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Evidence-based urban greening: a missing piece in biodiversity conservation

Johan Kjellberg Jensen [1,*], Marcus Hedblom[2], and Anna S. Persson[1]

With calls for increased greenery in cities to safeguard biodiversity and its associated benefits to humans, urban vegetation must be managed carefully and efficiently. It is time to change paths from current spurious attempts to manufacture resilience and instead usher in evidence-based urban greening to secure ecosystems for the future.

Key ecosystems

'The future of humanity is undoubtedly urban', according to the UN World Cities Report 2022, but what does this mean for the future of all other species? As modern cities have emerged as a new type of ecosystem, a crucible of human impacts on nature and the main residence of the world's population, their importance to biodiversity conservation is increasingly decisive. Nature conservation is motivated by human experience, understanding, and appreciation of biodiversity; detachment from nature reduces support for conservation efforts, in addition to a loss of health benefits [1]. We therefore need biodiversity where people live – in cities. Urban areas can also be valuable refugia for some threatened species, where their native habitat is still preserved or where urbanization has unintentionally created suitable habitat. Achieving global biodiversity goals consequently requires urban areas to be recognized and included in conservation endeavors, as recently concluded in Target 12 of the Kunming-Montreal Global Biodiversity Framework [the UN Convention on Biological Diversity (CBD)].

However, cities are far from reaching their conservation potential [2]. Urban areas are linked to species loss and often carry local extinction debts [3], and can act as ports for biological invasions, a leading cause of species extinctions [4,5]. Taken together, urban ecosystems are crucial battlegrounds in the fight against biodiversity loss. We therefore argue for a paradigm shift in urban ecosystem management, moving away from arbitrary design decisions and 'expert opinion' towards evidence-based urban greening (Box 1) rooted in ecological and evolutionary knowledge. We focus on urban greening – the incorporation, configuration, and composition of vegetation in urban environments – which is arguably the most efficient tool for managing local biodiversity since urban ecosystems are dominated by bottom-up effects [6].

Evolutionary refugia or beachheads of invasion

The key objectives of urban conservation, as outlined in the CBD, are to secure the continued provisioning of urban ecosystem services and integrate cities into regional biodiversity conservation efforts. To reach these goals, urban ecosystems should be resilient to disturbances and urban biodiversity should reflect the regional context of flora and fauna.

Despite biodiversity being fundamental to ecosystem services, and beneficial to human health *per se* [1], contemporary urban greening seldom considers biodiversity or ecological prerequisites. Initiatives instead typically emphasize aesthetics and human interventions aimed at building resilience [5,7], although attempts to engineer ecological resilience are often fraught with uncertainty and may be short-sighted [8]. This discrepancy comes to a head in species choice; use of locally native plant material is a well-documented, but largely missed, opportunity to improve urban ecosystems [5]. Based on the projected high tree mortality in cities under global warming, stakeholders may instead attempt to engineer resilience towards urban heatwaves [7] by augmenting local tree communities with heat- and drought-tolerant non-native species. Such interventions are, however, prone to a lack of proper ecological evidence and risk assessment, and create artificial resilience [8]. For one, cities act as hubs for the spread of non-native species [5,9]. Horticulture is linked to nearly half of all non-native plant invasions, and an invasion debt from past introductions is still being paid [4]. In other words, with current practice, cities risk becoming beachheads of biological invasions and cause great ecological damage to surrounding ecosystems: invasive species are estimated to globally cost a rapidly growing US$423 billion each year [4]. The resilience that non-native tree introductions may achieve is therefore outweighed by probable damage, in addition to the missed biodiversity benefits of planting native species [5]. This damage can be exacerbated by indirect effects, such as a general loss of native tree diversity, which further increases invasion severity [9], or artificial resilience towards one disturbance (e.g., drought) inhibiting resilience towards other unknown, future disturbances (e.g., disease) [8,10]. Taken together, plant species choice exemplifies the risks of not considering available ecological evidence in urban greening. It also highlights the lack of controlled empirical studies, such as common-garden experiments, that provide species-specific, quantifiable evidence on traits of non-native species or genotypes to objectively weigh potential advantages against risks like invasiveness and pathogen introductions.

