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Editorial

Urban Ecosystem Services in a Rapidly Urbanizing World: Scaling up Nature's Benefits from Single Trees to Thriving Urban Forests

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1. Introduction

The rapid advancement of urbanization, evident in the relentless expansion of concrete jungles, poses a significant threat to the delicate balance of ecosystem services. Throughout history, cities have endeavored to cultivate thriving human environments [1], a pursuit aligning with Elkington's [2] vision of full-cost accounting for nature and the imperative of sustainable urban development in the long term. Consequently, it becomes crucial to cultivate connections with nature for all urban dwellers while simultaneously mitigating the adverse effects of urbanization on these essential ecosystem services [3]. However, research reveals that only a paltry 13% of city residents live close enough to nature to enjoy its well-documented mental health benefits [1]. This stark reality underscores the challenge of reconciling the needs of a burgeoning urban populace with the imperative to maintain a healthy and sustainable built environment. Achieving sustainability in urban development requires a holistic approach that considers social, economic, and environmental factors. By integrating principles of sustainability into urban planning and design, cities can create resilient communities that thrive in the face of challenges. Measuring progress toward sustainability involves not only environmental metrics [4] but also indicators of social equity and economic prosperity [5], ensuring a balanced and inclusive approach to urban development.

Recent research highlights the potential of integrating nature into the urban landscape [6,7]. These intentionally designed or preserved nature-based solutions (NBSs), spanning from urban forests, tree-lined streetscapes, parks, and gardens to vegetation strategically embedded within the urban fabric, such as green roofs and walls, play a pivotal role in mitigating the adverse impacts of urbanization [8,9]. As a result, within fragmented urban landscapes, residual green patches can serve as vital habitat refuges [10]. These refuges offer crucial habitats for a diverse array of plant and animal species, thereby fostering and sustaining urban biodiversity [10,11]. This, in turn, promotes human health and wellbeing by providing opportunities for recreation, stress reduction, and communion with nature [12]. Moreover, they contribute to enhanced air and water quality by filtering pollutants and reducing rainwater runoff [13,14]. Additionally, green patches can assist in regulating urban temperatures and mitigating the adverse effects of urban heat islands [15,16], thereby creating a more pleasant and habitable environment for citizens.

Advancements in urban greening and the proliferation of tree cover across global cities represent encouraging progress [17,18]. Nevertheless, to effectively confront the biodiversity extinction crisis and make substantial contributions to human welfare, a more focused and inclusive strategy is needed. Local governments must explicitly incorporate initiatives within their urban planning frameworks that champion the preservation and enrichment of biodiversity alongside the correlated ecosystem services that bolster human

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wellbeing [17]. This involves not only conserving existing natural areas but also strategically implementing NBSs to enhance urban ecosystems altogether. Achieving these goals requires a nuanced understanding of the optimal design, placement, and management of NBSs within urban landscapes [19]. While progress has been made, there remains a critical knowledge gap in fully grasping how to maximize the benefits of these solutions across interconnected dimensions. This includes considerations of biodiversity conservation, ecosystem resilience, and human health and wellbeing.

Sustainability lies at the heart of this endeavor. Urban development must strive for sustainability by balancing economic growth, social equity, and environmental stewardship [9,20–22]. This entails fostering communities that are resilient to environmental challenges while promoting inclusivity and equitable access to green spaces and natural resources. Moreover, unlocking the measurability of sustainability requires developing robust metrics [23] that capture not only environmental indicators but also social and economic dimensions of urban wellbeing. By prioritizing sustainability principles in urban planning and policymaking, cities can pave the way toward a more resilient, equitable, and livable future for all inhabitants.

This Special Issue (SI) represents a significant attempt to bridge gaps in the existing urban ecology and sustainable city planning literature. Comprising eight articles and two reviews, it thoroughly explores various dimensions of ecosystem services within urban environments. Notably, this SI stands as the fourth edition in a comprehensive series dedicated to urban ecosystem services, building upon solid groundwork laid by preceding research [24–26]. It underscores a continued dedication to advancing our comprehension of urban ecology and sustainable urban development.

