robinia pseudoacacia	0.640	1.470	0.480	
Liriodendron tulipifera	0.460	1.240	0.230	

Source: Korea Forest Research Institute (2019); Ministry of Environment (2013, 2014, 2017, 2018), Author Rewriting.

by 0.04 for each tree and then converted to kg by multiplying by 1,000. Wood density (WD), biomass expansion factor (BEF), root content ratio (R), and carbon conversion coefficient (CF) were calculated for each tree species according to the National Greenhouse Gas Emissions and Uptake Coefficient provided by the Ministry of Environment's Greenhouse Gas Information Center (Table 5).

Finally, to calculate the annual carbon uptake per single tree, the number of residual trees equivalent to an area of 0.04 ha was derived based on the residual trees (number/ha) by major tree species by the age of stand suggested in the "standard carbon uptake of major forest species" (Korea Forest Research Institute 2019). This number was then divided by the corresponding figure (Table 6).

The second method was used to calculate the annual carbon uptake of trees in the forested areas using the "annual CO_2 uptake per tree (kg/tree/year)" (Table 7). For the tree species listed in Table 7, among the trees measured in the 30 survey districts, the annual CO_2 uptake per tree was derived based on the age class presented in the forest floor map. To calculate the amount of carbon from the annual CO_2 uptake per tree, the annual carbon uptake per tree in the forest was calculated by multiplying the carbon fraction by 12/44.

To calculate the annual carbon uptake of trees growing in the planting space around the building, two regression equations were selected to calculate the annual carbon absorption, and the average value was derived. The annual carbon uptake of the planting space around the building, similar to carbon storage, was also calculated using a regression equation developed for each tree species, specifically for the urban landscape trees growing in open areas (Table 8).

Table 6. Residual trees (number/ha) by major forest species by age of stand

Species of trees	Age of stand												
	10	15	20	25	30	35	40	45	50	55	60	65	70
Pinus densiflora	5,475	3,041	2,030	1,499	1,181	1,017	917	811	732	670	621	581	549
Pinus koraiensis	3,314	2,037	1,362	994	868	733	644	583	541	511	489	473	462
Larix kaempferi (Lamb.) Carrière	2,114	2,013	1,144	873	693	594	536	501	488	482	477	472	468
Pinus rigida	4,941	2,965	2,033	1,504	1,170	946	878	764	679	614	564	526	495
Quercus acutissima Carruth	1,814	1,383	1,172	1,021	995	902	826	761	706	658	616	579	545
Quercus mongolica	7,360	4,591	2,689	1,850	1,399	1,123	955	819	697	602	554	509	477

Source: Korea Forest Research Institute (2019), Author Rewriting.

Table 7. Annual CO_2 uptake per tree (kg/tree/year) by major forest species

Species of trees	Age of stand												
	10	15	20	25	30	35	40	45	50	55	60	65	70
Pinus densiflora	1.4	3.2	5.0	6.7	8.1	8.8	9.0	9.2	9.2	9.0	8.6	8.1	7.6
Pinus koraiensis	1.6	5.2	8.6	11.6	12.5	13.6	14.1	14.2	14.0	13.7	13.3	12.8	12.3
Larix kaempferi (Lamb.) Carrière	4.3	4.7	9.2	11.5	13.6	15.0	15.8	16.2	16.1	15.8	15.6	15.5	15.3
Pinus rigida	0.9	3.6	6.8	9.2	10.6	11.1	9.9	9.3	8.6	7.9	7.3	6.7	6.4
Quercus acutissima Carruth	6.2	9.4	13.5	14.6	14.1	14.5	14.9	15.2	15.5	15.8	15.9	16.1	16.3
Quercus mongolica	1.2	2.6	5.6	6.4	6.7	8.1	8.8	9.7	10.7	11.8	12.3	12.8	13.1

Source: Korea Forest Research Institute (2019), Author Rewriting.

