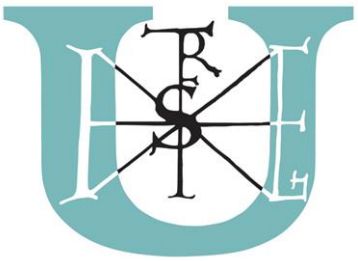

SZENT ISTVÁN UNIVERSITY

Landscape change analyses from nature conservation perspective in the Gödöllő Hills

Doctoral (PhD) Thesis Statements

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1. ANTECEDENTS AND OBJECTIVES

The carrying capacity of the Earth's natural ecosystems is finite. With the disruption of the ecological balance, the needs of humanity exceed the available resources of the planet. In light of today's economic development, "there [is] growing evidence that humanity [is] moving further into unsustainable territory", Meadows et al. (2005) warn in their book entitled *Limits to Growth: The 30-Year Update*. One of the biggest global challenges of the 21st century is climate change: although climate has changed several times already in the geological history of the Earth, the current changes are primarily induced by anthropogenic factors (Kertész et al. 2011). Climate change has wide-ranging consequences: it affects the change of the natural environment and the economy alike. Quasi-natural ecosystems react sensitively to small-scale changes already, but these changes equally affect human-related forms of cultivation such as forest management (Somogyi 2017) and crop production (Jolánkai et al. 2005, Surányi 2016).

One of the inherent implications of the development of human civilization is the transformation of the natural environment, the "adjustment" of our immediate environment to our purposes and the shaping of it to "our image". Changes are the most conspicuous in areas that have been considered "natural" in the 19th–21st centuries such as the rainforests of Amazonia (Dale et al.1994) and of Papua–New-Guinea (Shearman et al. 2009). Since the 1970s, about 20% of Amazonia's forests have been cut (Williams 2002), which gives reason for concern, especially regarding the loss of biodiversity.

Landscape change has a significant impact on the shrinking of certain habitats (Tilman et al. 1994). The global rate of deforestation over the past 5,000 years is estimated at 1.8 billion hectares, which corresponds to 326,000 hectares per year on average (Williams 2002). The rate and tempo of deforestation is one of the best indicators of the transformation of natural – or by now, only quasi-natural – landscapes.

Another driver of the dramatic reduction of natural or quasi-natural areas is urbanisation. Europe is one of the most urbanised regions of the world. 73% of the European population lives in towns, and according to estimates, this figure will reach 82% by 2050 (EEA 2015). Land use – and consequently, its impact on the environment – has changed dramatically not only in Europe but also beyond the continent. The changing land use needs are clearly shown by the change in the proportion of artificial areas, which grew by 3.7% between 2009 and 2012 and by 3.9% between 2012 and 2015 in the member states of the European Union. Greece, Belgium and Hungary are among those countries where the rate of the increase of artificially covered surfaces was way above 10% between 2009 and 2015 (Eurostat 2018). Within Europe, the country with the biggest built-up area – 16.27% in 2012 – was Malta (Http1).

Partly due to the above massive changes, the study of landscape change and changes in nature and the environment has become increasingly important. Landscape-related research has especially come to the fore.

There have been numerous research projects into landscape change both in Hungary and abroad, be it landscape descriptions in the traditional sense or analyses in landscape metrics. These research projects are motivated by the need to understand the changes in the spatial structure of the landscape (which have accelerated in the past couple of decades), and also the need to counter the narrowing and fragmentation of the natural environment, or at least to slow it down. Various surveys approach the problem from different angles in an effort to support landscape design.

In Hungary, economic and social transformation after the political changeover played a major role in the evolution of the rapidly changing structure of the landscape. In order to reconstruct the earlier conditions, we need to familiarise ourselves with the history of the landscape. As the quality of the landscape has been deteriorating at a growing pace, we also need to examine the main parameters of the landscape components. Moreover, we need to devote special attention to the areas most sensitive from the perspective of nature conservation (e.g. the

situation of wetlands and forest lands) to be able to monitor their alteration and mitigate the anthropogenic impact if possible.

The area that my research has focused on is the Gödőllő Hills, a micro-region situated near the capital, in the metropolitan belt of the city. The proximity of the capital is both an advantage and a drawback for the Hills. Thanks to the favourable traffic system and its geographical situation, its population has been steadily growing. The development of the area has been determined not only by population growth, but also by industrial suburbanisation (Demény 2008, Koós 2004, Koós & Tóth 2007).

However, all of the above may turn into a disadvantage: the growing number of inhabitants entails a heightened burden on the environment, one of the biggest stress factors for the region. Despite the trends of suburbanisation, society has a growing need for a natural, "intact" environment, and ironically, in some cases, this desire seems to be the very motif of suburbanisation. This is why research monitoring changes in landscape use is so important – research that simultaneously examines the extent of degradation and stability of the landscape.

Regarding their physical geography, the Gödöllő Hills constitute an area of geomorphological transition, but due to their natural and landscape values their preservation is a key priority. Another reason why the specification of natural and quasi-natural areas is a quintessential task is that there are more and more factors leading to or projecting changes in this area, e.g. the construction of the M31 freeway and the expanding population of the Hills (the population of Veresegyház has doubled over the past 15 years). All of these trends impose a growing stress on this micro-region, which also entails a bigger challenge from the perspective of nature conservation.

When analysing a landscape and any related aspects, it is of key importance to treat and interpret landscape as a complex system.

The basic aim of my research is to analyse and assess landscape changes in the Gödöllő Hills from the perspective of nature conservation, namely:

- to prepare a historical landscape analysis of the area through a literary review in order to embed my research;
- to prepare the land cover map series of the area on the basis of military and historical maps in order to conduct further quantitative research;
- to analyse, in the selected periods, the extent of landscape change and landscape intensity change with the help of the Bowen–Burgess Landscape Dissection Index;
- to compare and contrast the changes that have occurred in the individual landscape use forms (forests, wetlands, meadows and pastures, arable fields, hobby plots, orchards, built-up areas);
- to examine landscape fragmentation and permanence, and delineate stable and non-stable areas as well as stationary patches;
- to examine the anthropogenic transformation of the micro-region, determine quasi-natural and anthropogenic areas, and examine the fragmentation of the landscape.

