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Gradient of Land Cover and Ecosystem Service Supply Capacities- A Comparison of Suburban and Rural Fringes of Towns Dresden (Germany) and Poznan (Poland)

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Abstract

Quantifying landscape pattern and its change is essential for the monitoring of changes in ecosystem services caused by urbanization and other processes. Landscape indicators can be very useful for such assessments. The authors used landscape metrics for a gradient analysis of land cover between cities and protected areas. The two cities Dresden (Germany) and Poznan (Poland) were chosen, because they are comparable due to inhabitants, area and location in former socialistic regimes. The biggest difference affects legal and socio-economic conditions. Overall, the study shows decrease of ecosystem services and diversity indices with increasing distance from the protected area, but the lines of trend near Dresden and Poznan have a different course. In comparison to Poznan, around Dresden are more protected areas and much more settlement areas are located near or even inside them. Protected areas around Poznan are more aggregated and more distant from the town center, have character that is more natural and are more diversified in terms of land cover configuration. On the other hand, in Dresden, thanks the more compact character of built-up areas and accompanied green urban areas, the landscape of suburban zone is more diversified and the benefits of ecosystem services are closer to the people. The reason are more restrictive legal aspects of spatial planning in Germany.

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1. Introduction

Change of land use and landscape structure by urbanization, fragmentation and intensification are one of the most dramatic form of land transformation that profoundly influences biological diversity and human life (Luck and Wu, 2002; Walz, 2008; Walz, 2011). Particularly strongly is the influence of these processes on protected areas located near the cities. The threat is primarily influenced by the process of cutting the protected areas by roads and build up areas due to moving of the citizens to the suburban zones. Another threat is the intensification of agricultural areas by homogenisation of land use and the forming of large cultivation units in combination with loss of natural landscape elements. In contrast, risks arising from tourism seem to be less important. Rather, tourism demands for a high level of ecosystem services, e.g. in landscape aesthetics, local produced food etc. In this sense, it has a big influence on the level of ecosystem services. There is a different extent, depending on the category of service, to which changes in ecosystem services caused by people may be revealed. It is presented by the research concerning the level of services depending on the intensity of land use (Braat and ten Brink, 2008). Quantifying landscape pattern and its change is essential for the monitoring of changes in ecosystem services caused by urbanization and other processes (Hou et al., 2015). Landscape indicators can be very useful for such assessments (Syrbe and Walz, 2012). Combining gradient analysis with landscape metrics, we attempted to quantify the spatial pattern of urbanization in Poznan (PZ) and Dresden (DD) agglomerations. Monitoring of such processes in Europe is important, because fragmentation and urbanization are major threats to biodiversity. The conservation and development of biodiversity is a major goal of European politics (European Commission, 2011) to beware a healthful environment for the living of people. Unfortunately, the last goal for 2010 to stop the decline of biodiversity was failed. One reason could be that the loss of biodiversity is a result of the sum of a lot individual impacts. Such cumulative processes of individual impacts are less perceivable from perspective of individuals. We try to detect such processes from which we assume that they take place through all of Europe.
The main thesis of this paper is that there is a gradient of ecosystem services potential from towns to suburban areas and to protected areas in the surroundings. Structural indicators can be used to describe selected ecosystem services and their gradients from town to surroundings. Changes in the intensity of land cover near cities depends i.a. on the legal and socio-economic conditions and will be different in Poland and Germany. Thus, the gradients of ecosystem services potential near DD and PZ will have a different course. The objective of this paper is to answer the following questions: 1. Are the differences among functional zones and along the transects reflected in landscape metrics? 2. For which zones are the ecological networks and ecosystem services potentially the highest in the two cities? 3. What are the implication for spatial planning?

2. Material and methods

2.1. Transects

A suitable base for a comparative GIS-based analysis in Germany and Poland could be digital international datasets with an extent of both states or national datasets with comparable nomenclatures. The European Urban Atlas (EEA 2011) provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings (more than 100.000 inhabitants) for the reference year 2006.
To detect the gradient of changes the method of transect analysis was used. Ten transects in two directions were defined with grid cells of 1 km². They connect the city and two kinds of protection areas: national park and landscape protection area. The legal status of these protection areas are nearly similar for Germany and Poland. Five types of land cover in transects were analysed: 1. artificial surfaces, 2. green urban areas, 3. agricultural areas, semi-natural areas and wetlands, 4. forests, 5. water. The analysis affected differences in every grid cell of the transects and in four functional zones: core area of protection sites, buffer zone of protection sites, suburban zone and downtown. We defined core area of protection sites as the grid cells which are completely within protected area, buffer zone of protected area are the grid cells partly connected to protected area, suburban zone are the grid cells outside of protected area and outside of the city and downtown are the grid cells outside of protected area and inside of the city.

