

OPTIMIZING MULTIFUNCTIONALITY AND ECOSYSTEM SERVICES SUPPLY IN EUGENE'S GREEN SPACES

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Abstract: Urban green spaces play a role in mitigating environmental challenges and enhancing urban sustainability and resilience. The paper aims to assess the four regulating ecosystem services (carbon storage and sequestration, runoff control, and air pollutant removal) in ten neighborhood parks in Eugene, Oregon (USA). Using the I-Tree Eco model, the contribution of urban trees to ecosystem services supply is evaluated. Similarities and dissimilarities between the neighborhood parks are analyzed using Multidimensional Scaling (MDS). The major findings show significant variation in ecosystem service supply, influenced mainly by the parks' tree canopy and leaf area index. Mature and large-canopy trees emerged as critical contributors, underlining their importance in optimizing regulating services. The fact that no single park offers all four ecosystem services at optimal levels highlights the necessity for a comprehensive, city-wide strategy for green space management. The study provides guidelines for urban green space planning and management, emphasizing the importance of preserving mature trees and adopting targeted planting strategies to enhance ecosystem services supply. These findings contribute to sustainable urban planning, supporting the development of more ecosystem services-friendly urban green spaces to address societal challenges.

Keywords: urban green spaces, regulatory ecosystem services, neighborhood parks

1. INTRODUCTION

Expanding built-up areas represent a major threat to urban ecosystem services supply (Grădinaru et al., 2023; Lourdes et al., 2022; Llabrés & Cariñanos, 2022). Urban landscapes are characterized by complex interactions among biophysical, socioeconomic, and technological infrastructure (McPhearson et al., 2022). These interactions generate unique human-dominated landscapes influencing ecosystem functions (Alberti, 2005) and ecosystem services supply (Haase et al., 2014).

Green spaces, considered paramount constituents of urban landscapes (Zhang et al., 2018), offer many ecosystem services, which have a critical role in addressing existing societal challenges (Raymond et al., 2017; Csete & Gulyas, 2019; Das et

al., 2022) and improving human well-being. Additionally, it creates opportunities for social interaction, recreation, and fostering a connection with nature (Breuste & Artman, 2020, Sousa-Silva & Zanocco, 2024).

However, significant gaps remain in understanding the optimization of ecosystem services within the fragmented and dispersed configurations of urban green spaces (Steiner, 2011; Ernstson, 2013; Hepcan, 2013; Coşkun Hepcan & Hepcan, 2018). Limited research has focused on the comprehensive assessment of regulating services across different park types, and few studies provide standardized guidelines for the designing and maintenance of these services in neighborhood parks.

Furthermore, the ecological characteristics of green spaces directly impact their delivery of

provisioning urban ecosystem services (Calderon-Contreras & Quiroz-Rosas, 2017; Sikorski et al., 2021; Chen et al., 2022). Thus, they require special attention to planning and design. More specifically, many ecosystem services in green spaces are mainly influenced by factors such as plant species structure (mainly trees), green space characteristics, and maintenance measures (Zhao et al., 2023).

Considering the statements, two key contexts appear for approaching urban green spaces with a focus on optimizing ecosystem services: a) The need for a green infrastructure system aimed at eliminating the fragmented and dispersed configuration of green areas within cities. b) The ecological characteristics of each green area and the necessity of considering applicable principles in its management, including plant selection—especially tree species—on a basis that optimizes ecosystem services.

This study focused on neighborhood parks for quantifying ecosystem services supply. Neighborhood parks, defined as urban green spaces found within biking and/or walking distances of users, are mostly prioritized for recreational amenities and services (Eugene Parks and Recreation, 2018). Beyond recreation, these parks also provide cultural ecosystem services, including aesthetic value, opportunities for relaxation, and social interactions, which shape visitor experiences and contribute to

urban well-being (Zwierzchowska et al., 2018; Vierikko et al., 2020). Their value mainly lies in their proximity to the urban residents (Aerts et al., 2022; Julfikar et al., 2022; Konijnendijk, 2022) because they are easily accessible.

The paper aims to assess the four regulating ecosystem services (carbon storage and sequestration, runoff control, and air pollutant removal) in ten neighborhood parks in Eugene, Oregon (USA). More specifically, it aims to answer the following research questions:

1. How do parks with different vegetation characteristics perform in terms of the four regulatory ecosystem services?
2. Is there any park in Eugene, which extensively provides all four services?
3. Is there a standardized plan or general guideline that can be applied to each park to optimize the regulating ecosystem services?

