Development of a Combined Typology to Co-Assess Urban Sprawl and Habitat Network Structure

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Abstract: This contribution combines, based on dispersion metric DIS, urban sprawl metrics with considerations on landscape connectivity. The motivation to do so comes from the question of ecological impacts from urban sprawl. Based on calculations of DIS-based metrics for both settlement and habitat-network structures a land typology is introduced which helps to identify different situations of co-existence of sprawl and habitat-network.

Keywords: Urban sprawl, habitat networks, landscape connectivity

1 Introduction

Urban sprawl is a complex phenomenon, covered by different theories and described by various indicators. The term addresses a process as well as a pattern, and both are subject to demographical, socioeconomic, economic and physical planning related studies. From a landscape point of view, visual appearance and physical structure of land patterns resulting from urban sprawl are of special concern. In general, we have to state that urban sprawl changes social-ecological balances by changing land-use and land-cover systems. Growth of scattered settlements, densification of transportation networks, displacement, intensification and loss of agricultural land, deforestation, but also the need of land for recreation purposes are key examples for such transformative and often conflicting processes related to urban sprawl, which mainly takes place at the fringes of urban centres and development axes.

We must discuss urban sprawl also concerning its environmental and ecological consequences. Water balance, thermal pollution, air pollution caused by traffic and visual/recreational landscape quality are closely linked to patterns of urban sprawl. Above all, however, in particular habitat disturbance and habitat loss caused by urban sprawl must be brought to the fore. At the fringes of our cities, a lot cite specific habitat structures and biodiversity patterns exist that get under pressure if urban sprawl is in process.

This contribution deals with the effects of urban sprawl on habitat connectivity. We know that in a biotope or habitat network connectivity is a key parameter for successfully establishing exchange of individuals and genes, for accessibility of resources and for enabling migration and dispersal. Settlement and transportation infrastructures and thus patterns and dynamics of urban sprawl directly affect permeability of landscape and its bio-connectivity. Hence, landscape pattern assessment concerning conflicts between settlement patterns and habitat networks is a tool to proactively prevent or to mitigate serious impacts on biota from urban sprawl.

JAEGER et al. (2010) have presented a concept for measuring urban sprawl. They use metrics that analyse the neighbourhood of an urban location. This metrics can also be – but up to now was not – applied to basic questions regarding bio-connectivity. Appropriate adjustments of them can be used to describe form (e. g. mainland type, patchy type, linearity) and, when

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considered in a combined analysis, they can answer questions like: which pattern of urban sprawl restrict permeability? How did urban sprawl and permeability develop in settlement history? Where do bottlenecks exist, and which patterns do cause them?

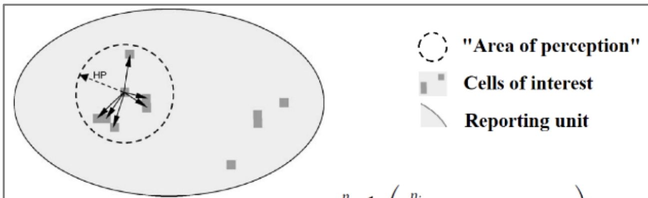
The objectives of this contribution is to apply the concept of JAEGER et al. (2010) in parallel both to the settlement patterns and to grassland habitat network patterns which can be found in the federal state of Baden-Württemberg, and then to combine the results for a comprehensive typology of land structures. The paper discusses the resulting types with regard to its ecological and planning related implications and suggests further steps in co-assessing urban and habitat structures.

2 Material and Methods

The study uses data from the grassland habitat network provided by the Environmental Agency of the State of Baden-Württemberg (LUBW 2014) and OpenStreetMap[1] data on settlement, both covering the complete territory of Baden-Württemberg. Grassland habitat network addresses a species guild, whose habitat requirements are linked to extensively used grassland types such as dry grasslands or orchard meadows. Settlement data include groundcover by buildings.

