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Beyond urban–rural dichotomies: Measuring urbanisation degrees in central European landscapes using the technomass as an explicit indicator

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ABSTRACT

Urbanisation is transforming landscapes across the world. As the urban matrix is extending across all landscape types, new spatial configurations have blurred the former contrast between urban and non-urban land uses. The spatial complexity of urbanisation challenges current landscape-scale assessments based on land cover methods and standard Boolean classifications of urban–rural. In this study, we quantify urbanisation as a continuous spatial process based on Technomass, a three-dimensional indicator that accounts for anthropogenic material stocks in the form of buildings and technical infrastructures. The aim is to perform a spatially explicit quantification of urbanisation degrees across the landscape by more accurately capturing the volumes of different types of anthropogenic stocks. The use of the technomass as an explicit indicator can more accurately describe the complex spatial structure of urbanisation. This allows a robust characterisation of urbanisation degrees at the landscape scale, useful for different ecological assessments. The research was conducted in the functional urban areas of Ostrava (Czech Republic) and Katowice (Poland), where cross-boundary asymmetric landscape configurations can be observed. This spatial characterisation of urbanisation can help to improve innovative and inter-disciplinary approaches used in landscape ecology, urban ecology, industrial ecology and spatial planning.

1. Introduction

1.1. Urbanisation: a great conceptual and operational challenge

Urbanisation is one of the most challenging issues for humankind in the twenty-first century. Over the last 50 years, urbanisation has been mostly understood in demographic terms as the share of the population living in cities (Arriaga, 1970). Accordingly, urban and rural conceptual definitions and operationalisations – commonly used in broad applications from economics to ecology – have been developed on the basis of demographic statistics and administrative boundaries (Bai et al., 2012; Brenner, 2013). This demographic conceptualisation of urbanisation leads to the arbitrary spatial separation of urban from non-urban space. Such an approach produces conceptual confusion and operational shortcomings (Inostroza, 2015). Urbanisation is a complex physical and spatiotemporal process encompassing broader aspects of society and development (Lefebvre, 2003), depicting complex spatial structures that are no longer possible to describe using a dichotomous – i.e., Boolean – "urban versus rural" approach (Brenner, 2013). Indeed, urban and rural are concepts that describe the demographic dimension and do not necessarily convey urbanisation as a spatial and, ultimately, a physical issue (Linard et al., 2012). The conceptual, spatial and physical complexity of urbanisation presents challenges to society, producing controversies around theoretical, conceptual and methodological implications (Esch et al., 2014). Such limitations gave rise to a broad set of varying concepts, definitions, and methods. Functional urban regions (Antrop, 2004; Forman, 2008), urban ecoregions (Schneider et al., 2010), territories in between (Alexander Wandl et al., 2014), mega-city (Fuchs et al., 1994), mega-region (Marull et al., 2013; Taubenböck et al., 2014), meta-city (McGrath and Pickett, 2011), megapolitan region (Gustafson et al., 2014), and landscape urbanisation (Bai et al., 2012), are among the multitude of concepts used to describe urbanisation. Thus, it challenges researchers and planners to conceive and use a set of explicit indicators that can help address this

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problem more effectively.

In spatial terms, urbanisation is not only restricted to cities and urban areas. It is a planetary process currently reaching even the "last of the wild" (Brenner, 2013; Inostroza et al., 2016). Therefore, all types of landscapes are becoming increasingly urbanised (Inostroza, 2012, 2008), including the areas extending far beyond urban cores towards the hinterlands, such as suburban, exurban and rural areas (Alexander Wandl et al., 2014; Gustafson et al., 2014). The omnipresence of urbanisation makes current categorical differentiations – i.e., urban versus rural – inadquate for describing the spatial structure of urbanisation.

As urbanisation is an extensive process reaching all types of landscapes, continuous degrees and intensities are more meaningful than dichotomous categories. Measuring levels and intensities of urbanisation is fundamental for landscape ecology and related disciplines (Antrop, 2000; McDonnell and Hahs, 2008). Since urbanisation changes the structural forms and functionality of landscapes, landscape characterisation is indispensable for monitoring in support of policy making (Antrop, 2004). Understanding how urbanisation is impacting landscape patterns and processes outside of the urban core is particularly crucial for the fields of landscape and urban ecology (McDonnell et al., 1997).

1.2. The gradient paradigm in urban ecology

Since its inception, the concept of an urban–rural gradient that explores the relationship between environmental variation and ecological patterns and processes has been applied in a broad range of ecological research (McDonnell and Pickett, 1990). This concept explains how urbanisation affects biodiversity, the impacts of pollution on biota and other ecosystem changes (Concepción et al., 2016; Cuevas-Reyes et al., 2013; Sadler et al., 2006; Simon et al., 2016, 2014). From an ecological point of view, gradient analysis conceptualises the influences of urbanisation as continuous rather than Boolean. Rather than creating spatial dichotomies between urban and rural, urbanisation transforms landscapes in continuous ways, "from natural and semi-natural environments to increasingly urbanised landscapes" (Esch et al., 2014; Simon, 2008). Yet, spatially explicit indicators to characterise, describe and analyse urbanisation as a continuous variable are largely missing (Mcintyre et al., 2000). Landscape research has treated urbanisation as a categorical variable using mutually exclusive land categories including urban, industrial and rural, which is far beyond ground reality and portrays urbanisation as a geostatistical phenomenon with loosely connected variables of urban land use (Qureshi et al., 2014).