2. MATERIALS AND METHODS

2.1. Study area

Eugene, Oregon, located at the southern end of the Willamette Valley, is characterized by a temperate climate with an average annual precipitation of 1172 mm



Figure 1. The locations of the neighborhood parks: 1. Brewer Park, 2. Country LN Park, 3. Fairmount Park, 4. Marche Chase, 5. Mulligan Park, 6. Oakmont Park, 7. Tandyturn Park, 8. University Park, 9. Washburne Park, 10. Willakenzie Park.

and average monthly temperatures ranging from 7.7°C in December to 28.3°C in August (US Climate Data, 2018). The city's population of 172,622 inhabitants (US Census Bureau, 2018) benefits from numerous neighborhood parks managed by the city. Ten parks—Brewer Park, Country Lane Park, Fairmount Park, Marche Chase, Mulligan Park, Oakmont Park, Tandyturn Park, University Park, Washburne Park, and Willakenzie Park—were selected for this study based on their diversity of vegetation and physical attributes (Figure 1).

2.2. Methods

The I-Tree Eco (USDAFS, 2008) model inventory was applied to compute each park's contribution to four regulating ecosystem services based on tree structure: carbon storage and sequestration, runoff control, and air pollutants removal. Utilizing the I-Tree Eco model involves the computational representation of the functionalities offered by vegetation, predominantly trees. This model encompasses various parameters derived from empirical data across various climatic regions. Its primary aim is to evaluate the ecosystem services made by urban trees, encompassing stormwater regulation, carbon sequestration, and ancillary benefits (Soares et al., 2011).

2.2.1 Data Collection

Tree data were collected through on-site field surveys conducted in each park from June to July 2018. During these surveys, each tree was identified and measured, with species, diameter at breast height (DBH), overall height, height to the base of the crown, width of the crown, percentage of missing canopy, and light exposure of the crown recorded. Measurements were taken following the protocols outlined in the I-Tree Eco Manual (2013) to ensure consistency and accuracy. Ecosystem services were estimated in the I-Tree Eco model using various parameters derived from experiences across various climatic zones.

The data collection process, including tree species, DBH, and canopy metrics, follows the general principles outlined in the established urban ecosystem services evaluation frameworks. The process aligns with best practices in ecosystem service assessment, ensuring the data is consistent with widely recognized standards for evaluating urban green spaces in terms of regulating services (Sara Maia et al., 2015).

2.2.2. Air pollutants removal

Air pollutants removal was evaluated through field data, air pollution concentration, and

meteorological data (I-Tree software database). The I-Tree Eco model is employed to estimate the dry deposition of air pollutants (Baró et al., 2014; Hirabayashi et al., 2011; Nowak et al., 2013). The estimates of air pollution reduction are derived from computed hourly tree-canopy resistances for O₃, NO₂, and SO₂. The calculation method is based on the I-Tree model, following the techniques outlined in Nowak et al., (2006, 2013) and Hirabayashi et al., (2011).

2.2.3. Carbon storage and sequestration

The urban trees' carbon storage and sequestration capacity were assessed using the I-Tree Eco model v6. The biomass estimates are later integrated with diverse factors, encompassing base growth rates found by the duration of the growing season, tree health, and competition (Nowak & Crane 2000, 2002; Nowak et al., 2008). The annual gross amount of carbon sequestered is estimated by calculating the difference between consecutive years' estimates of carbon storage (Nowak & Crane, 2002). The net carbon sequestration is calculated following Nowak & Crane's (2002) estimate, which accounts for approximately 75% of the gross sequestration.

2.2.4. Runoff control

In I-Tree Eco, runoff is assessed by calculating the avoided runoff, which refers to the portion of runoff intercepted by trees. Estimating avoided runoff involves contrasting the hourly precipitation patterns and the overall annual surface runoff volume simulated for the area with trees against the scenario where trees are not present (I-Tree Eco manual, 2013). In the present study, the calculation of avoided runoff relies on local weather data from the user-selected weather station.

2.2.5. Multidimensional Scale Analysis (MDS)

The A Z-score transformation was applied to each factor since there are scale differences between the factors (four ecosystem services and three environmental variables) thought to impact the parks (Field, 2013).

To determine the parks' similarities and dissimilarities in terms of ecosystem services and environmental variables, the Euclidean distance measure was applied. This measure involves squaring the differences between the observation vectors, summing the differences, and then taking the square root of these sums to calculate their geometric distance (Boyd & Vandenberghe, 2019).