2. MATERIALS AND METHODS

Location of the area under examination:

According to the micro-region typology of Marosi & Somogyi (1990), as well as Dövényi (2010), the Gödöllő Hills are part of the macro-region called North Hungarian Mountains. Within that, they are located in the northern part of the group of micro-regions called Gödöllő–Monor Hills in the meso-region of the Cserhát. The Gödöllő Hills (stretching over 550 km^2) are situated between 130 and 344 m above sea level, and gradually become lower towards the southeast (Marosi & Somogyi 1990). Their location, geological and climatic conditions make them a transitory zone between the North Hungarian Mountains and the Great Hungarian Plain. Their independent hills are wedged between the latter two macro-regions.

The landscape change survey was carried out according to several criteria and on various levels. The main aspects were the following: land cover survey, stability survey, intensity survey. Analysis was conducted on the level of the region, settlement, and landscape protection area. Field surveys needed to be carried out along the border of the settlements and the landscape protection area because this procedure allowed for establishing a more accurate picture of the changes having taken place in landscape use.

In the case of the land cover and stability surveys, I carried out my analysis on the level of the region whereas the intensity survey was conducted on the level of the settlements – but only for four towns that I selected from the totality of the settlements located in the Gödöllő Hills (Veresegyház, Szada, Gödöllő and Isaszeg).

Land cover survey:

I examined the changes in the landscape use of the Gödöllő Hills over the past 200 years on the basis of literary sources and military survey maps (I-III, 1763–1885), as well as a topographic survey (1989) and a Corine survey (1998).

Using GIS tools and the ArcView 3.2 software, I digitalised the maps, identified the typical land use types, and prepared a comparative analysis between adjacent survey dates, displaying my findings on a map. I used Microsoft Excel to prepare a mathematical statistical analysis: I calculated the distribution of the individual land use types and expressed the difference between the various periods in percentage.

I distinguished seven typical land use forms: built-up/residential areas (artificial surfaces: built-up areas, farm buildings and industrial buildings, traffic routes); forests (scrublands and bushes); wetlands (surface waters, reedy marshlands); meadows and pastures; hobby plots and orchards; and vineyards.

Stability survey:

After the examination of the land cover of the micro-region, and taking into consideration the landscape change between the given dates, I identified stable and non-stable areas. I considered an area stable if the land use form did not change compared to the previous period, and non-stable if changes occurred in comparison with the previous period. After that I projected earlier and later maps onto each other, which yielded a change map.

In order to get an even more accurate picture of the direction of changes in landscape use, I graded the different land use categories according to anthropogenic impact/intensity, with a primary focus on aspects of nature conservation: 1. built-up areas, 2. arable fields, 3. hobby plots, orchards and vineyards, 4. meadows and pastures, 5. forests, 6. wetlands. During the creation of this ranking, I made reference to Rakonczay's classification (2002). I recoded the polygons on the revised change map, then I ranked changes on the basis of the above according to their direction (positive, negative, no change).

As a result of the above, I ended up with an 11-grade scale from (-5) to (+5), where the section between -5 and -1 denotes negative change, the section between 5 and 1 shows positive change (from the perspective of nature conservation), and 0 means that the area of the given polygon was stable and free of change, and it preserved its original function.

After preparing the map displaying the stable patches, I looked at the direction of changes and identified the so-called stationary patches. I defined stationary patches as areas whose land cover was the same on all the maps I examined, i.e. as an area that did not change over the past more than 200 years. I delineated stationary patches partly on the basis of historical maps and partly through field surveys. Field surveys were necessary in order to verify the condition of the patches identified on the map as stationary. I also surveyed whether the areas were in good natural condition or rather, reflected anthropogenic influence, and if yes, what sort of influence.

During the field survey of the stationary patches, I based my observations on a 12-point list of criteria (focusing primarily on the presence of anthropogenic influence). I carried out field surveys at the following five sites (these forest patches are not under protection yet, but are

indicated as stationary patches): Szentjakab, Tölgyes (Mogyoród), Szár Hill (Kerepes), Bolnoka Forest (Kerepes), Csomád Forest (Hátulsó Hill) and Vácegres Forest.

As the greatest extent of stability could be detected in the case of forest lands, I also examined the condition of the forests along the border of the Gödöllő Landscape Protection Area (GLPA), and grouped the tree specimens surveyed according to trunk diameter. I carried out my survey at eight sites along the border of the GLPA.

Intensity survey:

I used the following classification to express the extent of the anthropogenic transformation affecting landscape change, i.e. to describe the manner and extent of the expansion of anthropogenic areas:

I grouped the seven land use types identified into two categories:

1. "Quasi-natural" areas affected by minor human influence (wetlands, forests, meadows and pastures).
2. "Anthropogenic" areas affected by more significant human influence (built-up areas, roads, farmsteads, farm buildings, arable lands, hobby plots, orchards, vineyards).

I considered those areas quasi-natural where there had been little human intervention. The opposite of quasi-natural areas were anthropogenic areas, disturbed and heavily transformed by man. The analysis was carried out between three points in time: in the periods of the Second Military Survey, the survey of the Unified National Mapping System (EOV) and the Corine Land Cover (CLC50) survey.

Intensity survey according to the Bowen–Burgess Landscape Dissection Index:

In order to analyse the landscape intensity change and establish the extent of change in the different periods, as well as to describe the degree of anthropogenity or naturalness, I used the Bowen–Burgess Landscape Dissection Index (1981). I focused on the following four settlements within the boundaries of the region: Veresegyház, Szada, Gödöllő and Isaszeg. Drawing on my earlier findings, I narrowed down the time interval to the period between the EOV and CLC50 surveys, when changes were the most intense.