Table 8. Regression equation 1 for calculation of the annual carbon uptake in single trees by landscape tree species

Species of trees	Regression equation*	Range of diameter at breast height	R^2
Acer palmatum	Y=0.9608+0.1535D	5-20 cm	0.9491
Zelkova serrata	lnY=−2.8177+1.7715lnD	5-28 cm	0.9810
Prunus yedoensis Matsum	lnY=−3.0939+1.7702lnD	5-23 cm	0.9764
Ginkgo biloba	lnY=−3.6471+1.8287lnD	5-25 cm	0.9906
Pinus densiflora	lnY=−2.6720+1.5251lnD	5- 25 cm	0.9999
Pinus koraiensis	lnY=−4.4881+2.2262lnD	5-31 cm	0.9818
Abies holophylla Max	lnY=−3.1386+1.6158lnD	5-19 cm	0.9228
Chionanthus retusa	lnY=−2.2695+1.7554lnD	3-11 cm	0.9503
Cornus officinalis	lnY=−3.1622+1.8844lnDg	3-15 cm	0.9593
Prunus armeniaca var. ansu Maxim	lnY=−2.8278+1.8824lnD	4-14 cm	0.9737
Taxus cuspidata	lnY=−4.7726+1.8554lnDg	2-15 cm	0.9909

*Y, carbon storage (kg/tree); D, diameter atbreast height (cm); Dg, diameter of root (cm); R^2, coefficient of determination.
Source: Jo and Ahn (2012); Jo et al. (2013, 2014), Author Rewriting.

The second regression equation (Table 8) was adopted to calculate the annual carbon uptake of trees growing in the planting space around the building for broad-leaved trees and conifers and was adopted as the second regression equation to calculate. This regression equation was developed by classifying the trees at the target site into broad-leaved trees and conifers, calculating the average diameter at breast height, and applying the corresponding values. In this study, the average diameter at the breast height of broad-leaved trees and conifers was calculated and applied to each of the 30 survey areas installed in the planting space around the building to determine the annual carbon uptake of trees in those areas.

To calculate the annual carbon uptake of trees growing in the street space, street trees were regarded as landscaping trees and selected in the same way as that for the regression equation for calculating the annual carbon uptake of the planting space around the building. However, the regression equation for the annual carbon uptake calculation in single trees by landscape tree species (Table 8) was designed to calculate the annual carbon uptake by applying the number of trees occupying a certain area and the average diameter at breast height and was deemed unsuitable for tree growth in the street space in this study. Therefore, only the regression equation for calculating the annual carbon uptake of single trees by landscape tree species was used (Table 8).

To estimate the annual carbon uptake of all trees at the target site, the total annual carbon uptake of trees for each of the 30 sample survey areas in the forest and the planting space around the building was divided by the survey area. In other words, the total annual carbon uptake by trees was calculated for each survey area and divided by 400 m^2, i.e., the survey area, to calculate the annual carbon uptake of trees per area with a unit of kg/m^2. Subsequently, standard errors between the values were confirmed. Finally, the average annual carbon uptake by trees per unit area in the forest and the planting space around the building was multiplied by the total area of the forest (205,785 m^2) and the area of the planting space around the building (160,909 m^2). Additionally, by adding the average annual carbon uptake by trees in the street space to this value, the average annual carbon uptake by trees was estimated for all tree growth spaces at the target site.

Estimation method of annual oxygen production of trees

In this study, the annual net oxygen production of the trees was calculated by subtracting the amount of oxygen consumed during respiration from the amount of oxygen produced through photosynthesis. The formula for calculating the amount of net oxygen produced per year by trees is given as Formula 2 and is estimated from the annual carbon uptake based on the atomic amount (Nowak et al. 2007).