By synthesizing fresh perspectives and innovative insights, this edition strives to optimize the delivery of ecosystem services while addressing potential disservices inherent in urban areas. Covering a broad range of topics, the contributions within this SI offer a multifaceted exploration of ecosystem services, enriching our understanding and informing future urban planning strategies. Each contribution, whether exploring green infrastructure or mapping cultural ecosystem services (CESs) for urban conservation, offers valuable insights into the creation of more sustainable and resilient cities. Figure 1 visually presents the geographical distribution of the research and the authorship locations within this SI. This graphical representation offers a comprehensive overview of the diverse origins of the research showcased in this SI, emphasizing the global scope and collaborative ethos driving progress in this field.

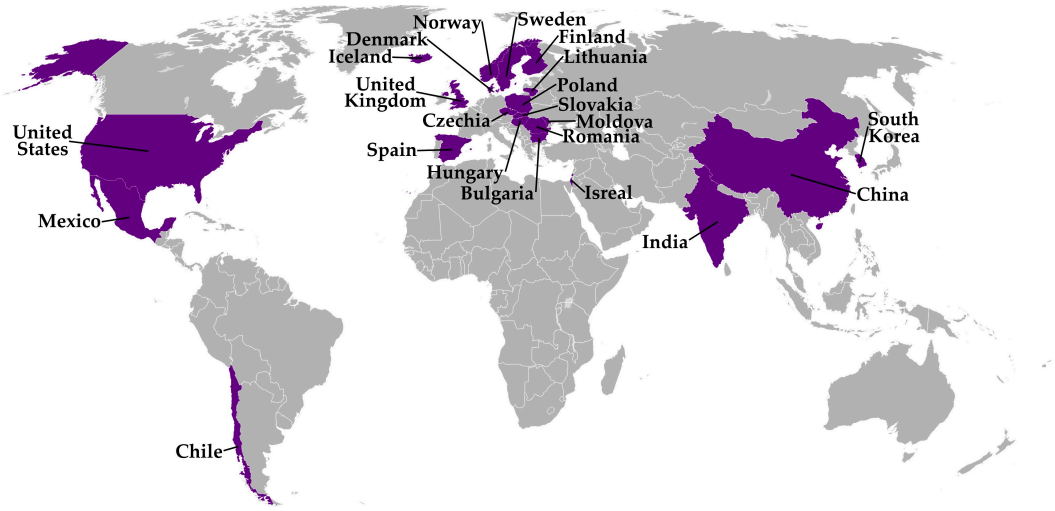

Figure 1. Dispersion of research contributions and authorship locations for this SI.

2. Synopsis of Contributions

In their recent study, Schueller et al. explored the potential of urban green spaces in addressing the concerning decline in pollinator populations. With pollinators playing a key role in plant reproduction and overall ecosystem health, their dwindling numbers due to habitat loss necessitate innovative interventions. The research explores the design of urban green spaces to effectively support diverse pollinator communities, aiming to provide habitats conducive to their survival and proliferation. Central to the study is the identification of key research questions aimed at optimizing the design of urban green spaces to meet the needs of pollinators. These questions encompass several crucial aspects, including the identification of target pollinator groups for conservation efforts, the determination of preferred plant species and optimal planting arrangements to support these pollinators, and an exploration of habitat requirements that extend beyond mere floral resources. Additionally, the study seeks to evaluate how surrounding landscapes influence the prioritization of creating new habitats within urban areas, considering factors such as connectivity, habitat fragmentation, and land use patterns.

By addressing these fundamental questions, Schueller et al. aim to provide valuable insights into the design and management of urban green spaces to support pollinator populations effectively. Ultimately, this research holds significant implications for urban planners, landscape architects, and policymakers involved in the development and maintenance of urban green infrastructure, offering guidance on how to enhance biodiversity and promote ecological resilience within cities. Through the implementation of evidence-based practices informed by this study, urban environments can become more hospitable to pollinators, contributing to the conservation of biodiversity and the sustainability of urban ecosystems.

