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Compact, eco-, hybrid or teleconnected? Novel aspects of urban ecological research seeking compatible solutions to socio-ecological complexities

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ABSTRACT

Scientists in this urban century have published numerous studies proposing a wide range of theoretical and technical methodologies for addressing the complex challenges posed to urban livelihoods. The most critical challenge that has yet to be overcome is how to respond to the demands of decision-makers who seek ready-made and rapidly implementable solutions for sustainable urban development. This paper introduces and briefly discusses the contemporary concepts and overarching ideas in urban ecology research, which should be of relevance to the wide range of compact, yet sprawling, and eco-cities, as well as to researchers investigating the ecology of cities. This work serves as an introduction to the Special Issue of Ecological Indicators resulting from the First Congress of the Society for Urban Ecology, held in Berlin in July 2013. A combination of theoretical and technical papers is included. A mixture of exploratory urban indicators is proposed, and some existing indicators are further tested with novel methods in cross-continental, interdisciplinary case studies.

1. The 'urban phenomenon'

Cities occupy approximately 4% of the world's total land surface (Ramankutty et al., 2006) but accommodate more than half of the world's population, and this number will only continue to increase (Lutz et al., 2001; United Nations, 2011a), especially in developing countries (Grimm et al., 2008; Wu, 2008). Hence, urbanisation has been proven as a major driving force of global change and sustainability (Qureshi et al., 2014; Wu, 2008). The unprecedented growth of human populations and rapid urban development have led to several urgent questions regarding the future of human life and its quality in cities (Elmqvist et al., 2013; Qureshi et al., 2013). These factors will have an increasingly significant impact on the biophysical assets of the environment on multiple scales (Berry, 1990; Millennium Ecosystem Assessment, 2005). The rapid expansion of cities complicates the continuum of the urban fabric, which leads to rapid and unsustainable changes in the dynamics of peri-urban and surrounding rural areas, including agricultural lands (Pauliet et al., 2010; Breuste et al., 2013).

As an irreversible and intensive phenomenon, urbanisation affects flora, fauna, atmosphere and soils in urban areas. Cities and their peri-urban surroundings are primarily human-dominated ecosystems (Williams et al., 2009). Therefore, Wu et al. (2011, p. 1) claim that "urbanisation is the most drastic form of land use change affecting biodiversity and ecosystem functioning and services far beyond the limits of cities". Any threats to these critical ecosystems will lead to serious challenges across the world, including energy crises, climate change, ecosystem instability and human health issues, all of which affect societal well-being (Seto et al., 2012; Williams et al., 2009; Müller and Munroe, 2014; Pauchard et al., 2006). However, any positive impact of technological and scientific development in cities will help make our world more sustainable (Haase, 2014).

Many of these 'Janus-faced' situations face urban areas. For example, while the loss of arable land reduces ecosystem productivity, the loss of urban green space has a negative impact on human health and well-being (Rohde and Kendle, 1994; Tzoulas et al., 2007; Ulrich, 1984). Changes in urban vegetation cover lead to alterations in the microclimate of the human habitat, as well as in climate dynamics and the environment at local and regional scales (Gill et al., 2007; Lehmann et al., 2014). These effects originate from urban areas, but their influence extends into peri-urban and rural areas and continues into natural environments such as forests, mountains and rivers. Therefore, the pattern of the urban-rural gradient is constantly influenced by human pressure and the

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exploitation of natural resources (Qureshi et al., 2010, 2014) while remaining a human habitat of growing importance (Kabisch and Haase, 2014).

In addition to facing the aforementioned ecological challenges, cities, as global junctions, offer considerable potential for global transformation, as they are confronted with particular challenges of transport, traffic, health issues, telecommunications, energy supply, water supply, construction and housing (Haase, 2014; Qureshi, 2009). Cities serve as 'laboratories of humanity' in which solutions for these challenges must be developed (Kraas, 2007; Qureshi et al., 2010). Cities offer many advantages to their inhabitants, such as labour and employment, better quality of life, easier access to health and education services, and a rich cultural life. The current perception of cities, particularly that of megacities, has been shifting from one of 'global risk areas' (Kraas, 2003) towards one of 'engines of global change' (Kraas and Nitschke, 2006).

