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ECOIND-3550; No. of Pages 15

ARTICLE IN PRESS

Ecological Indicators xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original article

Implementing the connectivity of natural areas in cities as an indicator in the City Biodiversity Index (CBI)

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ARTICLE INFO

Article history:
Received 13 August 2016
Received in revised form 15 February 2017
Accepted 18 February 2017
Available online xxx

Keywords:
Connectivity
Connectors
Convention on Biological Diversity
Effective mesh size
Green infrastructure
Landscape fragmentation
Landscape metrics
Planning scenarios
Singapore Index
Urban ecology
Urban biodiversity
Wildlife corridors

ABSTRACT

The City Biodiversity Index (CBI), or Singapore Index on Cities' Biodiversity, serves as a tool to monitor biodiversity in cities and was endorsed by the Convention on Biological Diversity in 2009. Indicator 2 of the CBI measures the connectivity of natural areas in cities. We propose an improved and straightforward method for measuring connectivity based on the effective mesh size metric to replace the previous method used in the CBI. The previous version did not account for intra-patch (within-patch) connectivity nor for major barriers. Our evaluation of the new version of Indicator 2 through its application to Montréal and Lisbon confirmed its reliability. In Montréal, natural areas have a total connectivity value of 581.7 ha, the majority of which exists between, rather than within, patches of natural area. Smaller patches (<15 ha) contribute significantly to overall connectivity, which may have implications for future conservation efforts. In Lisbon, connectivity (342 ha) is concentrated within patches. We also applied the improved Indicator 2 to a case study in southwestern Montréal, where a greenway network ("green infrastructure") has been proposed by a local community organization. We assessed the contribution of Meadowbrook Golf Course to connectivity in scenarios of the proposed greenway network and the effect that residential development would have. Not only would this development eliminate the golf course's current contribution to connectivity, but also its much greater potential contribution to connectivity in future scenarios. Restoring and establishing additional natural areas would significantly increase connectivity in the network. Our results demonstrate that the improved version of Indicator 2 is a suitable method in the CBI. It is equally useful for identifying options to increase the connectivity of natural areas within cities in the future and for determining the impacts of urban development on connectivity. More advanced methods for quantifying connectivity exist and may also be included in Part I of the CBI. However, they are often challenging to use and this frequently discourages city planners from including any indicator of connectivity in their biodiversity monitoring. The connectivity metric presented here overcomes this problem through its practicality in a wide range of planning structures while still generating meaningful results which may then inspire city planners to move towards using more advanced methods of measuring connectivity. We dedicate this paper to the memory of Bernice Goldsmith (1934–2014).

1. Monitoring biodiversity in cities

Urban wildlife populations are negatively affected by habitat fragmentation, which limits access to resources and mating partners. This may result in the loss of genetic diversity and in higher rates of extinction, in particular among groups of species with highly specialized habitat requirements (Brook et al., 2003; Di Giulio et al., 2009; Taylor et al., 1993; Tischendorf and Fahrig, 2000).

The City Biodiversity Index (CBI), or Singapore Index on Cities' Biodiversity, was developed as a tool to evaluate and monitor the state of biodiversity in cities and to provide insights for improving conservation efforts. It was proposed by the Minister of National Development in Singapore, Mr. Mah Bow Tan, at the 9th Meeting of the Conference of the Parties (COP-9) to the Convention on Biological Diversity (CBD) in May 2008. The CBI was established by the National Parks Board of Singapore and the Secretariat of the CBD in collaboration with the Global Partnership on Cities and Biodiversity from 2009 to 2011 (Chan et al., 2014). The Index is comprised of 23 indicators (Table 1), characterized as "native biodiversity in the city; ecosystem services provided by native biodiversity; and

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http://dx.doi.org/10.1016/j.ecolind.2017.02.028

governance and management of native biodiversity" (Chan et al., 2014; p. 4). Few studies have analyzed the CBI and its implementation in urban areas so far. However, existing research focusing on the application of CBI indicators accounts for both biological and social factors, including the development of partnerships between academics and policy makers, which are important for promoting conservation efforts (Kohsaka, 2010; Kohsaka et al., 2013; Kohsaka and Okumura, 2014). We focus on Indicator 2, which measures the connectivity of natural areas in cities.

1.1. Connectivity

Connectivity is defined as "the degree to which the landscape facilitates or impedes movement among resource patches" and it can be "measured by the probability of movement between all points or resource patches in a landscape" (Taylor et al., 1993; p. 571). Urban landscapes contain a wide range of physical elements, including connectors that serve as linkages by facilitating species movement between resource patches (e.g., some types of railway lines) (Rudd et al., 2002; van der Ree et al., 2015) and barriers that impede movement (e.g., roads) (Taylor et al., 2006). For the purposes of this study, we refer to an ensemble of barriers in a city as a "fragmentation geometry" (Jaeger et al., 2008).