1.3. Limitations of LULC-based assessments of urbanisation

Land use change is a key aspect of urbanisation (Bai et al., 2012; Grimm et al., 2008). Thus, land use land cover (LULC) methods are commonly used to assess urbanisation. However, current LULC-based methods fail to provide detailed and well-grounded spatial characterisations of urbanisation degrees at different spatial scales, making quantitative comparisons difficult to apply (Esch et al., 2014). LULC methods delineate discrete land units that are more or less homogeneous based upon land cover/land use pattern (Anderson et al., 1976) but tend to be categorically coarse, composed of homogeneous classes that convey land uses, land surfaces, or a combination of both. For instance, the Corine land cover dataset developed by the European Environment Agency describes combined land use/land cover classes including 11 "artificial surface" types (https://www.eea.europa.eu/publications/COR0-landcover). This approach generalises surface categories to 100 m, obscuring the variety of land types that exist but are only detectable at finer spatial scales. A biotope classification, designed to describe habitat types through a combination of land use and land cover description, has been applied to urban areas but is also limited in its categorical resolution (Lofvenhart et al., 2002). Categorical limitations are particularly problematic for urbanising landscapes, as the heterogeneity of land surfaces in these landscapes only appears over relatively fine scales (Cadenasso et al., 2007; Hamstead et al., 2016). LULC approaches are not well suited to describe the fine-scale spatial heterogeneity of urbanisation (Zhou et al., 2017). As a consequence, a false perception of landscape "naturalness" can appear (Inostroza, 2012).

Data formats, which are used to spatially represent urbanisation, represent additional limitations. Common assessments rely on two-dimensional LULC indicators. However, urbanisation is a tetra-dimensional process that includes three spatial dimensions and time. Height characteristics of buildings and technological infrastructure are necessary to capture three-dimensional (3-D) information (Wurm et al., 2014). Recent landscape research emphasises the relevance of the third dimension (Walz et al., 2015), but that scholarship focuses on vegetation structure and topographic features rather than buildings and technological infrastructure. Infrastructure such as train tracks, roads, electrical lines, water pipes and sewer pipes tend to be represented by one-dimensional polyline shapefiles that appear negligible in relation to other dominant land uses. Spatial representations that do not account for the third dimension are inadequate for developing spatial indicators of urbanisation.

1.4. Industrial ecology approaches for characterising urbanisation as a physical, metabolic process

Landscapes have most commonly been characterised by the biophysical conditions of the land surface (Wrbka et al., 2004). While anthropogenic aspects of land cover such as sealed surfaces are components of these characterisations, anthropogenic stocks – such as buildings, technological infrastructures, and other human-made structures – are not explicitly considered (Inostroza, 2015, 2014). Landscape representations have a bias towards natural features, which overlooks the anthropogenic dimension. This is a relevant shortcoming, considering that the global demand for construction materials has tripled in the last 50 years (Krausmann et al., 2009; Steinberger et al., 2010). Most of these materials are stocked in landscapes in the form of buildings and technological infrastructures, such as roads, train lines, electrical lines, water and sewer pipes (Wiedenhofer et al., 2015). As the built dimension of landscapes increases, it remains underrepresented in many landscape assessments.

Technical infrastructures are gradually and persistently changing the structure and function of landscapes, modifying the distribution of organisms, altering flows of water and nutrients and changing land use patterns (Grimm et al., 2008; McDonnell and Hahs, 2008). At the same time, fundamental landscape processes and multiple anthropogenic functions – such as the movement of people, materials, information, and energy – depend on matter, energy and information fluxes through technical infrastructure (Boone et al., 2014; Kavaliauskas and Veteikis, 2004). Industrial ecologists have analysed urbanisation as a physical process of material accumulation, measured based on the accumulation of anthropogenic stocks (Inostroza, 2014; Schiller et al., 2017a; Tanikawa et al., 2015; Tanikawa and Hashimoto, 2009; Wiedenhofer et al., 2015). The approach of measuring anthropogenic stocks at the landscape scale using a physical unit (volume per area) provides a strong description of the spatial structure of urbanisation as a continuous process.

1.5. Objectives

In this study, we quantified urbanisation degrees at the landscape scale using the technomass indicator. We measured urbanisation as a continuous variable in a central European cross-boundary landscape that includes urban areas, agriculture, and forest. The technomass indicator has been used to measure material productivity of the urban ecosystem, a process taking place in urban cores. In this research, the