2.2. Landscape pattern analysis

The Fragstats software was used for counting of following landscape composition and configuration indices (McGarigal and Marks, 1994): *Class Area* (CA), *Number of Patches* (NP), *Largest Patch Index* (LPI), *Total Edge* (TE), *Mean patch size* (AREA), *Core Area Index* (CAI), *Division* (DIVIS), *Aggregation Index* (AI), *Patch Richness Density* (PRD), *Shannon Diversity Index* (SHDI). As an indicator for the status of ecological networks we choose Indicator 2 on connectivity of ecological networks (Formula 1) from the City Biodiversity Index (CBD 2012, Jaeger et al. 2013). Formula 1: Indicator of ecological networks:

$$\text{CBI\_IND2} = \frac{1}{A_{total}} \left(A_1^2 + A_2^2 + A_3^2 + \ldots + A_n^2\right) \tag{1}$$

where: n = total number of natural areas (forests and water); A_1 to A_n = sizes of the natural areas from natural area 1 to n (patches which are closer from each other than 100 m are treated as one patch); A_{total} = the total area of all natural areas.

2.3. Evaluation of ecosystem services

For the assessment of ecosystem services, the three types of ecosystem services were considered: provisioning, regulating and cultural. According to Sukhdev (2010) we defined: 1. provisioning services as ecosystem services that describe the material outputs from ecosystems. They include food, water and other resources; 2. regulation services as services that ecosystems provide by acting as regulators eg regulating the quality of air and soil or by providing flood and disease control; 3. cultural services include the non-material benefits people obtain from contact with ecosystems. They include aesthetic, spiritual and psychological benefits. We used the approach from Burkhard et al. (2014) which is based on land cover types. Every land cover type of the Urban Atlas dataset a value of capacity to provide the ecosystem service is assigned (see
Table 1). Then an area-weighted mean value could be calculated for every reporting unit: Formula 2. Mean Ecosystem Service

$$ESLU = A_1 * X_1 + A_2 * X_2 + \ldots + A_n * X_n \tag{2}$$

where: n = the total number of land cover types; A_1 to A_n = sizes of the land cover type type 1 to type n; X = average value of ES for land cover type.

Table 1. The average value for the assessment of the land cover types' capacities to provide ecosystem services (Burkhard et al. 2010).

Land cover types	Urban atlas category	Provisioning services (PS)	Regulating services (RS)	Cultural services (CS)
Artificial surfaces	1 (without 1.4)	0.4	0.3	0.1
Green urban areas	1.4	1	10	4
Agricultural areas, semi-natural areas and wetlands	2	8	8.8	3.6
Forests	3	21	39	10
Water	5	13.6	8.8	8.2

2.4. Study areas

Our methods were testet at two test sites, so that the results could be compared. For this purpose we choosed two towns of Poznan (PZ) and Dresden (DD). This two cities are comparable in the following issues: 1. inhabitatants (548,028 in Poznan and 535,810 in Dresden), 2. area (26,200 ha in Poznan and 32,831 ha in Dresden), 3. situated at a river, 4. national parks not far from city, 5. historical cities since the middle age, 6. location both in former socialistic regimes, 7. strong development since the political change in the 1990ties. Statistical data show that the DD and PZ are very similar in terms of demography and land use. The main differences lie in the share of forests, which is higher in Dresden. In Poznan, as opposed to Dresden, there is a large share of undeveloped land covered with spontaneous urban vegetation. It constitute a large part of the green areas of Poznań. In the polish city very explicitly is delineated the problem of urban sprawl. In last few years' approx. 0.5% residents per year moved out from Poznan city (CSO). Simultaneously, before 2035 an increase in the county population by about 153 thousand

(47%) people compared to year 2010, is expected (Łowicki and Piotrowska, 2015).

3. Results and discussions

3.1. Class-level differences

At the level of the four zones of the agglomerations, diffrenece between Poznan and Dresden are visible (Tab. 2). The main difference between the cities are related to the intensity of development, both in the city and outside.

Table 2. Land cover in zones of the agglomerations Dresden (DD) and Poznań (PZ) (%) according to Urban Atlas (EEA).

