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A LANDSCAPE ECOLOGICAL ANALYSIS OF THE GREEN INFRASTRUCTURE IN AGRICULTURAL AREAS

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1. BACKGROUND AND OBJECTIVES

In nature conservation, one of the biggest challenges of the 21st century is biodiversity conservation on agricultural areas. The primary purpose of cultivated areas is to provide food and resources to meet the constantly increasing demands of humanity, and this increasing trend will continue in the future, according to projections. The transformation of natural ecosystems to food production areas has been the main global cause of the losses in the extent and diversity of precious habitats. Today, agriculture is globally taking up an area 5 and a half times larger than in the 1600s.

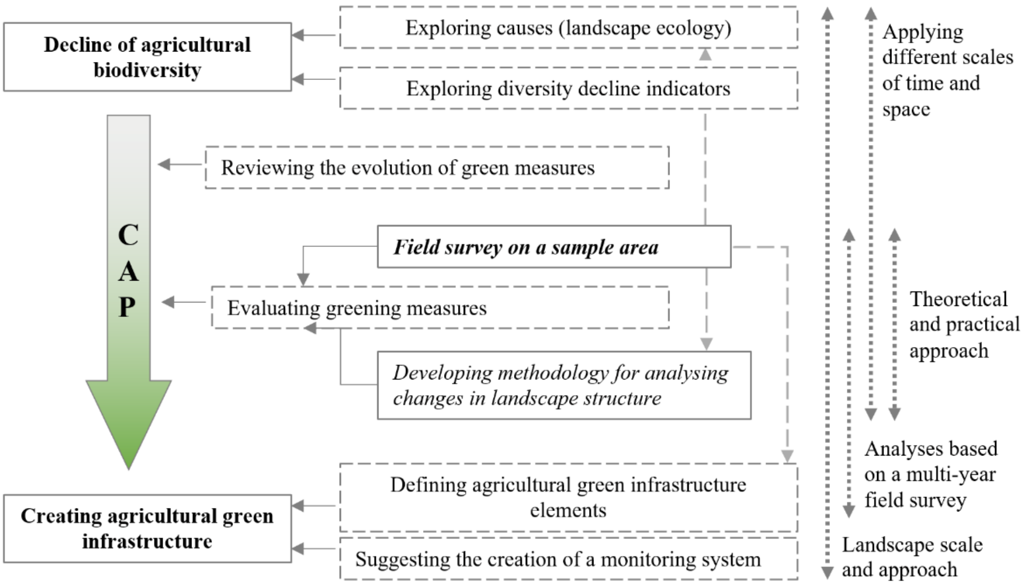
The negative biodiversity trends are driven by various factors. On agricultural areas, the goal is to maximise production efficiency. This is leading to increasing field sizes, a decrease in the variety of crop types, disappearing border habitats, and an ever-increasing pesticide use. Conserving biodiversity is not possible in the current natural and semi-natural habitats (due to their limited extent), and alongside the current agricultural practices. Arable lands are in a crossfire of various interests, but with a new approach in managing them they could play a critical role in reaching biodiversity conservation goals.

The 2030 Biodiversity Strategy of the European Union states that degraded ecosystems should be restored, and protected areas should be enlarged, aided by the deployment of green infrastructure. The EU's Green Infrastructure Strategy, adopted in 2013, promotes the introduction of green infrastructure into agricultural practice via the Common Agricultural Policy. CAP subsidies constitute a significant part of the total EU budget. By now, the green future vision for agricultural areas has become deeply connected to subsidy schemes.

In my thesis, I explore the relationship system and possible synergies of the three subject areas mentioned above (biodiversity conservation, green infrastructure and the Common Agricultural Policy) in an agricultural environment. I am looking for an answer to the question whether the system of green measures in CAP is suitable for implementing the development of green infrastructure on agricultural areas, and thus indirectly for stopping the decline of biodiversity. The goal of my research is to analyse a complex and current problem using the widest possible range of methods, and to highlight crucial points. The practical usability of the developed methodologies could contribute to the protection of nature "with humans, for the humans".