The formula for calculating the Bowen–Burgess Landscape Dissection Index is the following (%):

$$LDI = 100 * P/2\sqrt{\pi SA}$$

where P = the total perimeter of the patches, A = the total area of the patches, S = the area of the patch examined.

Regarding the Gödöllő Hills, the main indicator of change seems to be the intensification of the level of residential development, which can be clearly put down to population growth. In addition to the number of inhabitants, I also looked at the changes in population density in the individual settlements. Population density, that is, the number of inhabitants per area unit, perfectly demonstrates the anthropogenic stress of a given area. I consider this indicator applicable to each type of land use within a settlement because a growing number of inhabitants means growing demands, and not only with respect to the local community network (schools and kindergartens). When a settlement has more and more inhabitants, more and more people will "use" nature as well – i.e. hike in the forests and wetlands around the settlement for recreational purposes –, which indisputably poses a stress on the natural environment.

Using population density as supplementary data, I incorporated it in the formula as follows (changing its name to landscape stress index in order to express stress due to population growth):

$$Landscape\ stress\ (\%) = 100 * P/2\sqrt{\pi SA} * \sqrt{PD}$$

where PD = population density.

3. RESULTS

Landscape change survey in the Gödöllő Hills on the basis of historical maps

At the end of the 1700s, at the time of the First Military Survey, the area examined was sparsely populated: the ratio of built-up/residential areas was a mere 0.62%. After the 150-year Ottoman occupation, nearly half of the settlements of the Gödöllő Hills were registered as uninhabited and abandoned. At the same time, Szada, Veresegyház, Mogyoród, Gödöllő, Pécel, Valkó and Úri emerged from the Ottoman rule as inhabited settlements. The population of the settlements began to rise again at the beginning of the 1700s (Galgóczy 1877a). In this period, the main land use form was meadow and pasture management, which was important for animal husbandry. Apart from that, forest lands also played a significant role: there were extensive and contiguous forests in the eastern part of the Hills (forests of Gödöllő and Isaszeg).

Between the First (1763–1787) and Second (1806–1869) Military Surveys, the most remarkable change took place in the proportion of arable lands (it rose from 2.32% to 19.97%). Grasslands were broken especially in the northern and southern parts of the area, most likely parallel to the population increase. The breaking of the grasslands led to the decline of animal husbandry. There was a negative change in the proportion of forest lands: by the mid-1800s, their ratio dropped from 39% to 32%. It was especially between Gödöllő, Isaszeg and Pécel that forests were cut down, for instance, at the site of the Battle of Isaszeg. There were efforts of reforestation as well, especially to capture the sand and to line roads and estates with trees (Galgóczy 1877a). No significant change occurred regarding vineyards and orchards. Nearly all of the settlements of the micro-region had their own vineyards, which were considered to be the main source of livelihood in many places.

By the end of the 1800s, the most characteristic land use form was the cultivation of the arable lands, which accounted for nearly half of the area examined (46.6%). The trends described above continued in this period as well. The proportion of meadows, pastures and forest lands decreased, and grasslands continued to be broken for farming. Deforestation was also pursued. It was mostly the forests of Gödöllő and Isaszeg that were cut down, and the previously extensive forests became fragmented. This is clearly indicated by the number of polygons of the forest lands. There were 142 polygons on the map of the Second Military Survey versus 329 on the third military map. There were minor changes in the other land use forms; viticulture and fruit production continued to have a decisive role in the life of the settlements.

Regarding land use forms, the land cover map (1989) prepared on the basis of the EOV topographical map showed the sustained preponderance of arable lands (36.32%) in addition to forests (37.06%) in this period. True enough, there was a decrease compared to the previous period: up until the 1970s, the proportion of arable lands dropped in nearly all of the settlements of the Gödöllő Hills. The growth (9.18%) of residential areas (built-up areas, industrial areas, traffic roads) signalled the restructuring of the micro-region. There was an increase in the distribution of hobby plots and orchards. This growth could be clearly put down to the flourishing of recreational areas in settlements near the capital. Not only orchards gained territory, but vineyards as well.

Although the time interval between the EOV survey and the CLC50 survey is shorter than the period previously examined, it still demonstrates the restructuring of the spatial structure of the landscape at the time of the political changeover. Transformation manifested itself in the form of the growth of the residential (or rather, built-up) areas (15.11%). This process was driven by the population increase due to the proximity of the capital. In the 1990s the settlements of the Gödöllő Hills, too, were increasingly affected by suburbanisation. Population swelled in each of the settlements: in the north, the growth rate was above 60% while it remained well below this figure in the middle and southern areas. It was especially high in Veresegyház (124%), where the number of inhabitants doubled in comparison with 1990, whereas in Erdőkertes (89%) and in Szada (86%), there was almost a twofold increase. The population of these two settlements has been growing at the same rate ever since.

Landscape stability survey in the Gödöllő Hills

According to the comparative analysis prepared on the basis of the First and Second Military Surveys, there was no change in 55.54% of the territory, which means that land use forms underwent a change in 44.46% of the Hills compared to the previous period. During these two periods, the most stable land use forms were forests (66.18%), arable lands (53.62%) and meadows and pastures (51.61%). With respect to the location of the forest lands that proved to be the most stable, it can be declared that extensive contiguous forests could be found in the middle and eastern parts of the Hills (forests of Gödöllő and Isaszeg), which preserved their original functions (Figure 1).

From the mid-18th century till the mid-19th century, changes occurred in approximately half of the territory of the Gödöllő Hills. As to the distribution of non-stable areas, we can say that transformation was the greatest in the case of wetlands, which are the most sensitive from the perspective of nature conservation (72.35%), but changes in hobby plots, orchards and vineyards were significant, too (52.95%).

Typical directions of change: built-up/residential areas → hobby plots and orchards; forests → meadows and pastures; wetlands → meadows and pastures; meadows and pastures → arable lands; arable lands → meadows and pastures; hobby plots, orchards and vineyards → meadows and pastures. The most typical transformation trend points towards meadows and pastures. The overall changes can be considered positive from the perspective of nature conservation. However, if we examine the situation according to land use forms, negative changes become dominant.