Zone	Artificial surfaces		Green urban areas		Agricultural areas, semi-natural areas and wetlands		Forests		Water	
	DD	PZ	DD	PZ	DD	PZ	DD	PZ	DD	PZ
Core of protected area	2.5	0.8	0.2	0.0	25.8	12.8	71.0	85.7	0.3	0.7
Buffer zone of protected area	33.8	9.7	5.8	0.9	35.2	42.9	21.7	46.1	3.3	0.5
Suburban zone	31.3	20.4	6.0	1.2	47.1	72.1	15.5	5.8	0.1	0.4
Downtown	72.7	45.9	14.4	11.5	10.0	26.9	2.6	11.9	0.3	3.8

In PZ the share of built-up areas is much smaller than in DD. This is also true for protected areas. In the case of DD building areas in the immediate vicinity of protected areas are bigger even than in the suburban zone. In Poznan a significant difference in the share of green areas in the city and its surroundings can be noticed. Fig. 1 shows that in DD more patches of artificial surfaces are in the core and buffer zones of protected areas, but they are larger and more compact than in PZ. This can be shown also with the metrics of *Number of Patches* (NP), *Area of land use class* (AREA), *Largest Patch Index* (LPI) or the *Core Area Index* (CAI) (see Fig. 3).

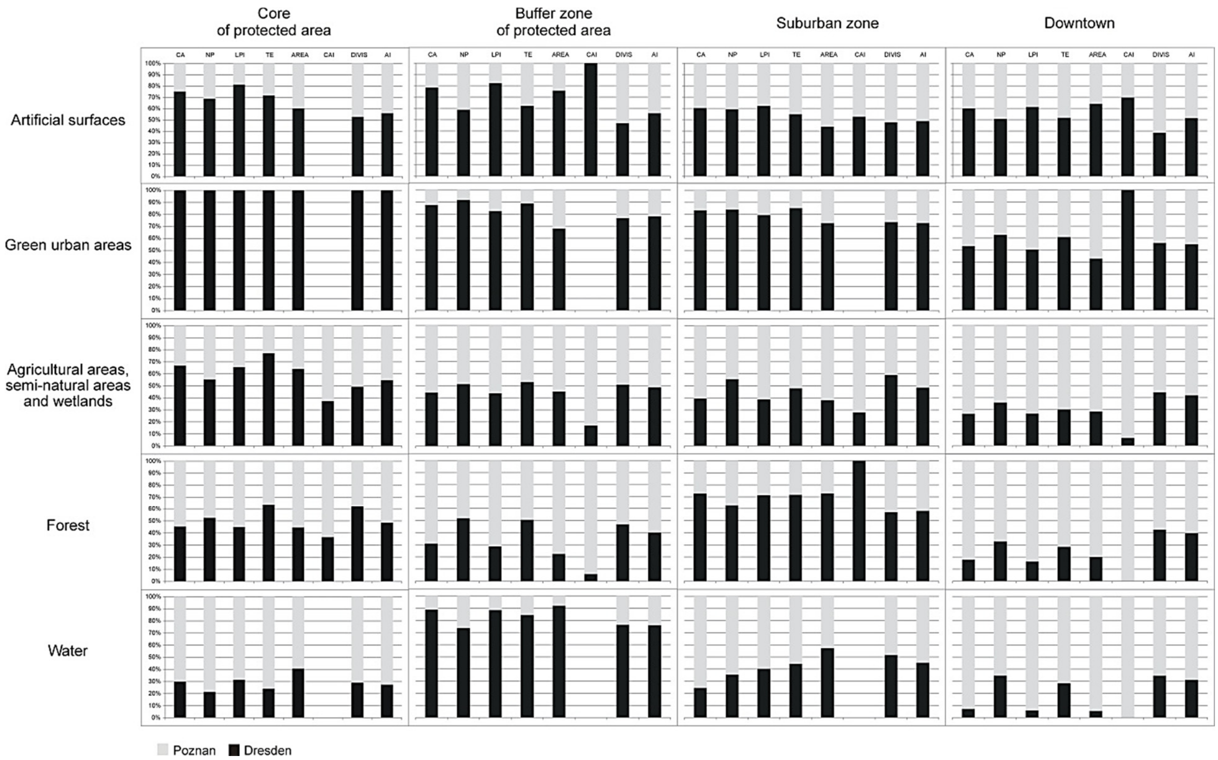

Figure 1. Comparison of the cities Poznan and Dresden according to landscape indicators for land cover types (class-level metrics).

