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Strengthening Urban Green: Planning and design considerations for ecological networks using green infrastructure for target species biodiversity improvement

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Introduction

Increasing recognition of the world's expanding population and current global rural-to-urban migration necessitates a better understanding and integration of urban ecological processes into the framework for urban design (Sandström, 2006). Urban areas have seen a significant increase in recent decades in the number of inhabitants with the current rural-to-urban migration pushing the percentage of people living in urban areas over 50% worldwide for the first time in history (United Nations, 2001). Urban development has been found to disrupt ecological processes resulting in fragmentation of wildlife habitats and reduced connectivity - ultimately reducing urban biodiversity (McKinney, 2002). Incorporating ecological processes and characteristics such as species dispersal and resilience into urban design requires special attention to urban landscape features such as green infrastructure that are capable of supporting biodiversity.

This research developed a general method for the assessment of the potential of green infrastructure to support biodiversity based on: urban form, structure, composition, configuration, and diversity. The method developed analyzes the spatial configuration and composition of green infrastructure based on the habitat requirements of specific target species. The assessment method uses the spatial analysis program FRAGSTATS to analyze biodiversity-related spatial characteristics of land-cover types and built-environment features. By applying the urban biodiversity assessment method, green infrastructure can be assessed for its potential to support or increase urban biodiversity and to build urban ecological networks at the neighborhood scale. This assessment is based on specific target species that are selected to represent the potential of an urban environment to support a larger guild of urban wildlife species.

Background/Literature Review

Over half the world's population now lives in urban areas compared with approximately 14% from a century ago (United Nations, 2001). This urban growth trend has the capacity for dramatically altering urban ecological processes globally. Loss and fragmentation of natural habitat has reduced the richness of taxa including plants, birds, insects, and mammals in the urban core to less than half of that found in rural areas (McKinney, 2002). Biodiversity has been defined in many ways but is generally considered to mean the variability of life, and the ecosystems and habitats that support it (Savard, 2000). Biodiversity has been shown to play a key role in the

long-term functioning of ecosystems (Alvey, 2006) and relates directly to ecological resilience (Alberti, 2005) and long-term sustainable development (Loreau et al. 2001). Degradation, loss, and fragmentation of habitat are considered the greatest threats to biodiversity at the global scale (Fahrig and Meriam, 1994). These same factors are the greatest challenges to biodiversity strengthening in the urban environment. And while urban environments have typically been thought of in relation to their negative impact on biodiversity (Wackernagel and Rees, 1996) they arguably have the ability to support increasing levels of biodiversity in urban green infrastructure.

Green infrastructure is the collection of all natural and artificial features comprising a connected and multi-functioning network of ecological systems. Green infrastructure elements found within cities include parks, playgrounds, community gardens, greenways and recreational trails, street and parkland trees, public plazas and landscapes, green roofs, unused abandoned land, and public and private land used for recreation (Schilling & Logan, 2008). These green infrastructure features can function as important reserves of biodiversity (Alvey, 2006). Green infrastructure emphasizes the quality and quantity of urban green and the multifunctional role of these features (Sandström, 2002), as well as the connections of these habitats (van der Ryn and Cowan, 1996). Green infrastructure has the potential to guide urban development by providing a framework for both conservation and economic growth if implemented into a proactive planning and development process *(*van der Ryn and Cowan, 1996; Schrijnen, 2000; Walmsley, 2006). While green infrastructure can have a significant effect on the ecology of the urban environment, its specific use for urban ecological networks to strengthen biodiversity has yet to be assessed and recognized (Ahern, 2007). Because of green infrastructure's focus on spatial configuration and connectivity, it is inherently compatible with neighborhood-scale urban ecological network design for strengthening urban biodiversity. Furthermore, green infrastructure has the ability to maintain habitat integrity and provide the physical basis for the development of urban ecological networks (Tzoulas, 2007). Urban green infrastructure can also increase the overall natural and semi-natural vegetation cover, further contributing to the conservation of biodiversity (Tzoulas, 2007). The implementation of green infrastructure into an integrated functioning system to support urban biodiversity requires attention to the spatial configuration and composition of green infrastructure as well as its functional and structural diversity (Forman, 1995).

