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Editorial

Structure and Function of Urban Forests and Green Spaces in a Changing World

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Abstract: Green infrastructures (e.g., forests, parks, and other types of green spaces) in urban areas provide people with a huge volume of ecosystem benefits. However, the quality of urban green infrastructure varies among cities in different countries/regions, and key ecological processes, maintaining mechanisms, and policy decision routes remain unclear. Here, we recognize four themes that link studies from the Asia-Pacific and European regions presented in this Editorial: (1) indicators and services of urban green spaces; (2) assembly of and changes in diverse plant communities; (3) utilization and evaluation of urban forest landscape; and (4) patterns and drivers of urban agro-forestry systems. These investigations enlarge our understanding on the theoretical exploration and methodological innovation of urban forestry studies in response to the changing environment, and shed some light on routes to achieve sustainable development goals in the context of rapid urbanization.

Keywords: forest biology; plant–environment interaction; sustainable development goal; urban green infrastructure; urban forestry

1. Introduction

The planet is moving towards a complex future under multiple factors such as climate change and rapid urbanization. According to a report by the United Nations, there was an estimated average urbanization rate of ~80% and 55% in developed and developing countries as of the end of 2021 [1], respectively. Recently, numerous studies have addressed fundamental issues concerning the monitoring, management, and service of urban forests and green spaces, as well as human–nature interactions [2–7].

The aim of this Editorial is to help fill this void in the current research by focusing on the complicated structure and multiple functions of urban forest and green spaces under the context of a changing world. The 25 papers reviewed here consist of 12, 6, 4, 2, and 1 article(s) published in the five journals of Forests, Sustainability, Land, Remote Sensing, and Biology, respectively, from the Topic "Urban Forestry and Sustainable Environments". They can be best categorized under four basic themes: (1) indicators and services of urban green spaces; (2) assembly of and changes in diverse plant communities; (3) utilization and evaluation of urban forest landscape; and (4) patterns and drivers of urban agro-forestry systems. Together, the editors of this Editorial conceptualized these four themes as a means to provide an open discussion of urban forestry and sustainable environments. Our proposal for this Topic coincided with the common interests of broad research communities, such as ecology, forestry, and biology. This Editorial includes research performed mostly in the Asia-Pacific region, and Europe, with studies originating from Australia, China, Italy, Poland, Saudi Arabia, Spain, and Turkey.

This Topic, in part, is also an important platform showcasing scientific output for the 60th anniversary (1962–2022) of the Research Institute of Tropical Forestry (Chinese

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Academy of Forestry), National Urban Forest Innovation Alliance (China's National Forestry and Grassland Administration), the joint work of the Sino-Australian Collaborative Innovation Research Team "Urban Forestry and Livable Habitat", and the China National Key R&D Program Sino-EU CLEARING HOUSE project research team. We have tried our best to create a more internationally inclusive and relevant review, and are very proud to participate as the Editorial Editors of this collection on urban forestry and sustainable environments.

2. Theme 1: Indicators and Services of Urban Green Spaces

This theme includes five papers investigating multiple ecological effects of urban green spaces, and a framework to identify critical indicators for ecosystem protection. To enhance the particulate matter (PM) removal effect of green spaces at multiple scales, the authors provided new insights into an integrated model, incorporating the utilization efficiency of vertical space and time into the multi-cycle PM removal model. The study was carried out at five scales based on the urban green space planning: the species scale, the community scale, the patch scale, the landscape scale, and the urban scale. The results showed that (i) at the species scale, plants should not only have the characteristics to match the local climate, but also a high utilization efficiency of time and space; (ii) at the community scale, increasing the hierarchy and structural complexity could help improve the utilization of vertical space; (iii) at the patch and landscape scales, the factor affecting the PM removal efficiency of GS lay in precipitation frequency, and large/small green patches with low/high landscape fragmentation in climates with low/high precipitation frequency were recommended; and (iv) at the urban scale, it was necessary to increase the degree of temporal and spatial distribution matching between PM and GS [8].

