Master's Thesis of Landscape Architecture

Types and management of urban green spaces identified by the high resolution remotely sensed indices

– A case study of Gyeonggi–do Uiwang urban park –

고해상도 원격탐사 지수 기반 녹지 유형분류 및 관리방안 도출

– 경기도 의왕시 도시공원을 대상으로 –

August 2023

Graduate School of Environmental Studies
Seoul National University
Landscape Architecture Major

SOKYOUNG YI

Types and management of urban green spaces identified by the high resolution remotely sensed indices

– A case study of Gyeonggi–do Uiwang urban park –

Prof. Song, Youngkeun

Submitting a master's thesis of
Public Administration
August 2023

Graduate School of Environmental Studies
Seoul National University
Landscape Architecture Major
SOKYOUNG YI

Confirming the master's thesis written by
SOKYOUNG YI
June 2023

Chair _____
Vice Chair _____
Examiner _____

Types and management of urban green spaces identified by the high resolution remotely sensed indices

- A case study of Gyeonggi-do Uiwang urban park -

서울대학교 환경대학원 환경조경학과

SOKYOUNG YI

위 논문은 서울대학교 및 환경대학원 환경조경학과 학위논문 관련 규정에 의거하여 심사위원의 지도과정을 충실히 이수하였음을 확인합니다.

2023년 8월

위 원 장 _____ (서울대학교 환경대학원 교수)

부위원장 _____ (서울대학교 농업생명과학대학 교수)

위 원 _____ (서울대학교 환경대학원 교수)

Abstract

With growing environmental challenges in city, urban parks maintain the quality of the landscape and play an important ecological role. In particular, trees are closely linked to the maintenance of healthy ecosystems. However, the tree-based ecology of urban parks is often overlooked, and there is also a lack of ecological guidelines. Hence, a thorough evaluation of tree ecology becomes imperative, particularly for the future management of urban parks. Green space monitoring and evaluation is necessary to increase the environmental value of urban green spaces and to meet the needs of urban residents. The high-resolution data such as LiDAR and hyperspectral imagery has an advantage with fast and accurate information acquisition and measurement range. Also to assess green spaces, many studies have used green indicators, which can measure important changes in green spaces and their components over time and space, and can provide important information for park management decisions.

This study aims to identify the ecological characteristics of various parks in the city, mainly trees, using high-resolution data. In addition, by sequencing the characteristics, we aim to discover the value of ecological aspects by classifying parks according to ecological characteristics rather than park types that have been classified according to the purpose of use.

The spatial scope of the study is 40 urban parks in Uiwang City. Airborne LiDAR from two seasons, slam LiDAR, and hyperspectral imagery data were collected and merged for 40 parks, and 13 indicators were selected through prior research analysis. Individual tree characteristics and park-specific characteristics were extracted, and were analyzed using NMDS to divide the 40 parks into six clusters. As a result, the distribution of the distance between the parks and the differences between the six clusters were visually represented, and the park management plan was suggested through the comparison of characteristics by cluster. Furthermore, through the identification of parks with high ecological characteristics and potential facilities, we proposed a more effective urban park management plan that considers both the natural environment and park users.

This study is significant in that it attempts to derive ecological characteristics of trees and green areas through high-resolution data and suggest management plans. In the future, it is believed that a more systematic management plan for urban parks can be proposed by considering the ecological differences of trees by species, environmental

variables that affect the growth of trees, and the effects of intensity of use by users, which were not considered in this study.

Keyword : Urban ecology, Ecological indicators, NMDS, Remote sensing
Student Number : 2020-23477

Table of Contents

Lists of Tables

Lists of Figures

Chapter 1. Introduction

1. Background and research purpose

1) Research background

▌ Ecological value of city parks and trees followed by urbanization

Green infrastructure within a city is one of the most important issues in the 21st century. This is attracting attention as the importance of green spaces in cities is highlighted along with population and economic development due to changes in land use, especially due to the increase in urban space. Due to accelerated urban development, various environmental problems such as carbon dioxide emission, air quality degradation, and heat island phenomenon are occurring, which lead to risk exposure and biodiversity vulnerability for urban citizens' adaptation to the environment (Satterthwaite, 2009; Solecki & Marcotullio, 2013; McGranahan et al., 2007). This has been expected to play a key role in changing the environment and ecosystem (Eigenbrod et al., 2011), and highlighted the need for green infrastructure in cities.

Urban green infrastructure, that is, green space, not only maintains the quality of the landscape within the city, but also plays an important role ecologically. It provides various welfare for humans and ecosystems, and plays an important role in making cities more resilient by increasing their ability to adapt to climate change (Elmqvist et al., 2013; Kates & Wilbanks 2010; Lafortezza et al., 2019). Among various types of green infrastructure, such as greening rooftops, greening walls, urban forests, and gardens, urban parks are areas determined by urban management plans to protect urban

natural landscapes and improve the health, recreation, and emotional life of urban residents. It is a space that is frequently used and offers various benefits (Lee & An, 2021). In particular, modern urban parks are a key space that provides solutions to urban problems such as environmental management and environmental education, and their functions in terms of urban ecosystem are expanding (Park et al., 2023).

In particular, trees, a key component of urban parks, are closely related to the maintenance of a healthy ecosystem. Accordingly, studies on the environmental benefits provided by trees are also being actively conducted. First, trees in cities generate oxygen and store a large amount of carbon in branches, roots, and stems through photosynthesis during growth, making a great contribution to reducing carbon (Lee et al., 2014). . In addition, previous studies have revealed that trees reduce energy consumption in cities such as buildings, provide a cooling effect, and improve pollution (Akbari et al., 2001; Brack, 2002; Russo et al., 2014). In addition, they provide air purification, water quality control, habitat provision, and wind and noise reduction (Lovell & Taylor, 2013; Andersson et al., 2014).

Despite the social demand for the benefits to the city's ecosystem and quality of life and the expanding ecological function, the tree-centered ecology in city parks is not very prominent due to the purpose of 'use by city citizens' that city parks have. . In the existing management of urban parks, partial improvement of existing facilities is mainly carried out, and guidelines reflecting the ecological status are insufficient (Cho, 2018). Therefore, an appropriate current status evaluation of the ecology of city parks should be conducted centering on trees that play a large role in ecological functions, and based on this, management plans should be

established to improve the ecological functions of city parks to pursue ecological sustainability of the city (Gret-Regamey et al., 2015).

▮ Utilization of high-resolution data in the ecological evaluation of urban green spaces

Methods for assessing the ecological status of existing urban green spaces are time and labor intensive, or spatially correlated (Alonzo et al., 2014). Therefore, in the case of trees that play an important role in the ecological status, field surveys are generally required, but measurement is uncertain and time-consuming because there are many spatial and structural variables (Beland et al., 2019). In addition, due to the variability of forest structure, many errors occur in the sampling process (Alonzo et al., 2016).

The use of LiDAR and hyperspectral data can overcome these problems. LiDAR is Light Detection and Ranging, a surveying technology that can relatively quickly and accurately acquire 3D location information of all objects on the ground using laser pulses, mainly producing digital elevation models (DEMs). and has been used for 3D modeling of cities (Cho & Kim, 2010). Compared to traditional methods, LiDAR has advantages in speed of data acquisition, accuracy, and range of measurements, In forests, it has been used to derive high-resolution topographic maps and to estimate forest structure, including vegetation height and tree canopy structure, which is significant in the field of ecological science (Beland, 2019).

Hyperspectral images also provide high-resolution spectral information from a wide range of electromagnetic spectrum, making it possible to distinguish objects with minute differences in spectral characteristics. In particular, in Korea, forest classification is classified by stand rather than tree species, so

the accuracy is low. However, hyperspectral images have the great advantage of enabling detailed tree species classification (Cho & Lee, 2014). In particular, in the case of cities without clinical maps, tree species information can be obtained by minimizing field surveys (Dalponte et al., 2009).

As mentioned above, remote sensing in forests can provide different information depending on the method, time, and location of data acquisition. However, when properly overlaid, these data can provide more information values for analysis than when used individually (Li, 2019). For example, combining satellite imagery and LiDAR data can provide more accurate estimations of forest stand structure and carbon stocks (Raciti et al., 2014). It has also been shown that the overlap of leaf-off and leaf-on LiDAR data from different seasons can provide more explanatory power than single-season models, with the potential for shrub and tree modeling as well as understory vegetation modeling (Brubaker et al., 2018; Davidson et al., 2020).

2) Analysis of prior research on urban green space and vegetation evaluation using indicators

In order to increase the environmental value of urban green spaces and meet the demands of urban residents, sustainable management, such as securing urban park green spaces and ecological improvement measures for existing green spaces, is necessary (Chan, 2018). Accordingly, various studies have been conducted to efficiently preserve and manage urban green spaces, and among the methods for monitoring and evaluating them, many studies using green space indicators have been conducted. Green space indicators

are variables that can measure important changes in green space and its components over time and space, and through the use of indicators, can provide important information for decision-making about park management (Jenkins & Pigram, 2003; Astleithner et al., 2004).

Domestic and foreign studies that evaluated green spaces in cities using green space indicators presented and utilized indicators according to various evaluation purposes and functions, such as natural ecology, landscape ecology, and utilization aspects (Table 1).

Among the types of green space, studies evaluating various aspects of parks and green buffer zones have been conducted. In the study of Seong and Hwang (2013), they established and evaluated factors for evaluating the status of urban park green spaces, such as land use, connectivity with surrounding green spaces, and vegetation, and based on these, proposed measures to secure ecology within the park and respond to climate change. Kim (2012) evaluated the ecological health of buffer green spaces in cities by dividing them into green space system and water system. of was used. Both of the above studies have limitations in that the quantitative elements of green spaces were used for evaluation when setting evaluation factors for green spaces, but the qualitative aspects of vegetation itself were not considered.

In a follow-up study, Sung (2015) selected urban parks considering the resupply of ecological functions of forests and rivers in cities, compared and evaluated the degree of ecology of parks. Characteristics and land use characteristics such as green area and forest area were used as indicators. In addition, Park and Han (2009) divided the planting function of urban neighborhood parks into landscape function, recording function, buffer

function, and ecological function to evaluate urban parks in qualitative rather than quantitative evaluation. Although both studies carried out drawing surveys and field surveys in parallel to understand the structure of green spaces and vegetation in the city in detail, they have limitations in that they did not consider the health of vegetation, which is an important criterion in terms of quality.

Research on the evaluation of urban green spaces using satellite images has also been actively conducted. Lee (2016) divides the functions of park-type green spaces into natural ecology, environment control, and useful functions, and selects indicators and weights through AHP analysis for each function. The individual functions of the items were evaluated, and among them, green area, green area connectivity, and NDVI were used as evaluation indicators for natural ecological functions, and temperature reduction rate, air purification, and carbon absorption were used as environmental control indicators. Also Wang et al. (2022) used satellite imagery to divide the urban area into ecological space, production space, and living space, and detected temporal and spatial changes in the green area and environmental control function. Both studies analyzed the green area by dividing it into pixel units, and have limitations in that they did not specifically consider trees, which are important elements in the green area.

Studies to evaluate green spaces using high-resolution data such as LIDAR or spectroscopic images have mainly focused on the precise structure and identification of species, health, or environmental functions of vegetation in green zones. Plowright et al. (2016) evaluated tree health by deriving a calculation formula using two factors using the tree trunk density and effort of individual trees acquired by LiDAR, but since they evaluated the health

through physical changes or conditions of trees through LiDAR, it has a limitation in that they were unable to identify the health through physiological characteristics such as changes in the color of trees. Kayet et al. (2019) used multiple hyperspectral indices to evaluate the health of forests around mining areas through vegetation vitality, moisture content, and photosynthetic function, and Kim (2012) analyzed the physical status of urban green spaces by analyzing the green coverage and vegetation vitality of elementary schools using multispectral imaging to discover implications for green space accessibility. Both studies have the limitation that the physiological evaluation was done at the forest unit, but the structural aspects of green space were not considered.

[Table 1] Prior research on urban green space and vegetation evaluation using indicators

Year	Author	Description
2009	Park & Han	Evaluation of the quality of urban parks by dividing the planting function of urban neighborhood parks into landscape function, greening function, buffer function, and ecological function.
2012	T.S.Kim	Evaluate the ecological health of the buffer green space in the city by dividing it into green space system and water system. When evaluating the ecological health of the green space system, green space area, green coverage rate, green space coefficient, layered structure, species diversity, naturalness, and green space connectivity (surrounding green space size) were used.
2012	H.O.Kim	Evaluate the current status of urban green spaces centering on elementary schools using multispectral imaging. Analyze the physical status of urban green spaces by analyzing the green area ratio and dietary life of school zones, discovering significance in terms of green area accessibility

2013	Sung & Hwang	Establish and evaluate factors for evaluating the current status of green spaces in urban parks, such as land use, connectivity with surrounding green spaces, and vegetation, and propose measures to secure ecology within the park and respond to climate change based on these factors
2015	Sung	A 'directly connected' urban park located within 300m, which can resupply the ecological functions of forests and rivers in the city, and an 'isolated' urban park located more than 1km away from which resupply are difficult, compared the degree of ecology of the two types of parks. evaluation
2016	Lee	The functions of green spaces are divided into natural ecology, environment control, and utilization functions, and individual functions for each item are evaluated through the selection of indicators and weights through AHP analysis.
2016	Plowright et al.	In measuring tree health, the crown density and height of individual trees obtained by LiDAR are used to derive a calculation formula using the two factors to evaluate tree health.
2019	Kayet et al.	Evaluation of the health of forests around mining areas using various hyperspectral indices
2022	Wang et al.	Detect temporal and spatial changes in the ecology of green areas in urban areas using satellite images

3) Research objectives

This study aims to understand the ecological characteristics of trees in various parks in the city using high-resolution data. In addition, through NMDS analysis, parks are classified according to their ecological characteristics, rather than park types classified according to the existing purpose of use, to discover values in the ecological aspect.

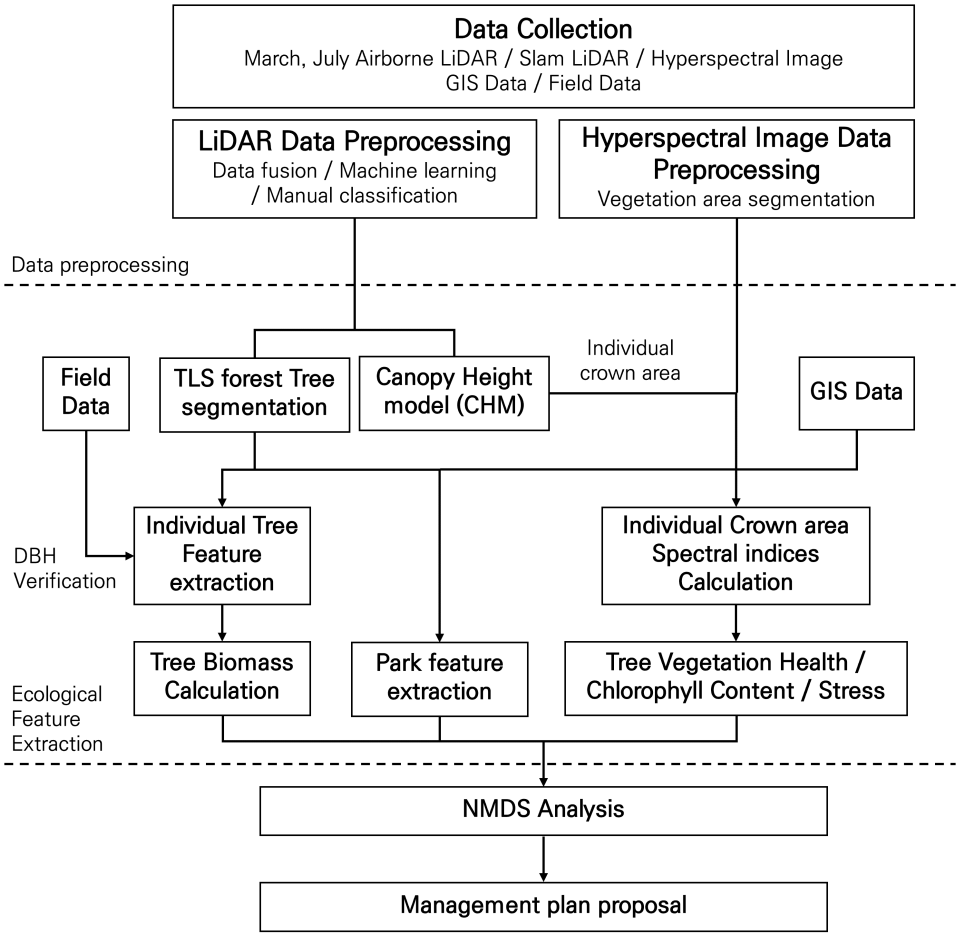
Specifically, we (1) classify urban parks into groups using ecological characteristics based on a tree inventory built on high-resolution data, (2)

identify the ecological structure and characteristics of the classified groups, and (3) propose a management method for urban parks based on the ecological meaning of each group. Even based on high-resolution data, there is a lack of studies that focus on individual trees to evaluate their ecological characteristics. In this study, we aim to identify more accurate park characteristics by considering the inventory of individual trees in building the tree data, and to propose a park management plan by considering the target site and surrounding green spaces.

Chapter 2. Methods

1. Study flow

In this study, we collected four types of high-resolution remote sensing data, spatial information data, and field survey data for 40 urban parks located in Uiwang City. In addition, to identify individual trees in 3D space more accurately, we merged and classified March and July airborne LiDAR data and Slam LiDAR data, and carried out preprocessing such as extracting vegetated areas from hyperspectral image data. Afterward, park-specific characteristics were extracted using the matched LiDAR data and GIS data, and individual tree segmentation and canopy height model (CHM) were generated. The generated tree segmentation data was used to extract the characteristic values of individual trees and was verified with field survey data. The generated CHM data was also used in conjunction with the hyperspectral image data to calculate attribute values for each tree. Finally, the extracted characteristics were analyzed by NMDS to divide the 40 parks into clusters, and a park management plan was proposed through the comparison of characteristics by cluster (Figure 1).

