The Rural-to-Urban Gradient and Ecosystem Services

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Dagmar Haase

23.1 Introduction

Urbanisation is a significant form of land take that has various impacts on the pattern, functionality, and dynamics of natural landscapes, and thus also on the ecosystem services provided [1]. Such effects become particularly obvious if observed and analysed along an urban-to-rural gradient. This article presents a case study on long-term land-use and impervious cover change along the urban-to-rural gradient in the city of Leipzig, Germany. Any broad range of empirical studies and modelling exercises can show that soil sealing towards the rural periphery imposes the risk of a diminishment through a complete decline of ecosystem services provisioning in an urban region. At the same time, urban land perforation, decline, and temporary brownfields create new open spaces after demolition and de-sealing in inner parts of the city, and interim uses such as community gardens, as well as large remnants of nature such as rivers, riparian zones, and wetlands represent ecosystem services provisioning units of great importance that lower the risk of an ecosystem "desert" along and most importantly in the centre of the rural-to-urban gradient [2]. The gradient concept offers a promising approach to, first, integrate historical data into current land-use change impact assessment and, second, to uncover effects of iterative and simultaneous phases of urban growth and decline, including sprawl and compaction [1].

Which ecosystem services are addressed? A multitude of ecosystem services, including provisioning (including food production, gardening), regulating (including water regulation, flood protection), and cultural ES (including recreation).

What is the research question addressed? A case study on long-term land-use and impervious cover change along the urban-to-rural gradient in the city of Leipzig, Germany, and its impacts and risks on the provision of ecosystem services.

Which method has been applied? GIS, statistics, field mapping, modelling.

What is the major result? Soil sealing towards the rural periphery imposes the risk of a diminishment through complete decline of ecosystem services provisioning in an urban region. Urban land perforation, decline, and temporary brownfields create new open spaces after demolition and de-sealing in inner parts of the city, interim uses such as community gardens as well as large remnants of nature such as rivers, riparian zones and wetlands represent ecosystem services provisioning units of great importance that lower the risk of an ecosystem "desert" along and in the city centre.

What is concluded, recommended? The gradient concept offers a promising analysis approach for assessing ecosystem services at risk under long-term spatial urban land-use change.

23.2 Setting the Scene

Urbanisation is arguably the most significant form of land-use and cover change because it has considerable effects on the pattern, dynamics, and functionality of landscapes and ecosystems, including the services they provide [3]. The process of urbanisation can be observed along the urban-to-rural gradient, that is, the ideal typical transect that links "the urban" (built/sealed) and "the rural" (open, vegetated), which displays a typical configuration in terms of population and built-up density, impervious cover, and demographic structure next to (with decreasing tendency) living habits and lifestyles [1, 4]. Along this gradient, an increasing amount of land consumption, i.e., the transformation of vegetated into built surface, has been reported on by a multitude of authors based on empirical research and the analysis of statistical data [5–8]. At present, the transformation of the urban-to-rural gradient is detected to a great extent by remote sensing methods [9].

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23.3 Effects on Ecosystem Services Along the Rural-to-Urban Gradient

Numerous studies have shown that land consumption is a real risk for the human-environment-complex in various regards [10] as it could affect ecosystem services [11–13] and, consequently, reduce the ability of nature to fulfil human requirements [13]. Many of the negative effects of land consumption along the rural-to-urban gradient can be attributed to the sealing of soils [10]. The transformation of open or arable land to impervious cover can thus be taken as a key variable when it comes to mapping and evaluating land-use change and its impacts along the urban-to-rural gradient. Individual ecosystem services that are impaired by the spread of impervious cover include the production of food, the regulation of energy and matter flows by soil particles and vegetation, freshwater supply, the provision of recreational space, habitats for species, and natural aesthetic values (Fig. 23.1) [2].

In the following, single ecosystem services are discussed in terms of the impacts on them along a rural-to-urban gradient in urban regions: Potentials and risks are shown for provisioning services such as food production in cities, and regulation services such as surface water retention, air temperature regulation, and pollutant filtration.

