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Applying a novel urban structure classification to compare the relationships of urban structure and surface temperature in Berlin and New York City

Neele Larondelle [a, b, *], Zoé A. Hamstead [c], Peleg Kremer [d], Dagmar Haase [a, e], Timon McPhearson [d]

[a] Humboldt University Berlin, Institute of Geography, Lab of Landscape Ecology, Mat-Nat Faculty II, Institute of Geography, Unter den Linden 6, 10099 Berlin, Germany

[b] Potsdam Institute for Climate Impact Research, Climate Impacts & Vulnerabilities – Research Domain II, Telegrafenberg 31, 14473 Potsdam, Germany

[c] Milano School of International Affairs, Management and Urban Policy, The New School, 72 Fifth Avenue 5th Floor, New York, NY 10011, USA

[d] Tishman Environment and Design Center, The New School, 79 Fifth Avenue 16th Floor, New York, NY 10003, USA

[e] Helmholtz Centre for Environmental Research – UFZ, Depart. Computational Landscape Ecology, Permoser Straße 15, 04318 Leipzig, Germany

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A B S T R A C T

This study introduces a novel approach to classifying urban structure using land cover and building height. The goal of the study was to improve comparability of urban structure–function relationships across cities through development of a novel classification framework that can facilitate urban studies of ecological patterns and processes. We tested the suitability of the classification in two very different urban settings – continental Berlin and coastal New York City. Using Landsat temperature data as an ecological function variable, we compared how urban structures in both cities relate to temperature. Results show that in both cities a large range of urban structure classes show similar trends with respect to land surface temperature, despite differences in climate and structure of the two cities. We found that approximately 68% of the area of Berlin and 79% of the area of New York City can be represented with the same fifteen urban structure classes. Results indicate that these common classes share very similar temperature patterns and may indicate broader utility of the classification framework. Among the classes which have the most dissimilar temperature trends between the two cities, we find large differences in inner-class composition and neighboring classes. Findings also show that the presence of water has a strong influence on temperature regulation, as classes containing water have the lowest surface temperatures, indicating a need for prioritizing aquatic ecosystems in urban planning and management.

Introduction

Characteristics of urban form and structure, such as the presence of vegetation and other land covers, as well as spatial configurations of structural elements such as buildings, can influence ecological functioning and human well-being in cities. Structural elements are linked to health of urban residents through air quality, local climate impacts, hydrologic processes, and by influencing mental well-being among other impacts (Alberti, 1999; Hamin & Gurran, 2009; Jackson, 2003; Marquez & Smith, 1999; Stewart & Oke, 2012; Stone & Rodgers, 2001; Velarde, Fry, & Tveit, 2007; Yu & Hien, 2006). Understanding ways in which structural elements are related to functions is necessary for understanding ecology in cities (Jansson, 2013), and in order to guide urban development in a way that utilizes ecological functions to enhance environmental performance.

However, since most ecological studies have focused on areas with low human population densities, knowledge of these relationships is not developed enough to glean generalities about the structure and function of cities. Urban comparative approaches can help to build our understanding of urban system properties that underlie structure/function relationships, examine causal factors

* Corresponding author. Humboldt University Berlin, Institute of Geography, Lab of Landscape Ecology, Mat-Nat Faculty II, Institute of Geography, Unter den Linden 6, 10099 Berlin, Germany. Tel.: +49 30 2093 6843.

E-mail addresses: neele.larondelle@geo.hu-berlin.de, n.larondelle@gmail.com (N. Larondelle), hamsz235@newschool.edu (Z.A. Hamstead), kremerp@newschool.edu (P. Kremer), dagmar.haase@ufz.de (D. Haase), mcphearp@newschool.edu (T. McPhearson).

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and generate general principles to help guide planning and urban design (McDonnell & Hahs, 2009). Comparative approaches can also help to evaluate the extent to which local conditions versus global drivers influence structure/function relationships (Niemelä, Kotze, & Yli-Pelkonen, 2009). However, a lack of standardized variables and common datasets between cities makes it challenging to conduct cross-city comparison (Hahs, McDonnell, & Breuste, 2009). In order to conduct cross-city comparative research on relationships between urban structures and ecological functions, classification systems that use comparable structures and spatial scales appropriate to the functions of interest are necessary.