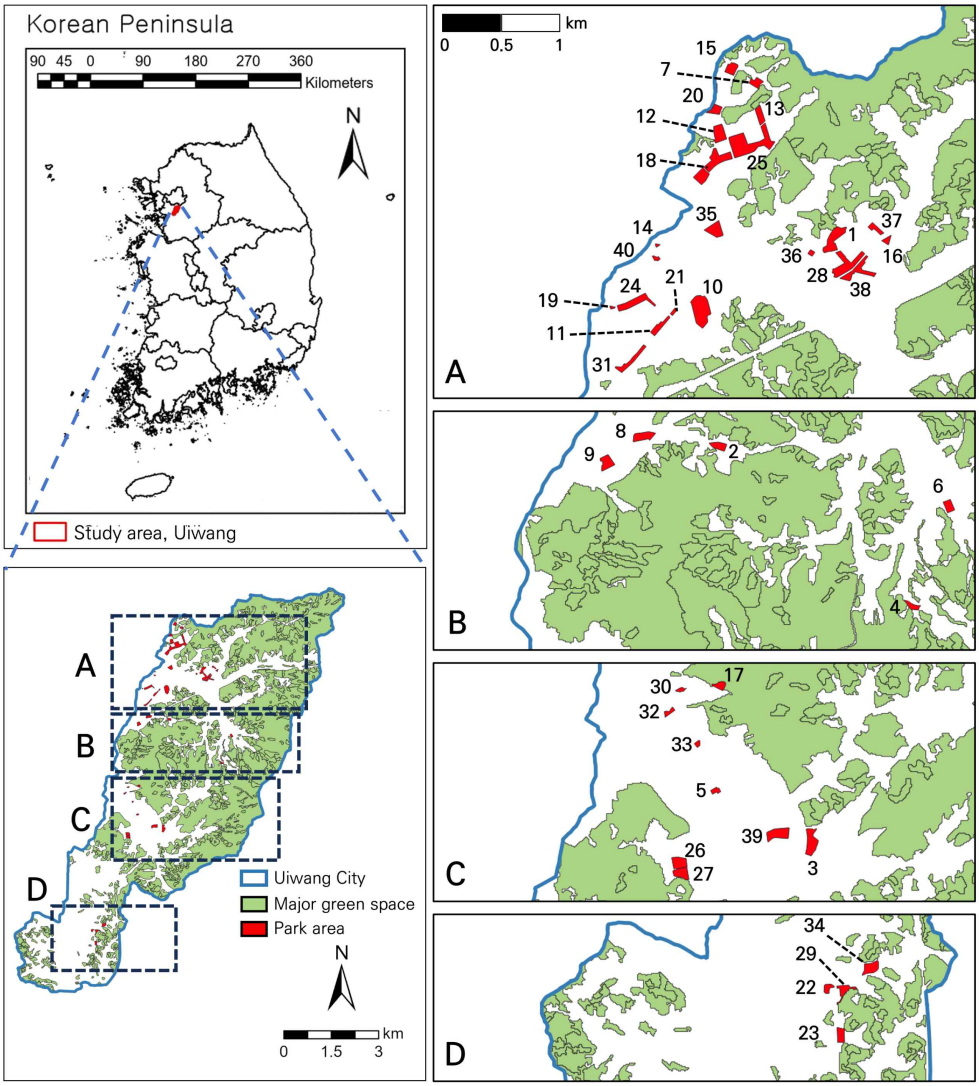


[Figure 1] Study flow

2. Study area

The research site is located in Uiwang City, Gyeonggi-do, Korea (126° 55′ ~127° 03′ east longitude, 37° 18′ ~37° 24′ north latitude). Uiwang City is located in the mid-western part of Gyeonggi-do, and has a population of 163,208 and an area of 54.04㎢. Among them, the development restricted

area is 45.687 ㎢, accounting for 84.6% of the city's area. In addition, the space regulated as an urban park according to the Act on Urban Parks and Green Areas is 2.16㎢. Uiwang City is currently conducting an urban ecological status map project for the creation of a nature-friendly city, such as conservation and restoration of urban ecology and development projects, and restoration and creation of urban parks as part of the urban planning facility(neighborhood park) project. In addition, there are many forest areas in Uiwang City, and parks that are separated from forests and adjacent parks are distributed in various ways (Figure 2). Considering the characteristics of the research content, this study covers a total of 40 urban parks in Uiwang City, excluding mountainous parks, parks currently under development or inaccessible, and areas with high missing data (Table 2).



[Figure 2] Spatial extent of Uiwang City study area

[Table 2] Types and basic information of Uiwang city parks selected as study sites

No.	Park category	Park name	Adress	Year	Area (ha)
1	Neighborhood Park	Gamakdeul Park (가막들공원)	41-2, Yangjipyeon-ro	2003	1.99
2	Cultural Park	Galmi hangeul Park (갈미한글공원)	65, Munhwayesul-ro	1999	0.73
3	Sports Park	Gocheon sports Park (고천체육공원)	18, Ojeon-ro	2011	1.69
4	Waterside Park	Hakui-dong Park 1 (학의동공원1)	961-3, Hagui-dong	1995	0.50
5	Small Park	Park 48 (공원48)	324-2, Ojeon-dong	1981	0.32
6	Waterside Park	Park 62 (공원62)	590, Hagui-dong	2004	0.67
7	Children’ s Park	Kkachi Park (까치공원)	648, Poil-dong	2004	0.64
8	Neighborhood Park	Naeson 1 Park (Literature) (내손1공원(문학))	48, Gyewondaehak-ro	2006	1.10
9	Neighborhood Park	Naeson 2 Park (Middle) (내손2공원(중앙))	45, Galmi-ro	2006	1.01
10	Sports Park	Naeson Park (내손공원)	16, Naesongongwon-gil	2006	3.20
11	Children’ s Park	Naeson children’s Park (내손어린이공원)	710-11, Naeson-dong	2006	0.79
12	Waterside Park	Sunset Park (노을빛공원)	646-1, Poil-dong	2003	1.28
13	Children’ s Park	Daramee Park (다람이공원)	651, Poil-dong	2009	0.78
14	Small Park	Doosan weve Park (두산위브공원)	638-2, Poil-dong	2016	0.07
15	Children’ s Park	Duteobi (두터비공원)	644-2, Poil-dong	2006	0.81
16	Children’ s Park	Malgeunnae Park (맑은내공원)	970, Cheonggye-dong	2004	0.33
17	Children’ s Park	Morak Park (모락공원)	236-29, Ojeon-dong	2006	0.54
18	Neighborhood Park	Moolbit Park (물빛공원)	647-1, Poil-dong	2004	3.05
19	Small Park	Minbaek Park (민백공원)	843-1, Naeson-dong	2002	0.08
20	Children’ s Park	Bandi Park (반디공원)	645-1, Poil-dong	2004	0.64
21	Small Park	Bokji Park (복지공원)	710-15, Naeson-dong	2014	0.18
22	Waterside Park	Bugok Park (부곡공원)	629, Sam-dong	2000	0.45

23	Sports Park	Bugok sports Park (부곡체육공원)	6, Bugokgongwon-gil	2004	0.77
24	Neighborhood Park	Bitsol Park (빛솔공원)	847-1, Naeson-dong	2014	1.63
25	Neighborhood Park	Sanbit Park (산빛공원)	44, Poilsegeori-ro	2006	4.51
26	Small Park	Small park 62 (소공원62)	171-6, Gocheon-dong	2015	1.11
27	Small Park	Small park 62 (소공원63)	171-10, Gocheon-dong	2015	1.03
28	Children’s Park	Sodam Park (소담공원)	981, Cheonggye-dong	1991	2.34
29	Waterside Park	Aretgol Park (아랫골공원)	624, Sam-dong	1991	0.80
30	Children’s Park	Children’s Park 31 (어린이공원31)	16, Bosikgol-ro	2013	0.21
31	Neighborhood Park	Unduk Park (언덕공원)	722, Naeson-dong	2014	1.08
32	Children’s Park	Ojeon-ro Park (오전로가족공원)	185, Ojeon-ro	1991	0.32
33	Children’s Park	Ojeon-dong elementary school Park (오전초교앞공원)	845-3, Ojeon-dong	1998	0.20
34	Waterside Park	Uttgol Park (웃골공원)	608, Sam-dong	1987	1.07
35	Neighborhood Park	Park in Indeokwon prugio elcentro apartment complex (인덕원푸르지오 엘센트로 아파트 단지 내 공원)	487, Poil-dong	2003	1.30
36	Children’s Park	Cheonggye yangji Park (청계양지공원)	985-3, Cheonggye-dong	2003	0.19
37	Children’s Park	Chorok Park (초록공원)	967, Cheonggye-dong	2003	0.55
38	Neighborhood Park	Hanjik, Pureunnae Park (한직공원, 푸른내공원)	993, Cheonggye-dong	2003	1.58
39	Neighborhood Park	Memorial tower Park (현충탑공원)	47-18, Wanggok-ro	1991	1.55
40	Children’s Park	Lake village Park (호수마을공원)	639, Poil-dong	2006	0.19

3. Study materials and preprocess

1) Data acquisition

Airborne LiDAR data acquirement of Uiwang City was conducted on March 23rd and July 23rd to 27th, 2021 by Samah Aerial Survey Co., with CESSNA 208 (HL 5116) aircraft, and Litemapper-6800 (IGI) airborne laser scanner. Litemapper-6800 perfoms in maximum 400KHz Pulse repetition rate, and has accuracy and precision of ±20 cm. The data on each condition signifies leaf-off season, which has more information on understory structure and canopy shape, and leaf-on season to more specifically identify upper canopy of the tree (Hill & Broughton, 2009).

SLAM LiDAR, a mobile LiDAR, is a simultaneous localization and mapping technology that creates maps in real time using sensors that can measure relative distances from any location. Slam LiDAR data acquirement was conducted from October 10th to 14th, 2021, with STENCIL 2-16 (KAARTA), equipped with a Velodyne LiDAR VLP-16 channel LiDAR sensor. Point cloud data were collected from each of 40 parks were collected. STENCIL 2-16 performs in range of 100m and 328ft, with the accuracy of ±30mm and data rate of 300,000 points per second. Table 2 shows the specifications of STENCIL 2-16.

Hyperspectral imaging is a technology that collects continuous spectral information of various land objects using hundreds of spectral channels. The hyperspectral image data was collected in October 2021 by Asia Aero Servey Co., Ltd. using the AISA Eagle sensor. The AISA Eagle sensor exhibits 127 bands with 0.44-0.48nm spectral resolution (404-996nm) in the visible and near infrared (VNIR) region (Table 3).

[Table 3] Specifications of LiDAR and hyperspectral image data

	Category	Description
Leaf-off, leaf-on airborne LiDAR data	Acquisition date	March 23rd, 2021 / July 23rd-27th, 2021
	Model	Litemapper-6800
	Shooting altitude	6000ft
	Accuracy	±20mm
	Precision	±20mm
	Spatial Resolution	16bit per return
	Scan angle	±30deg=60deg
Mobile LiDAR data (Slam LiDAR)	Acquisition date	October, 2021
	Model	STENCIL 2-16
	Scan distance	100m
	Point cloud density (average)	12000 points/㎡(pp㎡)
	Point cloud acquisition per second	300,000 point / s
	Accuracy	±30mm
Hyperspectral imagery data	Acquisition date	October, 2021
	Model	AISA Eagle
	Spatial resolution	0.7m
	Spectrum range	404-996nm (127 bands)
	Spectral resolution (FWHM)	0.44-0.48nm
	Radial resolution	12bit

Field data acquired for LiDAR data validation was conducted in early November 2021 and included a total of 40 parks where data was acquired with Slam LiDAR. An average of 30 trees per park were measured for tree species and diameter at breast height, and an average of 30 trees per park were randomly selected based on Slam LiDAR, 1196 trees in total. In the case of trees in Uiwang City parks, the proportion of broadleaf trees was generally high, and the highest proportion of tree species were Prunus yedoensis (19%) and Zelkova (19%), followed by Pinus densiflora (12%), Chionanthus retusus (12%), and Acer palmatum (10%), which are representative tree species in Uiwang City parks. In addition, the maximum DBH was 85.1cm, which was found in Zelkova, and the minimum DBH was 1.2cm, which was mostly for trees with multiple branches below the breast height. These trees were treated as individual trees for the purposes of the DBH measurements (Table 4).

[Table 4] Summary of field surveyed tree

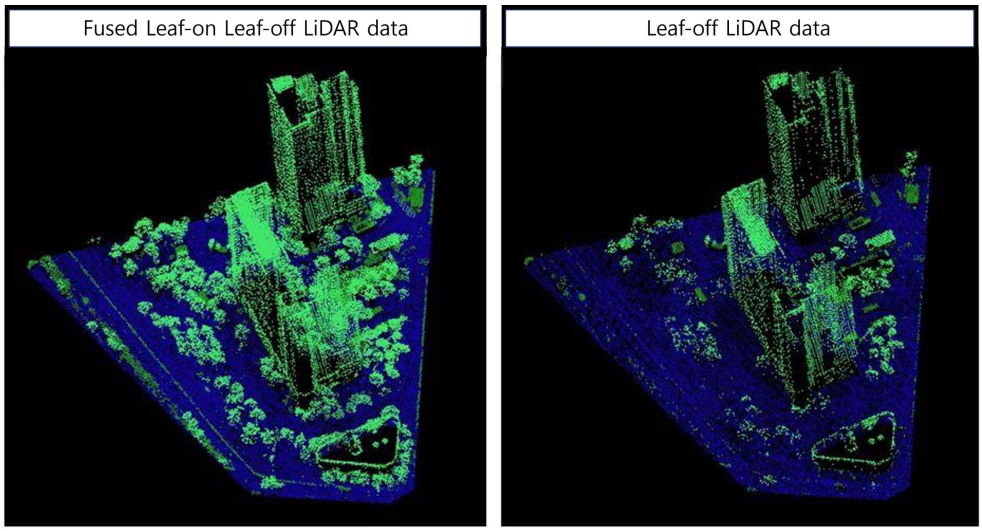
Field Surveyed Tree species	Number of tree	Coniferous/Deciduous	Ratio
Prunus yedoensis	226	Deciduous	19%
Zelkova	222	Deciduous	19%
Pinus densiflora	147	Coniferous	12%
Chionanthus retusus	143	Deciduous	12%
Acer palmatum	116	Deciduous	10%
Quercus palustris	44	Deciduous	4%
Metasequoia glyptostroboides	40	Coniferous	3%
Ginkgo biloba	29	Deciduous	2%
Cornus officinalis	23	Deciduous	2%
Magnolia kobus	17	Deciduous	1%
Quercus acutissima	12	Deciduous	1%
Cornus kousa	10	Deciduous	1%
Other	167	-	14%
Total	1196		100%

2) Preprocess and fusion of LiDAR data

Leaf-off and leaf-on airborne LiDAR data went through the same preprocessing process. The LiDAR data acquired at each time period was preprocessed to georeference Korea 2000 Korea Central Belt 2010 using RIWORLD software. In addition, TerraScan was used to filter and classify all point clouds in each dataset to remove outliers and generate DTMs.

In the case of slam LiDAR data, the loop closure process was performed by a function built into STENCIL 2016. The noisy point cloud was then filtered with Cloud Compare software for DTM generation (Zeybek & Şanl ı oğlu, 2019).

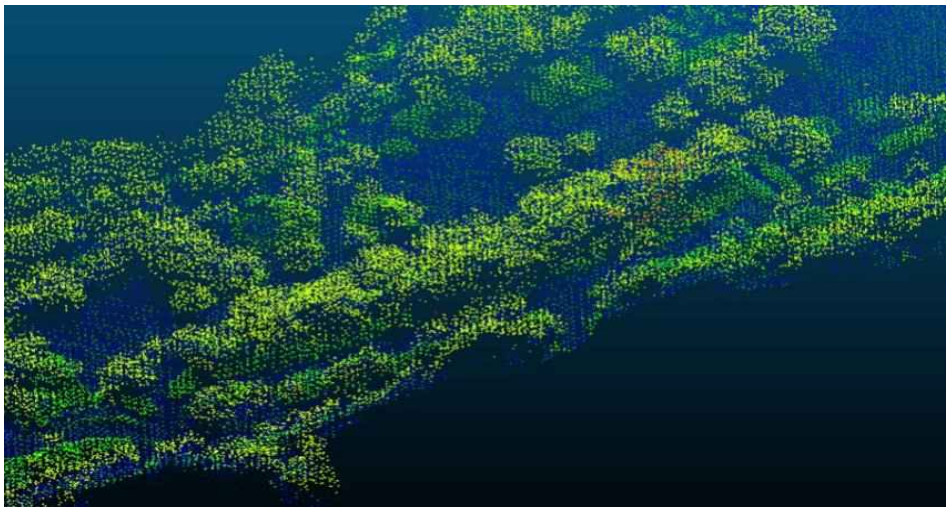
Previous studies have shown that fusion of leaf-off and leaf-on LiDAR data can provide a more accurate measure of forest structure (Davison et al., 2020; Froidevaux et al., 2016). The data were clipped with a 2m buffer around each park boundary and then fused using Cloud compare, a 3D point cloud mesh generation and processing software, and LiDAR 360 software. Nine reference points were selected from the leaf-on season LiDAR data and fused with the leaf-off season data by alignment with a final RMS value of 0.046159 (Figure 3).