23.4 The Example of the Water Regulation and Flood Risk Mitigation

There is a rural-to-urban gradient of surface-water-runoff regulation as shown in Fig. 23.2 for the city of Leipzig, Germany [10]. At a total water balance of 560 mm per year, we find surface-runoff of >250–300 mm up to 400 mm in the central parts of the city. Also in the outer parts, where large newly-built commercial areas (holding companies such as Porsche, BMW, German Post, and Amazon to list a few) and the delivery companies of the Airport Leipzig-Halle have been built, surface water runoff reaches up to 450 mm or 80% of the total annual water balance [10, 14]. Surface runoff regulation in the central floodplains is high (not highest due to small filtration paths and high groundwater levels in wetlands); this refers also to large urban parks. Thus, we cannot state a clear rural-to-urban gradient when it comes to rainwater-induced flood retention and risk mitigation, but the clear risk that the surface water regulation capacity of the city area is being diminished is particularly relevant when it comes to heavy local precipitation events.

23.5 The Example of Pure Air Supply

The picture is different for air purification and the ecosystem service of pure air supply [11]. Here, Fig. 23.3 shows a clear rural-to-urban gradient with maximum values of >2.5 t/km²*a of PM_{10} in the central parts of the city due to high traffic volumes over the whole day and at night time [14]. As Leipzig is a compact city, traffic concentrates in the centre and decreases with increasing distance to the periphery (Fig. 23.3). In addition to the pollution sources for particulate matter in the central parts of the cities, the risk for the urban population is high as a) most people live in the inner parts and thus are directly affected in their daily life; and b) other stressors such as noise and heat "pollution" also concentrate in the city centre of compact cities [14, 15]. However,

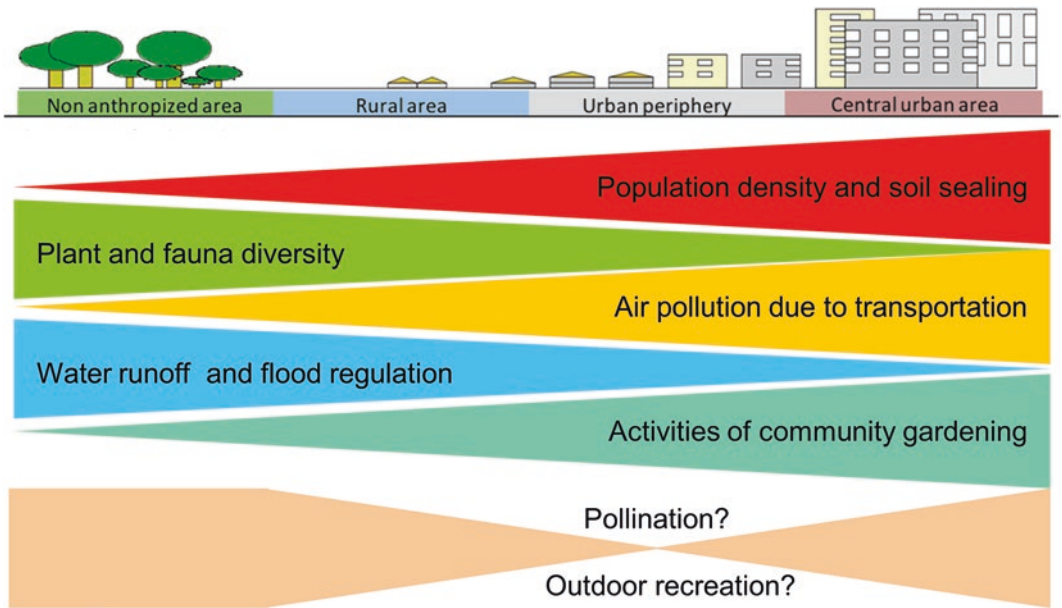

Fig. 23.1 Dynamics of ecosystem services provisioning along the rural-to-urban gradient