Urbanisation is possibly the definitive land-use phenomenon of the 21st century, comprising climate, environmental and quality-of-life effects, and its investigation demands new scientific and technological developments. Particularly the scientific development opens the field for intensified interdisciplinary research cooperation and provides opportunities to advance international efforts towards urban sustainability on a global scale (Elmqvist et al., 2013; Elliott et al., 2000; Breuste et al., 2013). Because cities are home to more than the half of the world's population, they are hotspots for research related to contemporary issues such as climate change, demographic change, food shortage, the energy crisis and the use of ecosystem services (Krausmann et al., 2009; Gómez-Baggethun and Barton, 2013; Breuste et al., 2013a,b; Breuste and Qureshi, 2011).

2. Urban teleconnections and urban-ness vs urban hybridity

Several new approaches have been suggested on how to conceptualise the 'urban phenomenon'. Both the magnitude and rate of recent urbanisation are redefining and reshaping urban land area, land cover and cities at different scales (from the local to global), both processes and patterns of urbanisation require a re-examination in the context of urban sustainability (Grimm et al., 2008; Seto et al., 2012). The urban population is projected to increase by almost 3 billion people by 2050 (UN, 2011a), and the amount of urban land had been simulated to grow by more than 1.5 million km^2 by 2030 (Seto et al., 2012). In addition, urban economies currently generate more than 90% of the global GDP and host the majority of the world's financial transactions. The worldwide area unaffected by urbanisation is constantly shrinking (UN, 2011b). Given these trends, the concept of urbanisation and 'the urban' including the linkages between cities and non-urban land needs a reconceptualisation. A large body of literature has considered many proximate land cover/use changes initiated by and occurring due to urbanisation, ". . . but the more distant and implicit land-use impacts of urbanisation remain under examined" (Seto et al., 2012, p. 1).

The virtual decline of the distances between urban and non-urban areas due to (tele)communication and transport technologies and the growing separation between places of consumption (e.g., energy, food and mineral resources) and production have resulted in today's 'telecoupled' socio-ecological systems (Seto et al., 2012a). In this sense, urban land teleconnections (ULT) represent the distal flows and connections of people, economic goods and services, and land use changes that both drive and respond to urbanisation (Seto et al., 2012a). Thus, urbanisation and linked sustainability must be evaluated from at least two different viewpoints: drivers and impacts (upon areas). ULT therefore emphasises a process-based instead of place-based conceptualisation of the 'urban phenomenon' (Seto et al., 2012a); a framework that, to some extent, has been resonating in the urban footprint concept (Bond, 2002).

In an era of ULT-like urbanisation, in which the structure and function of space/land may affect one another at great distances and at near instantaneous speeds, even seemingly remote areas may have urban characteristics. Accordingly, traditional concepts of 'the urban' and 'the rural' have become increasingly less useful in describing the function and structure of land as a place of human activity, as well as sustainability (Pauliet et al., 2010). Thus, the 'urban-ness' of an area (i.e., place or patch) and its economic/communication activity and population characteristics should define its sustainability. Urbanity is defined by how people use and impact their various livelihoods, their material culture and patterns of consumption representing different lifestyles, their spatial connectivity (e.g., communication, information exchange and transport, travel), and how they identify with the place they reside in and rely upon (Tittle and Grasmick, 2001). The magnitudes and qualities of these livelihoods, lifestyles, connectivities, and places create the 'degree of urban-ness' of intertwined human experiences and land configurations (Boone et al., 2014). Based upon that, it is possible to define a continuum of urbanity defined not by any administrative boundary of a city (Qureshi, 2010) but by the activities and functions that occur in places that may be far removed from what are traditionally understood as cities/urban areas.

Both ULT and urban-ness are connected to another novel, but more social science-based, concept: urban hybridity, which is mainly applicable to the formerly colonised parts of the world that currently exhibit the highest urban growth rates. Hybridity, acknowledged as one of the key terms in postcolonial space theory, usually refers to "the creation of new transcultural forms within the contact zones produced by colonization" (Ashcroft et al., 1998, p. 20). Two of the key themes related to postcolonial urban hybridity are (a) the rethinking of the notions of hybridity in urban contexts and the post-colonial city in Asia, Latin America and Africa and (b) contests over land use and ownership (e.g., gentrification, eviction, ethnic and spatial "cleansing") that also affect cities (Toro, 2001, 2002). Integrating these three concepts and relating them to the development and sustainability of cities worldwide clearly represents an interdisciplinary research challenge.

