Planning and Design of Urban Green networks in Stockholm

Na Xiu[1], Maria Ignatieva[1], Cecil Konijnendijk van den Bosch[2]
[1]*Swedish University of Agricultural Sciences, Department of Urban and Rural Development,* [2]*Swedish University of Agricultural Sciences, Department of Landscape Architecture, Planning and Management*

Introduction

Green and blue spaces, together with other land use changes are determining factors of habitat fragmentation, biodiversity loss and decline of ecosystem services in urbanized areas (Adriaensen et al., 2003; Collinge, 1996; Kong et al., 2010; Teng et al., 2011). In attempt to tackle the issue, network connectivity is regarded as a suitable approach from an ecological (CookVan Lier, 1994) and social perspective (Teng et al., 2011). Landscape-scale connectivity is normally built on a 'patch-corridor-matrix' model to describe structural or functional continuity in a spatial and time configuration (FormanGodron, 1986). A graph-theoretic approach therefore can provide an operable way of framing and evaluating features of connectivity (Bunn et al., 2000; MinorUrban, 2008; Zetterberg et al., 2010).

In this paper, the concept of 'green networks' is expanded into a concrete analytical framework for studying green and blue linkages, as well as social and ecological connections and integrations. We selected Stockholm, capital city of Sweden and green capital of Europe 2010, as an example of a city with ample urban green spaces, but also with challenges in terms of green space fragmentation. The main research questions of this paper are: how can the green network concept provide a comprehensive framework for analysing landscape and habitat fragmentation, and how current city green-blue spaces planning can and design benefit from it.

Background

Graph theory is the theory of graphs application through mathematical algorithms. It is well recognised within geography, information technology and computer science. Algorithms and data structures can be easily adapted at the landscape level, as shown by Bunn et al. (2000) and as demonstrated within ecology by Urban and Keitt (2001). The graph is a network that always represented according to a graph drawing of nodes (N) and links (L). Based on the graph theory, spatially and geographically defined land-cover grids of fragmented regions can be transformed into two-dimensional graphs for further analysis – for example in a least-cost modelling approach.

Stockholm, capital city of Sweden, is located in northern Europe. The test area for this study, with an area of 215 km2, covers the City of Stockholm with its approximately 900,000 residents (Fig.1). The city of Stockholm comprises of 14 islands of districts on the coast of Lake Mälaren and Baltic Sea. It includes narrow valleys with lakes, remnant forests hills (50-90 m in altitude), grassland and agricultural fields, constructed buildings and roads.

Goals and objectives

Stockholm was awarded the European Unions ‘Green Capital Award’ in 2010 and is considered good example of green space planning (Stockholm Municipality). However, Stockholm is also a fragmented city due to its topography, continued urban development and from an ecological perspective. Based on the Stockholm City Habitat report published by Stockholm Municipality in 2012, Stockholm has been facing challenges in terms of biodiversity loss, green space loss and conflicts between green/blue and grey spaces since 1998. So we test the green network framework in Stockholm to see how to connect green/blue spaces in a fragmented city as a functional network.

Method

This paper presents two theoretical and methodological components. The first of these comprises the theoretical background and framework of green networks for green-blue connections and social-ecological integration. Next, the specific methodology for testing the framework in a specific city – Stockholm, Sweden – is introduced. Fig.1 shows the overall process of framework.

The test used GSD -Swedish vector maps (1:1,000,000) of the General Map, Land cover map, Property map and Topographic pap (1:50,000), Swedish raster elevation map with 50m resolution and Population vector map. The biotope and the vegetation databases used from City of Stockholm published in 2009. The digital sociotope map is from the City of Stockholm that built in 2004 and updated in 2009.

European crested tit (*Lophophanes cristatus*), European common toad (*Bufo Bufo*) and human being were selected in this study as three species indicators also referred in the reports of Landscape Ecology Analysis by City of Stockholm. All three are focal species according to these reports. In terms of habitat selection, source habitats (nodes or valuable habitats) were based on two reference maps (biotope and sociotope maps) as well as on analysis of scientific literature and local expert assessment. We built a set of criteria to select node patches: 1) the land patches which can be potential habitats in biotope map for crested tit and common toad, and commonly used habitats in sociotope map for humans; 2) large areas of habitats suffer more acutely from landscape fragmentation, so we selected larger habitats as high priority of connection. The minimum area of patches was 1 ha; 3) the patches' central point should be located inside of area because irregular polygons of habitats may centre outside the graphs.