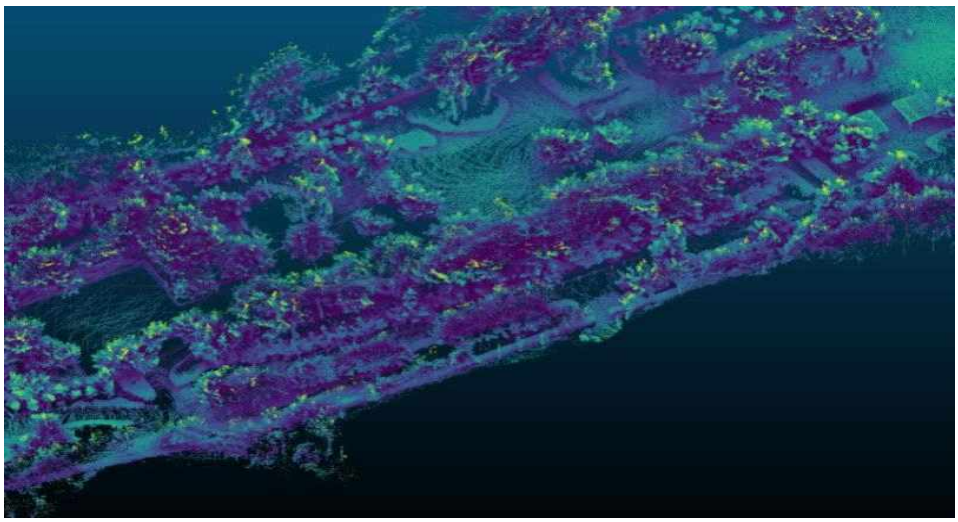
[Figure 3] Park in the Indukwon prugio elcentro apartment complex

Next, the data of the 40 parks acquired by the slam LiDAR were aligned

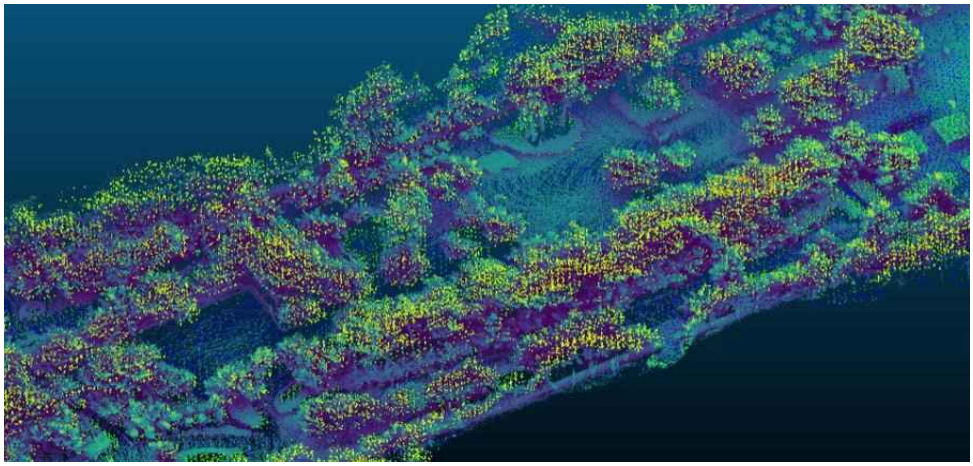
with the airborne LiDAR data using the GCP and point alignment tools in Cloud Compare and LiDAR 360. The fusion process for each park was performed with an RMS value of less than 0.7. The aligned SLAM data was then combined with the airborne LiDAR data (Figure 4).



(A) Fused March and July airborne LiDAR data



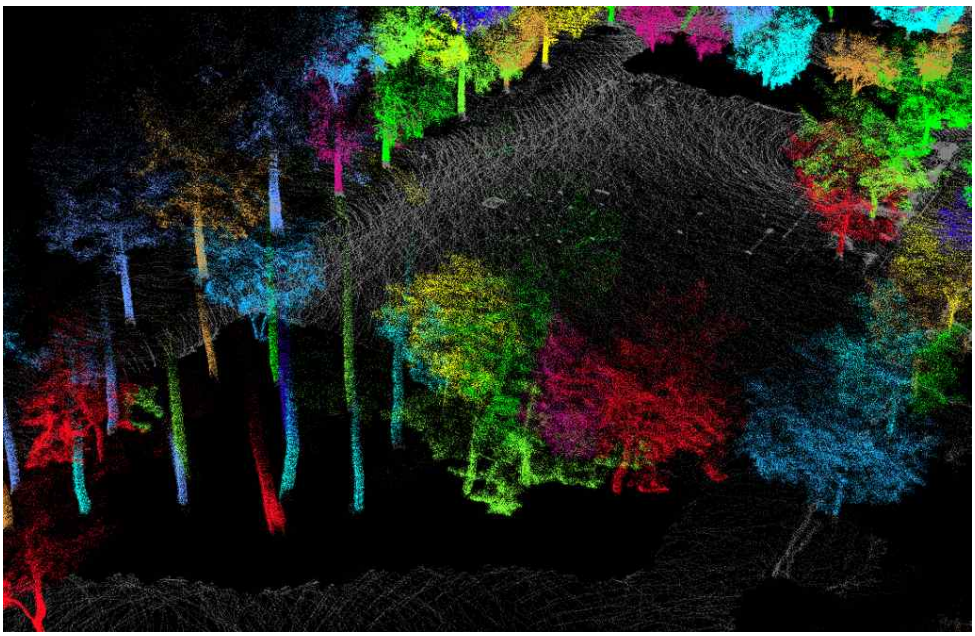
(B) Slam LiDAR data



(C) Fused airborne LiDAR and Slam LiDAR data

[Figure 4] Fusion of airborne LiDAR and mobile LiDAR (Slam LiDAR)

The fused LiDAR data was subjected to subsampling, outlier removal, ground point classification, and normalization by ground point. Tree segmentation was performed using LiDAR 360 software, which utilizes LiDAR 360's machine learning capabilities to classify and remove artifacts such as buildings and vegetation other than trees. A training dataset was created with seven classes: trees, buildings, understory vegetation, fences, electricity poles, sunshades, and tree splints, which were used to classify the entire point cloud within the park. For some unclassified points, we manually classified them using the manual classification function, and after removing taxa other than trees and ground, we performed tree segmentation using TLS forest analysis (Figure 5). The TLS point cloud segmentation method utilizes a bottom-up approach which originally developed by Tao et al. (2015). It uses the segmentation algorithms from the observed tree stem information to distinguish the spatial extents of individual trees within a forest or stand.



[Figure 5] Individual trees categorized by tree segmentation

3) Preprocess of hyperspectral imagery data and crown area derivation

The hyperspectral imagery went through radiation correction, geometric correction, atmospheric correction, strip matching, noise filtering and orthorectified using ENVI 5.6.2 software. To distinguish between vegetated and non-vegetated areas, the Normalized Difference Vegetation Index (NDVI) was calculated, and the vegetated areas within the target area were extracted as raster data using the NDVI of 0.2~0.9 range, which is a typical value for vegetation.

4. Indicator selection and calculation

1) Indicator selection

Considering the indicators used in previous studies and the types of data used in this study, a total of 13 indicators were selected to analyze the ecological status of Uiwang City's urban parks, divided into quantitative, qualitative, and spatial factors (Table 5).

First, tree height, DBH, biomass, crown volume, green coverage, and tree density were selected as quantitative indicators, while vegetation vitality, chlorophyll content, and stress index were selected as qualitative indicators. Finally, park area, green area within 300m, park perimeter length per area, and impervious area percentage were selected as spatial indicators.

Vertical and horizontal metrics such as tree height and diameter at breast height within urban green spaces are quantitative indicators of ecological resources and vegetation structure within cities, as they can predict the abundance of wild plant and animal species and assess habitat characteristics (Park et al., 2005; Listopad, 2015; Gutzat, 2018).

The estimation of biomass in urban green spaces is directly related to carbon uptake, one of the important roles of trees, and is one of the leading indicators to assess the health of urban ecosystems and the value of ecological resources (Chae & Kim, 2020; Zhang & Shao, 2021). Tree crown volume is also used as one of the indicators to measure tree vigor and quantify tree functions and benefits, such as habitat function for urban species (Hinsley et al., 2002; Zarnoch et al., 2004; Winn et al., 2010). Green cover is one of the indicators used by many studies to assess urban green space and is a fundamental factor considered in urban green space

management and prioritization (Clark et al., 1997; Heckmann et al., 2008; Park & Han, 2009; Lee, 2010; Ordonez & Duinker, 2012; Parmehr et al., 2016, Lee, 2016;). Tree density is one of the factors used in the broader analysis of urban green space. The quantitative distribution of trees helps in the management and protection of green spaces by analyzing various factors that affect the ecosystem (Zipperer et al., 1997; Jim & Liu, 2001; Heckmann et al., 2008; Kim et al., 2010).

Vegetation vitality, chlorophyll content, and stress index can be used to evaluate the quality of vegetation by measuring biochemical characteristics from satellite images, and are highly useful indicators for identifying the ecological value and health of green spaces by comprehensively showing the surrounding environment and vegetation growth status such as climate, soil, and human interference (Berrang et al., 1985; Sampson et al., 2003; Gao, 2006; Tuominen et al., 2009; Lee, 2011; Velichkova & Krezhova, 2018; Kayet et al., 2019).

The area of parks, the area of major green spaces within 300m of each park, and the perimeter length per area are landscape indices, which are used in various studies to evaluate green spaces in terms of ecological networks (Jim & Liu, 2001; Lee et al., 2008; Kim, 2012; Ryu et al., 2012; Sung, 2015; Gotfryd & Hansell 1986). Impervious area is an important factor when evaluating green space as it affects ecological functions such as habitat and vitality of surrounding vegetation, water circulation, etc. depending on its proportion (Park et al., 2006; Sung & Hwang, 2013).

[Table 5] Selected ecological indicators

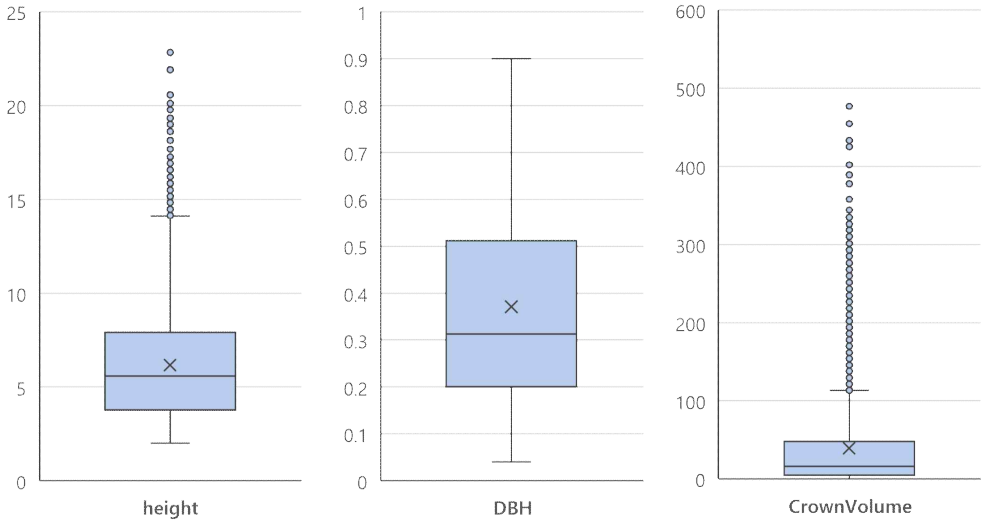
Indicator category	Ecological indicator	Data source	Reference
Quantitative	Height (m)	LiDAR	Park et al., 2005; Listopad, 2015; Gutzat, 2018
	DBH (m)		Park et al., 2005; Listopad, 2015; Gutzat, 2018
	Biomass (1000ton)		Zhang & Shao, 2021; Chae & Kim, 2020;
	Crown volume (m^3)		Hinsley et al., 2002; Zarnoch et al., 2004; Winn et al., 2010
	Green coverage (%) (Canopy projection area)		Lee, 2016; Lee, 2010; Park & Han, 2009; Clark et al., 1997; Parmehr et al., 2016; Heckmann et al., 2008; Ordóñez & Duinker, 2012;
	Tree density (n/ha) (number of trees/1ha)	LiDAR/GIS	Jim & Liu, 2001; Heckmann et al., 2008; Zipperer et al., 1997; Kim et al., 2010
Qualitative	Vegetation vitality	Hyperspectral	Lee, 2010; Kayet et al., 2019; Lee, 2011; Kim, 2012
	Chlorophyll content		Kayet et al., 2019; Gao, 2006; Velichkova & Krezhova, 2018; Sampson et al., 2003
	Stress index		Berrang et al., 1985 Tuominen et al., 2009; Ghosh et al., 2013; Kayet et al., 2023;

Spatial	Area of park (ha)	GIS	Jim & Liu, 2001; Lee et al., 2008; Kim, 2012
	Area of major green spaces within 300m (m^2)		Sung, 2015; Lee, 2016; Lee, 2010; Kim, 2012
	Perimeter length per area (m)		Kim, 2012; Ryu et al. 2012
	Impervious area (%)		Park et al., 2006; Sung & Hwang, 2013

2) Tree attribute and indicator value calculation

The height, DBH, and crown volume of individual trees were extracted from the LiDAR data after tree segmentation performed by the TLS forest tool. The LiDAR-derived data was validated with the DBH measured in the field survey, with a R^2 of 0.964 and an RMSE of 0.028 meters between the DBH of the trees measured in the field survey and the DBH derived from the LiDAR.

For DBH, trees with DBH greater than 0.9m were treated as outliers and excluded by referring to the maximum DBH derived from the field survey data. Therefore, the minimum height was 2m, the maximum height was 22.83m, the minimum DBH was 0.04m, the maximum DBH was 0.9m, the minimum trunk volume was 0.02m^3 , and the maximum trunk volume was 483.44m^3 (Figure 6).



Height(m)			
Min.	Max.	Mean	Sd.
2	22.83	6.17	3.10

DBH(m)			
Min.	Max.	Mean	Sd.
0.04	0.90	0.37	0.21

Crown Volume(m³)			
Min.	Max.	Mean	Sd.
0.02	483.44	39.14	57.77

[Figure 6] LiDAR-derived tree height, DBH, and crown volume

To calculate biomass among the quantitative ecological traits, we first calculated carbon storage using the derived tree height and DBH. The formula for calculating stem stock for carbon storage is as follows:

$$Stem\,stock = \frac{\pi}{4} \times DBH \times H \times form\,factor$$

where

DBH = Diameter at breast height

H = Tree height

$form\,factor$ = The ratio of a tree's volume to the volume of a cylinder of the same size as the tree's breast height diameter and

height. In this paper, we used 0.45, which is a common value when deciduous and conifers are not indentified.

To calculate the biomass of each tree, we used the stem density, above ground expansion coefficient, and below ground expansion coefficient of mixed-fertility forests using data from the National Institute of Forest Science, assuming that the mixed-fertility rate is 50%, and averaged the coefficients of deciduous and conifers (Son et al., 2007). The resulting equations are as follows (Table 6).

[Table 6] Basic biomass calculations and biomass calculations for deciduous, coniferous, and mixed forests from the National institute of forest science data

Category	Equation
General form of Biomass equation	Stem stock * Stem density * a_1 * b_1
Coniferous Forest Biomass equation	Stem stock * 0.47 * 1.29 * 1.28
Deciduous Forest Biomass equation	Stem stock * 0.80 * 1.22 * 1.41
Mixed Forest Biomass equation	Stem stock * 0.635 * 1.252 * 1.38

where

a_1= above ground expansion coefficient

b_1 = below ground expansion coefficient

The water pipe coverage data for the spectral data was constructed by performing the Canopy Height Model (CHM) analysis in the ALS forest tool from the LiDAR data. The Canopy Height Model is a technique that divides the area assuming that water flows by changes and differences in the pixel

values of the data through the watershed algorithm, and it was used to divide the water pipe area (Hwang et al., 2012). In the case of the segmented CHM model, the RMSE value was derived to see the location difference with the tree objects classified through the TLS forest tool, and the RMSE values for X and Y were 0.39 and 0.30(m), respectively.

After that, the hyperspectral image data and the derived tree canopy area data were set as individual regions of interest (ROIs), and hyperspectral index were calculated to evaluate the ecological characteristics of each tree canopy (Figure 7). The ecological characteristics evaluated were vegetation vitality, chlorophyll content, and stress index, which were evaluated through the calculation of 11 hyperspectral index (Table 7).

Vegetation vitality was assessed using four hyperspectral index (NDVI, GNDVI, EVI, and SRI). The Normalized Difference Vegetation Index (NDVI) is used to quantify vegetation and is an indicator of vegetation vitality (Rouse et al., 1974), with index values ranging from -1 to 1. As previously described, vegetated areas typically have values between 0.2 and 0.9. Higher values in that range indicate more vigorous vegetation. The Green Normalized Difference Vegetation Index (GNDVI) is an index that better reflects chlorophyll characteristics within vegetation compared to NDVI, and like NDVI, has an index range between -1 and 1 (Cho et al., 2020; Gitelson et al., 1996). The Enhanced Vegetation Index (EVI) is calculated similarly to the NDVI, but reduces distortions to the reflectance of vegetation caused by the ground and atmosphere, resulting in a more enhanced vegetation index (Liu & Huete, 1995). Index values range from -1 to 1, with vegetation typically ranging from 0 to 1 and healthy vegetation having values between 0.2 and 0.8. The Simple Ratio Index (SRI) is a simple vegetation ratio using

the ratio of reflectance values in the near-infrared and red wavelength regions. It can range from 0 to over 30, with healthy vegetation typically having values between 2 and 8 (Birth & McVey, 1968).