Kim et al. investigated an innovative approach to counteracting urban heat islands during nocturnal hours: harnessing cold air emanating from nearby mountains and green spaces. Their study focused on optimizing city layouts to effectively channel this cool air flow (CAF) to achieve optimal temperature reduction. Through a careful investigation, they uncovered that taller buildings with ample wall surface area facilitate airflow, while densely packed, sprawling urban developments impede it. The research suggests a range of design considerations aimed at maximizing the benefits of CAF, providing invaluable insights for urban planners and designers striving to cultivate cooler and more sustainable urban environments. By shedding light on the intricate dynamics of airflow within urban settings and proposing actionable design strategies, this study contributes to the ongoing discourse on mitigating the adverse effects of urban heat islands and promoting urban sustainability.

Le and Huang conducted a groundbreaking study on utilizing cellular automata models to enhance urban tree planting strategies with the aim of creating interconnected green infrastructure networks that maximize their positive impact. By integrating CycleGAN models and cellular automata to replicate mycorrhizal networks, they predicted optimal urban tree layouts. This innovative approach leverages spatial data to simulate post-planting network connectivity, identifying priority planting locations that enhance ecological stability and climate resilience. The research addresses existing limitations in urban tree planting methods and offers valuable insights for sustainable urban planning and green infrastructure development. By optimizing tree placement to foster network connectivity, the study contributes to the creation of resilient urban ecosystems capable of mitigating environmental challenges such as heat island effects, air pollution, and biodiversity loss. The findings have significant implications for urban planners, policymakers, and landscape architects seeking evidence-based strategies to enhance urban greenery and promote environmental sustainability. Through the adoption of these innovative approaches, cities can foster healthier and more resilient environments, benefiting both human populations and the natural world.

The study conducted by Espinosa Fuentes et al. sheds light on the intricate dynamics of urban soils, which are crucial for ensuring the vitality and sustainability of urban forests. Focusing on the Bosque de Tlalpan Natural Protected Area (BT), the research examined

the impact of conservation practices on soil quality. Through a comprehensive analysis of various soil properties such as exchangeable cations, heavy metal concentrations, soil carbon stock (SCS), and CO_2 effluxes, the authors examined four zones within the BT, each representing different levels of protection and public use across three climatic seasons. The investigation revealed that while concentrations of heavy metals generally adhered to Mexican regulations, mercury levels surpassed permissible limits. Significant variations in SCS and soil organic matter were observed among zones, with areas under stricter protection exhibiting higher values. Furthermore, CO_2 effluxes exhibited seasonal fluctuations, peaking during the rainy season. These findings underscore a positive correlation between conservation efforts and soil quality within the BT, with areas under stringent protection demonstrating enhanced carbon storage capacity and improved physicochemical properties. The study not only provides valuable insights into the current state of this urban forest ecosystem but also underscores the important role of conservation in preserving healthy soil conditions amidst urbanization pressures in densely populated areas.

In their review, Yadav et al. undertook a comprehensive evaluation of tree selection and plantation decision support systems (DSSs), analyzing their alignment with key objectives distilled from the existing literature. The review meticulously scrutinized the incorporation of multiple data sources and the usability of web interfaces within these DSSs. Five primary objectives for tree selection emerged from the analysis and were systematically compared across various existing systems: (a) climate resilience, (b) infrastructure/space optimization, (c) agroforestry, (d) ecosystem services, and (e) urban sustainability. Notably, the review highlighted a relative under-representation of climate resilience and urban sustainability considerations in current DSSs, indicating a potential gap in decision-making frameworks. The authors advocate for future DSS tools to adopt a more holistic approach by integrating these critical aspects into their frameworks.

Moreover, Yadav et al. proposed the utilization of deep neural networks (DNNs) to navigate the complexities inherent in achieving trade-offs between multiple objectives. By leveraging DNNs, decision-makers can address the intricate interplay between various goals, such as maximizing ecosystem services, ensuring the selection of climate-resilient tree species, and promoting agroforestry practices. In all, this review not only provides a comprehensive assessment of existing DSSs but also offers valuable insights into the potential enhancements needed to bolster their effectiveness in supporting informed tree-selection and plantation decisions. By advocating for a more inclusive approach as well as leveraging advanced technologies like DNNs, the study contributes to the ongoing discourse on sustainable urban forestry and resilient urban development.