2. MATERIALS AND METHODS

The fundamental question in this thesis is whether the system of measures in the Common Agricultural Policy is suitable for stopping the declining trends in biodiversity and landscape diversity on our agricultural landscapes, and thus for ensuring the long-term stability of agricultural green infrastructure. The task and goal system leading to answering this question is summarised in the figure below:



During the research, I have carried out landscape structure analyses and field surveys on a sample area in the Great Hungarian Plain. The sample area is in the vicinity of the town of Túrkeve, and covers an area of about 600 km^2 on the southwestern edge of the former Great Sárrét region. The long-term analysis, i.e. the exploration of historical spatial changes was carried out by using historical maps. In the short-term analyses of changes in permanent grasslands and in Ecological Focus Areas, I have used data from the Hungarian State Treasury. I have additionally analysed EFAs during a multi-year field survey as well. Effects of crop diversification were analysed using data from the multi-year field survey, and applying my own methodology relying on NDVI-based crop identification and landscape structure indicators applied to Sentinel-2 satellite imagery, also supported by field survey results.

3. RESULTS AND DISCUSSION

In my thesis, I explored the topic of agricultural green infrastructure. After a historical review, I described the definition of agricultural green infrastructure, and defined landscape elements with a significant potential for increasing biodiversity on agricultural landscapes. I evaluated the system of green measures of the Common Agricultural Policy from the aspect of whether it can meaningfully contribute to improving the landscape structure and thus indirectly to improving the green infrastructure. I developed methodologies for short and long-term monitoring of changes in landscape structure. Based on the experiences, I listed suggestions for future research, planning and controlling processes.

Based on literature research, I proved that in recent times, there is an increasing focus on the role of the matrix of the fundamental structure of agricultural landscapes, i.e. arable lands. The focus on arable lands is also supported by the latest Hungarian green infrastructure research, which identify a large portion of degraded ecosystems as arable lands. Research results so far have not clearly stated the role of arable lands within green infrastructure. I concluded that arable areas can meet green infrastructure expectations only if they are identified as multifunctional areas, and if their cultivation methods are reconsidered.

In the analysis of changes in small-scale landscape elements eligible as Ecological Focus Areas in the CAP subsidy system, I concluded that carrying out a field survey is indispensable in assessing their ecological state (species composition, vitality, habitat function, risk factors, type of usage (e.g. beekeepers)). For a precise tracking of changes and dynamics, a simple quantitative comparison of data from the beginning and from the end of a period is insufficient: an analysis of landscape elements about their spatial extent and their temporal continuity must also be carried out.

The developed methodology is suitable for the identification of small grasslands wedged between arable lands (which act as excellent refuge strips and feeding areas) and of small fields in the agricultural landscape. From a green infrastructure perspective, these elements are excellent providers of the connectivity function, as they can be "stepping stones" supporting the connection of larger habitats.

Landscape metrics can be applied to quantifying not only present but also future, expected or potential spatial structures. Using such indicators in the research, I demonstrated the changes in the spatial extent of arable lands in the examined time period, i.e. the results of the crop diversification measure achieved in the last 7 years. Regarding Ecological Focus Areas, a comparative analysis was made evaluating eligible landscape elements at the start of the greening period and at the beginning of the new budgetary period, thus quantifying the expected future spatial impacts of the most recent measures.

To evaluate the suitability of CAP, I used and developed methodologies for analysing landscape-level changes. The experiences can be applied in designating green infrastructure in agricultural landscapes, and in developing a monitoring system.

4. CONCLUSIONS AND RECOMMENDATIONS

The methodologies can support not only large-scale or development-focused projects. The methodology developed for crop identification (required for analysing crop diversification), and, building on that, a crop comparison over the years, is suitable for identifying small-scale grasslands (including recovering grasslands) which are crucially important in agrobiodiversity, on areas where agriculture is the dominant form of land use and for which Sentinel satellite imagery is available, meaning any parts of the world.

In the everyday nature conservation work, the developed methodology can be applied to a dedicated species and its habitat, especially the great bustard *(Otis tarda)*. Crop identification can be carried out on areas where no information is available other than satellite imagery. This can be important in the analysis of habitat preference of populations near national borders or outside the area of competence of a given organisation, as neither species nor satellite imagery know borders.

Identifying small-scale green infrastructure elements can help nature conservation in assessing which habitats could be connected with the smallest effort and the largest impact. The most current land cover map may not always be available for identifying preferred habitats, but the methodology allows for generating an approximately precise overview of the examined area.

My suggestions regarding the creation of the agricultural green infrastructure and its monitoring system can serve as a starting point for research communities determining restoration priorities and for planner communities. I am convinced that in an ecological-minded development of agricultural landscape, it is crucial to involve specialists capable of thinking on a landscape level and on strategic scales.