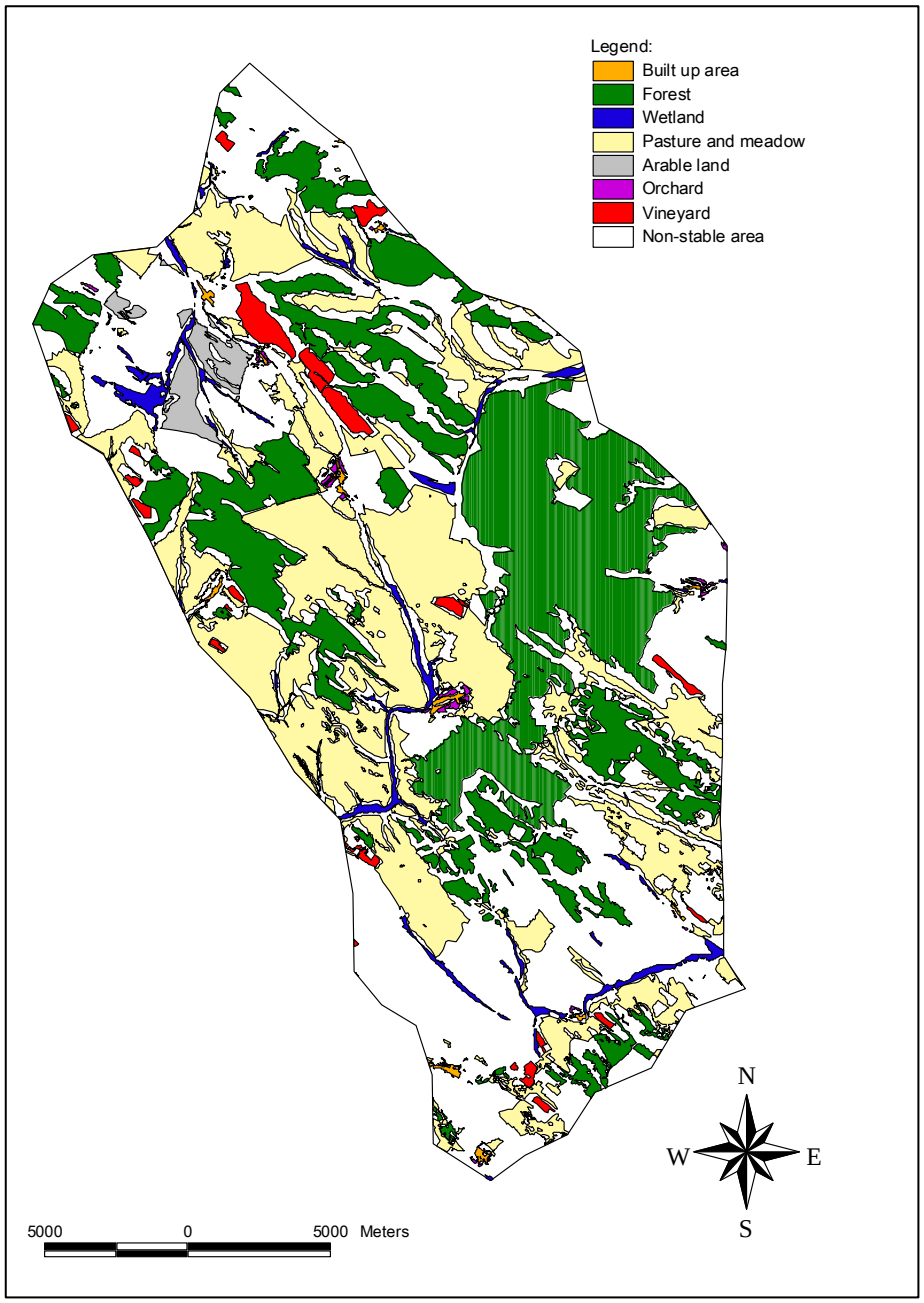

Figure 1: Stable, non-changing land use forms based on the comparison of the First and Second Military Surveys

By the end of the 1800s, regarding the period between the Second and the Third Military Surveys, land use forms remained stable in nearly half of the territory of the Gödöllő Hills (52.22%). By this time, the most stable land use form was arable lands (87.49%), followed by hobby plots, orchards and vineyards (56.67%) and forest lands (53.97%). More extensive arable lands were located in the northern and southern parts of the Hills, whereas vineyards were situated right next to the statutory urban zones of the settlements. The stability of forest lands (53.97%) continued to be dominant. At the same time, fragmentation is more and more conspicuous in the arrangement of stable land use forms (Figure 2). The biggest change according to non-stable area change distribution affected wetlands (65.86%) and meadows and pastures (65.24%).

Typical directions of change: built-up/residential areas → meadows and pastures; forests → arable lands; wetlands → arable lands; meadows and pastures → arable lands; arable lands → meadows and pastures; hobby plots, orchards and vineyards → meadows and pastures. The most typical conversion trend points towards arable lands. Considering the directions of change, it can

be asserted that in the period between the Second and Third Military Surveys, changes were negative from the perspective of nature conservation. The extension of arable lands increased mostly due to the breaking of grasslands and the filling of wetlands (especially in the central parts of the Hills and south of Isaszeg).

