Mapping Urbanisation-related Landscape Change near Roads Using Spatial Gradients: A Case Study from Estonia

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Abstract

The quantification of landscape patterns and the changes caused by suburbanisation processes is essential to the understanding of the causes and consequences of the human-induced spatial patterns. By using spatial gradients along main roads near cities, we attempted to quantify the influence of roads on the suburbanisation process and settlement structure in Estonia. Results showed that the urbanisation-related fragmentation of landscapes decreases with distance from the road. Distance from the city causes less difference in fragmentation than distance from the road. Spatial gradients effectively detected the urbanisation-related landscape pattern changes in space and time.

1 Introduction

Urbanisation changes the landscape pattern and therefore very dramatically influences biodiversity and the quality of human life. In rural areas, residential development usually occurs along major roads and mainly consists of single-family homes, thereby resulting in the fragmentation of rural landscapes by residential development (WENG 2007). The problems associated with this form of development are: the loss of open space including prime farmland, the disruption of natural habitats and the creation of more impervious surfaces and artificial structures. Therefore there is also a need for information and methods for the analysis and planning of suburbanisation and related processes. One of the most popular approaches in this field is the use of urban-rural gradients. Most of the gradient studies investigate the change in the landscape pattern along straight-line urban-rural gradients but do not analyse the influence of roads. It is known that urban sprawl is influenced by roads, but there is disagreement regarding the strength of the relationship.

Spatial gradients are usually calculated using landscape metrics as an indicator value of landscape pattern. It is well known that the analysis of landscape pattern is very scale dependent (WU et al. 2002), and so is urban structure. Although most of the studies are performed with 30 m or larger pixel size, there are several studies that require the use of more detailed data for landscape analysis and also for urban pattern (BHATTA et al. 2010). An average low-density house leaves a footprint of 200 m^2. Therefore in order to pick up

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the pattern created by low-density housing, it is necessary to use spatial resolution of at least 10 m which we also did in the current study.

In this paper we seek to understand how roads have affected the pattern of suburbanisation and the degree of fragmentation. The aim of the study was to obtain information about spatial patterns near main roads by using spatial gradients. The main research question was: is fragmentation related to urban growth greater near roads, and is it detectable by spatial gradients?

2 Methods

We selected three main roads around Tallinn: Tallinn–Haapsalu, Tallinn–Tartu and Tallinn–Narva. The selection and length of the roads was limited by the availability of the Estonian Basic Map (1:10 000) for two different selected years: 1997/1998 (later referred to as 1998) and 2004/2005 (later referred to as 2005). The 4 km wide buffers along the roads from urban to rural areas were analysed. Road segments were from 23 km (Tallinn–Haapsalu road) to 55 km (Tallinn–Narva road) long. The majority of segments lie in municipalities with rapid population growth in Harju County. All of the gradients started as close to the city limits as possible, depending on the availability of the data.

Landscape metrics – edge density (ED), mean shape index (SHAPE_MN), and patch richness (PR) – were calculated in FRAGSTATS 3.4 (MCGARIGAL et al. 2002) using a moving window of 50 m radius. We assumed that the number of buildings is an important factor influencing landscape heterogeneity on large-scale maps, and is also an indicator of the process of suburbanisation. Therefore we also calculated the number of buildings (NB). For the three selected road sections, 100 m, 200 m…., 1000 m, 1200 m and …2000 m buffer lines along them were generated in ArcMap 10.0 (ESRI) and exported to Idrisi Andes. The profile module in Idrisi Andes was used to calculate gradients for all of the gradient lines. The profile obtains the value of each pixel crossing the line i. e it generates gradients of the landscape metrics along the major roads. These gradients make it possible to determine how the settlement and landscape pattern are influenced by major roads and how the patterns have changed over time. We compared the gradients from different times and analysed how landscape pattern changes simultaneously with increasing distance from cities and roads. According to the Kolmogorov–Smirnov test for normality, the gradients under consideration were not normally distributed. Therefore we calculated the median values of the gradients in order to determine the general trend of the landscape metrics values moving away from the roads. For the statistical analysis of data, the computer program STATISTICA 6.0 and Microsoft Excel 2010 were used.

3 Results and Discussion

All of the gradients for different roads showed similar behaviour. The fragmentation of landscape (values of ED, SHAPE_MN and PR) was highest near roads and it had increased over time at all distances (see figure 1). The number of buildings was highest between 100 and 500 meters from the road. However, there was no clear decreasing trend in the number of buildings and in fragmentation as one moves away from the city. We expected that the number of buildings and fragmentation would clearly decrease with increasing distance from the city, as there are more settlements in the periurban area. Instead, the values fluctuated as one moves away from the city. Therefore we can say that distance from the city causes less difference in fragmentation than distance from the road. There was a noticeable trend towards more new settlements in the vicinity of Tallinn (in a c. 20 km radius) and also outside pre-existing settlements.