For the study, a geographical land model is defined which regards a landscape as a data driven simplification, such as presented in Fig. 2. Connectivity area consists of habitat core-areas and habitat linkage-area and lies embedded in a configuration of settlement barrier and matrix barrier, both not further differentiated.

The concept of urban sprawl metrics as introduced by JAEGER et al. (2010) starts with the calculation of dispersion *DIS*. The calculation sums up the weighted distances between cells covered by settlement. A brief summary gives Fig. 1, for a deeper discussion of *DIS* calculation and its linkage to urban sprawl refer to JAEGER et al. (2010).



$$DIS(b) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{n_i}\left(\sum_{j=1}^{n_i} f(d_{ij}) + WCC(b)\right)$$

$$f(d_{ij}) = \left(\sqrt{2|\vec{x}-\vec{y}|+1} - 1\right)$$

where n_i denotes the number of urban cells that are closer to cell i than the horizon of perception, d_{ij} is the distance between (the centers of) cell i and cell j, and $WCC(b)$ is the within-cell contribution.

Fig. 1: Calculation of Dispersion DIS by JAEGER et al. (2010)

[1] https://download.geofabrik.de/

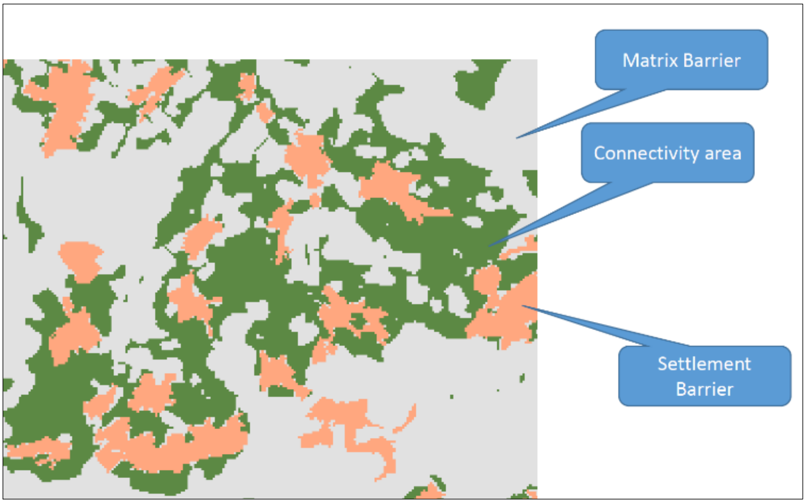


Fig. 2: System of considered land mosaic

Dispersion metrics *DIS*^{u} is calculated for buildings and in parallel *DIS*^{h} is calculated for the habitat core-areas in the Habitat-network. Both is calculated for hexagonal reporting units (Fig. 5). When calculating *DIS*^{h} "Area of perception" in the *DIS* concept can be interpreted for an (species) individual radius of being able to identify habitat quality. The concept of summarizing distances between habitat network cells indicates the total effort to access "good habitat quality" cells from a "good habitat quality" cell.

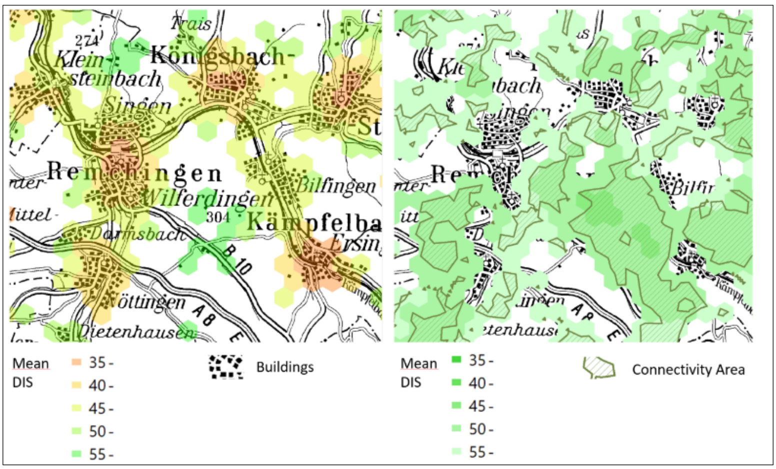


Fig. 3: Dispersion of buildings *DIS*^{u} (left) and habitat network *DIS*^{h} (right)