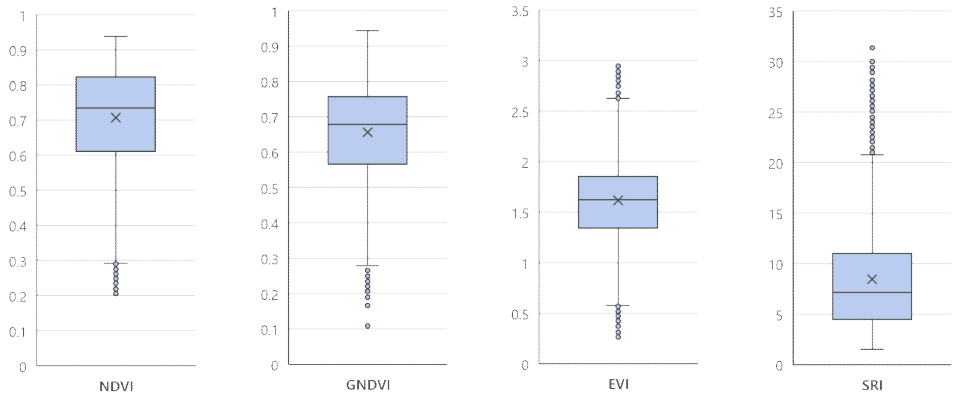
Chlorophyll content was assessed by four hyperspectral indices (MRESR, RENDVI, GCI, and VREI1). The Green Chloropyll index (GCI) is a widely used index for estimating the chlorophyll content of vegetation (Gitelson et al., 2003). The Modified Red Edge Simple Ratio (MRESR) is an index that utilizes the red wavelength region and is a correction for leaf reflectance in the SR. It has an exponential value range from 0 to 30, with values typically between 2 and 8 in vegetated areas (Sims & Gamon, 2002; Datt, 1999). It has also been shown to be sensitive to the chlorophyll content of vegetation compared to NDVI and SR (Velichkova & Krezhova, 2019). The Red Edge Normalized Difference Vegetation Index (RENDVI) is an NDVI-corrected index that is often used to measure chlorophyll content (Sims & Gamon, 2002; Gamal et al., 2020). Index values range from -1-1, with typical vegetation ranging from 0.2-0.9, similar to NDVI (Gitelson & Merzlyak, 1994). Vogelmann Red Edge Index 1 (VREI1) is an index sensitive to chlorophyll content, leaf area, and moisture content, with values ranging from 0-20, and a typical range for vegetation is 4 to 8 (Vogelmann & Moss, 1993).

For the assessment of vegetation stress, we used the Agricultural stress tool, which calculates the degree of stress on a scale of 1-10. The Agricultural stress tool focuses on the growth efficiency of plants and determines the level of stress through nitrogen and light utilization. For this purpose, it uses plant vitality, water content, and photosynthetic efficiency index, and the indexes used for each item are NDVI, WBI, and PRI. In the case of WBI (Water Balance Index), it measures the sensitivity to water

conditions in the tree crown and shows a value between 0.8 and 1.2 in general vegetation, and in the case of PRI (Photochemical Reflectance Index) in the photosynthetic function category, it shows the efficiency of using light for photosynthesis. PRI ranges from -1 to 1, with healthy vegetation typically exhibiting values between -0.2 and 0.2.

[Table 7] Hyperspectral index selection and calculation formulas for each ecological trait category

Ecological trait category	Hyperspectral index and parameter selection	Calculation formula by index used
Vegetation vitality	Normalized Difference Vegetation Index 1	$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$
	Green Normalized Difference Vegetation Index	$GNDVI = \frac{(NIR - Green)}{(NIR + Green)}$
	Enhanced Vegetation Index	$EVI = 2.5 \times \frac{(NIR - Red)}{(NIR + 6 \times Red - 7.5 \times Blue + 1)}$
	Simple ratio	$SR = \frac{NIR}{Red}$
Chlorophyll content	Modified Red Edge Simple Ratio	$MRESR = \frac{\rho_{750} - \rho_{445}}{\rho_{705} - \rho_{445}}$
	Red Edge NDVI	$RENDVI = \frac{\rho_{750} - \rho_{705}}{\rho_{750} - \rho_{705}}$
	Green Chlorophyll Index	$GCI = (\frac{\rho_{NIR}}{\rho_{Green}}) - 1$
	Vogelmann red edge index 1	$VREI1 = \frac{\rho_{740}}{\rho_{720}}$
Stress index	Agricultural Stress Tool (Parameters : NDVI, WBI, PRI)	$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$ $WBI = \frac{\rho_{970}}{\rho_{900}}$ $PRI = \frac{\rho_{531} - \rho_{570}}{\rho_{531} + \rho_{570}}$



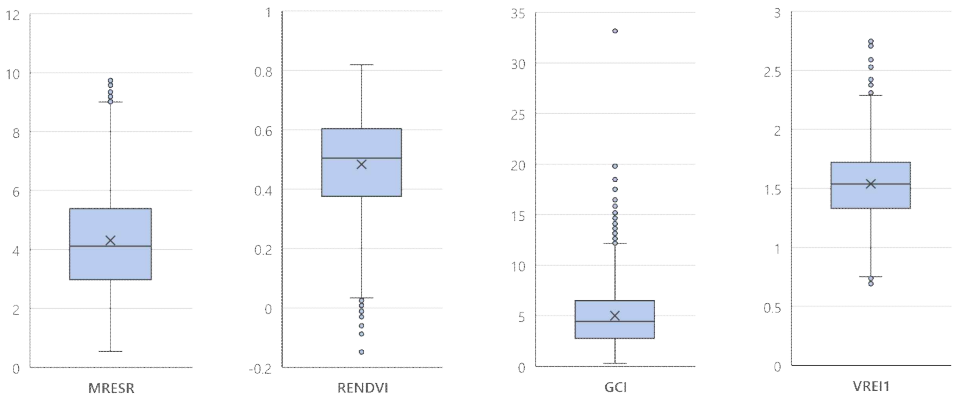
NDVI			
Min.	Max.	Mean	Sd.
0.21	0.94	0.71	0.15

GNDVI			
Min.	Max.	Mean	Sd.
0.11	0.94	0.66	0.13

EVI			
Min.	Max.	Mean	Sd.
0.26	2.99	1.62	0.41

SRI			
Min.	Max.	Mean	Sd.
1.52	31.35	8.46	5.26

(A) Vegetation vitality index



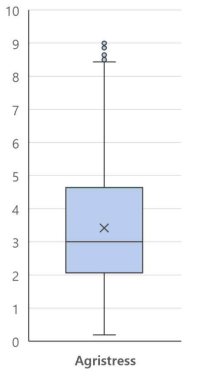
MRESR			
Min.	Max.	Mean	Sd.
0.54	9.89	4.31	1.78

RENDVI			
Min.	Max.	Mean	Sd.
-0.15	0.82	0.48	0.16

GCI			
Min.	Max.	Mean	Sd.
0.31	33.17	5.01	2.94

VREI1			
Min.	Max.	Mean	Sd.
0.69	2.76	1.54	0.29

(B) Chlorophyll content index



Agristress			
Min.	Max.	Mean	Sd.
0.19	9.00	3.42	1.71

(C) Stress index.

[Figure 7] Summary table of indices derived from hyperspectral images

For vegetation vitality and chlorophyll content, the indices calculated for each tree crown were standardized and averaged for each ecological characteristic and used in the assessment. Since most of the indices does not follow normal distribution, and such indices may distort the evaluation results, they were standardized from 1 to 100 by scaling using the equation presented by Lee (2010):

$$IS = \left[E \times \frac{(X - X_{\min})}{(X_{\max} - X_{\min})} + (1 - E) \times \frac{(X_{\max} - X)}{(X_{\max} - X_{\min})} \right] \times 100$$

where

IS = Evaluation score for each indicator

E = 1 if the indicator is a positive effect, 0 if it is a negative effect

X = Indicator value

X_{max} = Maximum value of an indicator

X_{min} = Minimum value of an indicator

The calculated ecological traits for each tree location point were matched to their corresponding park location using the Spatial join function in ArcGIS Pro. In this process, a total of 7059 tree characteristics were extracted from the 40 parks, excluding trees that were removed from the park by a 2m buffer.

Furthermore, using the data derived from the lidar and GIS, the area of each park, green cover (canopy projection area), tree density, surrounding green area, and impervious area percentage were calculated and added as variables to evaluate ecological quality. For the surrounding green area, the ecologically isolated value of 300m, proposed by Sung (2015), was used to consider the functional relationship with the surrounding green areas of the park. For impervious area, it was calculated according to the land cover classification presented in Choi & Cho (2013). There were 17 land cover classifications within the study area, of which 7 were classified as impervious and 10 as pervious (Table 8).

[Table 8] Classification of impervious area based on land cover classification

Level 2 classification	Level 3 classification	Pervious/impervious
Residential area	Detached house facilities	impervious
Residential area	Apartment complex facilities	impervious
Commercial area	Commercial facilities	impervious
Cultural · Sports · Recreational facilities	Cultural · Sports · Recreational facilities	impervious
Transportation area	Roads	impervious
Public Utility Area	Education · administration facilities	impervious
Public Utility Area	Other public Utility Area	impervious
Upland field	Uncultivated field	pervious
Facility cultivation	Facility cultivation	pervious
Deciduous forest	Deciduous forest	pervious
Artificial grass	Graveyard	pervious
Artificial grass	Other grass	pervious
Inland wetland	Inland wetland	pervious
Other barren	Playground	pervious
Other barren	Other barren	pervious
Inland water	River	pervious
Inland water	Lake	pervious

In summary, to assess the ecological status of parkland, tree characteristic values were derived for 13 indicators using the above methods. Each indicator was then summarized as an average value per park to group ecological characteristics (see Appendix A).

5. Park type analysis through sequencing

Non-metric Multi-dimensional Scaling (NMDS) is a method of visually representing information of multi-dimensional data through dimensional scaling. It is used when variables have a sequential or nominal scale, and the closer the points represented in 2D or 3D, the higher the similarity between variables or populations. NMDS is characterized by the ability to study the interrelatedness of objects by visually representing the interrelatedness of large amounts of data, and new information can be obtained by condensing large amounts of data (Kenkel & Orloci, 1986). Unlike general cluster analysis, it uses the distance matrix of the data as a measure, not the distance according to the similarity between variables. Among them, a commonly used distance measure is the Bray-Curtis distance. The groups categorized using this distance measure can be tested for statistical significance using the ANOSIM test (Okubo & Sugiyama, 2009).

NMDS repeats the process of finding an array that converges to the optimal value, and the data loss due to dimensionality reduction can be judged through stress-evaluation. The stress decreases as the number of dimensions increases, with models less than .05 being the most misinterpretable, followed by models greater than .05 but less than .10, .10 but less than .20, and greater than .20 being unusable (Clarke, 1993).

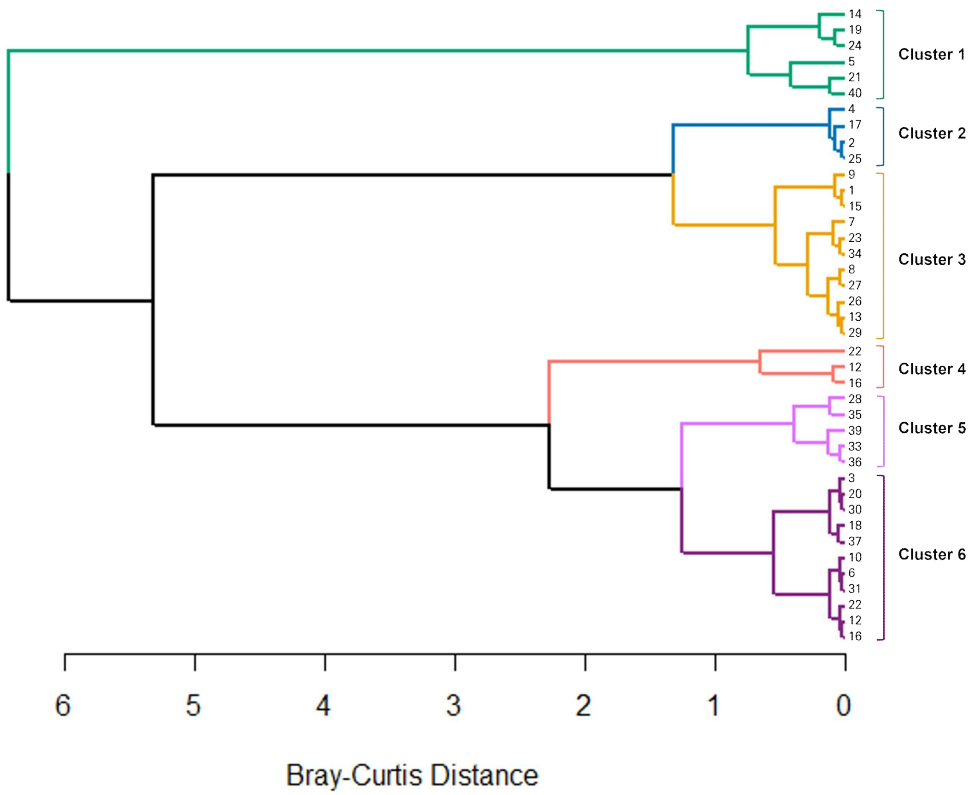
Bray-Curtis distance analysis was performed using the index values calculated for each park, and the number of groups with appropriate number of parks distributed among the groups and significant statistical differences was adopted. NMDS analysis was performed by adding the cluster information derived from the above analysis. After integrating the differences between

parks and groups by the used indicator values on a two-dimensional plane, the fit of the model was evaluated by stress-evaluation, and the main indicators that determined the axis were also derived. The NMDS analysis was performed using the Vegan package of the R program (version 4.3.0).

Chapter 3. Results

1. Ecological traits by park type

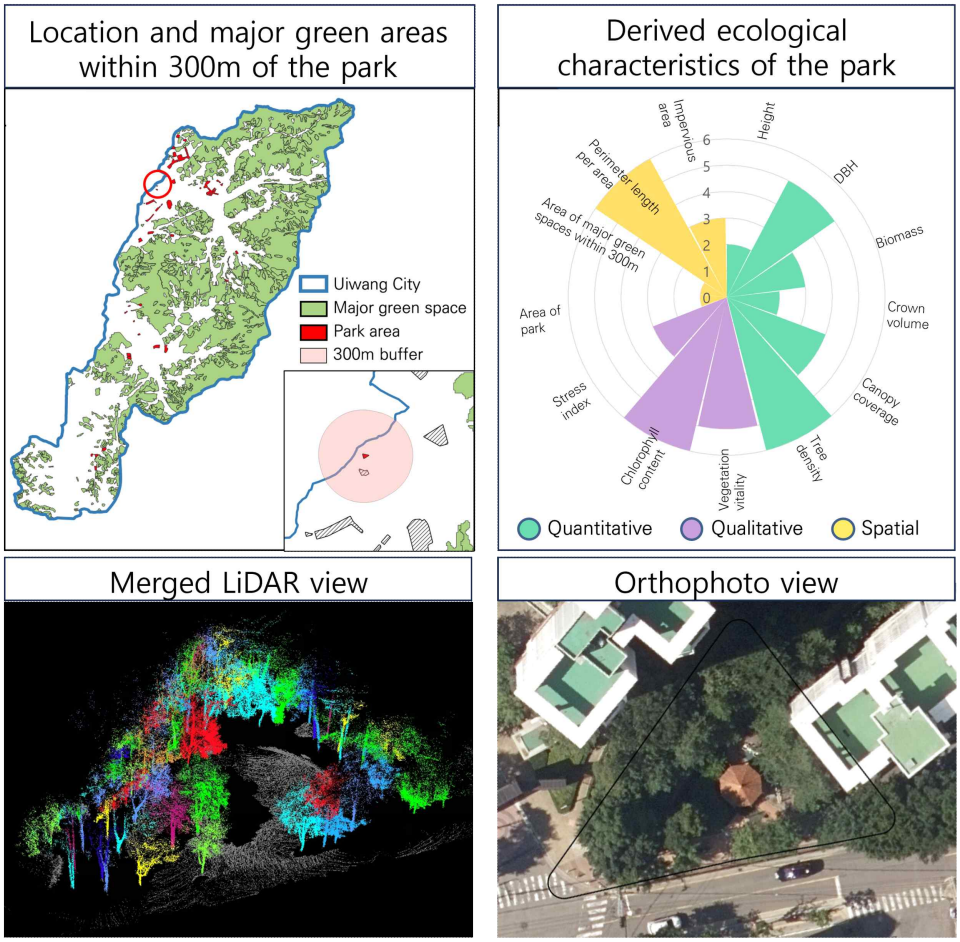
Using the Bray-Curtis distance dendrogram, which is an NMDS distance calculation method, and the 13 indicators selected for grouping urban parks, the 40 parks in Uiwang City are categorized into six groups (Figure 8).