Net annual oxygen (O_2) production (kg/year) = net annual Carbon (C) uptake × 32/12 (Formula 2)

Therefore, annual oxygen production was calculated by applying it to trees surveyed in forest areas, planting spaces around buildings, and street spaces (Formula 2). The estimation of the total annual oxygen production for the entire target site followed the same approach as the estimation of carbon storage and annual carbon uptake of all trees in the target site.

The amount of consumed carbon and oxygen in the study site

To understand the carbon emissions of the Kangwon National University Chuncheon Campus, the target site and annual greenhouse gas emissions data provided by the Gangwon National University Secretariat were used. Since Kangwon National University was designated a greenhouse gas emission management company (business site) in 2013, this dataset includes annual greenhouse gas reduction performance, reduction target achievement status, greenhouse gas emissions from emission facilities, and total greenhouse gas emissions. As of 2021, the greenhouse gas emission allowance on campus was considered as an indicator to evaluate the environmental contribution of trees in this study. The unit of greenhouse gas emissions in the data is carbon dioxide equivalent tons (tCO_2eq). Carbon emissions were derived by multiplying 12/44, the fraction of carbon in carbon dioxide, to compare the carbon storage and uptake of the trees calculated in this study.

To determine oxygen consumption by campus members, the 2021 Gangwon University Statistical Yearbook was referred to for information on the faculty, employees, and students. The statistical data indicated that there were 2,120 faculty members, 525 employees, and 15,204 students. Additionally, the average daily oxygen consumption per person was confirmed to be approximately 325 L (Loer et al. 1997). The annual oxygen consumption by members generated at the target site was calculated by multiplying the number of members on campus by the average daily oxygen consumption per person.

Results and Discussion

Carbon storage amount of trees

The total amount of carbon stored by the trees in each of the 30 circular survey areas in the forest was 88,203.91 kg. To estimate carbon storage by all trees in the target forest area, the average carbon storage per unit area of the forest, which was calculated based on the carbon storage of trees in 30 circular survey areas in the forest, was 7.35 kg/m^2. The standard error for the average carbon storage values per unit area from the 30 surveys was found to be 0.75. Therefore, the average carbon storage of 7.35 kg/m^2 can be used to estimate the total carbon storage of trees across the entire forest. By multiplying this value by the area of the forest, i,e., 205,785 m^2, the estimated amount of carbon stored by trees in the entire forest at the target site was found to be approximately 1,512,586 kg.

The total amount of carbon stored by the trees in each of the 30 circular survey areas in the planting space around the building was 9,774.03 kg. The average carbon storage per unit area of the planting space around the building was calculated as 0.81 kg/m^2 based on the carbon storage of trees in the 30 circular survey areas. The standard error of the average carbon storage values per unit area of 30 surveys was confirmed to be 0.14. Therefore, the average carbon storage of 0.81 kg/m^2 could be used to estimate the carbon storage of trees within the entire planting space around the building. By multiplying this value by the designated area of the planting space around the building (160,909 m^2) in this study, the estimated amount of carbon stored by trees in the entire planting space around the building in the target site was found to be approximately 131,061 kg.

The carbon storage of the 106 trees, including 66 zelkova trees, 32 cherry trees, and 8 ginkgo trees, surveyed in the street space was 9,570.63 kg. The amount of carbon stored by the 106 trees surveyed in the street space was estimated to be approximately 9,571 kg. This value shows a higher carbon storage capacity for street trees growing in a relatively small area than for those in the planting space around the building or forest due to growth at a sufficient distance from the surrounding trees and good solar radiation conditions.

Therefore, the amount of carbon storage by trees in the entire growth space of the target site of this study was estimated to be approximately 1,653,218 kg by adding all three of the above figures.