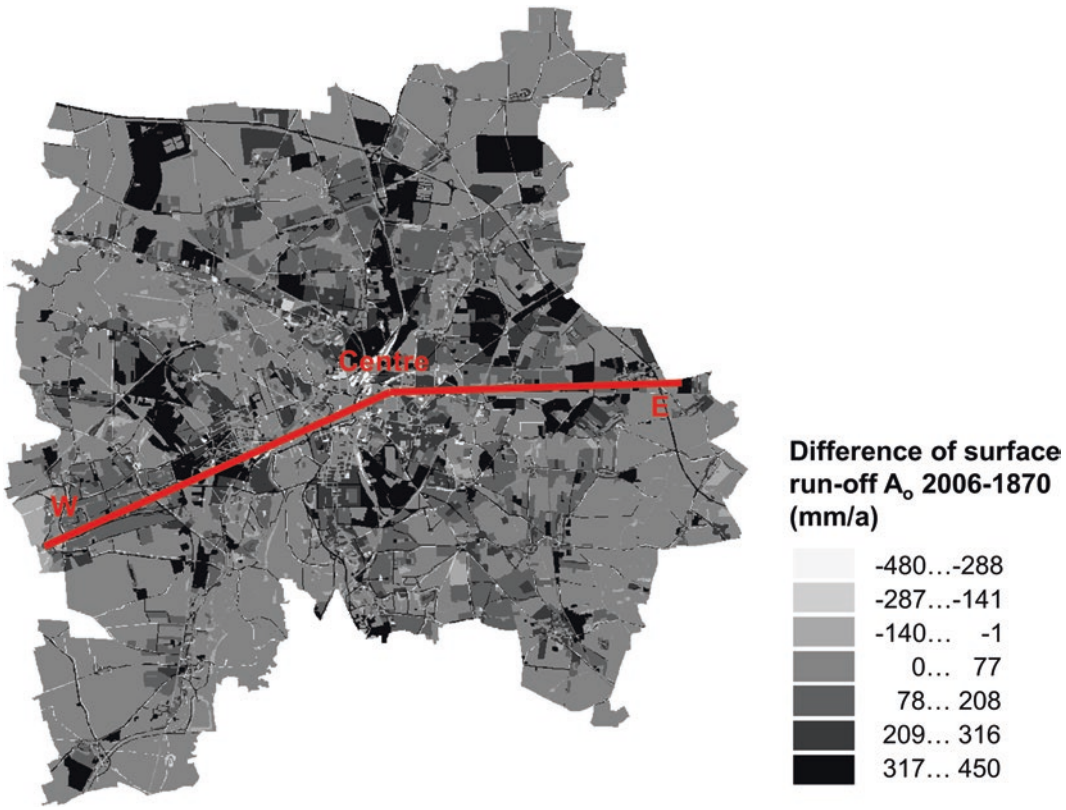

Fig. 23.2 Soil sealing and surface water flow retention capacity along the rural-to-urban gradient in Leipzig, West (W)-Centre and Centre-East (E)