3. Special issue: synthesis and contributions

This Special Issue broadly aims to bridge the knowledge gap in urbanisation, which demands both the creation and provisioning of ecosystem services in urban regions and fostering indicator-based approaches to urban governance and land use planning. We are especially interested in interdisciplinary studies presenting new and innovative ways of considering and processing spatial ecological data in urban scenarios that could lead to an in-depth understanding of urban sustainability issues. An indicator-based approach and systems thinking help address the complex issues related to the overall functioning of urban landscapes (Salman and Qureshi, 2009; Fanelli et al., 2006; Zhu et al., 2011). Therefore, this special issue presents a range of articles, separated under three subsections with overlapping ideas.

3.1. Novel indicators of urban systems

This section presents ideas proposing and testing several unique yet explicit indicators of urban ecosystems. Herrera-Dueñas et al. analysed the levels of oxidative stress on the house sparrow (*Passer domesticus*) generated by exposure to pollutants in the urban environment. This species was selected because of its worldwide distribution, non-migratory status and association with urban areas. Inostroza proposed the use of technomass as an indicator to measure the process of material accumulation, testing the indicator in the city of Bogotá in Colombia. Alfonso Piña and Pardo Martínez studied the same city, but instead applying material flow analysis to investigate a range of indicators representing flows of inputs (e.g., water, energy and food) and outputs (e.g., waste water, air pollution and solid waste) in the urban system. The final paper in this section proposes the analysis of heavy metal content in the soil as a prime anthropogenic indicator reflecting the influence of urbanisation on the ecological settings of urban areas (Karim et al.). This paper also reports on the spatial pattern of soil samples analysed across different land uses in an urban environment, thus exploring the pattern of heavy metal content across different urban forms.

3.2. *Urban ecosystem services: integrated approaches*

This urban era is under considerable stress to balance the demand and provisioning of ecosystem services, especially because the rapid growth of many cities generates micro-climatic changes due to land use changes. Therefore, Cavan et al., in an interdisciplinary study, proposed the concept of urban morphological types (UMTs) and apply it to two African cities (Addis Ababa in Ethopia and Dar es Salam in Tanzania) in combination with the temperature profiles of the cities. The results presented by these authors suggest that land surface cover proportions have a much greater potential to change neighbourhood-level surface temperatures than do projected climate changes. Lehmann et al. proposed the use of urban vegetation structure types (using Dresden in Germany as a case study) as a methodological approach for identifying ecosystem services and applied it to analyse the microclimatic effects in cities. Lauf et al., using a data-intensive modelling approach, developed linkages between ecosystem service provisioning, urban growth and shrinkage. The study presents six provisioning, regulation and cultural ecosystem services indicators for two scenarios from 2008 to 2030, considering Berlin in Germany as a case study. Finally, Li et al. (a) combined GIS and economic evaluation methods to assess the ecosystem services and landscape pattern changes from 1991 to 2006 for the city of Changzhou in China. The results of this research have already been adopted locally by the Changzhou Municipal Bureau of Urban Planning, who have applied it for the city's master plan. The simplicity of this approach supports its effective use by policymakers in formulating policies.

3.3. *Multi-criteria analysis of urban complexities*

This section summarises a range of approaches used to analyse the data on socio-ecological complexities in urban environments. Baus et al. used a GIS model based on principal component analysis (PCA) to statistically establish/identify interconnections between landscape pattern and urban dynamics in Bratislava in Slovakia, from 2002 to 2011. A range of behaviour rules were further defined to determine embedded distance, spatial pattern and transition probabilities, which are essential in the proposed logistic regression model. Iojă et al. innovatively used multi-criteria analysis to create a tool for integrating land-use conflicts in strategies for territorial- and city-level planning. The method was applied in the Bucharest Metropolitan Area in Romania by selecting ten major criteria grouped in categories of spatial indicators and development indicators. By combining pair-wise comparison with an expert-opinion system, this study determined the relative importance of each criterion in the form of criteria weights. The spatial indicators revealed high probabilities of land-use conflicts compared to the development indicators, which showed a scattered spatial distribution of land-use conflicts.