Annual carbon uptake amount of trees

The annual carbon uptake of trees surveyed in 30 circular surveys in the forest was calculated as 1,757.82 kg/year. To estimate the annual carbon uptake by all the trees in the forest within the target area, we used the average annual carbon uptake per unit area of the forest, which was determined to be 0.15 kg/m^2/year. This value was calculated based on the annual carbon uptake of trees in the 30 circular surveys in the forest, with a standard error of 0.02 for the average annual carbon absorption values per unit area of 30 surveys. Therefore, by multiplying this average value by the area of the forest set in the study (205,785 m^2), the annual carbon uptake by trees in the entire forest at the target site was estimated to be approximately 30,144 kg/year.

The annual carbon uptake of trees in the planting space around the building was calculated to be 597.85 kg/year. The average annual carbon uptake per unit area of the planting space around the building was 0.05 kg/m^2/year, with a standard error of 0.01 for the average annual carbon absorption values per unit area of 30 surveys. Therefore, we concluded that the value of 0.05 kg/m^2/year could be used to estimate the annual carbon uptake of trees for the entire planting space around the building. By multiplying it by the area of the planting space around the building in this study (160,909 m^2), the annual carbon uptake by trees in the entire planting space around the building in the target site was approximately 8,017 kg/year.

The annual carbon uptake by 112 trees surveyed in the street space, including 72 zelkova trees, 32 cherry trees, and 8 ginkgo trees, was 1,230.26 kg/year. This figure indicates a higher carbon uptake capacity of street trees growing in a relatively small area than of those in the planting space around the building or forest, owing to their growth at a sufficient distance from the surrounding trees and favorable solar radiation conditions.

Therefore, the annual carbon uptake by trees in the entire tree growth space of the target site in this study was estimated to be approximately 39,391 kg/year by adding all three of the above figures.

Annual oxygen production amount of trees

The annual oxygen production of trees surveyed in street spaces and 30 circular survey areas of the planting around the building and forest was estimated from the annual carbon uptake of the same tree multiplied by 32/12, which is the fraction of oxygen in carbon dioxide.

In order to estimate the annual oxygen production by entire trees in the forest in the target area, we calculated the average annual oxygen production per unit area of forest, which was found to be 0.39 kg/m^2/year. This value was determined based on the annual oxygen production of trees in 30 circular survey areas in the forest, with a standard error of 0.07. Therefore, we concluded that the value of 0.39 kg/m^2/year could be used to estimate the annual oxygen production of trees for the entire forest. By multiplying this value by the area of the forest (205,785 m^2), the annual oxygen production by trees in the entire forest in the target site was estimated to be approximately 80,385 kg/year.

The average annual carbon uptake per unit area of the planting space around the building was 0.13 kg/m^2/year. This value was calculated based on the annual oxygen production of trees in 30 circular surveys of the planting space around the building. The standard error of the average annual oxygen production values per unit area of 30 surveys was confirmed to be 0.02. Therefore, we concluded that the value of 0.13 kg/m^2/year could be used to estimate the annual oxygen production of trees for the entire planting space. By multiplying this value by the area of the planting space around the building (160,909 m^2), the annual oxygen production by trees in the entire planting space around the building in the target site was approximately 21,378 kg/year.

The annual oxygen production of the 122 trees surveyed in the street space was approximately 3,281 kg. Therefore, the annual oxygen production by trees in the entire tree growth space of the target site of this study was estimated to be approximately 105,044 kg/year by adding all three of the above figures.

The amount of consumed carbon and oxygen in the study site

To understand the carbon emissions of the Kangwon National University Chuncheon Campus, the target site, the annual greenhouse gas emissions data of Kangwon National University provided by the Gangwon National University Secretariat were used. The amount of greenhouse gas emission allowance on campus was considered as an indicator to evaluate the environmental contribution to the carbon uptake sector of trees by 2021. The greenhouse gas emissions were measured in tCO_2eq. Carbon emissions were derived by multiplying with 12/44, the fraction of carbon in carbon dioxide, and comparing with the annual carbon uptake of trees calculated in this study. Greenhouse gas emissions on the campus were 17,806 tCO_2eq in 2021, resulting in carbon emissions of 4,856,182 kg.