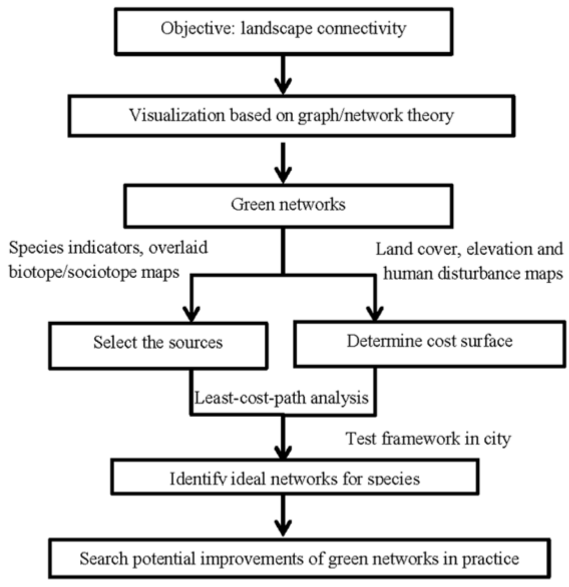

Figure 1. The green network analytical framework and its implementation into practice

Determination of cost values was based on literature and expert assessment by landscape architect Clas Florgård and Anders Larsolle. The cost values were determined in a range of relative numbers by summarising important factors and not the exact cost values. High numbers represent high cost of travelling and low suitability for dispersal of organisms. In this study we considered the following factors: land cover (Cl), human disturbance (Cd) and topography slope (Cs) (Table 1). Land cover (Cl) for the three indicator species was estimated in accordance with different land use type (from built areas to forested lands). We used population density to predict human disturbance (Cd) assuming that anthropogenic impedance directly relates to human density and activity. Slope (Cs) is an important factor in crossing between nodes and differs depend on species, indicating the relative costs of a terrain's surface represented by DEM (Digital Elevation Model).

Table 1. Costs and weights for land cover, human disturbance and slope variables used in the model of green networks in Stockholm

Variable	Attribute	Crested tit		Common toad		Human	
		Costs	Weight	Costs	Weight	Costs	Weight
Land cover (C_l)	Agriculture	50	0.5	100	0.4	7	0.7
	Coniferous/mixed forest	1		1		9	
	Deciduous forest	10		10		8	
	Other open land	400		3,000		1	
	Water	1,000		10,000		10	
	Closed construction	300		7,000		6	
	Low building	200		1,000		3	
	High building	500		8,500		4	
	Recreational building	600		7,500		2	
	Industrial area	800		8,000		5	
Human disturbance (C_d)	<20 people/ha	1	0.4	1	0.4	1	0.15
	20-40	10		150		2	
	41-60	20		300		4	
	61-90	45		500		6	
	91-120	70		700		8	
	121-180	85		900		9	
	>180	100		1000		10	
Slope (C_s)	0-10m	1	0.1	1	0.2	1	0.15
	11-20	30		300		3	
	21-30	50		500		5	
	31-45	70		700		7	
	45-60	90		900		9	
	60-90	100		1000		10	

Results

By carrying out the LCP analysis in ArcMap, 'ideal' green network maps for the three indicator species were generated. These maps represent the effective paths-connections for wildlife movement of crested tit and common toad, and citizen's connection to nature. Insight into these connections can be an important foundation for planning and design. Taking into consideration of different cost values we propose three separate maps of ideal green networks.

Our main goal has been to develop a comprehensive green network plan which can combine multiple essential parameters. Both ecological and social requirements, wildlife (in our research we used crested tit and common toad as representatives) and human needs should be taken into consideration in integral green network map. However, it is problematic to just merge the three separate ideal maps presented in the previous section as every map contains 1711 paths and 5133 corridors in total - although some of the paths in these three maps share the same routes (Fig. 2). Hence we identify path density through the line density tool in ArcGIS and analyse their relative potential utility for a comprehensive map. Higher density levels demarcate high performance and value of potential movement in practical planning and design. Then we classified this map into three simple classes using standard deviations (N=2.5) to show different levels of density. In Fig. 2 high and medium level density of effective corridors are shown. These areas are going to be crucial dispersal points for wildlife and humans, as these will help in more effectively connecting different parts of Stockholm. It is clear to see that ideal paths of the highest value link the Royal National City Park in the north-eastern part with north-western and southern part of the city.

When comparing our data with current land use conditions (see Fig. 2), the lack of important green networks in some areas can be clearly seen. They are specifically needed for improvement of connectivity, and this is especially the case for two corridors that can link up the Royal National City Park in the northeastern part of Stockholm. As one of the most crucial large habitat areas in the city, the National City Park provides a variety of ecosystem services. Thus the linkage between City Park and the rest of city becomes extremely important. The other path (corridor) starts from the lower south side of the Park and extends across the water body (Lake Mälaren) trying to converge all of the green networks in the southern part of Stockholm. These two corridors passing through compact infrastructures in the city centre will allow for sufficient migration to important habitat patches.