In PZ just a small proportion of built-up areas in the vicinity of the nature protection areas is recorded. Hence, there is also small area of green urban areas. In downtown zones landscape metrics for green areas are similar. It affects both, area of green areas (CA) as well as distribution in space (DIVIS, AI). In PZ a bigger mean patch area (AREA) of the green areas is recorded, but in DD is a very large park (called "Grosser Garten"), which covers an area of 1.7 km^2. It translates into a bigger *Core Area Index* (CAI). The share of agriculture and semi-natural areas is much higher in PZ. The exception is the protected area, where both the total *Class Area* (CA), as well as *Mean patch size* (AREA) of these areas is larger in DD. Although the total forest cover in DD is greater, in transect analysis it can be seen only in the case of suburban zone. Forest cover in the core of protected areas and its buffer zone is greater in the PZ. With the exception of suburban zone, forests in PZ have more compact character, expressing in the larger values of indicators AREA, CAI, AI.

3.2. Landscape-level differences

Figure 2 shows the differences between PZ and DD in the configuration of land cover patches and ecosystem services in zones. Indicators of CBI_IND2, diversity metrics (PRD, SHDI) and aggregation metric (DIVIS) suggests that the landscape of DD is more transformed. Also, ecosystem services potential in the PZ is slightly larger, especially in the buffer zone of protected area and in downtown zone. The exception is the suburban zone; value of CBI_IND2 is higher for DD in this zone due to the high share of forests and green areas. This translates into a slightly higher rate of regulating services in suburban zone of DD.

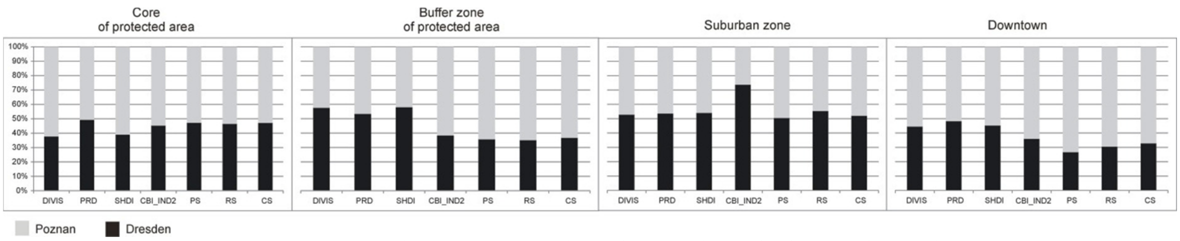

Figure 2. Comparison of the cities Poznan and Dresden according to landscape indices and ecosystem services potential for landscape types (landscape-level metrics).

3.3. Gradients of indicators

Overall, there is a decrease of ES and diversity indices with increasing distance from the center of the protected area towards the city center (Fig. 3).

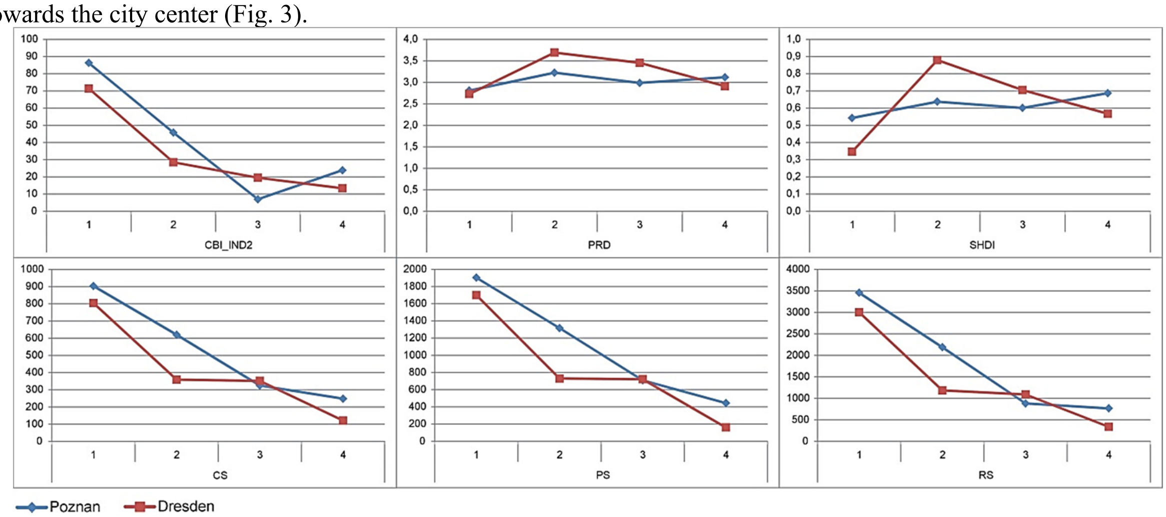

Figure 3. Comparison of the cities Poznan and Dresden according to chosen landscape indices and ecosystem services potential for landscape types (landscape-level metrics). 1. core of protected area, 2. buffer zone of protected area, 3. suburban zone and 4. downtown.