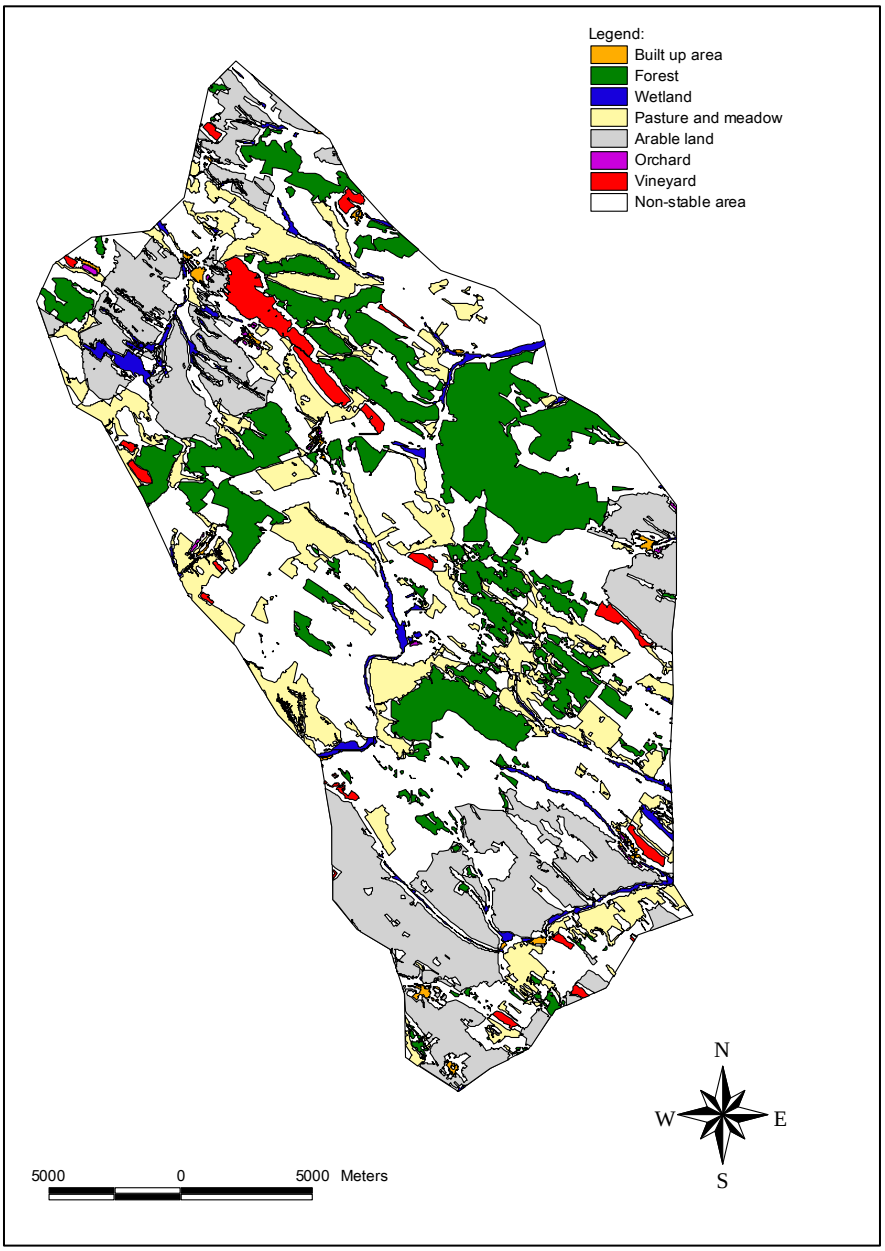

Figure 2: Stable, non-changing land use forms based on the comparison of the Second and Third Military Surveys

In the period between the Third Military Survey and the EOV survey, 46.19% of the Gödöllő Hills retained their original function. The most stable land use forms were the following: forests (76.06%), arable lands (55.03%) and built-up/residential areas (45.04%). Extensive contiguous forest lands located in the east of the Hills could be identified from Veresegyház (Erdőkertes) to Isaszeg; forest lands were not typically fragmented (Figure 3). The biggest change according to non-stable area change distribution affected wetlands (91.00%), hobby plots, orchards and vineyards (81.85%) and built-up/residential areas (54.96%).