JAEGER et al. (2010) derive from *DIS* metric *UP* which quantifies "urban permeation". This metric describes for a study region the degree of being interspersed by settlement bodies and twins the two components 'amount of settlement' and 'dispersion of settlement' by multiplying it, and thereafter relates the product to the size of the study region ($UP = DIS \times$ urban area /size of the study region). So, in this paper we correspondingly calculate as

"urban permeation": $UP = DIS^u \times$ settlement area /size of hexagon

"habitat permeation": $HP = DIS^h \times$ habitat network area / size of hexagon

To combine *UP* and *HP*, a land typology is introduced. *UP* and *HP* values are classified into 3 classes each by a mixture of considering standard interval and tertile intervals. This leads to 9 combinations called "permeation type" (PT) (Fig. 4), which are coded by combination of digits 1,…,3 and which can be assigned to the hexagonal cover of state of Baden-Württemberg.

Fig. 4 illustrates the different permeation types. PT11 represents a configuration of sparsely scattered settlements and habitat. PT13 shows a land configuration highly permeated by habitat and PT31 is highly permeated by urban structures. Finally, PT33 is characterized by a high degree of coexistence of habitat structures and urban structures. We can simplify the classification by considering PT21, PT31 and PT32 as "urban dominated", PT12, PT13 and PT23 as "habitat dominated" and PT11, PT22 and PT33 as being in "parity".

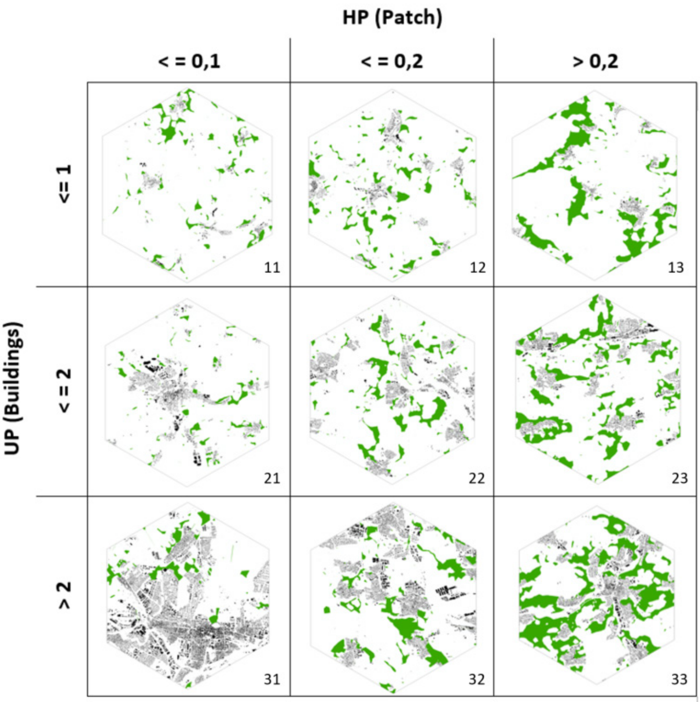


Fig. 4: Classification of dimensionless *UP* and *HP*; examples for land configuration in the resulting 9 combinations of *UP* / *HP* classes called "permeation types" (green = habitat core-area, black = buildings)

In a PT33 landscape, nature conservation collides with significant disturbance from the urban fabric. Here secondary landscape services from habitat networks – like recreation or ventilation – get an important issue in ensuring urban residential comfort. Those landscapes are at a climax of urban development. PT31 landscapes are in the situation of being over-urbanized when considering the chance to establish coherent habitat structures. PT11 land is not of concern in planning related considerations – no conflicts, no development options, and so, no problems to solve. And finally, PT13 points to landscapes where significant habitat network exists and can be easily be developed

For habitat-network management the most challenging type is PT31 and the best opportunities can be found in PT13. PT12 and PT32 can be considered as "good to be managed" and in PT12 or PT23 strong challenges must be tackled.

