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Multi-scale analysis of urban sprawl in Europe: Towards a European de-sprawling strategy☆

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ABSTRACT

Urban sprawl is a major challenge on the way to sustainable land use as highlighted by the International Year of Soils 2015. Because of increasing awareness of this threat in Europe, there is an urgent need to monitor urban sprawl and to guide European policy development. We found considerable sprawl in Europe at three scales with highly affected regions in the centre and along the Mediterranean coast using recently available consistent data across Europe from the European Copernicus programme. Based on our results, we propose a European de-sprawling strategy, including the implementation of targets and limits, and a set of concrete measures to control urban sprawl and to use land in a more resource-efficient way.

1. Introduction

The global human population will further increase by 30–70% in this century, which will lead to a population shift from rural to urban areas and to significant land-uptake for urban expansion (Montgomery, 2008; Gerland et al., 2014; United Nations, 2014). The need for both more food production and urban development will fuel the conflict between each, i.e., the need for locations with valuable soils and for suitable construction ground. For example, the Food and Agricultural Organization of the United Nations (FAO) expects an increase of 43% in global food demand by 2030 (FAO, 2011). While this competition is pronounced in continents with the strongest population increase, i.e., Africa and Asia (Lambin et al., 2001; Chen, 2007; United Nations, 2014), it is also strong in other regions where more land is taken for urban areas because of higher land-uptake per person and increasing dispersion of built-up areas (Eigenbrod et al., 2011).

Western and Central Europe are among the most densely populated regions (106 persons/km^2 in 2005) with 75% living in cities (EEA, 2007, 2010). While there are several regions (e.g., East Germany) where the human population is not growing, the expansion of built-up areas has continued in most regions, even where the population has declined (Haase et al., 2013). Several studies reported drivers of urban sprawl, including cultural, economic, demographic and social ones (e.g., Mann, 2009), i.e., population growth is not the only one. Increasing urban sprawl has many serious environmental, economic and social consequences. Important examples include the conversion of agricultural and other lands into built-up areas that are no longer available for food production, and have resulted in higher energy consumption, higher demand for mobility, higher landscape fragmentation, air pollution, higher spread of invasive species, degeneration or loss of most ecological soil functions, and reduced resilience of ecosystems (Ewing, 2008; Travisi et al., 2010; Wilson and Chakraborty, 2013). Urban sprawl is counteracting efforts to meet the stipulations of the Kyoto protocol to reduce greenhouse gas emissions (Bart, 2010; Hankey and Marshall, 2010; Jones and Kammen, 2014). Greater competition for land may result in the intensification of agricultural production, the lack of land for renewable energy production (Haber, 2007), and higher pressure on protected areas, which will, in turn, aggravate conflicts with conservation management due to light pollution, recreational activities, noise pollution, and other concerns (Güneralp and Seto, 2013; Mcdonald et al., 2009). Economic effects include higher costs for transportation infrastructure, traffic congestion, water provision and wastewater collection, electricity,

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waste management, and so on (Camagni et al., 2002; Carruthers and Ulfarsson, 2003). Social effects comprise longer commuting times, higher spatial segregation of social classes (Power, 2001; Le Goix, 2005), health effects due to the heat island effect and air pollution, and the altered perception of the landscape scenery and its character and identity due to the increasing penetration of the landscape by built-up areas. There are also some positive effects of urban sprawl, e.g., that it responds to the wish of people for affordable single houses with a garden and more privacy (Bruegmann, 2005).

From 2000 to 2006, Europe lost 1,117.9 km^2/y of natural and semi-natural areas (of which, on average, almost 50% was arable or cultivated land) to urban and other artificial land development (EEA, 2014). Between 2000 and 2030, there is a high probability (>75%) for about 77,500 km^2 of the European continent to be converted to urban area (Seto et al., 2012). Future projections suggest an increase in urbanization of up to about 80% by 2050 (United Nations, 2014).

The expected continuation of urban sprawl in Europe and its associated threats demands action to control and manage the spread of built-up areas. Although primarily a national or regional responsibility, this is also more and more reflected at the European policy level (e.g., the 2011 Road Map for Resource-Efficient Europe as part of the Europe 2020 Strategy and the upcoming EC land communication "Land as Resource"). Therefore, there is an urgent need to assess the extent of urban sprawl in and across Europe in a consistent and comparable way. In this paper, we determine for the first time the extent of urban sprawl at three scales for almost an entire continent.