Goals and Objectives

The goal of this paper is the development of a conceptual method (Fig. 1) for the assessment of green infrastructures' potential to increase biodiversity in urban environments. This is achieved by addressing two objectives: (a) undertaking a review of literature on the associations between biodiversity, green infrastructure, fragmentation, and target species – with particular attention to the application of landscape ecology research; (b) constructing a conceptual method for the assessment of green infrastructure for increasing urban biodiversity. This conceptual method

will help organize existing research and formulate new research on the connection between urban biodiversity and green infrastructure implementation. This method is intended to advance the integration of landscape architecture and landscape ecology.

Methods

An extensive literature review on the subject of the associations between biodiversity, green infrastructure, fragmentation, and target species was conducted. The literature review resulted in the determination that in order to measure biodiversity, target or representative species would be necessary to provide measurable habitat requirements of composition and configuration.

Using the keywords green infrastructure, biodiversity, fragmentation, and target species, relevant journal articles and books were identified. These were critically evaluated to identify the connections between green infrastructure, biodiversity, fragmentation, and target species. The relationships between these elements were difficult to establish and therefore the review focused on association rather than on causation. While the relationships between these elements were difficult to establish, the association of the elements through common factors is easily constructed.

The literature review, however, did provide a number of themes used to create connections between green infrastructure, biodiversity, fragmentation, and target species. These themes were used as the basis of the conceptual framework. Next, the connections between green infrastructure, biodiversity, fragmentation, and target species were established through the incorporation of spatial analysis and landscape composition and configuration. The conceptual method illustrates the development of a landscape assessment method based on the association of these elements in order to determine the potential of green infrastructure to increase urban biodiversity. The conceptual method also helps to link the fields of landscape architecture and landscape ecology by integrating ecological assessment into urban planning and design applications.

Results

The methods used for this study resulted in a conceptual method for the assessment of green infrastructure's ability to increase urban biodiversity based on configuration and composition of green infrastructure in relation to the habitat requirements of the target species (Fig. 1). The proposed method addresses the need to reduce fragmentation of habitat patches to establish successful ecological networks capable of supporting specific species of wildlife, which are assumed to represent a broader guild of urban wildlife species.

The first step is the development of biodiversity goals (Fig. 1, Box 1). This is a crucial part of the assessment method because these goals will help to determine the target species used for the assessment and for the monitoring, that should take place after the implementation of the green infrastructure.