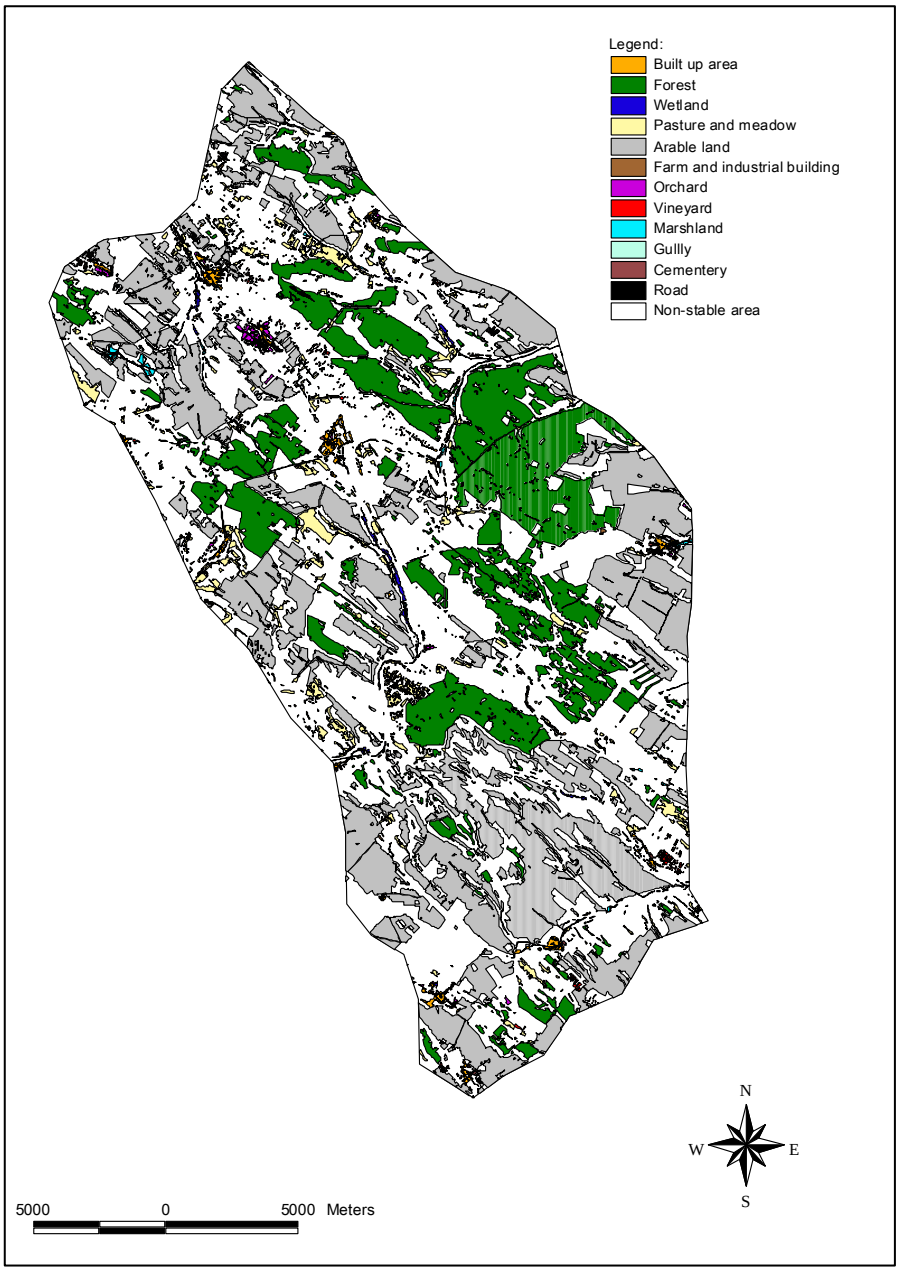

Figure 3: Stable, non-changing land use forms based on the comparison of the Third Military Survey and the EOV survey

Typical directions of change: built-up/residential areas → hobby plots, orchards and vineyards; forests → arable lands; wetlands → arable lands; meadows and pastures → forests; arable lands → forests; hobby plots, orchards and vineyards → built-up/residential areas. The most typical transformation trends points towards forest lands. The abandonment of the cultivation of meadows, pastures and arable lands led to an increased proportion of scrublands and bushes. In the period in question, the shifts in land use forms signalled positive changes from the perspective of nature conservation. However, the low stability (9%) of wetlands was worrying from the perspective of nature conservation. Parallel to that, the proportion of hobby plots and orchards did not change positively, either: based on the surveys, it can be stated that the majority of hobby plots and orchards disappeared in this period, and the level of residential development intensified. The abandonment of the cultivation of these plots forecast already the dominant phenomenon of the 1990s: suburbanisation.

The period between the EOV survey and the CLC50 survey covers the decade following the political changeover in Hungary. In this period, there were no changes in 79.63% of the territory of the micro-region, that is, land use forms remained stable in ¾ of the territory.

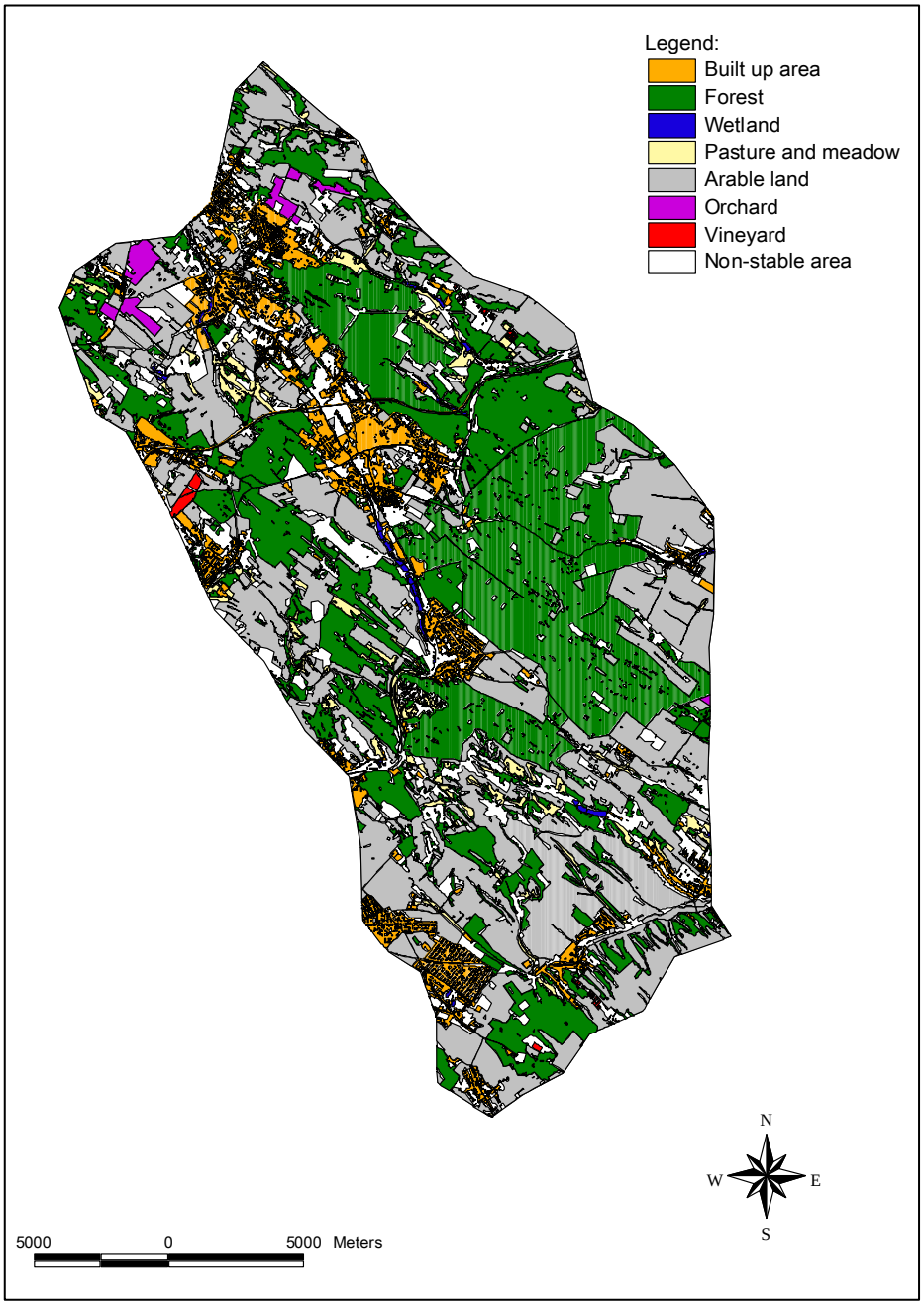

Figure 4: Stable, non-changing land use forms based on the comparison of the EOV survey and the CLC50 survey