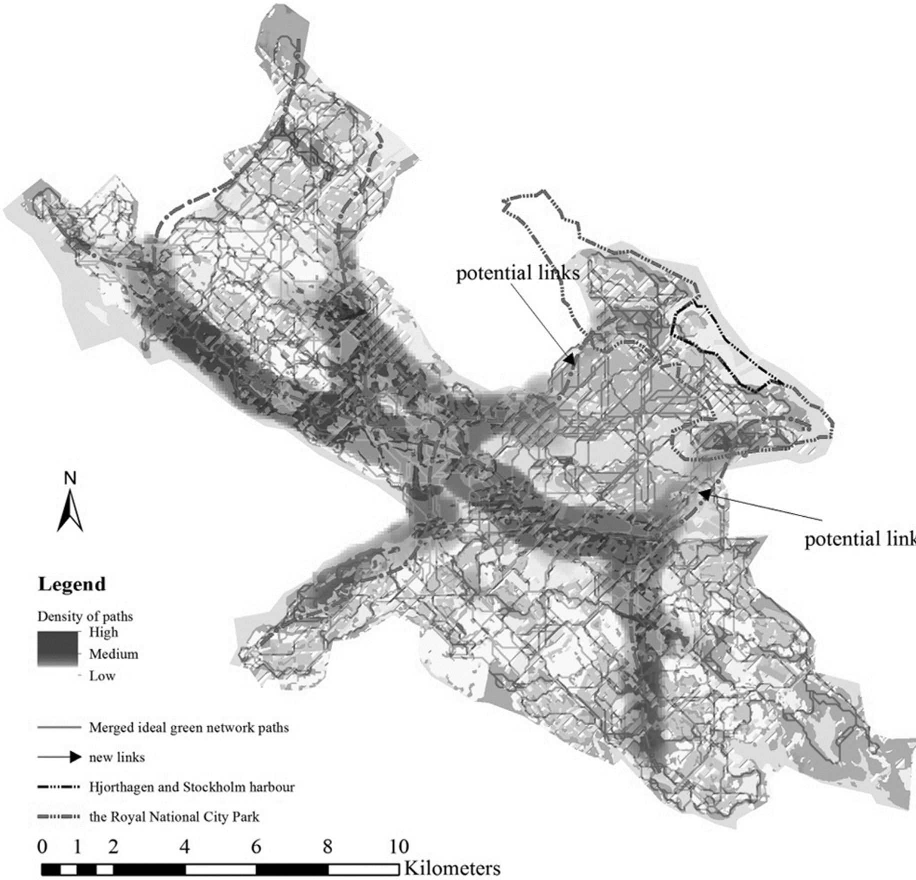

Figure 2. Comprehensive green network with density of paths in Stockholm. The more dense the path areas, the higher priority these should be given in urban planning

Discussion

Graph theory has proven to be a valid method into green-blue spaces planning. Its network analysis framework in combination with the corresponding spatial extents of the city can offer an integral approach to planning. One of the major issues of the visualizing network approach in green-blue space planning is choosing nodes. Nodes can then be the habitat patches in the green space layers that provide important functions of wildlife living and reproduction, or they can be fragile patches that need to be protected and preserved in front of urban densification and city's development. Selection of nodes also concerns network users for which species are proposed to use the graphic network. It relates to species indicators as a result of different criteria, such as focal species, umbrella or endangered species, and so forth. Apart from nodes selection, the LCP analysis needs another layer, namely that of the cost raster. Knappen (1992) proposed using the number to decide the cost of values response to patch accessibility based on simulated dispersers. Some researchers have an applied a similar way of simplifying the decision of cost values with different variables (Adriaensen et al., 2003; Graham, 2000; Teng et al., 2011). A variety of factors can affect the dedicated cost values, such as land use, vegetation cover, human activities, elevation, etc. The more elements considered the more accurate or comprehensive cost values can be reached. Setting cost through the LCP model is not only a valuable way to consider ecological and social aspects but also integrates economic feasibility into sustainable green-blue spaces planning.

Although the LCP model represents a potential method for development of green-blue space planning on the bases of current land use, there is still a problem related to the cost assumption of least cost – whether the plants, animals and human choose to use the ideal paths. The surrounding nature of the Stockholm city, addressed in regional planning, is an important provider of ecosystem services and component of larger-scaled green networks. This calls for future studies that first on better models of actual and ideal organism migration routes as well as the corresponding spatial extents of the connectivity zones, second integrate Stockholm as well as other municipalities into a wider range of green network analysis.

Conclusion

This research has looked at physical green-blue spaces extents and has applied visualized graph theory. It has illustrated how green networks can be expanded as a multiple-functioned framework that transfers between different scales. After testing this approach in Stockholm, the lest-cost-path analysis could be a valid way of providing references for city planners in other cities.

In future research we will apply the framework in more cities to check its operation ability and adjustment possibility. Additionally optimizing the analysing tool never ends, so as to green network framework and the LCP model. Crucial steps in the model – nodes and species selection, cost distance and LCP analysis – can still be optimized further. For example, this research only considered mostly-used green spaces from sociotope map. Aesthetic, cultural or educational values could also be integrated into the comprehensive planning. Different criteria of habitat and network users' selection will definitely lead to distinguished potential corridors and improvement strategies. But zooming in and out between scales would be a major advantage in discussing the planning and design of green network. Future tests and applications of this approach will be necessary in specific cases of accurate green networks in urban areas.

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