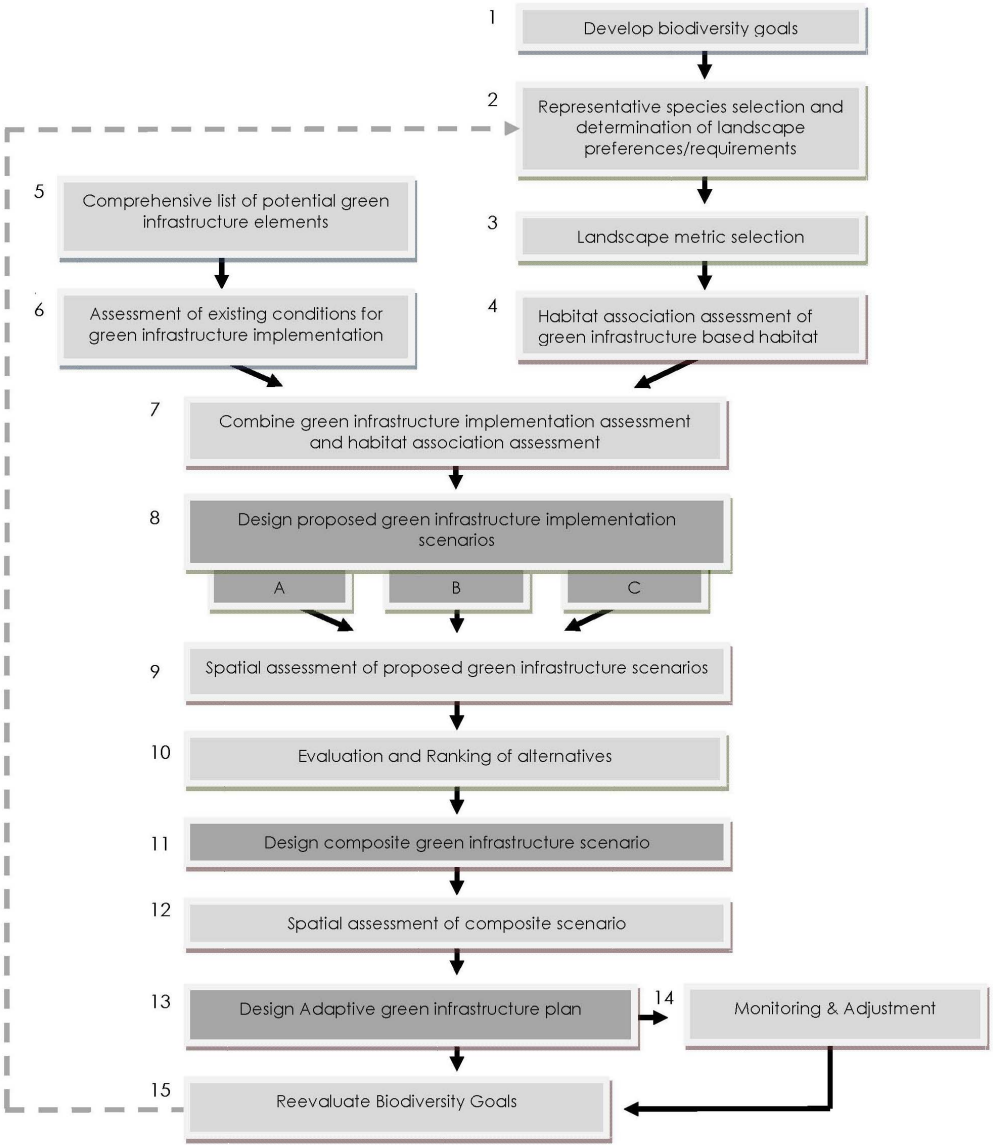

Figure 3 - Conceptual method for the assessment of green infrastructure's potential to increase urban biodiversity

The selection of target species (Fig.1, Box 2) provides measurable habitat requirements of composition and configuration that can be used objectively in biodiversity monitoring and assessment (Hess, 2006). Without specific target species, the selection of spatial requirements for the assessment is arbitrary. The selection of target species is based on their ability to support the assessment of habitat quality, under existing and alternative future configurations. In many instances, there is insufficient species data to determine the scale in which the selected target species perceive and respond to specific habitat patterns. In this

study, the determination of strengthening is based on the comparison of existing conditions with those of the proposed scenarios for the potential of increasing urban biodiversity.

Landscape metrics are selected (Fig.1, Box 3) based on their relation to measurements of biodiversity and habitat requirements of the target species. Landscape metrics are a standard of mathematical measurement that relates to configuration or composition of landscape elements. The ability to universally describe attributes of landscape structure aids in the understanding of interactions between ecological process and spatial pattern (Wu and Qi, 2000). Avian and certain arthropod species are more mobile, will react differently to fragmentation, and will have different habitat requirements than other urban species. These habitat requirements include connectivity of habitat areas, edge contrast, minimum patch size, and other specific requirements based on the target species selected.

A habitat association assessment of existing neighborhood planning district conditions (Fig.1, Box 4) is required to provide the base from which the proposed scenarios will be evaluated. This assessment also highlights areas in which green infrastructure implementation will have a higher potential for increasing urban biodiversity. These highlighted areas will often be areas that have high levels of connectedness, large patch sizes, low edge contrast, and a high patch density.

The next step is the development of a comprehensive list of potential green infrastructure elements (Fig.1, Box 5). This will guide the assessment of the study area for the implementation of green infrastructure.

The assessment of the study area for the implementation of individual green infrastructure features (Fig.1, Box 6) is based on existing conditions within the study area. The assessment uses the requirements of the individual features of green infrastructure determined in the previous step to highlight the areas most suitable for their implementation.