The alternative to the norms of artificial resilience is to allow processes that strengthen ecoevolutionary resilience [8]; there is mounting evidence that urban greening

Box 1. Evidence-based practice

The shift from practices based on convention towards anchoring decision-making in systematic evidence was first implemented in medicine [15]. The concept of evidence-based medicine was later proposed for nature conservation, as 'common sense' and 'expert opinion' not grounded in scientific evidence dominated conservation efforts [15]. However, evidence-based practice has not yet been implemented in urban greening, despite the importance of cities' vegetation to nature conservation and global health: reducing pollution and heat, while boosting mental health and immune systems [1,2]. Indeed, concepts such as nature-based solutions, which have received significant interest in policy (e.g., by the IUCN and European Commission), rely on verifiable knowledge. Yet, implementing such policies in cities, to safeguard public health and contribute to nature conservation efforts, will require increased focus on creating and integrating scientific evidence into urban greening. This includes optimizing practices, standardizing guidelines, and rapidly adopting new research. To reach these goals, evidence-based approaches must be prioritized in policy, funding, and praxis while recognizing the many stakeholders in urban areas and the need for transdisciplinary collaborations [2]. Specifically, systematic evaluations and long-term monitoring of how greening practices affect biodiversity and human health are often lacking today (e.g., regarding urban plant composition and soil conditions) [5]. To this end, evidence-based practice is a tried and proven concept – originally proposed for conservation in this very journal 20 years ago [15]. We argue that the seeds of evidence-based practice must now be sown in urban greening as well.

should strive towards increasing evolutionary potential to reach conservation goals [6]. Building the capacity of populations to adapt to changes through evolutionary processes requires that urban greening focuses on regional context, genetic diversity, and facilitating evolution [6]. Regional context (i.e., that urban species composition reflects the native biodiversity of the surrounding landscape) is vital if cities are to be part of larger conservation efforts. Parks and brownfields can hold relatively undisturbed habitats with high biological value (e.g., old-growth trees, seminatural grasslands), providing an evolutionary refugia and complement to landscapes with intensive forestry or agriculture. If managed correctly, such greenspaces can hold genetic diversity at a landscape scale and allow maintained evolutionary processes, including adaptations to human-induced disturbances [6]. Common greening practices, by contrast, restrict both genetic diversity and evolutionary processes. The reliance on narrow genetic material, such as plant clones, can effectively halt local adaptation: extreme examples include continuous use of 250-year-old tree clones [11]. While the genetic diversity in many species and varieties used in urban plantings is likely to be low, there is a need to characterize the genetic composition of urban plant populations to allow evidence-based interventions [6,10]. Urban plantings are more likely to be under selection for nursery growing conditions than local, heterogeneous city conditions, but how this impacts local populations and adaptation is unknown [11]. How to best facilitate genetic diversity and evolutionary processes in cities is an area that needs further evidence. Still, general principles suggest that more focus should be put on sourcing and retaining local and regional genetic material from a large set of species [10] (e.g., by propagating seeds from healthy, locally established urban individuals, whether planted or spontaneous). Simply put, urban greening should move away from the clone, towards the acorn: this will increase cities' ecoevolutionary resilience and conservation potential (Figure 1).

Again, it may be tempting to engineer these processes based on conceptual ideas (e.g., importing ecotypes from hotter or drier regions [7]). However, introducing new genotypes of non-native species can increase the intensity of introduction (propagule pressure) and, thereby, invasion risk [4]. Promoting genotypes of native species adapted for one disturbance may further result in gene-swamping and loss of genetic diversity, local adaptations, and resilience to other disturbances, if done without robust assessments [8,10]. When the goal is indeed to support biodiversity, we argue that promoting ecological processes follows the best current knowledge and should be the primary approach in urban greening. Interventions should always be based on empirical evidence and weighed against ecological and evolutionary risks, following the precautionary principle. Taken together, urban greening should strive towards creating self-sustaining (eco)systems.