In Fujian Province, eastern China, ecological sources were identified according to the ecological service function importance and ecological sensitivity. The ecological corridors were distinguished using the minimum cumulative resistance model, and the key areas of green spaces were identified using the circuit theory model. The authors found that (i) 62 ecological sources were present with a total area of 4696 km^2, while 151 ecological corridors were densely distributed in the southwest region; and (ii) the key areas of ecological restoration in the study area included 17 key ecological sources and 19 key ecological corridors, where the forest area accounted for the highest proportion (77.54% and 63.92%, respectively) [9].

In two greenbelts surrounding Foshan City, southern China, researchers proposed five service bundles (landscape–ecological–social–spatial–composite) based on the landscape–ecology–society–space systems, and assessed the trade-offs and synergies of the four systems using principal component analysis, the self-organization neural network model, and geographically weighted regression. The authors found that a high trade-off relationship was identified between the landscape and ecology systems, as well as a low synergy relationship between the ecology system and the society system. Moreover, they found structural differences in the physical characteristics of the parks in the greenbelts surrounding the city, showing that parks in the inner ring had higher social and spatial effects, while parks in the outer ring had higher landscape and ecological effects [10].

In the mountain regions of southwest Saudi Arabia, it is important to establish a framework designed to manage urban planning and sprawl that considers the topographical conditions, wildlife and forest protection, and investment in natural and renewable resources. Employing a focus group approach with different expert panels to discuss the sustainable development priorities, the authors highlighted the issues of urban sprawl management in cities that impact the environmental conditions and wildlife habitat, and concluded that the agriculture and tourism industries were the most important factors to be targeted by developers in the southwestern regions of the country [11].

In the west-central of New South Wales, Australia, the temperatures inside 13 natural hollows and 45 artificial chainsaw-carved hollows (CHs) were measured over the course of two summers, and it was found that CHs created in dead trees might not provide

suitable thermal conditions for hollow-dependent marsupials during summer heatwaves. Therefore, the authors concluded that the retention of large live trees and revegetation was crucial for conserving hollow-dependent fauna in natural and urban landscapes [12].

3. Theme 2: Assembly of and Changes in Diverse Plant Communities

Within this theme, seven papers explore the possible mechanisms and specific contributions of forest communities and ecological stoichiometry of typical tree species therein. Using phylogeny and functional traits to assess the community assembly of three habitat types with different anthropogenic disturbances in Dianchi lakeside, southwestern China, researchers found that the phylogenetic signals of all of the examined functional traits of the dominant species were weak, suggesting that the traits were convergent. The community phylogenetic and functional structures of the different habitat types showed random patterns, which were driven by competitive exclusion and neutral processes [13].

In Guangdong Province, southern China, based on the normalized difference vegetation index (NDVI) and climatic variables (temperature, precipitation, radiation) during 2001–2020, researchers used the Theil–Sen median trend analysis, partial correlation analysis, and residual trend analysis to analyze the spatiotemporal pattern of vegetation trends, the response of vegetation to climate variations, and the climatic and anthropogenic contributions to vegetation dynamics. The study revealed that the NDVI exhibited an increasing trend in most areas. Vegetation responded diversely to climate change, with temperature being the most influential climatic factor for vegetation improvement in most areas. Precipitation was the dominant climatic factor in the southern edge region, while radiation was the dominant climatic factor in the central and western regions [14].

By investigating and analyzing the species, quantities, distributions, and community characteristics of the rare and endangered plants in the Sanya River basin, Hainan Province, southern China, the authors found that the proportion of families and genera with fewer or single species was high, and the dominant species in each layer of the community were evident. Moreover, the community similarity in the urban areas was high, while in the suburbs was low. Threat factors and vegetation coverage degree had a significant impact on the number of species and population size of rare and endangered plants [15].

By examining tree species composition and diversity in urban forests (UFs) in 19 cities in China's subtropical zone and comparing them with rural forests (RFs), it was found that (1) the species composition similarity, Jaccard index (J~0.27), between UFs was significantly higher than that (J~0.15) of RFs; (2) the tree species richness and Simpson, Shannon–Wiener, and Pielou indices of UFs converged along the precipitation gradient; (3) the similarity of tree composition between UFs increased as the precipitation in the cities was more similar; (4) the UFs in the 19 cities contained a total of 932 tree species, among which the non-native species were more prevalent than the native species, and the top 37 species with high frequency appeared in 80% of the cities; and (5) *Salix babylonica*, *Ginkgo biloba*, *Platycladus orientalis*, and *Juniperus chinensis* were suitable for planting in UFs in subtropical zones, regardless of humidity [16].