The proportion of forests showed a high level of stability (94.43%), as did that of arable lands (90.42%) and built-up/residential areas (90.30%), all three land use forms being above 90%. Extensive contiguous forests continued to exist in the central and eastern parts of the Hills; their location grossly coincided with the area of the Gödöllő Hills Landscape Protection Area established in 1990. Forests were surrounded by arable lands. Regarding the location of built-up/residential areas, it can be observed that the settlements grew especially along the main traffic routes (roads, railway lines) – so much so that Gödöllő–Szada–Veresegyház have virtually merged by now (Figure 4). The change according to non-stable area change distribution

continued to be the biggest in the case of hobby plots, orchards and vineyards (80.85%) and meadows and pastures (77.44%).

Typical directions of change: built-up/residential areas → forests; forests → arable lands; wetlands → forests; meadows and pastures → forests; arable lands → forests; hobby plots, orchards and vineyards → built-up/residential areas. The most typical conversion trend pointed towards forest lands. It can be affirmed that the period in question was characterised by an overall positive change from the perspective of nature conservation. However, the biggest change affected hobby plots, orchards and vineyards, where the change was negative. At the same time, there was a growth in the proportion of built-up areas, which resulted not only in population growth in this period, but there were also industrial-scale developments in the certain settlements of the Hills (Veresegyház and Gödöllő). Thus, taking into consideration economic aspects, the relocation of the industry – mainly – from the capital to this area, and the new developments had a positive impact on people's livelihood.

Analysis of stationary patches in the Gödöllő Hills

Over the past 250 years, based on the maps examined, forests and arable lands showed high-level stability – in each case, they figured between the first three typical land use forms. As the next step of my research, I identified those patches that preserved the same land use form in each of the maps examined, that is, maintained their original function in each of the periods.

More than 13% of the territory of the Gödöllő Hills has a permanent land use form (Figure 5). As demonstrated by the analysis, there are five permanent land use forms that can be distinguished: built-up/residential areas, forest lands, wetlands, meadows and pastures, and arable lands. However, the high ratio of forests (12.58%) stands out even from these five categories. In other words, forest patches can be identified as stationary within this micro-region, which does not mean, of course, that the structure of the forests has remained unaltered over the past 250 years.

Stationary forest patches can be grouped into two categories: forest lands that are already under protection and those that are not. The status of forests is strongly influenced by the fact that their patches still constitute extensive contiguous areas. Extensive forests can be found in the eastern part of the Hills (forests of Gödöllő and Valkó) as well as around Isaszeg, which are already under protection within the Gödöllő Hills Landscape Protection Area.

Additional extensive stationary patches can be identified in the following locations:

- in the territory of Gödöllő, Isaszeg and Erdőkertes (forests that are not part of the Gödöllő Hills Landscape Protection Area); moreover, in the territory of settlements Csomád, Mogyoród, Kerepes, Őrbottyán, Vácegres and Maglód.

The scope of these contiguous land parts can be further classified according to the type of protection they enjoy (e.g. Natura 2000), or the international agreement by which they are protected, which reflects the value of the area in question. Accordingly, there are three more areas under protection: within the territory of the Gödöllő Hills (code: HUDI20023), the forest land between Vácegres and Váckisújfalu is a Natura 2000 area. The Veresegyház Basin (HUDI20055) and the peripheral hills of the Gödöllő Hills (HUDI20040) are also protected as Natura 2000 areas.

In consideration of the above, the following extensive forests are not yet under protection, but constitute stationary patches: Bolnoka Forest in Kerepes and Szár Hill Forest, Szentjakab Forest in Mogyoród, the forests south of Csomád (that are not Natura 2000 areas), and the forests south of Vácegres.

During the field survey, extensive contiguous forest patches were identified that are not part of the Gödöllő Hills Landscape Protection Area or Natura 2000 areas, and are not under any kind of protection at present. The aim of the field survey was to determine whether the condition

of these areas makes them suitable for protection or not, and whether these areas can be considered “natural”.