3 Result and Outlook

Fig. 5 shows territory of state of Baden-Württemberg covered by hexagons, which indicate the type of land configuration according to the typology.

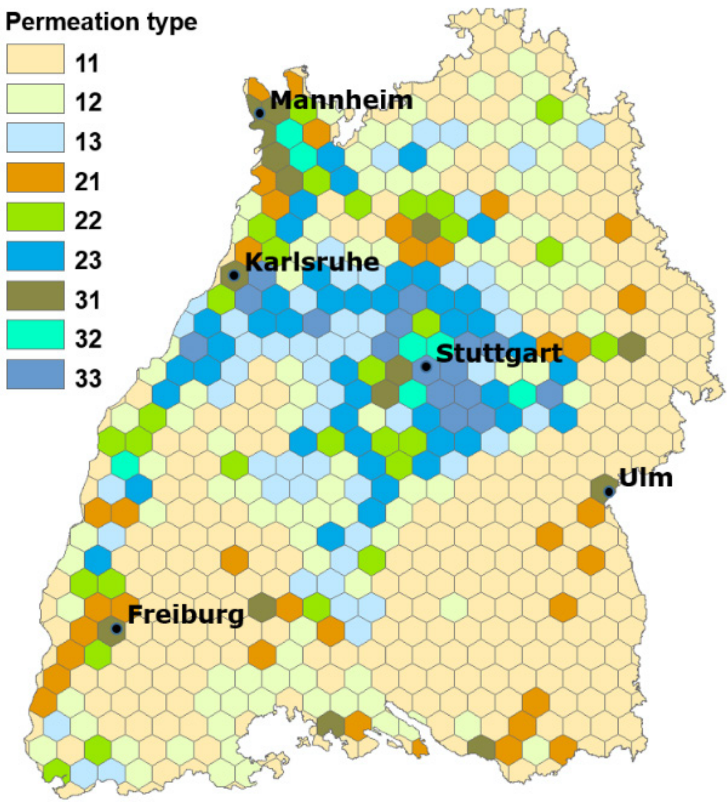


Fig. 5: Permeation types in Baden-Württemberg

PT11 is covering rural areas. A mixture of permeation types on the other hand covers the urbanized area. The centres of urbanized areas have different permeation types in their neighbouring periphery. Ulm is a rural centre, whereas urban dominated types surround Mannheim. Stuttgart (centre and periphery) and Karlsruhe show a more parity typed periphery. Freiburg is a mixture between Ulm and Mannheim.

There are a lot habitat dominated landscapes in the wider periphery of Stuttgart and Karlsruhe and in the urbanized axis in between. According to the permeation types assigned here, good and very good opportunities for enhancing and successfully fostering habitat-network development can be stated.

It is shown that *DIS* based metrics *UP* and *HP* help to characterize land configuration concerning both urban area and habitat network. Permeation types as suggested provide an appropriate method to separate different land structures, which clearly indicate different situations concerning urban sprawl pattern und habitat-network coherence, and which address fundamentally different planning arena and agenda. It is promising to run the proposed method in analyses of existing land configurations. The identification of permeation type is a helpful outcome, which helps in Green Infrastructure development control.

In a next step, permeability studies must be carried out to identify the specific permeability characteristics of each permeation type. Such analyses have the potential to identify optimal patterns of landscapes in terms of being both sprawled and bio-connective.

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