By measuring and analyzing the pigment content and physiological factors related to anthocyanin metabolism, leaves were detected from four color-change stages of *Acer tutcheri* (Aceraceae) during the spring, and it was found that the reduced anthocyanin/chlorophyll ratio was the direct cause of red leaf fading in spring. Phenylalanine ammonia-lyase and chalcone isomerase activities increased in the early stages of juvenile leaf development and decreased in the middle and late stages, whereas peroxidase activity continued to increase. The decrease in anthocyanin-synthesis-related enzyme activity reduced the accumulation of anthocyanin, whereas the increase in anthocyanin-degradation-related enzyme activity accelerated the depletion of anthocyanin. Increasing vacuole pH was a major factor in the degradation of anthocyanin [17].

In Binzhou City, Shandong Province, northern China, ecological stoichiometry was used to study the physiological mechanism of the growth difference between female and male plants of *Fraxinus velutina*. The authors found the fruit C, N, and P contents of female

plants were all lower than those of leaves in the early growing season, but higher than those of leaves in the middle and late growing season. During most months, the leaf C and P contents of females were higher than those of males, while the leaf N content was lower than that of males. Compared to the females, there were more significant correlations between the stoichiometric indices of branches and leaves in male plants. The leaf N/P of *F. velutina* was lower than 14 in the whole growing season, indicating N limitation. The female and male plants of *F. velutina* had different sex-specific resource requirements for sex organ formation [18].

By assessing the C, N, and P concentrations of mature leaves from 20 *Phyllostachys propinqua* populations in the urban forest across five provinces in northern China, researchers revealed that the average leaf concentrations of C, N, and P in *P. propinqua* were recorded at 0.46 g g^{-1}, 23.19 mg g^{-1}, and 1.40 mg g^{-1}, respectively. The leaf C and P concentrations, as well as the C/N ratios, exhibited significant increases with rising latitude. Conversely, leaf N concentrations and N/P ratios exhibited a marked decline with increasing latitude. In contrast, they found that only leaf C concentrations were correlated with soil N levels [19].

4. Theme 3: Utilization and Evaluation of Urban Forest Landscape

Theme three includes eight papers that investigate recreational functions of urban spaces and commonly used approaches to evaluate urban forests and particular habitats. In Beijing's central urban area, the authors employed the MSPA model to analyze the pattern and distribution characteristics of urban forests in six districts, and quantified the recreation services and the urban forest biodiversity preservation services by merging many sources of big data and the InVEST model. Furthermore, they calculate the crucial threshold interval between urban biodiversity services and recreation services for urban forest patch areas utilizing the coupling coordination degree model. The authors found that the ideal urban forest patch scale for achieving the synergy of the two types of services was an area between 0.5 and 1 ha [20].

In Shenyang City, northeastern China, based on the IPA model, the authors divided 44 landscape heritages into three subcategories, i.e., already designated for conservation (ADC), should be designated for conservation (SDC), and should be restricted in scale (SRS). They found that (i) ADC was composed of one historic (Chiyoda water tower), two cultural comprehensive (water sources), and three natural (ancient trees) landscape heritages; (ii) SDC was a landscape heritage with long construction age, high importance, poor conservation, and high utilization, which can represent the cultural characteristics of the park and the need to speed up the improvement of its protection system; and (iii) SRS weakened the cultural characteristics of the park, reducing construction intensity to highlight the core themes of the park [21].

In urban forests in Poznań (Poland), the authors proved that the majority of stands within the study area (81.86%) had medium potential for recreational purposes, based on the following evaluation criteria: types of forest habitats, age of dominant species, stand composition, stocking index, share of undergrowth, soil cover, canopy closure, and surface water [22].