2. Materials and methods

We used a recent method for measuring urban sprawl called Weighted Urban Proliferation (*WUP*), which combines three components (Jaeger and Schwick, 2014). While low-density development and the amount of built-up area are important parts of most definitions of urban sprawl in the literature (as reviewed by Jaeger et al., 2010a), the spatial distribution of the built-up areas is also an important dimension of urban sprawl. Accordingly, our definition of urban sprawl uses all three dimensions: "the more area built over in a given landscape (amount of built-up area) and the more dispersed the built-up area in the landscape (spatial configuration), and the higher the uptake of built-up area per inhabitant or job (lower utilization intensity in the built-up area), the higher the degree of urban sprawl" (Jaeger and Schwick, 2014). Various methods have been proposed to quantify sprawl patterns, ranging from single to multi-dimensional metrics (Galster et al., 2001; Hasse and Lathrop, 2003; Bhatta et al., 2010). One-dimensional metrics do not account for the multi-dimensionality of urban sprawl, while the combination of many sub-indicators raises the risk of including causes and consequences of sprawl rather than describing the phenomenon of sprawl itself (Jaeger et al., 2010a). The *WUP* metric combines the percentage of built-up area (*PBA*), the spatial distribution of built-up areas (*DIS*), and the land-uptake per person (inhabitant or job) (*LUP*) in the built-up areas (Jaeger and Schwick, 2014). The *LUP* is measured in relation to the number of inhabitants and jobs because some built-up areas are more used for working and others more for living. The product of *PBA* and *DIS* is called urban permeation of the landscape (*UP*), which measures the degree to which a landscape is permeated by built-up area (Jaeger et al., 2010b). Thus, urban permeation is influenced by how much built-up area there is in a landscape and how it is arranged spatially.

For the calculation of *WUP* and its components, we used data on built-up areas taken from the European Copernicus land services – High Resolution Layer (HRL) Degree of Imperviousness data set of 2006 (the European Copernicus land services are carried out with funding by the European Union; EEA, 2013), and on inhabitants and jobs from Eurostat (Eurostat, 2014).

We determined urban sprawl at three scales: country (NUTS-0 according to the Nomenclature of Territorial Units of Statistics), NUTS-2 (basic regions for the application of regional policies), and the LEAC (Land and Ecosystem Accounting) grid level with a cell size of 1 km^2 (Appendix A). For the grid level, we used weighted urban proliferation based on population data alone (WUP_p), because job data are not available for all of Europe at this level.

3. Results

3.1. Sprawl at the country level

Large parts of Europe are affected by urban sprawl (Fig. 1). The value of *WUP* for all of Europe (32 countries considered) is 1.56 UPU/m^2. The values of *WUP* for the countries vary considerably, ranging from very low values in Iceland (0.11 UPU/m^2) and Scandinavian countries to very high values in Benelux countries (6.48 UPU/m^2 in Belgium).

We present and discuss the results of sprawl for the countries that are members of the European Union (EU) or of the European Free Trade Association (EFTA), which includes all 28 countries of the EU, and Iceland, Liechtenstein, Norway, and Switzerland (EU28+4). The maps in Fig. 2 also include 7 additional countries (Albania, Bosnia, Kosovo, Macedonia, Montenegro, San Marino, and Serbia – not part of EFTA), for which we have some results at the country and NUTS-2 level, but no information about population at the 1 km^2 grid level.

The dispersion of built-up areas is very heterogeneous among the countries, ranging from high values in Benelux countries and the UK to low values in southeastern Europe (Figs. 1 and 2). The use of built-up area per person also varies largely at the country level. For example, the more mountainous the land, the more humans need to concentrate the construction of their dwellings and industrial areas. The percentage of built-up area shows a similar pattern as *WUP*, and the differences are due to *DIS* and *UD*.

Five factors are obviously involved in the development of the spatial pattern of sprawl in Europe: (1) climatic conditions (leading to lower population densities and lower levels of sprawl in Scandinavian countries); (2) a long history of industrialization (e.g., UK, BE, NL, parts of DE and FR); (3) socio-cultural building conditions, e.g., countries in southern Europe tend to have more compact built-up areas and lower *LUP* to increase shade; (4) topographic conditions (hills or mountains); (5) settlement history in former communist countries, which followed a different path of settlement development between 1945 and 1989.

The following example illustrates how the three components of *WUP* interact. Belgium (BE) and the Netherlands (NL) have different land property regimes and have followed different trajectories of urban development (Halleux et al., 2012). Both are among the most densely populated countries in Europe, but the level of sprawl is higher in BE (6.48 UPU/m^2) than in NL (6.41 UPU/m^2), even though the *PBA* is lower in BE (13.02%) than in NL (14.53%). This result is caused by the difference in dispersion (*DIS*) which is higher in BE (47.02 UPU/m^2) than in NL (46.48 UPU/m^2). About 16% of land in NL was reclaimed from the sea and lakes and is owned by the state. The use of the land was planned in a more systematic way, whereas BE is federalistic and every municipality has planned its land use for itself. The Netherlands has a polycentric urban structure in the Randstad region that exhibits some concentration of the population in urban centres, in clear contrast to Belgium which exhibits a disperse urbanization pattern due to the continuous increase in smaller urban centres in the countryside (Nijkamp and Esther, 2002).