La Rosa developed a GIS method to analyse the accessibility to green spaces for sustainable planning. He formulated a set of accessibility indicators aimed at quantifying different measures of accessibility to existing open spaces for the city of Catania in southern Italy. The categorised indicators were analysed using different thresholds of Euclidean and network distances. The results show that different scenarios, in terms of green space accessibility ranking, were strongly influenced by the chosen distance metric (Euclidean vs network) and thus emphasise the careful use of these indicators as planning support tools. Li et al. (b), using a data-intensive approach, applied the concept of spatial resilience to the assessment, planning, and ecosystem-based management of the urban wetland interface in the Taihu Lake watershed in China. Spatial resilience was assessed with an indicator-based system, a multi-criteria evaluation method, and spatial visualisation using a geographic information system (GIS) to create spatial zones in the context of different degrees of spatial resilience. The final paper, by Lookingbill et al., assessed the condition of national park resources along an urban-rural gradient in and around Washington, DC, USA. Twelve representative metrics of ecosystem condition were integrated into single park scores using four separate approaches for data aggregation. A range of data analysis methods were compared based on different criteria. The use of simpler methods was proposed, e.g., employing distance-based aggregation scoring for the long-term assessment of lands in this mixed-used landscape.

4. Epilogue: new hypotheses for new urban complexities

The resilience of urban systems to sustain the pressure of unprecedented growth while handling severe decline remains an open area of research, in which the integrated modelling of urban system indicators and phenomena requires in-depth investigation. Urban (ecological) modelling is a rapidly developing field but remains rather diffused across a wide range of international journals, including those devoted to the spatial sciences, ecology, forestry, agriculture, environmental management, geography and global change. Unfortunately, the issue of urban systems has been neglected in terms of applying landscape and ecological modelling approaches to represent the performance indicators of urban landscapes.

The current knowledge regarding the relationships between urban systems, their dynamics, the ecological services they provide and their land management is fragmented and provides weak support to policymakers. The scientific community appears to have failed at delivering the fruits of its research to society, or has at least been unable to communicate these contributions. Moreover, no 'digest' of valuation has been developed to properly account for the hidden values of urban ecosystem services in urban planning. It has been difficult to realistically encourage pragmatic actions by employing the concept of ecosystem services as a substantive component of sustainable urban development. This special issue aims to partially bridge this knowledge gap. However, many unexploited avenues of urban ecological research remain and are listed below as overarching hypotheses and questions:

- The resilient city of the 21st century, to provide a high quality-of-life, is compact. The city has the potential to optimise ecosystem functions and services in order to ensure urban resilience and social well-being.
- Inequality and environmental justice in the larger cities of the global South currently follows or will excessively grow in a similar pattern to that in the North/developed world.
- There is no overall form/concept for future cities. Do we really need one?

- Are megacities really different from other large cities, or are they simply bigger? What differences exist between the biotope networks of large cities and megacities? Or, in other words, is biodiversity a matter of scale?
- Man-made, 'improvised' natural habitats in the rural counterparts of urban areas around large cities help to develop ex-urban settlements and thus combat the corollary of invasive species.
- How can the functionality of squatter settlements/slum areas in megacities and the abandonment of areas in shrinking cities be integrated into the overall assessment of the ecology of cities?
- What should be expected, beyond urban sprawl, when population will quadruple and food demand double by 2050? And which indicators will help us assess urbanisation in the 21st century and beyond?
- Is it possible to connect the citizen-science approach to urban environmental stewardship as a way to achieve more sustainable cities in the current and future urban eras?

Despite all the complexities of cities, urban environments still hold unaccounted potential to answer the above questions, and scientists are currently exploring the concepts and tools needed to uncover this potential. Nevertheless, it is worth mentioning that the scientific understanding about the cities, how they (self-) regulate themselves and strengthen their resilience against socio-ecological pressure, has relatively improved in last couple of decades.

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