5. NEW SCIENTIFIC RESULTS

Thesis 1: I described the definition of agricultural green infrastructure and identified its elements

The pillars of agricultural green infrastructure are landscape elements and habitats which have developed spontaneously or as a result of human activity, and which do not take part in direct agricultural production. These natural or semi-natural habitat fragments are: scattered trees, tree groups, shrub groups, small ponds, roadside baulks, grassy field margins, roadside strips with trees and shrubs, tree lines, kurgans. I have classified grasslands of various sizes wedged between arable lands and other agricultural areas participating in food production (e.g. orchards, vineyards and gardens) as agricultural green infrastructure elements as well.

I concluded that classifying arable lands as multifunctional areas, provided that they meet strict agri-ecological criteria, enables them to fulfil the three conditions of green infrastructure, namely, providing ecological functions, supporting the connectivity of habitats, and providing ecosystem functions (supply functions) at the same time.

In the literature research, I explored the set of potential or real green infrastructure elements present in agricultural landscapes, and their roles in biodiversity conservation. Based on the reviewed literature, I conclude that stopping the decline of biodiversity with the current quality and quantity of agricultural green infrastructural areas is impossible. There is a global consensus that in agricultural landscapes, the role of arable lands must be reconsidered in relation to stopping biodiversity decline.

Thesis 2: I developed and applied a landscape ecology criteria system and methodology for measuring changes in agricultural landscapes

I defined a criteria system suitable for analysing long-term changes in agricultural landscapes which reveal direct and indirect causes and activities leading to the spread of agriculture and a decrease of green infrastructure in the long term.

Due to the spread of agriculture and landscape transforming human activities, an unprecedented loss of biodiversity is observed. The methodology relies on the classification of land cover recorded on historical maps (natural and semi-natural, transformed, or artificial). During the application of the methodology to the sample area, it became clear that from all the possible directions of change in land use, the dominant one is the transformation of natural and semi-natural habitats into agricultural areas. Based on analyses of the sample area I concluded that since the 1970s, there is a negligible growth in the extent of agricultural green infrastructure.

Thesis 3: I explored a range of landscape metrics suitable for analysing the landscape structure of agricultural areas, and applied them to analyses of a sample area

I defined methodologies and landscape metrics suitable for a landscape-level evaluation of structural changes in agricultural areas.

Recent technological developments allow for using satellite imagery to analyse land surface at unprecedented levels of frequency, detail and scale. In the past decades, the development of landscape metrics brought about the creation of numerous landscape structure indicators.

Class-level landscape metrics suitable for analysing changes in arable lands are: Percentage of Landscape, Mean Patch Area, Median Patch Area, Largest Patch Index, Interspersion and Juxtaposition Index, and Patch Cohesion Index.

Landscape-level indicators are: Shannon Diversity Index and Shannon Evenness Index.

Remote sensing and landscape metrics play a fundamental role in appropriate quantitative evaluation. However, I concluded that information collected during field surveys, mainly regarding ecological attributes, cannot be gained using landscape metrics, thus a combination of both methods is required for a precise evaluation.

Thesis 4: I evaluated permanent grassland protection measures and defined a criteria system for ensuring their long-term survival

Based on my analysis I conclude that comparing numerical values valid at the start and end dates of the examined period is insufficient in determining the extent of truly permanent grasslands and its changes. The spatial extent must also be examined.

By a small-scale, short-term comparative analysis I showed that there is a negligible decrease in the extent of eligible permanent sensitive and non-sensitive grasslands based on data at the start and end date of the examined period. However, after a GIS comparison, I concluded that there is a significant decrease in the extent of eligible permanent sensitive and non-sensitive grasslands which could be classified as such both at the start and at the end date (4.5% and 17%, respectively).

Thesis 5: I evaluated the criteria system for the protection of Ecological Focus Areas, the key components of agricultural green infrastructure

I concluded that ecological aspects have not played an important role in the centralised selection of eligible and non-eligible landscape elements. I also concluded that there is no detectable difference in whether the transformed or disappeared landscape elements were eligible for EFA or not. Based on the proportion of landscape elements eligible both at the start and at the end of the examined period, it can be stated that neither the eligibility nor its cancellation guarantee the survival of a landscape element.

Between 2015 and 2023, I have carried out a total of 5 field surveys, during which I monitored small-scale and short-term changes of a total of 48 landscape elements. The changes in the landscape elements consisting of both EFA eligible and non-eligible items were classified into 4 categories: disappeared, transformed, shrunk or expanded. Both the eligible and non-eligible landscape elements contain items of varying landscape ecological value.