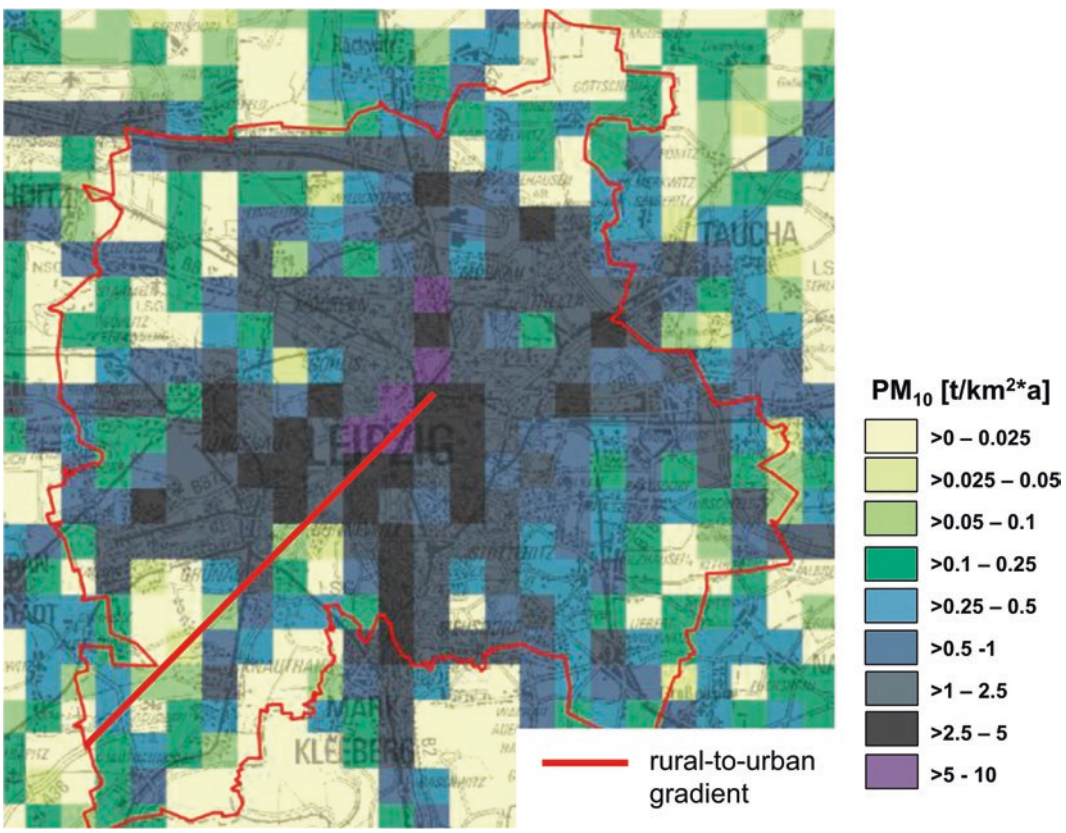

Fig. 23.3 Particle emissions (PM_{10}) from transport (Lagrangian particle dispersion model LASAT [14]; *with permission*)

Fig. 23.4 Community gardening and local food production in the inner parts of Leipzig and Berlin

Fig. 23.3 also provides evidence that green spaces exhibit much lower particle emissions (up to <0.25 t/km²*a) to be seen in the pixels where the floodplain forests are situated and where large parks are located. Thus, a combination of measures of traffic reduction and more (large and tree-rich) green infrastructure to filter particulate matter and buffer noise are urgently needed to reduce the health risk for the residential population.

23.6 The Example of Urban Food Production and the "Edible City"

As Fig. 23.1 already suggests, there is a reversed rural-to-urban gradient when it comes to the local food production ecosystem service in cities, studied in the cities of Leipzig and Berlin. Most of the community gardens are situated in the central parts of the city, predominantly as interim or non-permanent uses [10]. Here, local food is produced in a bottom-up and participatory way. The amount of food is not "commercial" in the sense of selling own-grown food to earn money, but the productivity of the gardens has shown that they could contribute to neighbourhood food supply and, what is even more, to social cohesion and education about nature and dealing with nature [11] (see also Fig. 23.4). Thus, the "edible city" shows a clear urban-to-rural gradient and a great potential to counteract "urban risks" of social segregation, fragmentation, and isolation (of children, low-income households, migrants, unemployed, etc.). But habitat connectivity and pollination could also be improved by community gardens, as they provide nicely structured vegetated spaces, including old fruit trees that are key for pollination.

23.7 The Example of Heat Mitigation

Last but not least, a clear rural-to-urban gradient can be found when we look at the risk of urban heat and the ecosystem service of heat regulation by green (vegetation) and blue (waters) infrastructure of the city. Leipzig as a compact city exhibits a clear urban heat island with high evening (surface) temperatures in the city centre in summer (Fig. 23.5) [11].