As a result of the preliminary analysis, it was decided that ALSCAL method (Alternating Least-Squares Scaling) has a better model-data fit than

PROXSCAL method (Proximity Scaling) (Schiffman et al., 1981). In addition, the stress value, which is a criterion for deciding model fit, is directly correlated with the number of dimensions used in the analysis and sample size. Stress value takes a value between 0 and 1 (Kruskal, 1964). In addition, the size of the R² value is considered as a measure of fit, saying that the multidimensional scaling model is the measurements well. An R² value ≥ 0.60 shows the analysis is reliable (Malhotra & Dash, 2011).

In this study, the 2-dimensional analysis determined that the stress value was small, and the R² value was high compared to other dimensions. This showed that two-dimensional positioning increased coherence. For this reason, the ALSICAL method was used as the multidimensional scaling method, and 2 was used as the best number of dimensions in the similarity assessment between parks. Pairwise distances between samples were computed as a function of Euclidean distance (Borg & Groenen, 2005).

3. RESULTS

The study's findings demonstrate significant variability among the parks in terms of tree cover, tree density, and their contributions to ecosystem services.

3.1 Tree cover and density

The parks showed a wide range in tree cover, with Washburne and University Parks leading (60.8% and 55.7%, respectively) and Mulligan Park having

the lowest (3.1%). Tree density also varied, with Mulligan Park having 200 trees/ha and CountryLN Park having just 22 trees/ha (Table 1).

3.2. Air pollutants removal

The capacity for pollutant removal varied widely, with Brewer Park standing out as the highest performer at 17.66 gr/m²/year, attributed to its high leaf area index of 0.95 ha. Fairmount Park, with one of the lowest leaf area indices (0.45), exhibited the lowest pollutant removal at 3.68 gr/m²/year. Most other parks performed similarly, with pollutant removal ranging from 4.09 to 4.91 gr/m²/year. Overall, the total estimated pollutant removal for the parks combined was 153.785 kg, indicating the significant role of urban parks in air purification (Figure 2, Table 1).

3.3. Carbon storage and sequestration

Carbon sequestration results revealed that Brewer Park, Oakmont Park, and Washburne Park made the largest contributions, with Washburne Park alone accounting for 16% of the total carbon sequestration in the area. In terms of sequestration per unit area, Brewer and Mulligan Parks performed the best. Overall, the study estimated a total of 1525.76 mt of carbon storage, which highlights the importance of parks in mitigating climate change. Parks with larger tree covers, such as Washburne and Marche Chase, contributed the most to carbon storage (Table 1, Figure 2).



Figure 2. Neighborhood parks and their graphically illustrated performance values ranging from 0.23 to 1.21.

Table 1. The Estimated contributions of the neighborhood parks to ecosystems services.

Parks	Environmental Variables			Ecosystem Services			
	Area m ²	Tree cover (%)	Tree density (tree/ha)	Pollutant Removal g/m ² /year	Net C seq (kg/m ²)	Carbon storage (mt)	Runoff Reduction (m ³ /year)
Brewer Park	2000	24.9	42	17.66	0.39	90.76	21.22
CountryLN Park	2700	19.1	22	4.09	0.03	23.93	2.413
Fairmount Park	2800	48.4	50	3.68	0.09	47.98	4.711
Marche Chase Park	10900	47.8	61	4.91	0.07	319.4	76.39
Mulligan Park	1700	3.1	200	4.11	0.35	52.62	0.314
Oakmont Park	23100	17.2	76	4.88	0.19	190.5	49.65
Tandyturn Park	5000	42	78	4.38	0.15	93.39	23.68
University Park	11400	55.7	69	4.54	0.16	238	74.67
Washburne Park	16800	60.8	80	4.41	0.13	411.2	127.5
Willakenzie Park	19200	10.8	30	4.60	0.04	57.98	25.44

3.4. Runoff control

Regarding runoff reduction, Washburne Park again outperformed other parks with 127.5 m³/year, owing to its diverse vegetation layers and permeable surfaces. Marche Chase and University Parks followed closely behind with 76.39 m³ and 74.67 m³ of runoff reduction, respectively. On the other hand, Mulligan and CountryLN Parks demonstrated the least capacity for runoff interception, with values of 0.314 m³ and 2.413 m³/year, respectively (Table 1, Figure 2). This suggests that parks with higher tree density and diverse vegetation cover are more effective in managing stormwater runoff.