Dabašinskas and Sujetovienė embarked on a comprehensive investigation into the dynamic interplay between the supply and demand for ecosystem services amidst urban expansion, stressing the critical need for ongoing monitoring and adaptability. Their research specifically investigated the spatiotemporal changes in ecosystem service provision, focusing on essential services such as food, carbon sequestration, and recreation, amidst the process of urbanization. The study rigorously quantified imbalances between the supply and demand for ecosystem services within the study area, with a particular emphasis on land use changes.

In particular, the most significant observed land use change entailed the conversion of agricultural land into forests and urban areas. Urban centers emerged as focal points, demonstrating the lowest supply and highest demand for all three ecosystem services investigated, thus underlining a stark negative correlation between the proportion of urban land and the provision of these vital services, especially in terms of food production. These findings underscore a pressing need for strategic interventions and policy measures aimed at mitigating the adverse impacts of urban expansion on ecosystem service provision. By highlighting these dynamics, the study provides valuable insights into the complex relationship between urbanization and ecosystem services, informing decision-making processes aimed at fostering sustainable urban development and bolstering the resilience of urban ecosystems.

In their innovative study, Krsnik et al. tackle the formidable challenge of comparing the value of various ecosystem services in urban settings. Their research aims to equip urban planners with the tools necessary to make informed decisions regarding urban development by prioritizing the services with the greatest potential benefits. The authors argue that existing methods for comparing the provision of ecosystem services in urban areas often produce misleading results. To address this issue, they propose a novel methodology that employs standardized thresholds to compare ecosystem service provision across different cities. This innovative approach promises to foster a fairer distribution of environmental benefits and wellbeing among urban populations, thereby contributing to more sustainable and resilient urban development strategies.

Although there is no consensus on the ideal level of ecosystem service provision, Krsnik et al. advocate for the adoption of standardized thresholds as a crucial step forward. By establishing a common framework for evaluating ecosystem service provision, their proposed methodology not only facilitates more accurate comparisons between cities but also lays the groundwork for future research and policy development in urban ecosystem management. In summary, this study represents a significant advancement in the field of urban ecosystem services assessment. It offers a systematic approach to evaluating and prioritizing ecosystem services in urban areas, potentially revolutionizing urban planning practices by promoting more informed decision-making and fostering greater equity in the distribution of environmental benefits across cities.

Gârjoabă et al., in their comprehensive study, explored the intricate planning strategies aimed at establishing resilient natural areas within urban environments. Their research focused on a comparative analysis between Nordic and Eastern European countries, recognizing the significance of their distinct political histories in shaping their approaches to this challenge. The researchers conducted a detailed examination of environmental laws and planning frameworks across these countries, seeking to uncover key elements that could offer valuable insights applicable to broader contexts within Europe. By identifying these crucial aspects, the study aimed to provide urban planners and policymakers with a robust foundation for effectively balancing urban development with the preservation of natural areas. This approach underscores the importance of considering local landscapes and urban layouts to ensure the sustainability and resilience of cities in the face of ongoing urbanization pressures. In all, by shedding light on the diverse approaches employed by Nordic and Eastern European countries, the study offers valuable insights that have the potential to inform and enhance urban planning practices across Europe, fostering the creation of more sustainable and resilient cities that harmonize with their surrounding natural environments.

In their research, Li et al. examine the critical importance of mapping CESs in river basins. This mapping is essential for identifying areas that require conservation efforts due to their significant contributions to CESs. However, existing studies often lack precise quantifications of the appropriate sizes for mapping units, which are fundamental for accurately assessing CESs. To bridge this gap, the study introduces the concept of the optimal area threshold of mapping units (OATMU). This approach involves the development of a multi-dimensional indicator framework and a validation methodology to determine mapping unit boundaries and suitable areas for CESs.