In the province of Málaga in southern Spain, researchers mapped the 5220* 5220* Habitat of Community Interest (HCI), evaluated its degree of conservation (DC), and identified the chronosequences of the evolution and fragmentation of this habitat from 1957 to 2021. They found that the DC obtained was from good to excellent. With an excellent DC value, one inland locality (Pizarra) was highlighted. However, the highest reduction in the value of DC was observed in the localities of Torremolinos and Málaga–Rincón de la Victoria, which had a reduced area of occupancy and was fragmented [23].

In order to combine color composition and human eye recognition ability to quantify forest colors more appropriately and to improve the ornamental effect of forest color landscapes more precisely, a forest color palette was constructed using k-means clustering based on the color information of 986 forest images from 40 national forest parks in China.

It was found that (i) forest color could be divided into eight color families—orange, yellow, yellow-green, green, blue-green, blue, purple, and red; (ii) for humans, the recognition accuracy was highest for green and lowest for blue-green; and (iii) for interior forest landscapes, the mean area proportion and fractal dimension of the color patches showed significant positive effects on color recognition accuracy, whereas the number and density of color patches showed significant negative effects. For distant forest landscapes, the density and Shannon's diversity index of the color patches showed significant positive effects for color recognition accuracy, whereas the number, edge density, division index, and cohesion of the color patches showed significant negative effects [24].

In Haitan Island, Fujian Province, southeastern China, terrain diversity index was used to assess habitat quality and Moran's I and LISA indices were used to examine the distribution characteristics of habitat quality. The findings revealed that (i) forest land was the primary land cover type, with blue-green space comprising forests, farmland, water bodies, and grassland, making up 66.8% of the island's area; (ii) the habitat quality distribution within the study area displayed spatial heterogeneity; and (iii) the combined method considering terrain and vegetation cover types yielded a more sensitive impact on habitat quality evaluation and improved the precision of identifying superior habitat quality by 56.7%. Spatial autocorrelation analysis revealed that the comprehensive habitat quality index in the study area exhibited a clustered distribution [25].

By investigating the effect of visitors on the effective planning and management of in Atatürk Arboretum, Turkey, research found that the visitor segments that differed significantly from each other were identified as recreationalists, photographers, and learners, and revealed that the arboretum was visited for reasons outside of its establishment purposes [26].

By comparing and evaluating the performance of different deep learning models for acoustic scene classification based on the recorded sound data from urban forests in Guangzhou City, southern China, researchers found that the DenseNet_BC_34 model performed best among the comparison models, with an overall accuracy of 93.81% for the seven acoustic scenes on the validation dataset [27].

5. Theme 4: Patterns and Drivers of Urban Agro-Forestry Systems

The five papers addressing this theme describe spatial–temporal patterns and socio-ecological functions across urban agricultural and/or forestry systems. Based on the changes in agricultural carbon emissions and carbon sequestration in Guangzhou City from 2002 to 2020, the Granger causality analysis method was used to investigate the interaction between urban agricultural multifunctionality and carbon effects, the grey association model to analyze the evolution process of associative degrees between the two and divide the agricultural development stages, and the carbon effects generated in the multifunctional transformation of urban agriculture were analyzed. Corresponding policy suggestions were put forward on how to solve the problem of excessive carbon dioxide emissions through agriculture in metropolitan areas. Four main results were listed: (i) urban agricultural production decreased, the economic and social function increased, and the ecological function climbed and then declined. The carbon sequestration of urban agriculture in Guangzhou was approximately four times more than the carbon emissions. Carbon emissions experienced a process of decreasing, increasing, remaining constant, and then decreasing, while carbon sequestration first decreased and then increased. (ii) The carbon emissions of urban agriculture in Guangzhou have a causal relationship with production, social, and ecological functions. Carbon emissions are the Granger cause of the economic function but not the opposite. The carbon sequestration of urban agriculture in Guangzhou has a causal relationship with production and economic functions. Carbon sequestration is the Granger cause of the ecological function but not the opposite. (iii) The interactive development process of urban agricultural multifunctionality and carbon effects in Guangzhou can be divided into three stages: production function oriented (2002–2006), economic and social function enhanced and production function weakened (2007–2015) and economic and social function exceeded the production function (2016–2020). (iv) The

multifunctional transformation of urban agriculture has brought about carbon effects of reducing emissions and increasing sequestration [28].