3.5. Overall performances

When combining all ecosystem services and environmental variables into a total performance score, the parks' performances ranged from 0.23 to 1.21. This normalization allowed for easier comparison across parks, with Washburne Park emerging as the top performer overall. It ranked highly in both tree density and runoff reduction and was second only to University Park in terms of carbon sequestration. Conversely, CountryLN Park exhibited the lowest total performance, indicating a need for improvement in providing ecosystem services (Figure 2).

3.6. MDS Analysis

The MDS analysis revealed four distinct groups of parks based on their environmental variables and ecosystem services (Figure 3). CountryLN and Fairmount parks were most similar, while Mulligan Park was the most distinct in its performance.

4. DISCUSSION

This study highlights the significant role of

large-canopy trees and high leaf area indices in enhancing ecosystem service regulation. By examining the performance of ten parks in Eugene, the findings provide a detailed view of how various environmental variables contribute to ecosystem services, such as air pollutant removal, carbon sequestration, and runoff reduction.

The study revealed significant variation in ecosystem service provision across parks. Large-canopy, broad-leaf trees, and diverse vegetation layers were found to enhance air pollutant removal, carbon sequestration, and runoff reduction. These findings align with similar studies (Moon & Kim, 2024; Zhao et al., 2023), but contrast with Steinparzer et al. (2023), who found evergreen conifers to accumulate more particulate matter.

No park provided all services at their highest levels. This highlights the need for a city-wide park system/green network where each park fulfills specific ecosystem services. As noted by Derkzen et al. (2015), different park designs should focus on optimizing specific services rather than attempting to balance all services in a single park.

No universal blueprint or template exists, but key factors such as tree species selection, tree health, and park design are critical. The inclusion of large-canopy trees, diverse vegetation layers, and permeable surfaces will optimize ecosystem services. Furthermore, maintaining mature trees and incorporating flexible management strategies are essential for enhancing these services (Moon & Kim, 2024; Muscas et al., 2024).

Results indicate that trees' ability to improve air quality is influenced by factors such as leaf area index (LAI) and tree species (Yang et al., 2005; Nowak et al., 2018). Studies by Kocić et al. (2014) and Yousofpour et al. (2024) support the critical role of large-canopy trees in capturing particulate matter and gases. In line with these findings, the substantial

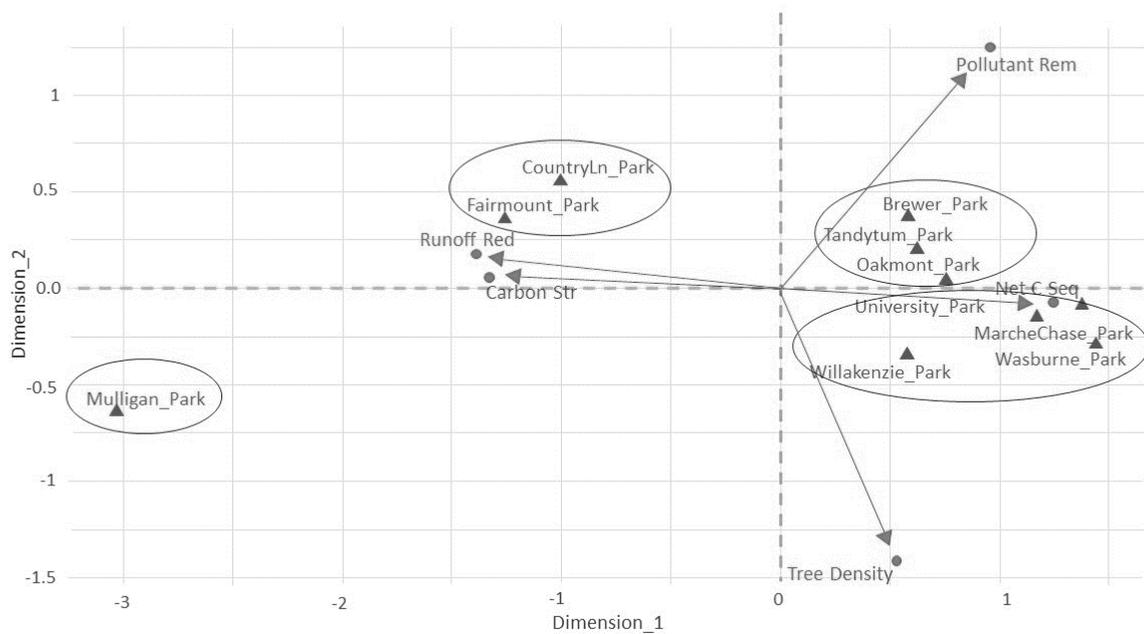


Figure 3. MDS plot of the first- and second-dimensions configuration using Euclidean distance. Red arrows show underlying ecosystem service and environmental variables vectors.

