DOCTORAL THESIS

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Development of a landscape diversity index system with statistical tools based on Earth Observation data sources

Doctoral (PhD) thesis

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Content

1. Aims and introduction

My doctoral work consists of the connection of three scientific fields. These fields are the Earth Observation, the (multivariate) statistics and the landscape modelling. The joint application of these fields establishes an objective landscape assessment process. **The scientific aim** of the work was to support the connection of these scientific fields and to provide an example for the connection with the introduction of a new index-system. The introduced INLAND[2] method and its indices were created by the author in order to provide this example. This way the framework of an objective landscape analytical method has been drawn up.

It derives from the scientific aim to create a certain application of the described method and index system in order to answer the defined functional and operational challenges. **The practical aim** of the doctoral work was to apply the introduced methodology. By the introduction of the model creation process and the possibilities for its application, the INLAND index system has been created to model landscape diversity.

The definition of landscape diversity is not self-explanatory. Among the relevant literature I kept the landscape definition of MŐCSÉNYI (1968) as a standard. Also observation of WU (2004) on scale-continuous spatial heterogeneity and critical approach of GUSTAFSON (1998) towards the application of landscape indices shall be

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[2] Interscale Landscape Diversity Modelling Methodology

highlighted in connection with the latter outcomes of the doctoral research. After the dedicated literature research, the creation of a new landscape diversity definition was required, which is consistent with the emerging scientific problem areas: **Landscape diversity is the percepted spatial heterogeneity, which is observed primarily as variability.**

Highlighted references:

MŐCSÉNYI M. (1968): *A táj és a zöldterület fogalmi problémái a tájrendezés nézőpontjából*. Településtudományi Közlemények; 1968 21 pp. 66-76.

WU J. (2004): *Effects of changing scale on landscape pattern analysis: scaling relations.* Landscape Ecology 2004 19 pp.125-138.

GUSTAFSON E.J. (1998): *Quantifying Landscape Spatial Pattern: What is the State of Art?* Ecosystems. Springer 1998 1 pp. 143-156.

2. Challenges

During the detailed deduction of the landscape diversity definition two main challenges has been observed:

1. Spatial heterogeneity – together with landscape diversity – are ubiquitous across all scales, meaning them to be scale-continuous phenomena. However, any (systematic) observation or data collection of landscapes is attributed with discrete scales. **The first landscape diversity modelling challenge is the need to approach a scale-continuous phenomenon with scale-discrete data.**
2. The other main challenge is that landscape diversity derives from the perception of spatial heterogeneity. But who is the preceptor? And how is he/she percepting? With a demonstratory example: which perception is more relevant, the perception of a Dakota huntsman, or the perception of an uptown boy? **The second landscape diversity modelling challenge derives from that landscape diversity is dependent from the quality (experiences) of its preceptor, and in parallel, it is dependent from the time quantity utilized for perception.**

To answer the defined landscape diversity modelling challenges, I introduced two new concepts: the concepts of “subscales” and “perception resolution”. These concepts provided the novelty of the defined INLAND methodology and of the results of my doctoral work.

3. Methods

The introduced INLAND (Interscale Landscape Diversity Modelling) method was based on the following two concepts:

1. **Subscales** are those indirect scales, of which data is derived by the regular aggregation of a source data of an ever finer scale (with smaller grain size). The introduction and integration of the sequence of subscales into the INLAND method gave a solution to the approach to the first landscape modelling challenge, thus to the modelling of a scale-continuous phenomenon with scale-discrete data. Earth Observation datasets are also considered to be scale-discrete sources.
2. Perception resolution is an independent parameter (variable), which stands for the quality of the perceptor (length of perception time) during the decision making of spatial variability. Its symbol is *d*. The real-life distribution of this parameter is unknown, but after its modelling (in the doctoral work constant distribution is hypothesised), it can be integrated into the decision making on variability, so the resulted landscape diversity can be observed in its function.

With the introduction and iterative application of the above mentioned concepts, the **numeric solution** of the INLAND methodology was formed that models the number of spatial differences (variability) in the function of the perception resolution and also their subscale dependent size with the utilization of multi-channel raster datasets (E.g.: multispectral Earth Observation data).

So the numeric landscape diversity model can be decomposed into quantity and size related components, which are interpreted in the function of perception resolution. The statistical modelling of these components resulted the two empirical parameter pairs (indexes) of the landscape diversity model:

- *IQ*: initial quantity of landscape diversity;
- *SQ*: sensitivity of quantity;
- *IS*: initial size of landscape diversity elements;
- *SS*: sensitivity of size.