Many studies have associated specific land use/cover types with indicators of human well-being and environmental performance (Breuste, Haase, & Elmqvist, 2013; Burkhard, Kroll, Müller, & Windhorst, 2009; Kroll, Müller, Haase, & Fohrer, 2012; Larondelle & Haase, 2013; McPhearson, Kremer, & Hamstead, 2013) However, few studies have tested structure/function relationships across cities, particularly across continental boundaries. A review of comparative approaches categorized studies according to their use of urbanization gradients, rural–urban gradients and change over time analysis (McDonnell & Hahs, 2009). For instance, urban to rural gradient comparative studies have included a comparison of minimum temperature in Baltimore, MD and Phoenix, Arizona (Brazel, Selover, Vose, & Heisler, 2000), a comparison of avian diversity and richness in Quebec, Canada and Rennes, France (Clergeau, Savard, Mennechez, & Falardeau, 1998), and a comparison of biodiversity and ecosystem performance along measures of urban form in five cities in the United Kingdom (Tratalos, Fuller, Warren, Davies, & Gaston, 2007). These studies all obtained direct measurement of function at study sites, rather than across the entire city area. Other studies have conducted comparative analysis over entire urban extents, including a comparison of relationships between urban green space and population, residential area, number of households and urban compactness in 300 European cities (Kabisch & Haase, 2013), a comparison of relationships between urban green space coverage, city area and population size in 396 European cities (Fuller & Gaston, 2009), and a comparison of ecological connectivity and urban form in 66 United States urban areas (Bierwagen, 2005). These studies use pre-existing land use/land cover classifications, such as the European Corine system, or U.S. National Land Cover Database (NLCD) for urban structure variables, assuming certain relationships between structure and function. Land uses indicate ways in which humans employ land, whereas land cover describes the character of the earth's surface (Meyer & Turner, 1992).

Boone et al. (2012) argue that comparative approaches “must be bound by some common denominators, such as the biophysical, social and historical commonalities of regions.” Additionally, in order to conduct comparative studies that test structure/function relationships across continents without obtaining direct measurement from a limited number of study sites, a classification system capable of characterizing urban environments in a more standardized way is necessary. Because the diversity of land cover types tends to be higher in urban areas than surrounding landscapes, and land cover elements change more quickly over fine spatial scales in urban environments (Cadenasso, Pickett, & Schwarz, 2007), urban structure classifications need to have relatively fine spatial resolutions. A standard classification also needs to include land cover or land use types that have similar meanings across cities. For instance, assumptions about the proportion of vegetation in residential land may lead to substantial inaccuracies when comparing across cities or even within a single city.

The objectives of this study are 1) to apply an approach to developing an urban structure classification, based on combinations of structural elements that emerge in the urban environment, to a comparative study of a European and North American city, 2) to test its sensitivity to an indicator of ecosystem function—surface temperature and 3) to examine the patterns in the relationship between urban structure and surface temperature in the two cities in order to assess the generic nature of the approach. We build on the generic classification procedure proposed by Stewart and Oke (2012), which is based on biophysical properties of the urban surface. In combining land cover elements with building height types, we derive urban structure classes that commonly occur in each city and use these classes to examine the relationship between urban structure and surface temperature. Although other studies have examined relationships between land cover or land use and temperature, our approach is unique in that rather than defining classes *a priori*, we instead generate a classification based on common combinations of structural elements emergent in the urban landscape. To evaluate the transferability and broader applicability of this classification approach, this study is carried out in two cities: the European continental city of Berlin, Germany and the coastal city of New York in the United States.

Study sites

New York City (NYC) is the largest city in the U.S. with over 8 million inhabitants (U.S. Census Bureau, 2012), and an average population density of 10,640 inhabitants per km^2. It is located at a natural harbor area on the east coast and contains more parkland than any other U.S. city. Due to the City's efforts to further increase green infrastructure, by 2030, the city's tree canopy cover proportion is projected to increase from 21% to 30% (Grove, O'Neil-Dunne, Pelletier, Nowak, & Walton, 2006). However, population growth and climate change impacts will put increased pressure on the city's ecosystems to reduce pollution, regulate temperature, manage stormwater, and provide green recreational spaces for NYC residents (McPhearson, Maddox, Gunther, & Bragdon, 2013).

Berlin is the capital and largest city in Germany with over 3.5 million inhabitants (Senatsverwaltung für Stadtentwicklung und Umwelt, 2012) and an average of population density of 4000 inhabitants per km^2 (Senatsverwaltung für Stadtentwicklung und Umwelt, 2013a). Located in the northeast of Germany, Berlin is one of the most populated areas in Europe and at the same time one of Europe's greenest cities, with a ratio of unsealed surface of almost 50% (Kabisch & Haase, 2014). Population growth is creating significant pressure for planning and management in Berlin while climate change impacts, such as heat and drought, are expected to increase stress on the city's ecosystems in the next decades (Senatsverwaltung für Stadtentwicklung und Umwelt, 2013b) (Fig. 1).

Material and methods

Data

In order to generate urban structure classes, we combined pre-existing land cover and building height data for each city (Table 1). For Berlin the Urban Atlas database (EEA, 2006) was used in combination with the LULC model for Berlin (Lauf et al., 2012) and assumptions for building height for certain building types. The Urban Atlas service offers a high-resolution land use map of urban areas with an overall minimum accuracy for all classes of 80% (European Commission, 2011). Based on Earth observation satellite images with a 2.5 m spatial resolution, the Urban Atlas provides comparable land use data for all of the European larger urban zones with more than 100,000 inhabitants. For NYC, we combined a 3 × 3 ft raster land cover dataset (NYC Parks and Recreation, 2010) with