removal of pollutants at Brewer Park can be attributed to its high LAI, particularly from large canopy trees like Bigleaf maples. Other research (Zhao et al., 2023) also emphasized that specific species, like broad-leaf trees, are more effective in pollutant removal than conifers. This reinforces the importance of selecting appropriate species for urban landscapes to maximize ecosystem services.

As demonstrated by Nowak et al. (2013), carbon sequestration rates can vary depending on local tree characteristics, with trees in parks like Washburne and Marche Chase contributing significantly to carbon storage due to their age and canopy size. On the contrary, parks like Mulligan, which have lower tree cover and many younger trees, offer less carbon storage (Stephenson et al., 2014) despite their sequestration potential. Similar findings were made by Moon et al. (2024), who emphasized the role of broad-leaf species in improving carbon absorption in urban green spaces.

The ability of urban green spaces to reduce surface runoff has been well-documented (Gotsch et al., 2017; Beidokhti & Moore, 2021). Their study suggests that the presence of diverse vegetation layers, particularly large canopy trees, is essential in maximizing runoff reduction. Washburne and Marche Chase Parks, with their wide vegetation diversity, serve as prime examples of how multiple vegetation layers, including shrubs and ground covers, contribute to reducing runoff. Furthermore, a study by Yang et al. (2005) found that increasing tree canopy

density is key to enhancing stormwater management in urban parks. Thus, creating multi-layered, permeable green spaces should be prioritized in park design to ensure effective stormwater management.

The MDS analysis in this study reveals distinct clusters of parks based on their ecosystem service provision. This aligns with Mexia et al. (2018), who argued that no single park can maximally support all ecosystem services. Their findings suggest that a diversified, city-wide green network is more effective than relying on individual parks to deliver multiple services at once. Similar clustering was observed in a study by Derkzen et al. (2015), who emphasized that park designs should optimize specific ecosystem services rather than attempting to provide them all equally.

5. CONCLUSIONS

This study sought to translate quantitative results from the analysis of ten neighborhood parks into qualitative strategies for enhancing the ecosystem services provided by urban green spaces. The findings indicate that no park currently meets optimal levels across all four regulating ecosystem services. Notably, vegetation characteristics, particularly the presence of broad canopy and large-leaf trees, had a greater impact on service provision than park size. Additionally, the integration of diverse plant species, with a mix of mature and developing trees, emerged as a key consideration for improving

ecosystem function.

While no universal plan or template for maximizing ecosystem services was proposed, the study presents key principles for the planning, design, and management of parks to optimize ecosystem service delivery. As emphasized by Jato-Espino et al. (2023), such principles are vital for urban sustainability and tackling climate change challenges (Popa et al., 2022). Services like pollutant removal, for instance, are influenced by a complex array of factors, including climate conditions and plant characteristics. As we lack control over external climate variables, it becomes essential to focus on those variables within our control, such as tree cover, tree species, tree age, and effective maintenance practices, including avoiding unnecessary or intensive pruning (Yang et al., 2005; Nowak et al., 2006).

In urban green spaces, it is equally important to prioritize the design of large permeable surfaces. These surfaces facilitate the infiltration of stormwater runoff, and when planned effectively, can function as sustainable stormwater management facilities, regulating rainfall according to the specific needs of the park and its size. Rather than expecting a single park to deliver all ecosystem services at peak capacity, a more rational approach would be to establish a city-wide green network/green infrastructure, where each park is designed to specialize in particular ecosystem services and contribute to the larger environmental framework.

A limitation of this study is its focus on just 10 parks, which may not fully capture the variability of regulating ecosystem services across a broader range of urban green spaces. A more extensive study that includes a larger sample of parks would provide a deeper and more comprehensive understanding of how these services can be optimized. Nonetheless, the modest findings of this research underscore the need for increased consideration of ecosystem services-friendly planning and design principles in the development and management of urban green spaces, potentially guiding future efforts to enhance urban sustainability and resilience.

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