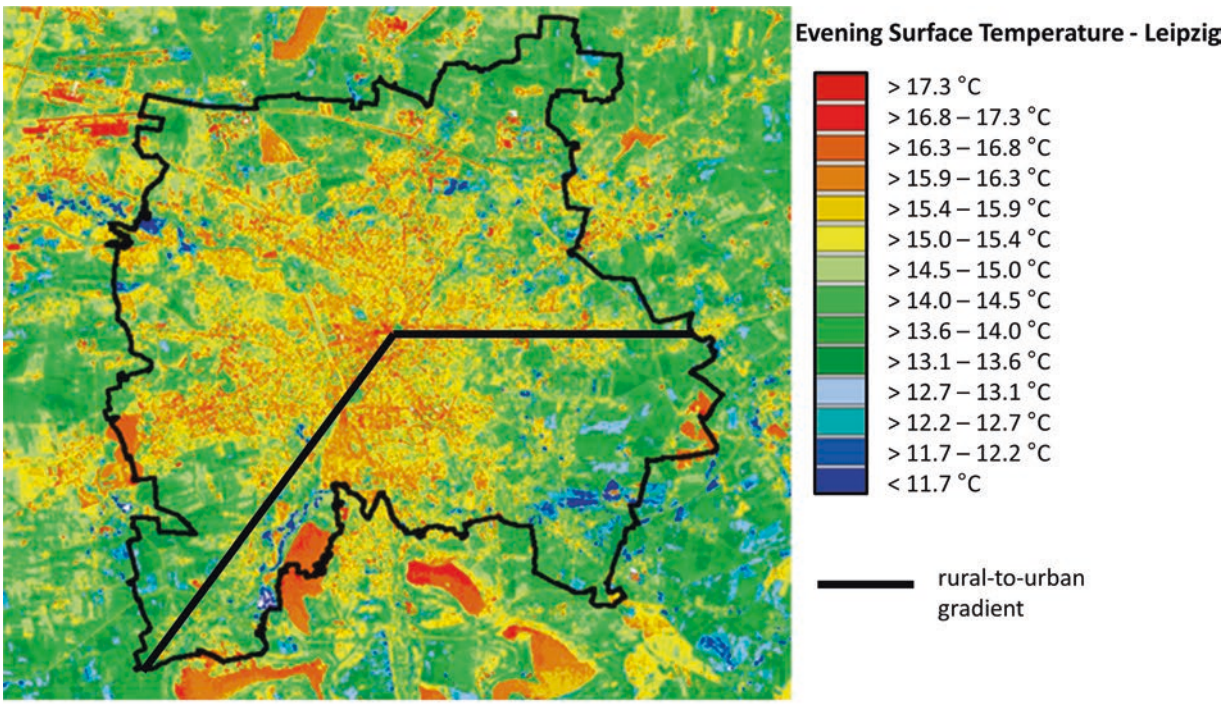

Fig. 23.5 (**a**, **b**) Rural-to-urban gradient (black line) of the evening land surface temperature in Leipzig showing a clear temperature increase from the outer, less surfaced, to the inner, highly sealed, parts of the city in relation to the land-use structure (lower part of the figure, based on Weber [14]; *with permission*)

A regression analysis showed a clear heat reduction at green spaces (parks, cemeteries, urban floodplain forest) in the morning and at night time [11]. For lawns and meadows, this heat regulation could not be found, so peripheral agricultural fields and shallow inland waters also appear warmer than inner-urban green spaces (Fig. 23.5).

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D. Haase (✉)
Department of Geography, Humboldt Universität zu Berlin, Rudower Chaussee 16, 12489 Berlin, Germany

Department of Computational Landscape Ecology, Helmholtz Centre for Environmental Research, Leipzig, Germany
e-mail: dagmar.haase@ufz.de