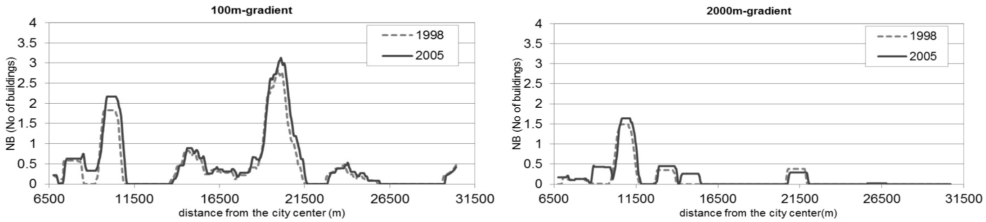

Fig. 1: 100 m and 2000 m gradients of the Tallinn–Tartu road for the years 1998 and 2005

In comparing the two different sides of the roads, the results showed that gradients were not symmetrical in relation to roads (see figure 2). The difference is very clear in the case of NB, which shows the asymmetry of the suburbanisation process. If there is settlement on one side of the road, there may only be agricultural areas on the other side, and this is also the case very near to Tallinn. The reason for the asymmetry is most likely that the intensive suburbanisation process has not filled in the gaps between older settlements. Settlement structure is scattered, and the suburbanisation process has not very closely followed the master plans.

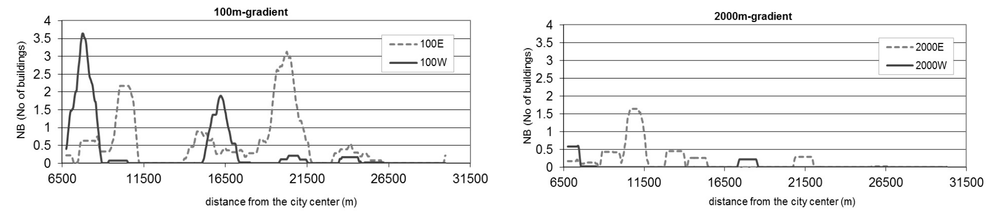

Fig. 2: 100 m and 2000 m NB gradients for Tallinn–Tartu roads on the west and east sides of the road (2005)

Gradients enable us to effectively detect urbanization-related changes. However, it is important to know that buildings and roads have the greatest effect on landscape pattern, and in order to pick up this pattern, enough detailed spatial resolution is required. Roads are long and narrow landscape elements, and buildings are compact and regularly shaped, but they can both create similar patterns in raster format and increase fragmentation (IRWIN & BOCKSTAEL 2007). The influence of buildings on landscape fragmentation is also reflected in the values of all landscape metrics, as the higher peaks of metrics very closely followed the peaks of NB. Therefore we could conclude that the main trends in landscape pattern evaluated by landscape metrics are caused by buildings in addition to roads. However, this conclusion most likely only applies for high resolution data which makes it possible to distinguish the pattern of buildings and roads (ZHU et al. 2006). In future analyses, a highly detailed structural analysis of the large-scale and heterogeneous inner structures of urban morphology using satellite data with higher geometric resolution (e.g. Ikonos or Quickbird) are expected to augment information for planning purposes.

Several studies also stress the importance of the comparability of gradient studies. However, comparability is very difficult if not impossible to achieve, as the spatial resolution, classification scheme and extent of the study areas are different. In our opinion it is more important that the metrics and methods chosen for the study are adequate, and interpretations made from the results are sound. Different areas may require a different approach depending on the availability of the data, the character of the study area and most of all the purpose of the study.

4 Conclusions

In our study we quantified the effect of roads on landscape pattern and suburbanisation processes by using spatial gradients of landscape metrics. Gradients make it possible to measure fragmentation along roads and to study landscape structure while simultaneously moving away from the cities and main roads. Distance from the road appeared to be a more important factor in fragmentation than distance from the city. Gradient analysis detected an asymmetrical housing pattern near roads, which was influenced by the pre-existing settlement pattern.

Our study has revealed some new aspects of the impacts of roads on urban landscape patterns – the fluctuating trend and asymmetry of the housing pattern near roads. Future studies should combine gradient analysis with landscape metrics, as illustrated here, in order to find measures for filling in the gaps in urban sprawl.

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