By investigating the decomposition and nutrient dynamics of leaf litter and fine roots from *Cinnamomum officinarum* and *Elaeocarpus decipiens* in an urban forest in subtropical China, researchers found that the leaf litter mass loss and the nitrogen (N) and phosphorus (P) mineralization of *E. decipiens* were faster than that of *C. officinarum* in the first 180 days, but during the whole decomposition period, the leaf litter decomposition constant of *C. officinarum* was higher than that of *E. decipiens*. There was no difference in the fine root decomposition constant or P mineralization. The leaf litter mass loss, decomposition rate, and nutrient mineralization were faster than fine roots for these two tree species. The soil microbial biomass showed positive effects on leaf litter decomposition and negative effects on fine root decomposition. The correlation analysis indicated that initial litter quality, soil physicochemical properties, and microbial activity mainly affected early-stage litter decomposition and nutrient mineralization. Leaf litter production and N and P storages of *E. decipiens* were higher than that of *C. officinarum* [29].

In Chongming eco-island, Shanghai City, eastern China, researchers constructed remote sensing estimation models of forest carbon density across different classification scales based on high-resolution aerial photographs and Sentinel-2A remote sensing images, and screened a large number of field surveys and optimal models by ten-fold cross-validation. They found that (1) in early 2020, the total forest area and carbon storage of Chongming eco-island were 307.8 km^2 and 573,123.6 t, respectively, among which the areal ratios and total carbon storage ratios of evergreen broad-leaved forest, deciduous broad-leaved forest, and warm coniferous forest were 51.4% and 53.3%, 33.5% and 32.8%, and 15.1% and 13.9%, respectively. (2) The average forest carbon density of Chongming eco-island was 18.6 t/ha, among which no differences were detected among the three forest types (i.e., 17.2–19.2 t/ha), opposite to what was observed among the dominant tree species (i.e., 14.6–23.7 t/ha). (3) Compared to simple regression models, machine learning models showed an improvement in accuracy performance across all three classification scales, with average rRMSE and rBias values decreasing by 29.4% and 53.1%, respectively; compared to the all-forests classification scale, the average rRMSE and rBias across the algorithms decreased by 25.0% and 45.2% at the forest-type classification scale and by 28.6% and 44.3% at the tree species classification scale, respectively [30].

Based on site-specific socio-ecological information, the authors analyzed ecological and cultural traits and compared the current state with a transformation scenario. They found that (i) the agro-eco-mosaic structuring and diversification improvement caused the agroforestry model spread; (ii) the cultural functions provided by participative practices, enabled cultural landscape rehabilitation processes; and (iii) the potential ES supply matrices and maps showed an increase in the total ESs delivered by natural components and agricultural components [31].

By calculating the deadwood biomass within a 20 ha permanent old-growth forest plot in Zhaoqing City, Guangdong Province, southern China, during two censuses and estimating deadwood biomass using allometric regression equations, it was found that there was a total of 11,283 (22.4%) dead individuals in the study plot and most of these dead trees had very small diameters (1–10 cm). The deadwood biomass storage was 142.5 t, where small (DBH: 0–30 cm) and medium trees (DBH: 30–50 cm) were the largest contributors (54.9% and 30.7%) to deadwood biomass storage. Three dominant tree species contributed 64.8% of the deadwood biomass storage, and the deadwood biomass of 38 tree species was less than 1 t ha^{-1} [32].

6. Conclusions and Future Directions

We are delighted to present this Editorial, and we believe that the studies included here from around the world will make a lasting contribution to biology, ecology, and forestry at various scales in a changing world. These case studies highlight the important role of emerging techniques, new methods, and novel theories in promoting the development of

urban forestry and sustainable environments. We anticipate that future contributions to this field could consider long-term, multiple-scale, and in-depth research topics [33–38]. Such studies may provide novel insights and new knowledge on fundamental theories relevant to terrestrial ecosystems and respond to major concerns worldwide.

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