[Figure 8] Parks clustered by the Bray-Curtis Distance method

The evaluation of the ecological characteristics of the six groups of urban parks classified on the basis of 13 indicator values (see Table 9, Table 11)

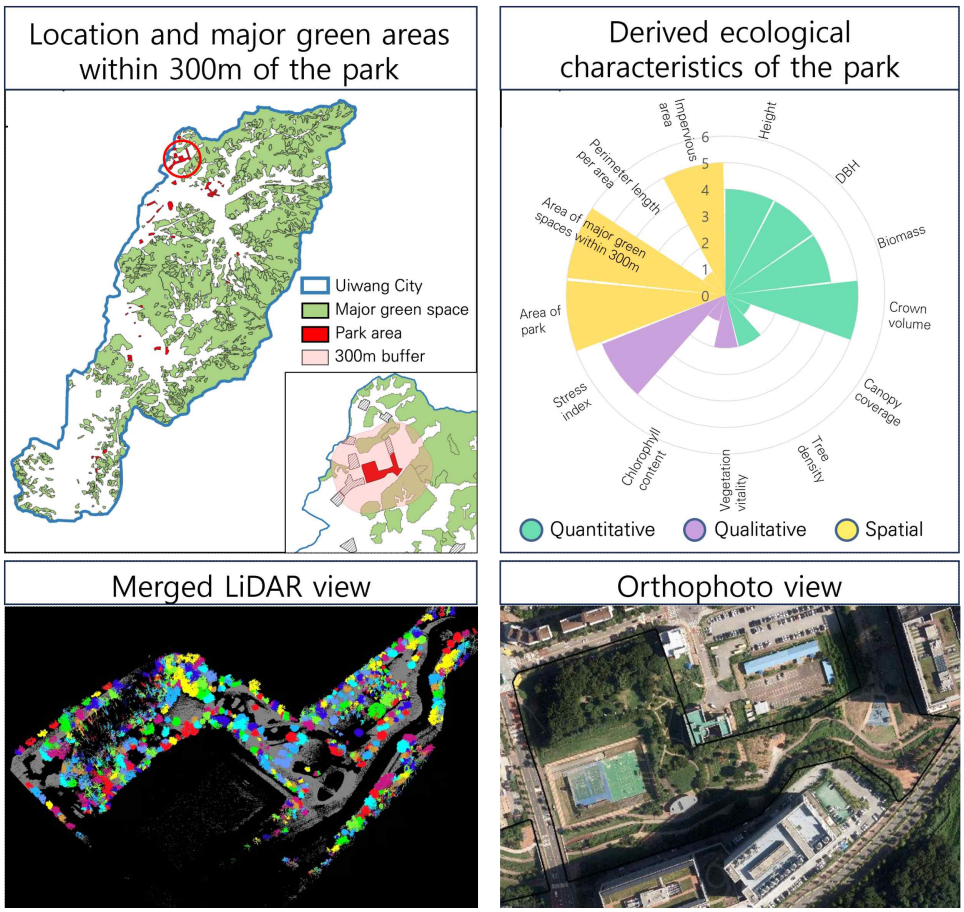
shows that the first group of urban parks consists of six parks, with an area of 0.41±0.55 m^2 , which is the smallest of the six groups. It also has the highest perimeter length per area and chlorophyll content of 0.11±0.04m and 44.17±7.86, respectively, and all included parks have 0m^2 of green area within 300m. The representative park of Group 1 is “Doosan Weve Park“, which has the smallest area of all the parks at 0.07ha. On the other hand, the perimeter length per area is 0.161m, which is the largest among all the parks, and the chlorophyll content is the second largest at 52.45 (Figure 9).



[Figure 9] Status of "Doosan weve Park" in group 1

The second group of urban parks consists of four parks and has the lowest green coverage, perimeter length per area, and chlorophyll content of 40.08±11.72%, 0.05±0.02m, and 35.88±5.81, respectively. On the other hand, the park area and surrounding green space area were the highest at 1.57±1.7m and 23.27±1.95m², respectively. The stress index was the second highest at 4.15±1.11. The representative park of Group 2 is "Sanbit Park", which has the second lowest perimeter length per area of 0.03m, and

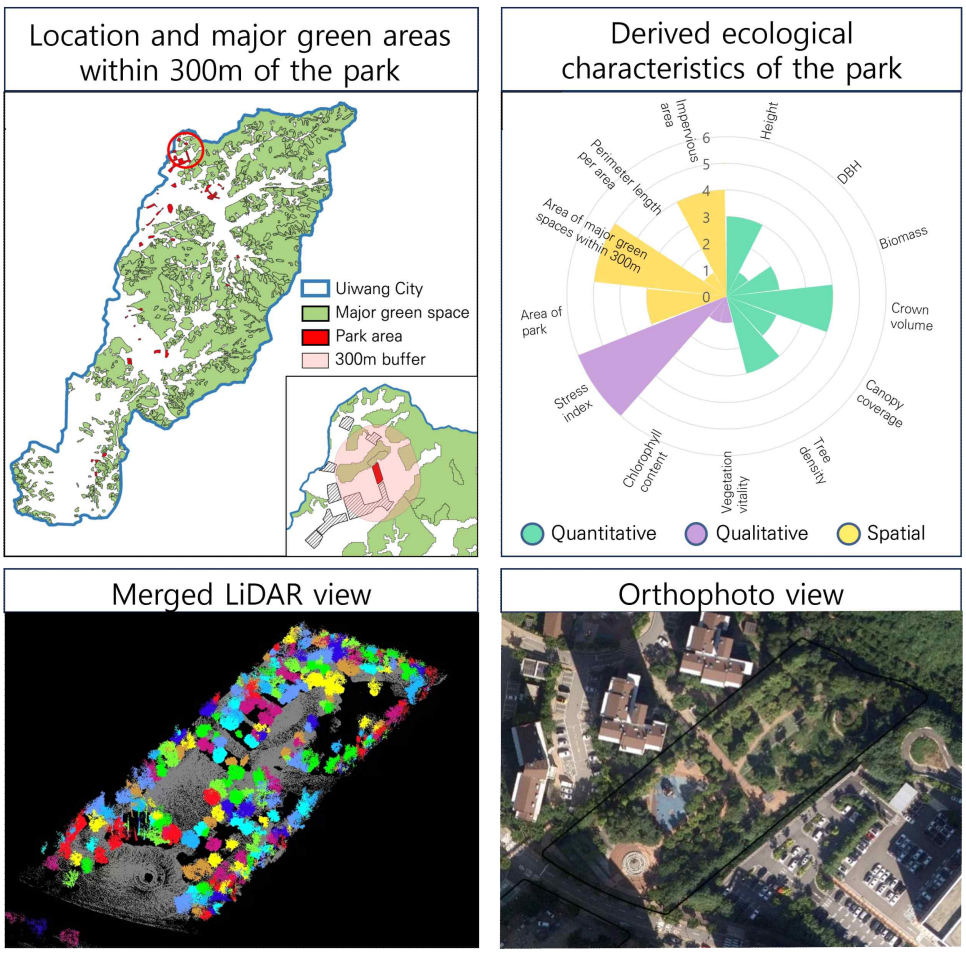
relatively low green coverage and chlorophyll content of 42.17% and 40.38, respectively. In addition, the park area is 4.51m² , which is the largest value among all parks, and the major green area within 300m is 23.57m² , which is the second highest value among all parks (Figure 10).



[Figure 10] Status of "Sanbit Park" in group 2

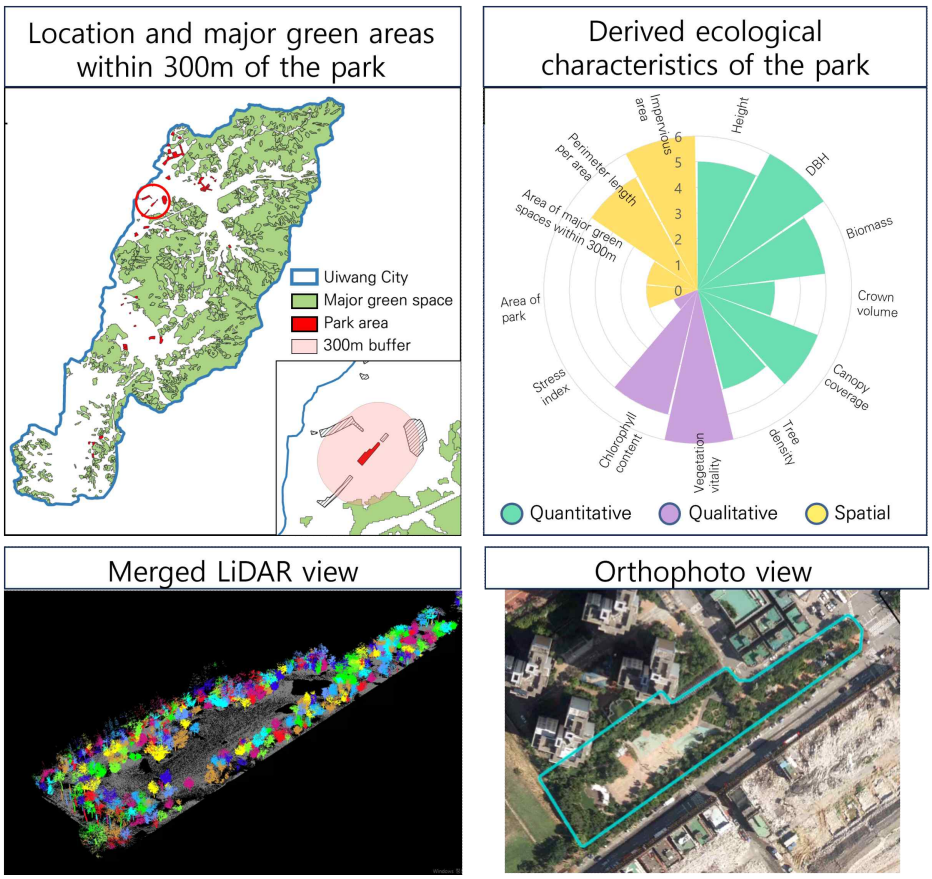
The third group of urban parks consists of 11 parks, with the smallest perimeter length, DBH, vegetation vitality, and chlorophyll content values of 0.05±0.01m, 0.34±0.04m, 46.1±11.12, and 35.88±6.4, respectively, and the highest stress index of 4.21±1.26. In addition, the surrounding green area of

12.45±2.33m² is the second highest among all groups. The representative park of Group 3 is "Daramee Park", which has a perimeter length per area of 0.052m, which is the lowest among all parks, a DBH of 0.37m, a vegetation vitality of 46.70, and a chlorophyll content of 35.81, which is relatively high within Group 3 but low among all parks. The stress index of 3.47 is also relatively low within Group 3, but higher than the median value of 3.18 for all parks. The surrounding green area is also relatively high compared to other parks at 13.11m² (Figure 11).



[Figure 11] Status of "Daramee Park" in group 3

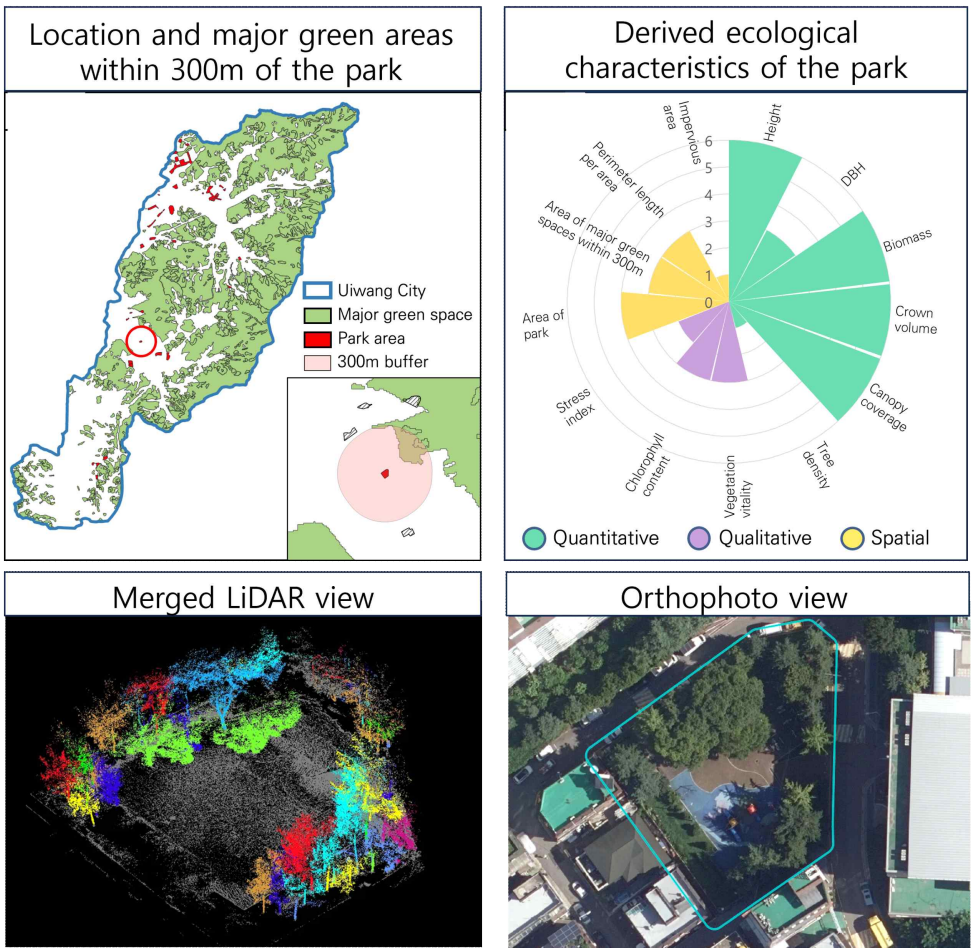
The fourth urban park group consists of three parks, with a green cover of 48.05±12.46%, a height of 6.69±0.81m, a DBH of 0.39±0.06m, and a biomass of 0.9±0.18 thousand tons, which is relatively high, and the size of height and trunk is large compared to other groups. It also has a relatively high vegetation vitality of 54.58±3.69, and a stress of 2.67±0.17. One of the parks in Group 4, "Naeson Children's Park", has a high green coverage of 60.80%, a height of 8.87m, a DBH of 0.39m, and a biomass of 1.20 thousand tonnes. Compared to all parks, it has a high vegetation vitality index of 53.86 and a low stress index of 2.72. The area of surrounding green space is low at 1.01m^2 (Figure 12).



[Figure 12] Status of "Naeson Children's Park" in group 4

The fifth group of urban parks consists of five parks, with a green cover of 50.81±18.25%, a height of 7.67±0.94m, a biomass of 0.95±0.33 thousand tons, and a crown volume of 56.41±7.05m³ , which is the highest among the six groups. On the other hand, the tree density is the lowest at 102.56±52.04n/ha. Among the parks in Group 5, "Ojeon-dong elemetary school park" has a high green cover of 44.45%, a height of 7.17m, and a canopy volume of 60.21m³ . The tree density of 177.64n/ha is high within the group but lower than the median value of 183.78n/ha among all parks.

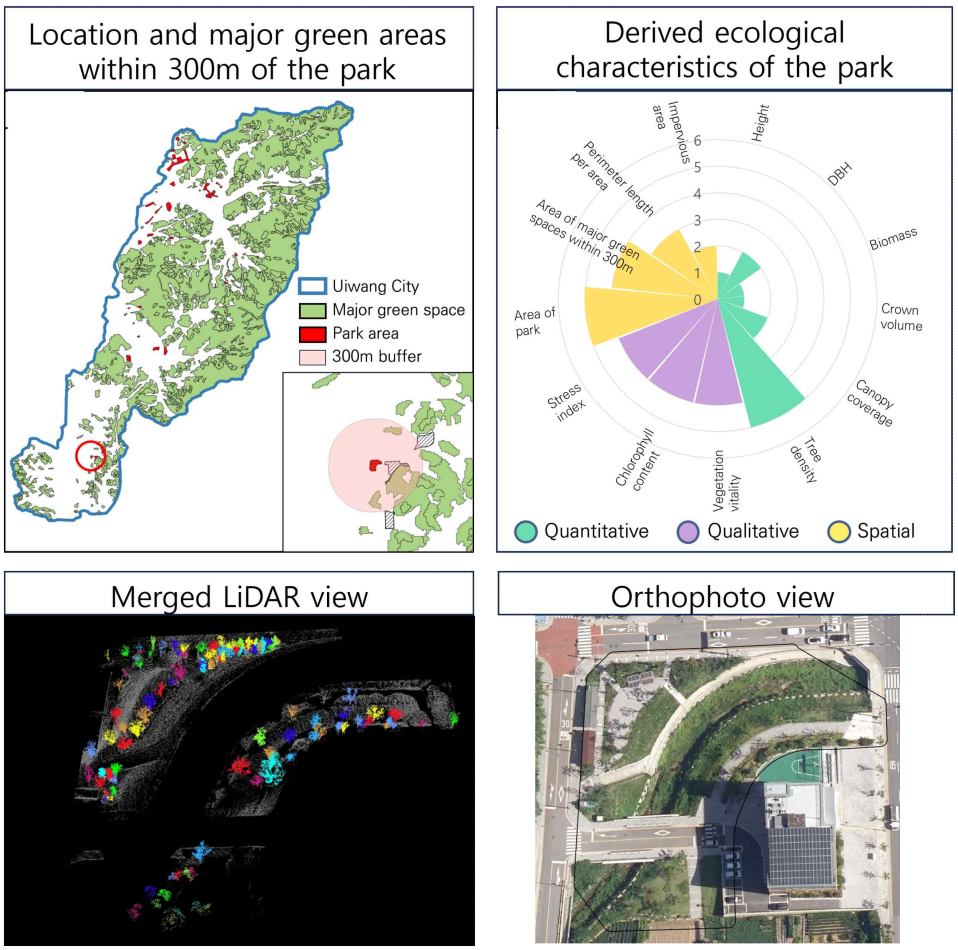
The area of surrounding major green spaces is 3.62m² (Figure 13).



[Figure 13] Status of "Ojeon-dong elemetary school Park" in group 5

Finally, the sixth group of urban parks, consisting of 11 parks, is the smallest among the six groups, with the values of height, biomass, and crown volume of 5.86±1.2 m, 0.7±0.22 thousand tons, and 33.78±18.4 m³, while vegetation vitality is relatively high at 52.06±9.77. Other ecological indicator values are in the median of the whole group. The representative park of group 6 is "Bugok Park", which has the second lowest values of all

the parks with a height of 4.41m and a canopy volume of 11.07m³ , and the lowest value of all the parks with a biomass of 0.41 thousand tons. For vegetation vitality, the value is 51.04. For the area of the surrounding major green space, it is 5.03 m² (Figure 14).