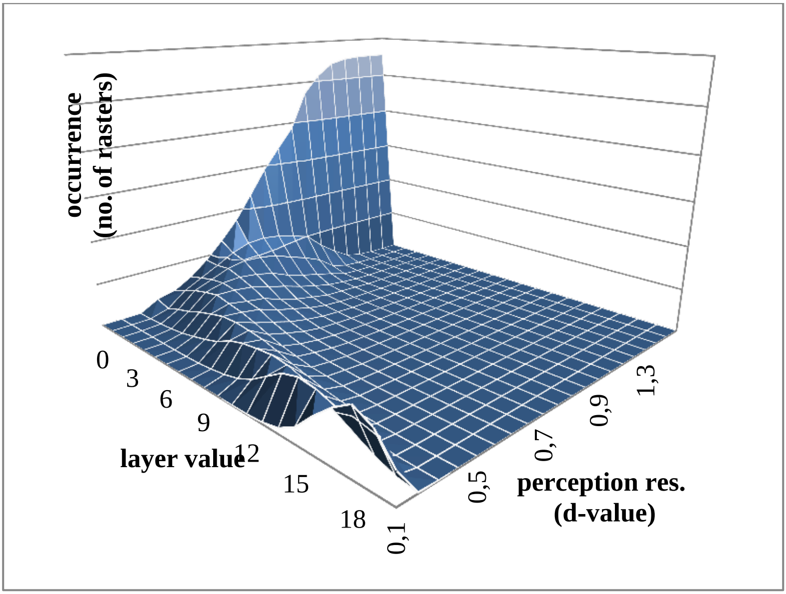
By the utilization of these **empirical landscape diversity indexes**, the landscapes can be described in their diversity, as the function of the perception resolution.

However, the numeric solution of INLAND suffers from the partial negligence of neighbourhood relations, thus it can be used only for sampling purposes (within functional landscape borders). By the integration of a moving-window system, the **mapping solution of INLAND** had been introduced, which allows the representation of modelling results in map format.

For the calculatory-informatic execution of the numeric and mapping solutions of INLAND methodology, I created two pieces of MATLAB code. With the required application protocols, the primary modelling process of INLAND method can be considered as automated. Model interpretation requires the manual analysis of the user. The automated quality supports the wide and broad model application and also its utilization in a repetitive manner.

4. Results

The distribution of the independent parameter of INLAND method and of its two solutions – so the distribution of perception resolution – are unknown. That is why the INLAND method and its results can be used **only in relative** (comparative) **analysis**. The absolute value of the outputs does not stand for real meaning. The idea of INLAND is rather based on the observation, how the percepted spatial heterogeneity is depending on the change in the perception resolution, and consequently, how this dependence is differing between landscapes.



The distribution (histogram) of landscape diversity of Transdanubia in the function of perception resolution (*d*).

The scientific results of the doctoral work can be summarized in the following theses:

Thesis 1

Elaboration of definitions on the scientific and application fields; overview of landscape diversity modelling state-of-art; conclusion of main modelling challenges and responses in the form of two concepts: system of subscales and perception resolution.

During the overview of related literature I precisely defined the definitions, which are widely used though are not fully agreed upon, however still required for the consequent elaboration of the doctoral research. These definitions might stand for the model-hypothesis of the work. Examples of these definitions are: Earth Observation, landscape modelling, landscape diversity and landscape diversity modelling.

During the systematic and critical overview of the state-of-art of landscape diversity modelling – as for the application field of the doctoral research - I drew up the mainstream trends and I derived those challenges to which the work shall provide solutions.

As part of the applied methods, I focused on the two main challenges of landscape diversity modelling, and I described their importance. As a solution for these challenges, two concepts have been introduced: the concept of subscales and the concept of perception resolution.

Thesis 2

Introduction of the numeric solution of INLAND, the empirical numeric landscape diversity model and theparameters of the numeric model (IQ, SQ, IS, SS indices); introduction of the mapping solution of INLAND, model-space of landscape diversity and map products of the model space.

By the integration of subscales and perception resolution into the spatial heterogeneity modelling, I defined a new modelling methodology (INLAND) for the purpose of modelling landscape diversity. I drew up the numeric solution of the new method, and the derived a general and empirical landscape diversity model. I introduced and described the empirical indices of the landscape diversity model (IQ, SQ, IS, SS) in order to prepare their latter application.

Besides the integration of the system of subscales and perception resolution, a sequence of moving windows has been fit into the modelling methodology in order to handle neighbourhood relations with better performance and by that, to realize the mapping solution of INLAND. By the application of the mapping solution, a model-space is resulted which could be interpreted in the form of map products. The mapping process and the output map products have been described in favour of later application.

For the operative execution of the introduced INLAND models, I created two pieces of MATLAB code, due to which – along strictly applied user protocols – the INLAND solutions can be kept to be automated, supporting repetitive application, application in various areas of interest and application with various input data types.