The multi-dimensional indicator framework integrates various indicators, including geo-hydrological, economic, and social management indicators. Each indicator's OATMU is calculated by identifying the inflection point in the second-order derivative of the power function. Through this process, the research defines the optimal size for mapping units, ensuring accurate CES assessment. The findings highlight the effectiveness of employing OATMU identification which, coupled with accessible basic data and simplified calculation methods, provides clear and universal technical support for optimizing CES mapping efforts. This approach enhances the precision and reliability of CES mapping, facilitating better-informed conservation and management decisions in river basin ecosystems.

Finally, Łukaszkiewicz et al. explored the potential of poplar trees (*Populus* L.) to enhance urban green spaces amidst the growing challenges of urbanization, population expansion, and climate change. The authors highlighted the rapid growth and adaptability of poplars across various environments, positioning them as a promising solution to address these complex urban issues. The study underscored the significant contributions of poplar trees to enhancing air quality and regulating microclimates within urban areas. However, the variable lifespans exhibited by different poplar cultivars present a notable challenge in their widespread adoption for urban greening initiatives. To address this issue, it has been recommended to employ strategic selection approaches that consider factors like growth rate and root system traits. It is proposed to integrate a diverse array of poplar species, each with different lifespans, to ensure the sustained and enduring presence of urban greenery efforts.

By exploring the potential of poplar trees in enhancing urban green spaces, Łukaszkiewicz et al. offer valuable insights that can inform urban planning and landscaping strategies. Their findings highlight the importance of selecting appropriate tree species tailored to the specific needs and challenges of urban environments, ultimately contributing to the creation of more sustainable and resilient cities in the face of ongoing urbanization and climate change pressures.

3. Conclusions

In an era of rapid urbanization, the importance of urban ecosystem services cannot be overstated. From mitigating climate change to enhancing public health and wellbeing, these services play vital roles in creating sustainable and resilient cities. At the forefront of this challenge is the need for strategic planning and decision-making. Urban planners and policymakers must recognize the value of urban green spaces and prioritize their conservation and enhancement. This involves not only preserving existing green spaces but also strategically integrating nature into the urban landscape. By doing so, cities can maximize the provision of ecosystem services while minimizing the negative impacts of urbanization. As noted by Łukaszkiewicz et al., poplar trees have shown promise in enhancing urban green spaces due to their rapid growth and adaptability. However, challenges such as variable lifespans will require strategic selection methods based on factors like growth rate and root system characteristics. By incorporating a diverse range of vegetation with varying lifespans, cities can ensure the continuity and longevity of urban greenery initiatives [27,28]. As such, this SI has uncovered compelling insights into the urgent task of scaling up nature's benefits within the context of rapid urbanization, transitioning from the scale of individual trees to the creation of vibrant and resilient urban forests.

In conclusion, prioritizing sustainability in the delivery of ecosystem services offers multifaceted benefits, including but not limited to enhancing the wellbeing of urban residents, safeguarding biodiversity, and mitigating environmental degradation. By embracing sustainable practices in urban planning and development, cities can significantly improve quality of life for their inhabitants. Sustainable urban landscapes not only provide essential ecosystem services such as clean air, water purification, and climate regulation but also offer opportunities for recreation, relaxation, and community engagement, enhancing the overall experience of the cityscape's look and feel [29]. Moreover, promoting sustainability fosters environmental conservation efforts, preserving natural habitats and protecting vulnerable species within urban ecosystems.

As a result, the integration of green infrastructure into a city enhances its resilience to extreme weather events, reduces urban heat island effects, and mitigates air and water pollution. The use of green spaces also serves as vital habitats for wildlife, contributes to urban biodiversity conservation, and promotes overall ecological health. Furthermore, sustainable urban development fosters social cohesion and equity by providing accessible green spaces for all residents, regardless of socioeconomic status.

In essence, the journey toward a greener and healthier future begins with a holistic understanding of the value of nature in urban settings. From the planting of single trees to the cultivation of thriving urban forests, each step toward sustainability in ecosystem services contributes to the creation of vibrant and resilient urban environments that benefit both present and future generations—an idea that has been underscored in the literature since the Brundtland Report [30]. Therefore, embracing sustainability as a guiding principle in urban development is not only essential but crucial for the wellbeing and prosperity of urban communities worldwide.

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