[Figure 14] Status of "Bugok Park" in group 6

[Table 9] Summary of ecological characteristics by categorized urban park groups

Indicator	group1	group2	group3	group4	group5	group6
Height (m)	6.09±0.99	6.3±1.36	6.28±1.02	6.69±0.81	7.67±0.94	5.86±1.2
DBH (m)	0.38±0.09	0.37±0.04	0.34±0.04	0.39±0.06	0.36±0.11	0.35±0.05
Biomass (1000ton)	0.77±0.2	0.78±0.18	0.72±0.16	0.9±0.18	0.95±0.33	0.7±0.22
Crown volume (m^3)	34.99 ±18.59	47.67 ±25.31	47.53 ±26.28	44.45 ±10.77	56.41 ±7.05	33.78 ±18.4
Green coverage (%) (Canopy projection area)	44.5 ±11.65	40.08 ±11.72	43.32 ±11.16	48.05 ±12.46	50.81 ±18.25	42.91 ±11.98
Tree density (n/ha) (number of trees/1ha)	316.33 ±155.99	131.61 ±36.86	205.02 ±101.27	213.28 ±32.93	102.56 ±52.04	217.16 ±115.44
Vegetation vitality	52.27 ±11.53	47.03 ±5.83	46.1 ±11.12	54.58 ±3.69	51.09 ±7.81	52.06 ±9.77
Chlorophyll content	44.17 ±7.86	35.88 ±5.81	35.88±6.4	41.62 ±2.24	38.86 ±6.71	39.85 ±8.09
Stress index	3.3±1.11	4.15±1.11	4.21±1.26	2.67±0.17	3.12±0.88	3.5±0.9
Area of park (ha)	0.41±0.55	1.57±1.7	1.01±0.34	0.89±0.52	1.12±0.83	1.19±1
Area of major green spaces within 300m (m^2)	0±0	23.27 ±1.95	12.45 ±2.33	0.85±0.37	3±0.65	5.39±0.76
Perimeter length per area (m)	0.11±0.04	0.05±0.02	0.05±0.01	0.07±0.01	0.06±0.02	0.06±0.02
Impervious area (%)	38.88 ±24.22	28.03 ±16.34	33.24 ±17.21	26.16 ±13.23	41.09 ±14.05	39.1 ±19.49

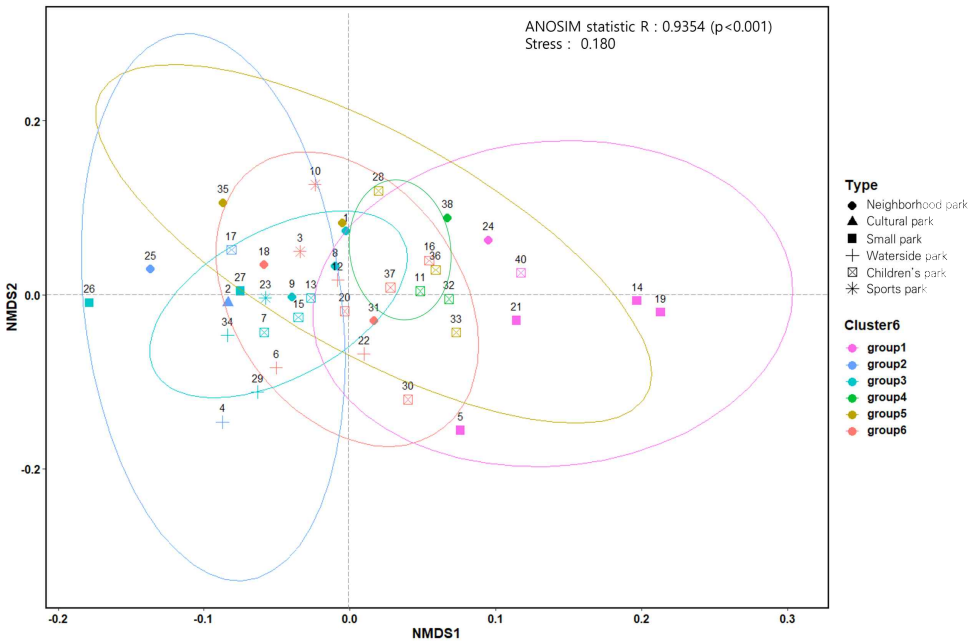
[Table 10] Summary of the number of original urban park types by group

Category	group1	group2	group3	group4	group5	group6
Neighborhood park	1	1	3	1	2	2
Cultural park		1				
Small park	4		2			
Waterside park		1	2			3
Children's park	1	1	3	2	3	4
Sports park			1			2
Total	6	4	11	3	5	11

2. Integrated distribution according to traits

NMDS analysis was conducted to comprehensively show the differences in similarity between parks and groups according to characteristics and types. The distribution of urban parks in Uiwang City was grouped into six groups according to 13 indicators previously calculated by Bray-Curtis distance, and the ANOSIM test showed an R value of 0.9354, with a significance lower than 0.001, indicating that there was a statistically significant difference between the groups (Figure 15).

Among the variables used to calculate the distance between parks, perimeter length per area and green area within 300 meters were the main determinants of the axis 1 of NMDS, while green cover, park area, biomass, vegetation vigor, chlorophyll content, and stress index were the main determinants of the axis 2 of NMDS (Table 11). The values indicate the strength with which each metric is correlated in distance space (Figure 16).

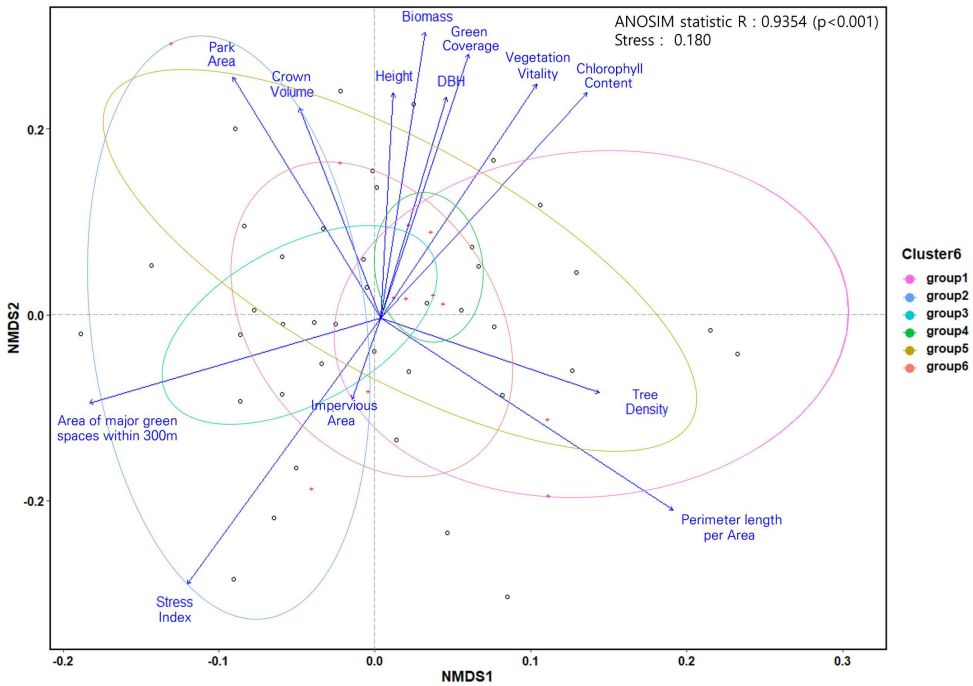


[Figure 15] Distribution of distances by park characteristics based on Non-metric Multidimensional Scaling (NMDS) analysis

[Table 11] Determinants of NMDS axis 1 and 2

Category	NMDS 1	NMDS 2	R^2	*Pr*(>r)	
Height (m)	0.061	0.998	0.286	0.002	**
DBH (m)	0.302	0.953	0.301	0.001	***
Biomass (1000ton)	0.162	0.987	0.472	0.001	***
Crown volume (m^3)	-0.381	0.924	0.290	0.002	**
Green coverage (%) (Canopy projection area)	0.336	0.942	0.441	0.001	***
Tree density (n/ha) (number of trees/1ha)	0.952	-0.306	0.338	0.001	***
Vegetation vitality	0.580	0.815	0.464	0.001	***
Chlorophyll content	0.699	0.715	0.559	0.001	***
Stress index	-0.612	-0.791	0.638	0.001	***
Area of park (ha)	-0.548	0.836	0.466	0.001	***
Area of major green spaces within 300m (m^2)	-0.964	-0.264	0.582	0.001	***
Perimeter length per area (m)	0.851	-0.525	0.756	0.001	***
Impervious area (%)	-0.352	-0.936	0.043	0.491	

Significance codes: p>0.05; *p < 0.05; **p < 0.01; ***p < 0.001



[Figure 16] The contribution of each metric to a group's categorization

Chapter 4. Discussion and Conclusion

1. Management based on the characteristics of park types

Through the NMDS analysis, the main determinants of each axis were scaled and the 40 parks were clearly categorized into six groups according to their ecological characteristics.

According to previous research, the ecological value of urban green space can be broadly divided into locational potential and internal components (Sung, 2015). Considering the values of each indicator, the six groups of parks classified in this study can be mainly divided into groups 1, 2, and 3 and groups 4, 5, and 6 by the explanatory power of the surrounding green area within 300m, which is an indicator of locational potential, and then by the internal components of each park, such as area, height, and vegetation vitality.

First, the area of green space within 300m of group 1, 2, and 3 is 0±0 m^2 , 23.27±1.95 m^2 , and 12.45±2.33 m^2 , respectively, which clearly shows the relationship with the surrounding green area. Group 1 appears to be an isolated park with no neighboring green space, while groups 2 and 3 appear to be connecting parks adjacent to major mountain areas.

The area of the parks in Group 1 is also smaller than the other groups, which may be due to the inclusion of many small parks that were established on small plots of land. The parks also have a large perimeter length relative to their area, which is an indicator of the flexibility of green space and is ecologically important as it is closely correlated with species richness (Gotfryd & Hansell, 1986; Ryu et al., 2012). It is also associated with

relatively high vegetation vigor, chlorophyll content, and tree density, suggesting that dense stands of vigorous trees are ecologically valuable (Scarascia-Mugnozza et al., 2000). According to Fung & Siu (2000), the effectiveness in terms of ecosystem services provided by vegetation increases on a zonal basis when forests or grasslands are located within a certain distance. Therefore, even small-scale parks can be expected to serve as ecological corridor, so it is necessary to maintain the ecological characteristics of the park and to consider the ecological aspects of the surrounding parks in terms of connectivity with external ecological spaces.

Group 2 has the largest surrounding green space of all the groups, while Group 3 consists of parks with the next largest surrounding green space. However, when vegetation vitality, chlorophyll content, and stress index are considered, groups 2 and 3 have relatively low vegetation health. In particular, group 2 has a large canopy volume but low tree density and green coverage, and group 3 has a large canopy volume but relatively low green coverage. This is believed to be due to high tree stress caused by lack of management, and in particular, group 3 has a lower DBH and biomass than the other groups, indicating poor tree growth. However, from the perspective of urban ecological network, it has a great potential as a location due to its high connectivity with other major green areas. Therefore, it should be managed in a direction that enhances the naturalness of urban green areas, such as utilizing and introducing ecology through planting plans that increase the connectivity with adjacent green area in order to be ecologically and functionally interconnected with external green areas (Ministry of Environment, 2012).

For groups 4, 5, and 6, the area of surrounding green space is

$0.85 \pm 0.37m^2$, $3 \pm 0.65m^2$, and $5.39 \pm 0.76m^2$, respectively, indicating that the maintenance of internal trees is more important than the relationship with surrounding green space.

In the case of group 4, although the park itself has a small area, it has the second-largest park perimeter length compared to the area after group 1, indicating a high flexibility of green space. It also has a low stress index, high vegetation vitality, chlorophyll content, height, DBH, and the biomass is also relatively large, which is closely related to the carbon and nutrients fixed in the trees, suggesting that it has high ecological value (Uhrin & Supuka, 2016). Therefore, group 4 can be defined as a type where large trees are growing well at an appropriate density. In order to maintain these ecological characteristics, it is recommended that the appropriate density of vegetation should be maintained through continuous monitoring and management such as tree thinning.

In Group 5, biomass and vegetation vitality are relatively high, and stress is among the lowest of all groups, suggesting that the trees themselves are in good health. However, tree density is generally low relative to green coverage, and crown volume, height, and biomass are the largest of all groups. This suggests that many of the trees are composed of trees with wide, dense crowns. Excessively high tree density in a single tree can result in less sunlight reaching the understory vegetation, leading to stunted growth and the tendency to maintain a monostructured vegetation zone (Kim et al., 2017). Urban parks perform important functions not only in terms of utilization, but also in terms of habitat for wildlife, and a study by Song (2015) found that shrub cover, as well as abundant planting of arbor and arborescent trees, is important for improving park habitat quality with

respect to wild bird diversity. Therefore, by maintaining the health of the understory vegetation by managing the trees that occupy the upper layer, the ecological value of parks can be further enhanced, thereby improving the ecological benefits to users.

Group 6 has low values for tree height, DBH, biomass, and crown volume, and the parks in Group 6 were all established after 2000. This suggests that they may be composed of relatively younger trees than the other parks. Group 6 also has a higher vegetation vitality, which can be defined as the type of recently planted young trees that are showing good growth. Therefore, if the ecological quality of the park is improved by adopting Group 4 as a model, it seems that its potential can be fully utilized. This can be managed in the direction of forming various planting structures by allowing trees of various ages to coexist as the age increases in the future and to allow the growth of lower vegetation (Sung, 2015).

2. Ecological potential of original park types

This study provides a new classification of park types that considers only the quantitative, qualitative, and spatial ecological characteristics of parks. Through this, parks with unexpected ecological characteristics were identified in addition to the functions according to the existing purpose of establishment.

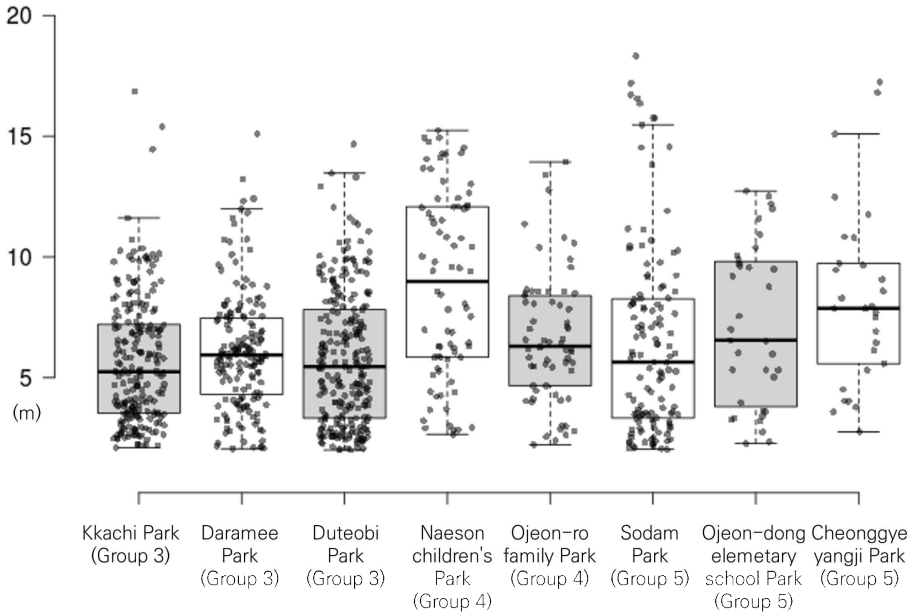
In the case of children's parks, according to the Act on Urban Parks and Green Spaces, the existing purpose of establishment is to provide a play area for the purpose of improving the health and emotional life of children living

in the neighbourhood, and facilities are important. However, the results of this study show that some children's parks have ecological unexpectedness.

Five of the 14 children's parks belong to the newly classified park types, Group 4 and Group 5, which have previously been shown to be characterised by their internal tree cover rather than their relationship to surrounding green spaces. Group 4 exhibited a pronounced level of qualitative and quantitative ecological integrity, attributed to its optimal planting density and robust vegetative health. In contrast, Group 5, identified as a park area, requires management strategies to ameliorate the condition of its lower vegetation zone by regulating the excessive canopy cover prevailing in the upper vegetation stratum.

When comparing the children's parks in groups 4 and 5 with the children's parks in group 3, which are considered to be particularly low in qualitative ecology, the difference is that the children's parks in groups 4 and 5 have higher quantitative ecological characteristics such as biomass, height, and density than those in group 3 (Figure 17). In group 3, the high density and tree distribution of the parks suggest that there is high competition between trees with relatively low height. On the other hand, the parks in groups 4 and 5 have a high proportion of healthy large trees while maintaining an overall moderate density. This is likely to have implications for the qualitative ecology of each group, as properly managed tree density prevents excessive competition, which can lead to increased stress and reduced water and nutrient uptake (Zhang et al., 2019; Farooq et al., 2021). In addition, Groups 4 and 5 are connected to a lower proportion of neighbouring major green spaces compared to Group 3, and on average have a smaller area but a higher degree of inflexibility compared to Group 3. This suggests that it is

more important to fully utilise the potential of park components, such as appropriate tree canopy placement and the creation of diverse planting structures, than the location of the park to enable ecological connectivity (Sung, 2015).



[Figure 17] Boxplot of height distribution for group 3,4,5

Overall, groups 4 and 5 are judged to have high ecological value and potential, considering the appropriate density of healthy trees, large trees with conservation value, and spatial location. Therefore, a management plan that maintains the function of the existing children's park and at the same time maintains and enhances the ecological characteristics of the park is required. This can be achieved by maintaining and controlling the density of multi-layered tree stands centered on large trees in the park management planning stage, and creating non-destructive nature and ecological learning

spaces using these structures. However, a limitation of this study is that it did not consider the impact of the frequency of use, types of users, and types of activities on trees in children's parks. Further research in this area is expected to provide effective management measures that consider both the function and ecology of urban parks.