Reducing the gradient is observed in Poznan on the border suburban/downtown zones, and in Dresden on the border buffer zone of protected area/suburban zone. This is due to small differences in the share of semi-natural areas on the borders of these zones. The gradients of indicators of CBI_IND2, SHDI or PRD show that in Poznan, both transformation as well as land cover diversity in the city is higher than in its immediate vicinity. In spite of generally lower indicator of ecological networks (CBI_IND2) in DD, composition and configuration of patches in zones 2 and 3 is more diverse. This is due to the larger amount (NP) settlement and forest patches. In suburban zones of PZ landscape is much more homogeneous due to the large patches of farmland (see Fig. 1).

4. Conclusions

4.1. Spatial pattern

The different functional zones of the agglomerations Poznan and Dresden exhibited distinctive spatial pattern, which is exemplified by landscape metrics. The zones differ mostly by percentage of artificial surfaces, forests and agriculture, what translates into the differences in ecological networks indicator. The gradients of landscape indices along the transects are usually similar for both agglomerations. The exception are water bodies, their occurrence is mainly subject of natural conditions. Aalthough protected areas are much bigger in Dresden agglomeration, the Poznan agglomeration is less transformed by human and offer the higher level of ecosystem services (Fig. 2). It affects especially the buffers zones of protected areas. In PZ mainly the forests are covered by nature protection, in much lesser extent are protected agricultural lands and settlements areas. Only the suburban zone is more transformed in PZ. Although the coverage of artificial surfaces in this zone is smaller, the share of agriculture in PZ is 50% higher than in DD. Hence, in PZ between zones 2 and 3 a big decrease of ecosystem services potential is observed. In DD is much more built-up areas, especially outside of the city. In comparison to Poznan, the settlement patches in Dresden are greater and have shape that is more compact. The occurrence of settlement areas and accompanying green spaces makes the Dresden landscape more diverse. It affects especially the buffer zone of protected area and suburban zone. It means that at the same time with ecosystem services supply it is necessary to consider also demands for ecosystem services.

4.2. Landscape planning

Combining gradient analysis with landscape metrics let us to quantitatively describe spatial pattern of urbanization and link it to ecological and socioeconomic processes (Luck and Wu, 2002). While Dresden is a city with already well-established spatial structure, in Poznan and surrounding towns actual dynamic changes are taking place. The landscape of Dresden agglomeration is heavily saturated by infrastructure and the protected areas are very diffused. Maintaining of such small natural fragments by the instrument of protected areas, especially in urban areas testifies to the effectiveness of the law. In Poland, due to weakness of spatial planning the protection of such areas would not be possible. The Federal Building Code of Germany (BauGB, § 35) has strong regulations for new buildings in the outskirts to avoid urban sprawl and landscape fragmentation. Mainly buildings for farmers are permitted. Outskirts are defined as areas outside of a continuous settlement and therefore not within the scope of eligible development plans. Furthermore, the land use plan and regional plan can contain commitments to keep areas free from buildings, e.g. by reasons for landscape protection. Inevitable new encroachments, for example new roads or railway lines or high voltage power lines should be bundled with existing infrastructure, to minimize the impacts (BNatschG §1(5)) into coherent unfragmented open space.

In contrast to Germany, in Poland construction is possible without local spatial plan, just on basis of an administrative decision. Few, but larger and compact protected areas exist more distant from the city, because they are easier to establish and to maintain. Spatial planning in Poland is less integrated with the investment planning and the process of public participation has just a formal character. Hence, there is a small appreciation of aesthetic qualities and small respect of public goods. Given existing economic and demographic trends, there is a high risk of littering the countryside. In Poznan, large areas of agricultural land are set aside and are waiting for investment. More than 30% of the Poznan County is designed in planning documents to build up in the coming years (MRC, unpublished).

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