Providing the evidence

The gap between urban ecosystem science and practice is in large part caused by a lack of actionable evidence; the limited focus in the scientific literature on how to apply findings in practice poses a barrier to implementation [2,12]. Given the large heterogeneity between cities, researchers should be incentivized to focus more on local projects to overcome this barrier. For example, restoration of degraded or informal greenspaces is important but underutilized in urban greening [12], but methods are highly dependent on habitat type, biophysical conditions, location, and target species. Similarly, understanding the gene flow of urban populations is key [10], but likely dependent on city size, configuration, and target species. Relevant and applicable evidence is thus often better derived from local projects, rather than attempting to find a silver bullet for all cities. However, researchers should continue to investigate and identify general risks, such as global patterns of invasive species and pathogens [4].

Actionable evidence is also needed on how to balance the two goals of urban greening: conservation and ecosystem service provisioning. Although these goals are closely intertwined [1], and both would benefit from increased recognition in urban ecosystem management in general, optimal spatial planning can differ depending on their prioritization [13]. While consensus is emerging that urban 'land-sparing' (dense urban fabric with large greenspaces preserved) tends to be optimal for conservation, urban 'land-

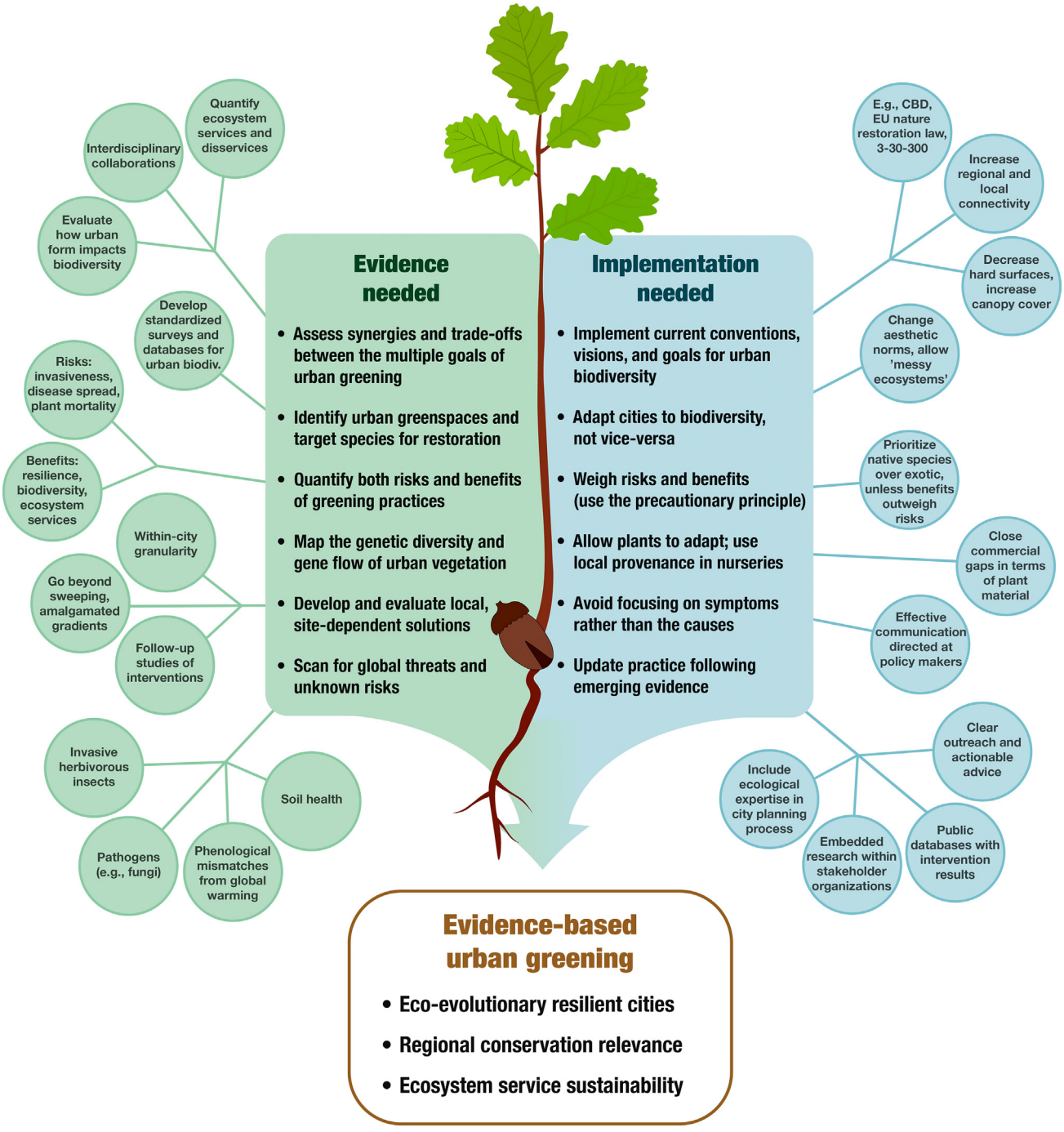

Figure 1. Outline of evidence-based urban greening. Urban greening faces a dual challenge: generating ecological evidence and implementing it effectively to support biodiversity. This figure presents the evidence, implementation, and examples of corresponding actions needed to achieve evidence-based practices. Closer and continuous collaboration between researchers and stakeholders is essential to meet urban conservation goals. To succeed, new objectives in both research and implementation must be adopted. Abbreviation: CBD, UN Convention on Biological Diversity.

sharing' (low-density urban fabric interspersed with patches of greenery) can be more beneficial in providing some ecosystem services [13]. This potential trade-off underscores the need for urban studies that consider the multiple goals of cities and how to optimize these within a limited space, including different ecosystem services and species groups [13]. We again argue that searching for overarching rules to obtain multifunctionality of urban greenery is unlikely to yield actionable evidence. Instead, studies should aim to provide context-dependent and specific evidence: the optimal set of species, or configuration, will largely depend on