3. Conclusions and limitations

Parks and trees in cities not only have social and usage values, such as providing a pleasant environment and a place to rest, but also environmental and ecological values, such as providing habitat for wildlife and reducing carbon. Recently, as the need for such spaces has increased, the creation of urban parks has become more necessary, and existing parks also need sustainable park management that considers both social and ecological values. However, in the case of urban parks whose main purpose is to be used by urban citizens, environmental and ecological values are not very prominent, and it is necessary to evaluate ecological values centered on trees, which are most closely related to healthy greenery ecology.

Therefore, in this study, we used high-resolution remote sensing data to more accurately identify the inventory of trees for the planning and management of urban parks, and derived the ecological characteristics of urban parks using green space indicators to propose management plans from environmental and ecological aspects. First, the ecological characteristics of 40 urban parks were evaluated using a total of 13 indicators, including indicators derived from high-resolution remote sensing data (LiDAR) and hyperspectral imagery, and then management plans were derived by dividing

them into six groups with statistically significant differences through NMDS analysis. The six groups were further divided into groups 1, 2, and 3 and groups 4, 5, and 6 based on their connectivity to surrounding green spaces. Group 1 was identified as an isolated park with high ecological value internally and expected to serve as an ecological connector through external linkages. In contrast, groups 2 and 3 were identified as parks with high location potential adjacent to surrounding green spaces, but with low ecological value internally and could further increase their ecological value through complements such as utilizing the surrounding ecology. Group 4 was characterized as a park with a moderate density of healthy giant trees, which requires continuous monitoring to maintain the current ecological characteristics. Group 5 was characterized as a park that needs to manage the health of the lower vegetation zone by controlling the high canopy cover of the upper vegetation zone. Group 6 was characterized as a park with good growth of relatively recently planted young trees, which needs to be managed to form a multi-layered vegetation structure with trees of various ages and understory vegetation as the tree age increases.

Furthermore, it was found that parks with important facilities such as children's parks have high ecological characteristics and potential, such as groups 4 and 5. Consequently, this finding opens avenues for the proposition of a more efficacious urban park management strategy that considers both the natural environment and park users. Such an approach entails the preservation and augmentation of current park functionalities while concurrently enhancing internal and external ecological attributes.

In response to the need for efficient urban planning and management, many local governments are seeking ways to generate and utilize basic data

through high-resolution remote sensing data. This study is significant for its attempt to derive ecological characteristics of trees and green spaces through high-resolution data and propose a management plan. However, despite the selection of green space indicators focusing on trees, there are limitations in that it does not consider various environmental variables such as temperature, humidity, soil characteristics, and stress caused by the intensity of use by users that affect the growth of trees, and does not consider ecologically significant understory vegetation other than trees. In addition, the analysis is limited in that it does not reflect variables that may differ by tree species, such as biomass, tree trunk volume, and effort, making it difficult to calculate accurate results for each indicator. Finally, the results of indicators such as chlorophyll content derived from high-resolution data were not verified with the actual field other than for DBH. In the future, high-resolution data can be used to more specifically consider greenery indicators such as tree species and understory vegetation, which were not considered in this study, and to develop field verification methods accordingly, which will provide a more systematic management plan for urban parks.

References

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy, 70(3), 295-310.

Alonzo, M., Bookhagen, B., & Roberts, D. A. (2014). Urban tree species mapping using hyperspectral and lidar data fusion. Remote Sensing of Environment, 148, 70-83.

Alonzo, M., McFadden, J. P., Nowak, D. J., & Roberts, D. A. (2016). Mapping urban forest structure and function using hyperspectral imagery and lidar data. Urban Forestry & Urban Greening, 17, 135-147.

Andersson, E., Barthel, S., Borgstrom, S., Colding, J., Elmqvist, T., Folke, C., & Gren, A. (2014). Reconnecting cities to the biosphere: Stewardship of green infrastructure and urban ecosystem services. Ambio, 43(4), 445-453.

Beland, M., Parker, G., Sparrow, B., Harding, D., Chasmer, L., Phinn, S., Antonarakis, A., & Strahler, A. (2019). On promoting the use of lidar systems in forest ecosystem research. Forest Ecology and Management, 450, 117484.

Berrang, P., Karnosky, D., & Stanton, B. (1985). Environmental Factors Affecting Tree Health in New York City. Arboriculture & Urban Forestry, 11(6), 185-189.

Birth, G. S., & McVey, G. R. (1968). Measuring the Color of Growing Turf with a Reflectance Spectrophotometer1. Agronomy Journal, 60(6), 640-643.

Brack, C. L. (2002). Pollution mitigation and carbon sequestration by an urban forest. Environmental Pollution, 116(SUPPL. 1), S195-S200.

Brubaker, K. M., Johnson, Q. K., & Kaye, M. W. (2018). Spatial patterns of tree and shrub biomass in a deciduous forest using leaf-off and leaf-on lidar.

Canadian Journal of Forest Research, 48(9), 1020-1033.

Chae, J., & Kim, W. (2020). A study on assessment of ecological value and management plans for neighborhood parks through CO2 storage measurement in Seoul. Korea Landscpe Council, 12(2), 217-231.

Chan, C. S., Si, F. H., & Marafa, L. M. (2018). Indicator development for sustainable urban park management in Hong Kong. Urban Forestry & Urban Greening, 31, 1-14.

Cho, D., & Kim, E. (2010). Extraction of Spatial Information of Tree Using LIDAR Data in Urban Area. Journal of Korean Society for Geospatial Information Science, 18(4), 11-20.

Cho, H., (2018). Healthy City Urban Design Guidelines for Gangdong District, Seoul(서울시 강동구 건강도시 도시설계 가이드라인). Seoul Institute.

Cho, H., & Lee, K. (2014). Comparison between Hyperspectral and Multispectral Images for the Classification of Coniferous Species. Korean Journal of Remote Sensing, 30(1), 25-36.

Cho, S., Lee, G., & Hwang, J. (2020). Drone-based Vegetation Index Analysis Considering Vegetation Vitality. Journal of the Korean Association of Geographic Information Studies, 23(2), 21-35.

Choi, J., & Cho, S. (2013). National impervious area rate survey and improvement plan study(전국 불투수면적률 조사 및 개선방안 연구). Ministry of Environment, Korea Environment Corporation.

Clark, J., Matheny, N., Cross, G., & Wake, V. (1997). A Model of Urban Forest Sustainability. Arboriculture & Urban Forestry, 23(1), 17-30.

Dalponte, M., Bruzzone, L., Vescovo, L., & Gianelle, D. (2009). The role of spectral resolution and classifier complexity in the analysis of hyperspectral images of forest areas. Remote Sensing of Environment, 113(11), 2345-2355.

Datt, B. (1999). A New Reflectance Index for Remote Sensing of Chlorophyll Content in Higher Plants: Tests using Eucalyptus Leaves. Journal of Plant Physiology, 154(1), 30-36.

Davison, S., Donoghue, D. N. M., & Galiatsatos, N. (2020). The effect of leaf-on and leaf-off forest canopy conditions on LiDAR derived estimations of forest structural diversity. International Journal of Applied Earth Observation and Geoinformation, 92, 102-160.

Eigenbrod, F., Bell, V. A., Davies, H. N., Heinemeyer, A., Armsworth, P. R., & Gaston, K. J. (2011). The impact of projected increases in urbanization on ecosystem services. Proceedings of the Royal Society B: Biological Sciences, 278(1722), 3201-3208.

Elmqvist, T., Setala, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., Gomez-Baggethun, E., Nowak, D. J., Kronenberg, J., & de Groot, R. (2015). Benefits of restoring ecosystem services in urban areas. Current Opinion in Environmental Sustainability, 14, 101-108.

Farooq, T. H., Shakoor, A., Rashid, M. H. U., Zhang, S., Wu, P., & Yan, W. (2021). Annual growth progression, nutrient transformation, and carbon storage in tissues of Cunninghamia lanceolata monoculture in relation to soil quality indicators influenced by intraspecific competition intensity. Journal of Soil Science and Plant Nutrition, 21(4), 3146-3158.

Froidevaux, J. S. P., Zellweger, F., Bollmann, K., Jones, G., & Obrist, M. K. (2016). From field surveys to LiDAR: Shining a light on how bats respond to forest structure. Remote Sensing of Environment, 175, 242-250.

Fung, T., & Siu, W. (2010). Environmental quality and its changes, an analysis using NDVI. International Journal of Remote Sensing, 21(5), 1011-1024.

Gamal, E., Khdery, G., Morsy, A., Ali, M., Hashim, A., & Saleh, H. (2020). Hyperspectral indices for discriminating plant diversity in Wadi al-afreet, Egypt. Plant Archives, 20(2), 3361-3371.

GAO, J. (2006). Canopy Chlorophyll Estimation With Hyperspectral Remote Sensing. Kansas State University.

Ghosh, P. P., Banik, P., Patel, N., & Pal, D. J. (2013). Vegetation Stress Detection With Hyperspectral Remote Sensing for A Winning Agribusiness. International Journal of Business Analytics and Intelligence, 1(1), 13-21.

Gitelson, A. A., Gritz, Y., & Merzlyak, M. N. (2003). Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. Journal of Plant Physiology, 160(3), 271-282.

Gitelson, A. A., Kaufman, Y. J., & Merzlyak, M. N. (1996). Use of a green channel in remote sensing of global vegetation from EOS-MODIS. Remote Sensing of Environment, 58(3), 289-298.

Gitelson, A. A., & Merzlyak, M. N. (1998). Remote sensing of chlorophyll concentration in higher plant leaves. Advances in Space Research, 22(5), 689-692.

Gitelson, A., & Merzlyak, M. N. (1994). Spectral Reflectance Changes Associated with Autumn Senescence of Aesculus hippocastanum L. and Acer platanoides L. Leaves. Spectral Features and Relation to Chlorophyll Estimation. Journal of Plant Physiology, 143(3), 286-292.

Gotfryd, A., & Hansell, R. (1986). Prediction of bird-community metrics in urban woodlots. WILDLIFE, 321-326.

Gret-Regamey, A., Weibel, B., Kienast, F., Rabe, S. E., & Zulian, G. (2015). A tiered approach for mapping ecosystem services. Ecosystem Services, 13,

16-27.

Gutzat, F., & Dormann, C. F. (2018). Decaying trees improve nesting opportunities for cavity-nesting birds in temperate and boreal forests: A meta-analysis and implications for retention forestry. Ecology and Evolution, 8(16), 8616-8626.

Heckmann, K. E., Manley, P. N., & Schlesinger, M. D. (2008). Ecological integrity of remnant montane forests along an urban gradient in the Sierra Nevada. Forest Ecology and Management, 255(7), 2453-2466.

Hill, R. A., & Broughton, R. K. (2009). Mapping the understorey of deciduous woodland from leaf-on and leaf-off airborne LiDAR data: A case study in lowland Britain. ISPRS Journal of Photogrammetry and Remote Sensing, 64(2), 223-233.

Hinsley, S. A., Hill, R. A., Gaveau, D. L. A., & Bellamy, P. E. (2002). Quantifying woodland structure and habitat quality for birds using airborne laser scanning. Functional Ecology, 16(6), 851-857.

Hwang, S., Lee, M., & Lee, I. (2012). Detection of Individual Trees and Estimation of Mean Tree Height using Airborne LIDAR Data. Journal of Korean Society for Geospatial Information Science, 20(3), 27-38.

Jim, C. Y., & Liu, H. T. (2001). Patterns and dynamics of urban forests in relation to land use and development history in Guangzhou City, China. Geographical Journal, 167(4), 358-375.

Kates, R. W., & Wilbanks, T. J. (2010). Making the Global Local Responding to Climate Change Concerns from the Ground. Environment: Science and Policy for Sustainable Development, 45(3), 12-23.

Kayet, N., Pathak, K., Chakrabarty, A., Singh, C. P., Chowdary, V. M., Kumar, S., & Sahoo, S. (2019). Forest health assessment for

geo-environmental planning and management in hilltop mining areas using Hyperion and Landsat data. Ecological Indicators, 106, 105471.

Kayet, N., Pathak, K., Singh, C. P., Bhattacharya, B. K., Kumar Chaturvedi, R., Brahmandam, A. K. S., & Mandal, C. (2023). Detection and mapping of vegetation stress using AVIRIS-NG hyperspectral imagery in coal mining sites. Advances in Space Research.

Kenkel, N. C., & Orloci, L. (1986). Applying Metric and Nonmetric Multidimensional Scaling to Ecological Studies: Some New Results. Ecology, 67(4), 919–928.

Kim, E., Wie, G., Cho, H., & Yang, I. (2010). A study for forest research using airborne laser scanning. Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography, 28(3), 299-304.

Kim, H. (2012). Study on the Current Status Analysis of Urban Green Spaces in Seoul Focusing on Elementary School Surroundings - Remote Sensing Based Vegetation Classification -. Journal of the Korean Institute of Landscape Architecture, 40(5), 8-18.

Kim, T. (2012). A Study on the Evaluation of Ecological Health for Buffer Green Space in City : In the case of buffer green space in Si-Wha industrial complex, Siheung City. [Master's thesis, Hanyang university]

Kim, W., Kang, J., Chae, J., Kim, J., & Kim, W. (2017). Improvement of Forest Management in Neighborhood Park. Seoul Institute.

Lafortezza, R., Carrus, G., Sanesi, G., & Davies, C. (2009). Benefits and well-being perceived by people visiting green spaces in periods of heat stress. Urban Forestry & Urban Greening, 8(2), 97-108.

Lee, D., Kim, D., Kim, E., Jeong, J., Oh, Y., Joo, S., & Kim, K. (2008). Evaluation Indicators for Creation and Management of Urban Forest. The

Korea Society of Environmental Restoration Technology, 11(5), 1229-3032.

Lee, D., & An, B. (2021). Analyzing the Economic Value and Planning Factors of Hubs within Urban Green Infrastructure - Focusing on the Case of Sejong Lake Park -. Journal of the Korean Institute of Landscape Architecture, 49(4), 41-54.

Lee, S., Park, J., & Kim, E. (2014). Development of Automated Model of Tree Extraction Using Aerial LIDAR Data. Journal of the Korea Academia-Industrial Cooperation Society, 15(5), 3213-3219.

Lee, W. (2016). An Integrated Assessment of Park-Type Green Space Considering Functional Characteristics in Daegu. Journal of the Korean Association of Geographic Information Studies, 19(1), 120-140.

Lee, W. (2010). The Assessment of Green Environment and Establishment of Planning Direction for the Sustainable Urban Space. [Doctoral dissertation, Kyungpook National University]

Lee, W. (2011). An Evaluation of Natural-Ecological Function for Planning and Management on Forest. Journal of the Korean Institute of Landscape Architecture, 39(5), 1-11.

Li, X., Chen, W. Y., Sanesi, G., & Lafortezza, R. (2019). Remote Sensing in Urban Forestry: Recent Applications and Future Directions. Remote Sensing, 11(10), 1144.

Listopad, C. M. C. S., Masters, R. E., Drake, J., Weishampel, J., & Branquinho, C. (2015). Structural diversity indices based on airborne LiDAR as ecological indicators for managing highly dynamic landscapes. Ecological Indicators, 57, 268-279.

Liu, H. Q., & Huete, A. (2019). A feedback based modification of the NDVI to minimize canopy background and atmospheric noise. IEEE Transactions on

Geoscience and Remote Sensing, 33(2), 457-465.

Lovell, S. T., & Taylor, J. R. (2013). Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landscape Ecology, 28(8), 1447-1463.

McGranahan, G., Balk, D., & Anderson, B. (2016). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment & Urbanization, 19(1), 17-37.

Ministry of Environment. (2012). Research on Preparation of Measures for Enhancing the Ecological Function of Urban Greenery(도시녹지의 생태적 기능 강화방안 마련 연구).

Okubo, A., & Sugiyama, S. (2009). Comparison of molecular fingerprinting methods for analysis of soil microbial community structure. Ecological Research, 24(6), 1399-1405.

Ordonez, C., & Duinker, P. N. (2012). Ecological integrity in urban forests. Urban Ecosystems, 15(4), 863-877.

Park, E., Seo, J., & Kang, K. (2006). Expansion and Ecological Management of Green Spaces through Improving Impervious Surfaces in Urban Areas. Gyeonggi research Institute.

Park, J., Han, B., & Kwak, J. (2023). Ecological renewal plan of urban parks for the revitalization of urban green axis in Gangdong-gu. journal of the Korean institute of landscape architecture, 51(2), 12-27.

Park, K., You, J., & Jung, S. (2005). A Study on Importance of Assessment Factors and Indicators of Natural Ecosystem for Environmentally Friendly Land Conservation. Journal of Environmental Impact Assessment, 14(4), 165-177.

Park, S., & Han, B. (2009). A Study on the Development of Evaluation

Indicators for Planting Functions in Urban Neighborhood Park- In Case of Ansan, Gyeonggi-do -. Korean Journal of Environment and Ecology, 19(1), 102-105.

Parmehr, E. G., Amati, M., Taylor, E. J., & Livesley, S. J. (2016). Estimation of urban tree canopy cover using random point sampling and remote sensing methods. Urban Forestry & Urban Greening, 20, 160-171.

Plowright, A. A., Coops, N. C., Eskelson, B. N. I., Sheppard, S. R. J., & Aven, N. W. (2016). Assessing urban tree condition using airborne light detection and ranging. Urban Forestry and Urban Greening, 19, 140-150.

Ra, Y., Cho, J., Kim, H., & Kwon, J. (2012). Landscape ecological shape analysis of urban neighborhood parks in Daegu. The Journal of Korean Institute of Forest Recreation, 16(4), 59-70.

Raciti, S. M., Hutyra, L. R., & Newell, J. D. (2014). Mapping carbon storage in urban trees with multi-source remote sensing data: Relationships between biomass, land use, and demographics in Boston neighborhoods. Science of The Total Environment, 500, 72-83.