The combination of the green infrastructure implementation assessment with the assessment of the study area for the potential increase of urban biodiversity (Fig.1, Box 7) highlights areas where green infrastructure is most suitable for implementation, and where it would have the greatest impact for increasing urban biodiversity. The assessment of potential areas for green infrastructure implementation combined with the assessment of existing habitat areas creates the base from which future scenarios will be evaluated for their ability to strengthen biodiversity. The use of the existing conditions analysis as a base is critical, without this base there is no way to determine the proposed scenarios potential to increase urban biodiversity.

Using the combined assessment described in Box 7 the user can design green infrastructure implementation scenarios (Fig.1, Box 8). Possible design scenarios include those based on population change, such as, a decrease in population

resulting in abandoned land that can potentially be converted to green infrastructure. Design scenarios based on population increase can also be evaluated to address the outcome of a loss of open space and green infrastructure for new urban development. In this instance within each study area, three scenarios are examined based on population change or stagnation. The first scenario addresses stagnation of the population at its current level and possible green infrastructure implementation at current development levels. The second scenario addresses an increase in population and therefore an increase of developed areas within the neighborhoods resulting in a loss of open/green space. The third scenario addresses a decrease in population resulting in the vacancy of parcels and an increase of available open space for green infrastructure implementation.

Once designed, the green infrastructure implementation scenarios are assessed (Fig.1, Box 9) using the landscape metrics previously used for the spatial analysis of the existing conditions within the neighborhood planning district. It is necessary that the proposed scenarios be assessed using the same landscape metrics for evaluation purposes otherwise the outcome is inaccurate.

Following the assessment, an evaluation is conducted of the proposed scenarios for their potential for increasing urban biodiversity by comparing the data from the existing conditions to that of the proposed scenarios (Fig. 1, Box 10). The design scenarios can then be ranked by the relative strengths and benefits of each scenario.

Using the assessment of the initial design scenarios the user can then design a composite green infrastructure scenario incorporating elements that were evaluated and shown to increase the potential for urban biodiversity (Fig.1, Box 11).

The spatial assessment of the composite design scenario (Fig.1, Box 12) incorporates the same methods as with the previous assessments allowing for the comparison of their ability to increase urban biodiversity.

Using the assessment of all previous design scenarios an adaptive green infrastructure implementation plan is developed (Fig.1, Box 13). The adaptive planning process works with the dynamic nature of urban environments allowing for adjustments to the design or future actions based on monitoring of the target species.

The monitoring and adjustment of the adaptive green infrastructure implementation plan (Fig.1, Box 14) provides information regarding the effectiveness of the use of green infrastructure for increasing urban biodiversity.

If the monitoring and adjustment of the adaptive green infrastructure implementation plan results in a failure to meet the initial biodiversity goals of the study then the reevaluation of the biodiversity goals are necessary (Fig.1, Box 15). In some cases, this will result in the need to design and develop additional green infrastructure implementation scenarios. These additional scenarios will also require an

assessment using new target species and a reevaluation of the landscape metrics used for the spatial analysis.

Discussion and Conclusion

The development of the conceptual method for the assessment of green infrastructure to increase urban biodiversity provides a crucial link for integrating landscape architecture and landscape ecology. The method provides a framework for guiding future research in the fields of landscape architecture and landscape ecology especially in the areas of green infrastructure, biodiversity assessment, spatial analysis, and urban planning and design. The expected outcome of the use of the conceptual method is that the potential of green infrastructure for strengthening species-specific urban biodiversity is high. However, the potential will vary greatly depending on the details of configuration and composition of existing and proposed green infrastructure, the ability to introduce new elements of green infrastructure, and the specific habitat requirements of target species. In addition, the development of green infrastructure based urban ecological networks as a tool for biodiversity strengthening promotes ecosystem services (Opdam et al., 2006) and advocates biodiversity conservation and strengthening as a key part of the development of sustainable urban landscapes. The intention of this paper is to encourage the continued integration of landscape architecture and landscape ecology and to establish a framework in which one of these integrations can occur.

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