The importance of landscape connectivity for biodiversity has been discussed extensively in the literature (Taylor et al., 1993; Di Giulio et al., 2009; LaPoint et al., 2015). For example, maintaining or restoring connectivity is the most often recommended measure to address the effect of climate change on biodiversity by enabling species to move to more suitable locations (Heller and Zavaleta, 2009; Nunez et al., 2013); a measure that has become increasingly relevant for organisms in cities (LaPoint et al., 2015; Wilby and Perry, 2006). One method commonly used to enhance urban connectivity involves the preservation or creation of greenway networks, also known as "green infrastructure", formed by a variety of interconnected natural areas (Braiser, 2011; p. 10). Greenways may contribute to enhanced survival rates among various groups of species by enabling movement within and between habitat patches amidst surrounding urban infrastructure (LaPoint et al., 2015; Rudd et al., 2002).

Since the designation of particular landscape features as 'natural' (e.g., subareas of parks, riverbeds) will have an impact on the results of any connectivity analysis, a comprehensive definition of natural areas is needed. For the purposes of this research then, we use the following CBI definition of natural areas (Chan et al., 2014): "Natural areas comprise predominantly native species and natural ecosystems, which are not, or no longer, or are only slightly influenced by human actions, except where such actions are intended to conserve, enhance or restore native biodiversity. Natural ecosystems are defined as all areas that are natural and not highly disturbed or completely man-made landscapes. Some examples of natural ecosystems are forests, mangroves, freshwater swamps, natural grasslands, streams, lakes, etc. Parks, golf courses and roadside plantings are not considered as natural. However, natural ecosystems within parks where native species are dominant can be included in the computation. The definition also takes into consideration 'restored ecosystems' and 'naturalized areas' in order to recognize efforts made by cities to increase the natural areas of their city. Restoration helps increase natural areas in the city and cities are encouraged to restore their impacted ecosystems" (Chan et al., 2014; p. 9).

1.2. Improved method for measuring connectivity in the CBI

We propose an improvement to the previous method used to measure connectivity in the CBI (Section 2.1) in order to produce more reliable results without compromising practicality in the application of the metric. This version of Indicator 2 applies the effective mesh size method, which is based on the probability that two randomly chosen locations in the landscape are connected and not separated by barriers (Jaeger, 2000). This improved method includes both intra-patch connectivity and inter-patch connectivity and is simple to calculate (Section 2.2). To illustrate the use of this method and its strengths and weaknesses, we applied the previous and improved versions of the connectivity metric to the Montréal Agglomeration (in collaboration with the Ville de Montréal, Service des grands parcs et du verdissement et du Mont-Royal) and the inner metropolitan area of Lisbon. The improved method has since been implemented in the CBI in collaboration with the National Parks Board of Singapore and the Secretariat of the CBD.

We also applied the improved method to an analysis of greenway networks in the southwestern region of Montréal (in collaboration with Les Amis du Parc Meadowbrook), where it was adapted to account for differences in landscape features (e.g., natural areas, semi-natural areas) that exist in urban areas. This case study illustrates the potential for city planners to modify the newly implemented Indicator 2 to examine and monitor the impact of their efforts in decreasing biodiversity loss.

1.3. Research objectives

This paper explains the method and illustrates its application to (a) two cities as part of the CBI, and (b) to a specific geographic area

Table 1
The 23 indicators used to monitor urban biodiversity in the CBI. The focus of this research is on Indicator 2 (in bold).

Component	ID	Indicator
Native biodiversity in cities	1	Proportion of Natural Areas in the City
	2	**Connectivity Measures or Ecological Networks to Counter Fragmentation**
	3	Native Biodiversity in Built Up Areas (Bird Species)
	4–8	Change in Number of Native Species
	9	Proportion of Protected Natural Areas
	10	Proportion of Invasive Alien Species
Ecosystem services provided by native biodiversity in cities	11	Regulation of Quantity of Water
	12	Climate Regulation: Carbon Storage and Cooling Effect of Vegetation
	13–14	Recreation and Education
Governance and management of native biodiversity in cities	15	Budget Allocated to Biodiversity
	16	Number of Biodiversity Projects Implemented by the City Annually
	17	Existence of a Local Biodiversity Strategy and Action Plan
	18–19	Institutional Capacity
	20–21	Participation and Partnership
	22–23	Education and Awareness