To determine oxygen consumption by campus members, we determined the number of faculty, employees, and students from the 2021 Gangwon National University Statistical Yearbook, which was confirmed to be 2,120, 525, and 15,204, respectively. Previous research indicated an average daily oxygen consumption per person was confirmed to be approximately 325 L (Loer et al. 1997). Considering the total number of members on the campus (17,849 as of 2021) and assuming that the average daily residence time per person was 6 h, the oxygen consumption per person was set to 80 L. In addition, using 150 class days in 2021, the annual oxygen consumption by members generated at the target site as of 2021 was calculated to be approximately 1,427,770 L.

Evaluation of the environmental contribution of trees

As a result of calculating the amount of environmental function by trees in the tree growth space at the target site, the annual carbon uptake by trees in the total tree growth space of the target site was estimated to be approximately 39,391 kg/year. As of 2021, the carbon emissions from the campus were estimated to be 4,856,182 kg. Therefore, compared to the carbon emissions on campus, the annual carbon uptake by trees was approximately 1%.

The annual oxygen production by trees in the total tree growth space of the target site was estimated to be approximately 105,044 kg/year, and the oxygen consumption by campus members by 2021 was estimated to be approximately 1,427,770 L. As the proportion of air is 1.2 kg/m^3 or 1.2 g/L, and the proportion of oxygen in the air is 21%, the oxygen consumption by campus members as of 2021 can be converted to approximately 53,975 kg. Therefore, the annual oxygen production by trees on campus was twice the amount of oxygen required by campus members in one year.

Conclusion

The purpose of this study was to select a calculation model based on the environmental functions of trees, classify tree growth spaces on campus that are similar to urban forests, and calculate the quantitative environmental function provided by trees by applying appropriate models according to space. Since the growth environment provided to trees by the planting and street space around the building and forest is quite different, it is necessary to use a calculation model that reflects the tree species and growth characteristics found in each space. The environmental function calculation model of trees by space used in this study was distinct.

Based on the findings of the study, trees growing in the forest exhibited poor competition with adjacent trees, had compromised crown health, and experienced suboptimal solar radiation conditions. However, compared to the trees in the planting and street spaces around buildings, the forest trees showed better growth density and contributed to a greater extent in terms of environmental functions, thereby enhancing the overall environmental conditions at the target site. In the case of further research in the future, a survey plot in which no trees exist should be included among the sample survey areas installed in the forest and the planting space around the building. In future research, it is crucial to conduct surveys in forest areas and planting space around buildings with no trees. Additionally, it is necessary to deploy survey areas that focus on tree growth spaces through on-site surveys of planting the space around the building and considering the floor and age of forest stands.

This study has some limitations. First, in deriving the regular average growth amount used to calculate the annual carbon uptake in forests, overestimation was made in calculating the growth by selecting a status index adjusted to the dominant tree's height. Thus, it is necessary to calculate more accurate growth for trees of various standards in the future. Second, when calculating the annual carbon uptake in the forest, it is necessary to supplement the future calculation method using the forest yield table produced based on real forests that are different from the forest at the target site and information on the number of remaining trees by major tree species and stand age. Third, when calculating the amount of environmental function, many trees were excluded due to too small or large a diameter at breast height or because no calculation model has been developed; therefore, further supplementary research is needed.

This study is meaningful because it presents a method for quantitatively evaluating the environmental functions of urban forest trees. The quantification of environmental functions provided by trees was conducted for campuses with the same environmental characteristics as urban forests consisting of forests, green areas, and street trees in the city. The findings of this study can be utilized to emphasize the need to improve qualitative value through the quantitative expansion of urban forests.

Acknowledgements

This study was carried out with the support of R&D Program for Forest Science Technology (Project No. 2019151D10-2323-0301) provided by Korea Forest Service (Korea Forestry Promotion Institute).

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