Rouse Jr, J. W., Haas, R. H., Deering, D. W., Schell, J. A., & Harlan, J. C. (1974). Monitoring the Vernal Advancement and Retrogradation (Green Wave Effect) of Natural Vegetation (No. E75-10354).

Russo, A., Escobedo, F. J., Timilsina, N., Schmitt, A. O., Varela, S., & Zerbe, S. (2014). Assessing urban tree carbon storage and sequestration in Bolzano, Italy. International Journal of Biodiversity Science, Ecosystem Services & Management, 10(1), 54-70.

Ryu, Y., Ra, J., Cho, H., Kim, J., & Kwon, O. (2012). Landscape Ecological Shape Analysis of Urban Neighborhood Parks in Daegu. Journal of the Korean Institute of Forest Recreation, 16(4), 59-70.

Sampson, P. H., Zarco-Tejada, P. J., Mohammed, G. H., Miller, J. R., & Noland, T. L. (2003). Hyperspectral Remote Sensing of Forest Condition: Estimating Chlorophyll Content in Tolerant Hardwoods. Forest Science, 49(3), 381-391.

Satterthwaite, D. (2009). The implications of population growth and urbanization for climate change. Environment & Urbanization, 21(2), 545-567.

Scarascia-Mugnozza, G., Bauer, G. A., Persson, H., Matteucci, G., & Masci, A. (2000). Tree Biomass, Growth and Nutrient Pools. In Carbon and Nitrogen Cycling in European Forest Ecosystems (pp. 49-62). Springer, Berlin, Heidelberg.

Sims, D. A., & Gamon, J. A. (2002). Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. Remote Sensing of Environment, 81(2-3), 337-354.

Solecki, W., & Marcotullio, P. J. (2013). Climate Change and Urban Biodiversity Vulnerability. Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment, 485-504.

Son, Y., Lee, K., & Kim, R. (2007). Estimation of Forest Biomass in Korea. Journal of Korean Society of Forest Science, 96(4), 477-482.

Song, W. (2015). Analysis of Bird Species Diversity Response to Structural Conditions of Urban Park -Focused on 26 Urban Parks in Cheonan City-. Journal of the Korea Society of Environmental Restoration Technology, 18(3), 65-77.

Sung, H. (2015). A Study on the Ecological Attributes Assessment and Comparison of Urban Parks according to Types of the Surrounding Green Areas. Journal of the Korea Society of Environmental Restoration Technology,

18(2), 119-131.

Sung, H., & Hwang, S. (2013). A Preliminary Study on Assessment of Urban Parks and Green Zones of Ecological Attributes and Responsiveness to Climate Change. Journal of the Korea Society of Environmental Restoration Technology, 16(3), 107-117.

Tao, S., Wu, F., Guo, Q., Wang, Y., Li, W., Xue, B., Hu, X., Li, P., Tian, D., Li, C., Yao, H., Li, Y., Xu, G., & Fang, J. (2015). Segmenting tree crowns from terrestrial and mobile LiDAR data by exploring ecological theories. ISPRS Journal of Photogrammetry and Remote Sensing, 110, 66-76.

Tuominen, J., Lipping, T., Kuosmanen, V., & Haapanen, R. (2009). Remote sensing of forest health. In Geoscience and remote sensing, 29-52.

Uhrin, P., & Supuka, J. (2016). Quality assessment of urban trees using growth visual and chlorophyll fluorescence indicators. Ekologia Bratislava, 35(2), 160-172.

Velichkova, K., & Krezhova, D. (2019). Comparative Analysis of Hyperspectral Vegetation Indices for Remote Estimation of Leaf Chlorophyll Content and Plant Status. RAD Association Journal, 3(3), 202-208.

Vogelmann, J. E., Rock, B. N., & Moss, D. M. (2007). Red edge spectral measurements from sugar maple leaves. International Journal of Remote Sensing, 14(8), 1563-1575.

Wang, S., Huang, L., Xu, X., & Li, J. (2022). Spatio-temporal variations in ecological spaces and their ecological carrying status in China' s mega-urban agglomerations. Journal of Geographical Sciences, 32(9), 1683-1704.

Winn, M. F., Bradley, L. S., & Araman, P. A. (2010). Urban crowns: crown analysis software to assist in quantifying urban tree benefits. Proceedings, Emerging Issues Along Urban/Rural Interfaces III: Linking Science and Society.

Auburn, AL: Auburn University, Center for Forest Sustainability, 86-91.

Zarnoch, S. J., Bechtold, W. A., & Stolte, K. W. (2011). Using crown condition variables as indicators of forest health. Canadian Journal of Forest Research, 34(5), 1057-1070.

Zeybek, M., & Şanl ı oğlu. (2019). Point cloud filtering on UAV based point cloud. Measurement, 133, 99-111.

Zhang, J., Finley, K. A., Johnson, N. G., & Ritchie, M. W. (2019). Lowering stand density enhances resiliency of ponderosa pine forests to disturbances and climate change. Forest Science, 65(4), 496-507.

Zhang, Y., & Shao, Z. (2021). Assessing of Urban Vegetation Biomass in Combination with LiDAR and High-resolution Remote Sensing Images. International Journal of Remote Sensing, 42(3), 964-985.

Zipperer, W. C., Sisinni, S. M., Pouyat, R. V., & Foresman, T. W. (1997). Urban tree cover: an ecological perspective. Urban Ecosystems, 1, 229-246.

Appendix A

[Table 1-1] Summary of ecological attribute values by park

Park number	Parkname (Kor)	Parkname (Eng)
1	가막들공원	Gamakdeul Park
2	갈미한글공원	Galmi hangeul Park
3	고천체육공원	Gocheon sports Park
4	공원(학의동공원1)	Hakui-dong Park 1
5	공원48	Park 48
6	공원62	Park 62
7	까치공원	Kkachi Park
8	내손1공원(문학)	Naeson 1 Park (Literature)
9	내손2공원(중앙)	Naeson 2 Park (Middle)
10	내손공원	Naeson Park
11	내손어린이공원	Naeson children's Park
12	노을빛공원	Sunset Park
13	다람이공원	Daramee Park
14	두산위브공원	Doosan weve Park
15	두터비공원	Duteobi
16	맑은내공원	Malgeunnae Park
17	모락공원	Morak Park
18	물빛공원	Moolbit Park
19	민백공원	Minbaek Park
20	반디공원	Bandi Park
21	복지공원	Bokji Park
22	부곡공원	Bugok Park
23	부곡체육공원	Bugok sports Park
24	빛솔공원	Bitsol Park
25	산빛공원	Sanbit Park
26	소공원62	Small park 62
27	소공원63	Small park 62
28	소담공원	Sodam Park
29	아랫골공원	Aretgol Park
30	어린이공원31	Children' s Park 31
31	언덕공원	Unduk Park
32	오전로가족공원	Ojeon-ro Park
33	오전초교앞공원	Ojeon-dong elementary school Park
34	웃골공원	Uttgol Park
35	인덕원푸르지오 엘센트로 아파트단지내공원	Park in Indeokwon prugio elcentro apartment complex
36	청계양지공원	Cheonggye yangji Park
37	초록공원	Chorok Park
38	한직공원, 푸른내공원	Hanjik, Pureunnae Park
39	현충탑공원	Memorial tower Park
40	호수마을공원	Lake village Park

[Table 1-2] Summary of ecological attribute values by park

Park number	Height (m)	DBH (m)	Biomass (1000 ton)	Crown volume (m^3)	Canopy coverage (%)	Tree density (n/ha)	Vegetation Vitality
1	7.71	0.42	1.09	54.29	61.69	177.33	62.24
2	6.38	0.41	0.88	60.66	38.42	162.44	43.03
3	6.62	0.30	0.67	66.98	52.73	90.31	52.52
4	5.02	0.31	0.53	14.08	21.69	157.18	40.07
5	6.47	0.22	0.48	32.46	25.55	78.47	30.70
6	5.23	0.27	0.47	14.71	13.69	64.32	34.08
7	5.69	0.38	0.71	31.86	51.48	337.15	38.03
8	8.20	0.30	0.86	49.94	34.20	302.84	62.28
9	7.06	0.31	0.75	51.75	46.54	349.40	43.61
10	5.53	0.46	0.86	36.08	38.13	92.81	66.20
11	8.87	0.39	1.20	66.69	60.80	257.23	53.86
12	6.29	0.33	0.72	37.89	47.53	231.73	44.39
13	6.10	0.37	0.80	41.36	50.75	213.99	46.70
14	6.68	0.31	0.67	21.65	60.23	562.24	60.70
15	5.81	0.36	0.69	32.82	48.60	301.17	38.61
16	5.72	0.31	0.69	33.65	41.37	232.97	63.68
17	8.48	0.35	1.02	80.91	52.04	69.95	54.91
18	5.34	0.34	0.61	26.67	41.86	130.65	47.19
19	4.73	0.47	0.75	12.77	42.15	408.21	48.30
20	5.77	0.36	0.68	31.04	43.13	280.27	43.21
21	5.75	0.44	0.88	43.04	41.29	227.52	48.26
22	4.41	0.29	0.41	11.07	35.16	193.74	51.04
23	5.10	0.29	0.51	54.54	49.76	150.26	59.99
24	5.20	0.41	0.72	29.06	40.12	390.00	60.88
25	5.31	0.39	0.71	35.03	42.17	136.87	50.10
26	6.57	0.32	0.71	114.33	37.11	34.35	26.66
27	6.61	0.38	0.80	63.69	45.04	110.73	42.26
28	6.51	0.44	0.94	43.06	84.81	54.32	55.41
29	4.72	0.34	0.50	10.84	19.19	88.44	50.78
30	4.30	0.32	0.46	15.05	39.65	311.11	50.09
31	5.50	0.39	0.73	22.01	42.53	472.81	53.27
32	6.65	0.31	0.87	40.56	37.27	204.67	50.47
33	7.17	0.19	0.49	60.21	44.45	177.64	51.82
34	5.57	0.30	0.53	17.39	32.14	189.60	35.95
35	9.14	0.39	1.28	56.56	29.96	81.67	36.01
36	8.34	0.50	1.36	63.54	45.15	150.20	54.09
37	6.62	0.38	0.88	43.38	56.77	287.99	67.01
38	7.69	0.43	1.13	59.14	65.51	177.95	59.41
39	7.18	0.30	0.71	58.69	49.69	48.97	58.10
40	7.69	0.42	1.12	70.97	57.66	231.54	64.75

[Table 1-3] Summary of ecological attribute values by park

Park number	Chlorophyll content	Stress index	Area of park (ha)	Area of major green spaces within 300m (m²)	Perimeter length per area (m)	Impervious area (%)
1	47.92	2.67	1.99	9.20	0.038	11.08
2	31.71	3.98	0.73	23.12	0.051	39.52
3	36.08	3.21	1.69	5.73	0.039	35.82
4	28.75	5.95	0.50	20.44	0.072	1.77
5	31.48	5.76	0.32	0.00	0.079	75.21
6	26.39	5.20	0.67	4.56	0.050	36.45
7	33.81	4.64	0.64	16.86	0.057	48.37
8	47.42	2.14	1.10	11.17	0.044	28.71
9	34.71	3.99	1.01	10.17	0.044	8.40
10	53.70	2.24	3.20	4.47	0.023	55.36
11	39.84	2.72	0.79	1.01	0.064	44.41
12	34.42	4.24	1.28	4.88	0.037	14.34
13	35.81	3.47	0.78	13.11	0.052	32.22
14	52.45	2.59	0.07	0.00	0.161	20.38
15	34.68	4.51	0.81	9.27	0.045	45.99
16	49.96	2.55	0.33	4.91	0.079	20.10
17	42.70	2.91	0.54	25.93	0.059	27.14
18	39.06	3.22	3.05	6.76	0.039	49.95
19	40.75	2.68	0.08	0.00	0.155	10.05
20	35.01	3.69	0.64	6.02	0.057	32.22
21	39.03	3.06	0.18	0.00	0.103	67.53
22	33.54	4.43	0.45	5.03	0.066	25.53
23	37.63	3.14	0.77	15.09	0.050	47.19
24	47.61	2.83	1.63	0.00	0.050	25.04
25	40.38	3.76	4.51	23.57	0.030	43.69
26	25.04	6.37	1.11	12.44	0.038	60.84
27	35.11	5.75	1.03	11.77	0.041	47.07
28	39.61	2.67	2.34	2.05	0.044	19.25
29	32.25	4.12	0.80	13.43	0.084	10.16
30	41.17	4.29	0.21	5.91	0.106	88.72
31	37.71	2.86	1.08	4.61	0.070	42.60
32	40.25	2.85	0.32	1.19	0.089	20.65
33	42.55	2.65	0.20	3.62	0.088	57.19
34	30.27	5.52	1.07	14.42	0.043	25.60
35	25.73	4.87	1.30	2.49	0.037	50.45
36	42.74	2.58	0.19	3.76	0.087	48.09
37	51.29	2.56	0.55	6.35	0.069	29.05
38	44.78	2.45	1.58	0.34	0.063	13.42
39	43.68	2.82	1.55	3.06	0.037	30.44
40	53.70	2.86	0.19	0.00	0.101	35.08

초록

도시공간의 증가로 인한 인구 및 경제발전과 함께 도시 내 그린인프라의 필요성이 지속적으로 제기되고 있다. 도시 공원은 여러 환경문제들이 발생하는 도시 내에서 경관의 질을 유지시킬 뿐만 아니라 생태적으로도 중요한 작용을 한다. 특히, 도시지역에서 가장 많은 녹지 공간을 제공하고 있는 수목은 건강한 생태계의 유지에 밀접하게 연관되어있는 요소이다. 하지만 도시 공원이 가지는 이용 및 조성 목적에 의해 도시 공원 내에 있는 생태성은 크게 두드러지지 않으며, 생태적 현황을 반영한 가이드라인 또한 부족한 실정이다. 따라서 도시 공원의 생태적 기능을 크게 담당하는 수목의 생태성에 대한 적절한 평가가 이루어져야 하며, 이는 추후 도시공원의 관리적인 측면에서도 필요한 것으로 판단된다. 도시 내 녹지가 가지는 환경적인 가치의 증대와 도시민의 요구 충족을 위해서는 녹지 모니터링 및 평가가 필요하다. 수목의 생태성을 평가하기 위한 기존의 방법은 노동 및 시간 집약적이지만, 라이다와 초분광 이미지 같은 고해상도 자료의 사용은 빠르고 정확한 정보 취득과 측정 가능 범위 등의 이점으로 인해 이러한 문제를 극복할 수 있게 한다. 더욱이, 고해상도 자료는 자료 취득 방식이나 시기 등에 따라 얻을 수 있는 정보에 차이가 있지만, 이 자료들을 서로 중첩함으로써 더 많은 정보값들을 얻을 수 있다. 또한, 녹지 평가를 위해 지표를 이용한 연구들이 다수 진행되어왔는데, 이는 시간 및 공간에 따른 녹지 및 구성요소의 중요한 변화를 측정할 수 있는 변수이며, 공원 관리에 대한 의사결정에 중요한 정보를 제공할 수 있다.

이에 본 연구는 고해상도 자료를 이용하여 도시 내의 다양한 공원들의 수목을 중심으로 한 생태적 특성에 대해 파악하고자 한다. 또한 특성들을 서열화하여 기존 이용 목적에 따라 구분되었던 공원 유형이 아닌 생태적 특성에 따라 공원을 분류하여 생태적 측면에서의 가치를 발굴해보고자 한다. 연구의

공간적 범위는 의왕시 내의 도시공원 40개이다. 40개 공원에 대해 두 시기의 항공 LiDAR와 슬램 LiDAR, 그리고 초분광 이미지 자료가 수집되어 정합되었으며, 선행연구 분석을 통한 13개의 지표 선정 또한 이루어졌다. 이를 통해 개별 수목의 특성값 및 공원별 특성값을 추출하였고, 추출된 특성값은 NMDS 분석을 거쳐 40개 공원을 6개의 군집으로 나누었다.

이후 공원들 간의 거리에 따른 분포와 6개 군집간의 차이가 시각적으로 표현되었으며, 군집별 특성 비교를 통해 공원 관리 방안이 제시되었다. 6개의 군집은 생태적 가치가 높은 고립형 공원으로 외부적으로 연결을 통해 생태적 징검다리의 역할이 기대되는 공원, 주변 녹지와 인접하여 입지적인 잠재성은 높지만 내부적으로는 생태성이 낮아 주변의 생태성의 활용이 필요한 공원, 건강성이 양호한 거목이 적정 밀도로 식재되어 지속적인 모니터링으로 현재의 생태적 특성을 유지해야 하는 공원, 높은 울폐율을 조절함으로써 하층 식생대의 건강성을 함께 관리할 필요성이 있는 공원, 비교적 최근에 식재된 유령목이 양호한 성장세를 가져 다양한 수령의 수목과 하층식생을 통한 다층적인 식생구조를 함께 이루도록 관리해야 할 필요성이 있는 공원으로 분류되었다. 또한 높은 생태적 특성과 잠재성을 가지는 시설이 중요시되는 공원의 발굴을 통해 자연과 이용객을 고려한 더욱 효과적인 도시공원 관리 방안을 제시하였다.

본 연구는 고해상도 자료를 통한 수목 및 녹지의 생태적 특성 자료를 도출 및 관리방안을 제시하려는 시도에 의의가 있다. 향후, 본 연구에서 고려하지 못했던 수종별 수목의 생태적인 차이, 수목의 생육에 영향을 주는 환경변수와 이용객들의 이용 강도 등에 따른 영향을 고려한다면 더욱 체계적인 도시공원의 관리방안을 제시할 수 있을 것으로 판단된다.

.....

주요어 : 도시생태, 생태지표, NMDS, 원격탐사
학　번 : 2020-23477