Thesis 3

Application of INLAND models, practical conclusions derived from application results; sensitivity assessment of the methods and their parametrization has been carried out in the applied studies; during the test phase, statistical behaviour of the models have been described; introduced parameters have been validated with well-known landscape metrics.

After the introduction of the numeric and mapping solutions of INLAND, I carried out the sensitivity assessment and parametrization of the numeric model. During the operative exploitation of the model, I utilized low resolution Earth Observation imagery acquired from European random sample sites (containing extremities). I described the statistical behaviour of the model during the application. Applying the numeric model on high resolution data samples, I carried out the comparison of geographically analogue areas. The study assessed the effect of climate change on landscape diversity and resulted in the objective observation of a threshold of land use in function of climate change.

During the application of the INLAND mapping solution I prepared the landscape diversity model of Transdanubia. I gave a practical example of utilization and potentials of INLAND map products in landscape planning and regional development on the example of the Rostock region (Mecklenburg-Vorpommern, Germany).

I validated the numeric index values of INLAND numeric model with the calculation of various well-known landscape metrics (Fragstats) in the Hungarian high resolution sample sights. The validation process verified the relevance of the INLAND indices (strong correlation in case of modelled number of landscape diversity patches), meanwhile the study also show the novelty and new approach of INLAND indices, being uncorrelated to any other applied metrics. INLAND methodology opens a “new window” on the understanding of landscape diversity.

Thesis 4

Introduction of the doctoral work itself as a landscape modelling process; supporting the development of the objectivity of landscape modelling and landscape assessment.

The doctoral work itself stands for the documentation of a landscape model definition, supporting the objectivity development of landscape assessment. During the conduction of the doctoral research, I consequently followed the modelling steps defined during the overview of related literature, thus the doctoral work itself stands for the documentation of such process.

During the documentation of the modelling process, I reported accurately the methodologic phases, which have been also indicated in the work, (e.g.: in the titles of chapters, as “[Notes]”). Thus the process can be transparently overviewed from conceptualization and formalization through model development, parametrization, test, sensitivity assessment and analysis of validation and model assessment.

The process monitoring in the doctoral work supported the aim of development the objective quality of landscape modelling – thus of landscape assessment. The transparency and objectivity of landscape assessment contributes to the acceptance of landscape planning, consequently supporting the profession to carry out its multi- and interdisciplinary role.

5. Conclusions

The doctoral research has led to the following conclusions:

1. The defined numeric and mapping solutions of INLAND can be well utilized for the modelling of landscape diversity; the models take the perception of landscape diversity into account in the function of the quality of the preceptor.
2. The coarser the perception resolution is at which the perception of landscape diversity is maximal, the lower the perceived maximal landscape diversity is. Thus landscape diversity has a self-balancing attribute, which is a systematic quality.
3. The empirical indices of the landscape diversity stand together; thus initial quantity (IQ), sensitivity of quantity (SQ), initial size (IS) and sensitivity of size (SS) are correlated, thus defining the scale of qualitative landscape diversity assessment to stand for a “rhapsodic-balanced” range in the function of perception resolution.
4. Climate change has an impact on landscape diversity. In case of intensive agricultural landscapes, this impact prevails in the direction of homogenization – thus intensifying the rhapsodic quality of landscapes.
5. Due to the impact of climate change, Northern Great Plain region of Hungary faces a challenge of necessary land use system conversion in the period of 2040-2070.
6. The introduced INLAND methodology provides a new (not-correlating) approach in the modelling of landscape diversity. which supports its application in landscape planning.

6. Proposals, outlook

The doctoral research intended to be a whole on its own, thus many emerging questions and possibilities have been excluded from further investigation.

Proposals are aiming the **broad utilization** of the introduced methodology by giving advices for the further development of recently introduced solutions and parameters of INLAND. In our case, they are open-source availability, reduced execution time reduced coding tasks, and user-friendly application definition. However, it must be highlighted, that the developments shall not endanger the robustness and generality of the models. It must be also acknowledged (in favour of the application expectations) that INLAND is a dedicated modelling methodology and not a mapping or planning tool.

Outlooks on **further application and development possibilities** call attention to the required new assessments which occasionally are of high importance. Application by utilizing broader input data palette (digital terrain models, very high resolution data, SAR), and exploitation for modelling purposes (times series analysis) are such necessities, which shall be assessed. Development of modelling process shall enable the extraction of more accurate statistical outcomes. Complex utilization of INLAND (mapping and numeric) solutions shall bring the model results closer to planning purposes. One of the most important further investigation, however, shall be the empirical assessment of the independent parameter of INLAND (*d*, perception resolution) which shall be achieved in the confines of a landscape-sociologic study.

7. Related publications of the author

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