regional context, location within the city, and the goals prioritized. Indeed, a combination of land-sharing and land-sparing, based on evidence, will be needed to meet these goals. In lieu of applicable studies, unverified 'expert opinion' may lead to urban expansion more akin to large experimental plots than ecosystems managed based on evidence [4,5]. Researchers need to prioritize translating their general ecological knowledge into actionable evidence. Last, we acknowledge that urban vegetation is a key piece of the puzzle but must be considered alongside multiple other factors to effectively address the biodiversity extinction crisis, including pollution (e.g., air, light, noise), habitat connectivity within cities, and surrounding land use [2].

Rethinking sustainable cities

A paradigm shift is needed in urban greening to achieve local and regional conservation goals and ultimately combat global biodiversity loss. We need to bridge research gaps with increased interdisciplinarity, applicability, and localized approaches. At the same time, we must reimagine cities and not be limited by current praxis or path. Today, scientific recommendations can be oblivious of practical realities [12] (e.g., by advising the use of plants that are not commercially available). Rather than adapting advice to suboptimal practices, we encourage researchers to collaborate with stakeholders to close such commercial gaps by identifying and resolving bottlenecks.

Urban greening must neither lack ambition nor deal with symptom treatment alone. Returning to the example of heat-tolerant trees, the surrounding proportion of surface paving can in fact matter more to urban tree growth and cooling effect than species choice [14]. Urban planning and greening should rather aim to deal with the problem, in this case the urban heat island effect, than ameliorating some of its symptoms. In the end, urban heatwaves are not only detrimental to trees but also deadly to people [2]. In essence, we must adapt cities to benefit biodiversity, rather than attempting to adapt biodiversity to fit into current planning norms. Evidence-based urban greening will be a vital tool in this endeavor.

Author contributions

All authors contributed equally to the conceptualization of article. J.K.J. wrote the original draft with input from A.S.P. and M.H. All authors provided edits critical to its finalization.

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Declaration of interests

The authors declare no conflict of interest.

[1]Centre for Environmental and Climate Science, Lund University, Lund, Sweden
[2]Department of Urban and Rural Development, Swedish University of Agricultural Sciences, Uppsala, Sweden

*Correspondence:
johan.kjellberg_jensen@cec.lu.se (J.K. Jensen).

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