I concluded that the group of eligible Ecological Focus Areas has decreased in three categories (tree and shrub groups, small ponds, scattered trees), and remained unchanged in two other categories (shadoofs and kurgans). From the aspect of raising awareness among farmers, the fact that the criteria system and the groups of eligible landscape elements change in each budgetary period can be particularly disadvantageous.

Thesis 6: I evaluated the landscape structural impacts of crop diversification

I developed a methodology for identifying areas covered by different agricultural crops based on the NDVI curves of crop groups. I demonstrated the impact of the crop diversification measure of the Common Agricultural

Policy on landscape structure regarding lands under extensive and intensive agricultural cultivation. I concluded that the achieved results of the measure are in the direction of its original goals, that is, there is a detectable (albeit minimal) decrease in field sizes, and an increase in areas covered by perennial crops. These suggest a fragmentation in the field structure and thus an increase in landscape structure mosaicity.

Using training areas, I determined three clearly distinguishable crop groups based on NVDI values. These groups substantially define the structure of agricultural landscapes on an annual rhythm by their different vegetation cover patterns over time. The groups are: perennials, early summer harvests (e.g. wheat, barley, oat) and late summer harvests (e.g. maize, sunflower, millet). I carried out the identification for each year between 2017 and 2023 on the sample area, which enabled a small-scale, short-term comparison and change tracking. Based on the results, in the examined period of 2017 to 2023, both the number of contiguous blocks and the total size of perennial crop areas have increased. This means that over the years, more and more areas have been covered by vegetation for an extended period or permanently, as a biologically active surface. At the same time, there was no increase in the number of contiguous blocks of either of the other two groups. The total size of late summer harvest crop areas shows a decreasing trend. This, together with the number of contiguous blocks and an increase in the median value, indicates that farmers have sown late summer harvest crops on increasingly smaller areas, and that they are preferring large contiguous blocks less. These are favourable trends from a landscape structure perspective, and the increasing proportion of perennial crops means an increase both of biologically active surfaces and of the proportion of feeding and refuge areas in the landscape.

Thesis 7: I developed a methodology for identifying small agricultural fields and small grass strips and field margins

Using NDVI based crop identification and methodologies developed for creating thematic maps of arable lands, I identified small grass strips and field margins within the arable lands of the sample area. This methodology also enables the identification of small agricultural fields.

The thematic maps of crop groups covering 7 consecutive years (2017 to 2023) form the basis of the methodology. A multi-year analysis of areas covered with the same crops can be carried out, without size restrictions, on any areas dominated by agriculture for which Sentinel-2 imagery is available. The result is also usable for providing a more detailed depiction of arable lands shown on the Ecosystem Map of Hungary.

Thesis 8: I developed a short-term analysis and evaluation methodology for structural changes in agricultural landscapes, applicable in a subsidy-oriented environment

I carried out a generic landscape structure change analysis and concluded that based on class-level and landscape-level indicators, there is an increase both in the proportion and in the mosaicity of semi-natural habitats, i.e. grasslands and areas covered by woody vegetation in the examined agricultural area.

The examination period (2017 to 2023) covers the period of the greening measure of the Common Agricultural Policy, thus the analysis is capable of detecting the landscape structural impacts of greening. The group of grown agricultural crops has not changed significantly, but the proportion and the patch sizes of areas covered by late summer harvest crops have decreased. At the same time, the proportion of areas covered by perennial crops has increased, while the average patch size has decreased, therefore mosaicity has increased.

Thesis 9: Based on my research I developed proposals for creating agricultural green infrastructure and its monitoring

Proposals for selecting small-scale landscape elements and reconsidering arable lands, and for choosing the temporal and spatial scales of a monitoring system:

- Ensuring the long-term survival of small-scale landscape elements by setting up a consistent and long-term subsidy rule system.
- Promoting the creation of new eligible landscape elements on areas dominated by agriculture.
- Applying a landscape-level approach to the centralised selection of eligible landscape elements.
- Considering arable lands participating in agro-ecological use when selecting agricultural green infrastructure elements.
- Applying appropriate temporal and spatial scales to the annual and periodical monitoring of the impacts of measures.

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Further publications of the author can be accessed on the public interface of the Hungarian Scientific Bibliography (MTMT) (under the keyword Klaudia Máté (Tájépítészet)):
https://m2.mtmt.hu/gui2/?type=authors&mode=browse&sel=10057715