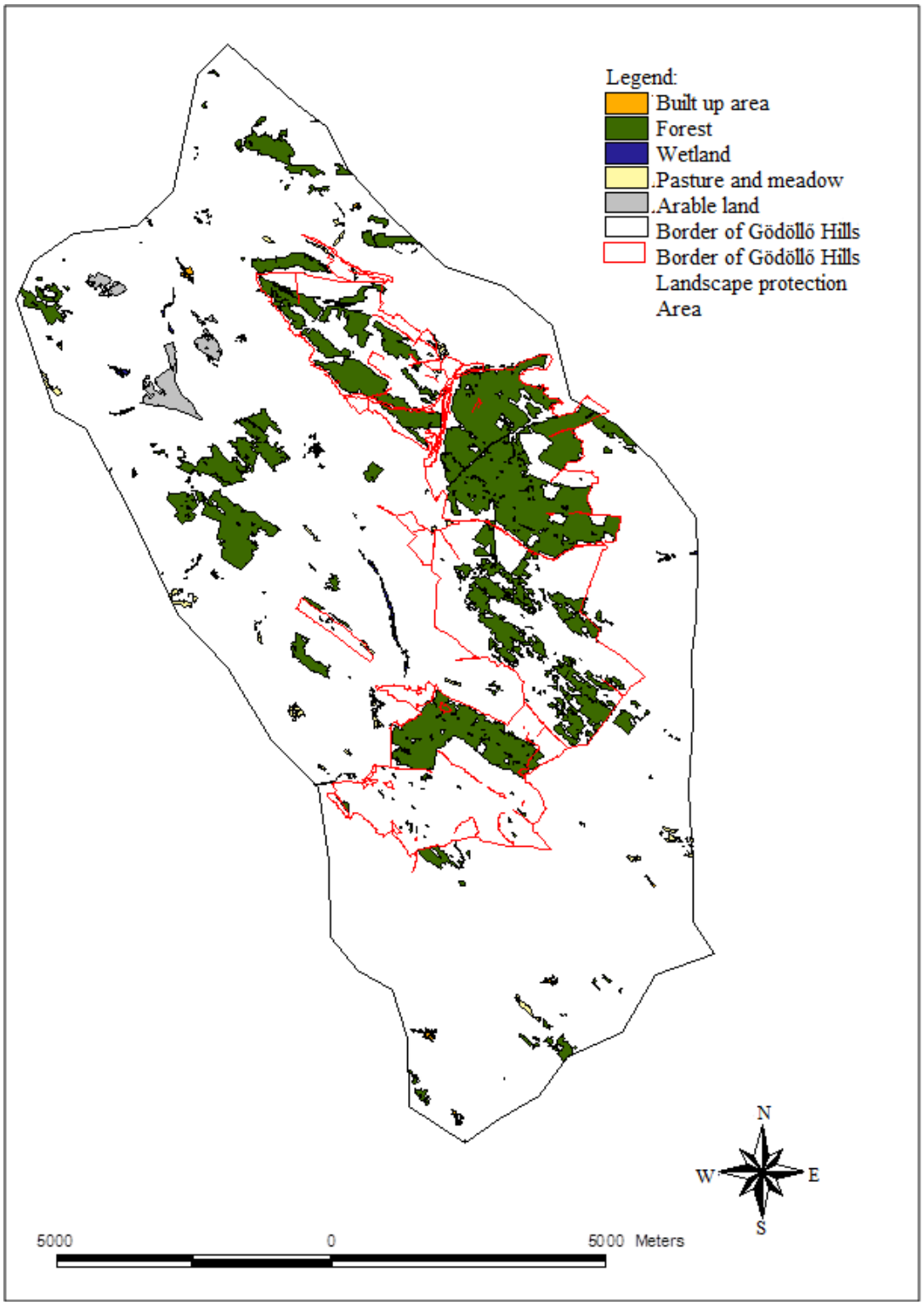

Figure 5: Stationary patches in the territory of the Gödöllő Hills

The areas surveyed were the following: Szentjakab Forest (Mogyoród), Szár Hill Forest (Kerepes), Bolnoka Forest (Kerepes), Csomád Forest, Vácegres Forest. In consideration of the naturalness list and the condition of the forest patches, two of the above five areas could apply for protection. Naturally, further (botanical and zoological) studies are needed in order to classify the areas in question and narrow down the size of the area recommended for protection. The two

areas that meet more than 50% of the naturalness criteria are the following: Bolnoka Forest in Kerepes and Szár Hill Forest. From the perspective of protection, it is important that the two selected areas are state-owned forest patches (i.e. not in private property). Moreover, as to the naturalness category of forests, Bolnoka Forest (Kerepes) is the only one of the five areas where a quasi-natural forest patch can also be found.

Analysis of landscape intensity according to the Bowen–Burgess Landscape Dissection Index

I applied the Bowen–Burgess Land Dissection Index to the area examined. I calculated its values for Veresegyház, Szada, Gödöllő and Isaszeg – settlements that are beginning to form a contiguous urbanised area along the central axis of the Gödöllő Hills. The period examined covered the decade following the political changeover. The percentage breakdown of the area and the land dissection index both confirmed changes in land use in this period.

At the time of the EOV survey, the settlements differed in the number of the patches. However, but in nearly all cases, it was meadows, pastures, hobby plots, orchards and vineyards that occupied the most patches – although representing all in all the smallest proportion of land. The most fragmented land use forms in this period were built-up/residential areas, wetlands and vineyards in all four settlements; the only difference between them was noted in their order of importance.

The other survey examined (CLC50) indicated the fragmentation of meadows, pastures and wetlands in all four settlements. The data also reveal that the least dissected, i.e. the most homogenous areas were forests and arable lands, and this result was also confirmed by the delineation of stationary patches. As to the number of patches, there was no significant difference between the settlements in this period. In the northern settlements, it was built-up/residential areas and forest lands that had the most patches while settlements in the south, it was arable lands and forests.

The fact that land use changed continuously is well-illustrated by the increase of built-up areas, which was an important phenomenon all over the Hills. Parallel to that, the population also increased. These four settlements are home to nearly 50% of the overall population living in the Hills, so it is safe to claim that they are heavily affected by anthropogenic influence. The population growth is a significant source of stress for these settlements and their natural environment: new areas become part of urban development (e.g. former holiday home zones are reclassified, new lands are subdivided, i.e. lands are taken out of cultivation and reclassified). In addition to the size of the population, its density also feeds this process. While the population density of this micro-region was 225 persons/km^2 in 1990, it was already 327 persons/km^2 according to the 2011 census. Based on the above, I calculated the so-called landscape stress index, where I complemented the original formula with population density. Population density is an excellent indicator of the population size living in a given area (settlement), that is, the amount of anthropogenic stress imposed on the area. In my opinion, the completion of the formula with population density is an even better expression of the anthropogenic stress on a landscape. It could be well-utilised in the case of urbanised areas where rapid population increase is to be expected.

New scientific results

1. I have established that over the 250 years examined, based on the five maps analysed, 13.72% of the area of the Gödöllő Hills preserved their land use form, of which 12.58% were forest lands. This method allows for identifying the so-called stationary patches, which are of key importance from the perspective of nature conservation, within an area heavily affected by anthropogenic influence, and for handling them with special care.

2. I have categorised the changing patches and land use forms of the Gödöllő Hills according to anthropogenic influence with the help of an 11-grade scale that took into consideration aspects of nature conservation. Built-up areas and wetlands proved to be the most intensively changing areas (above 60%< in all periods), with a negative impact on naturally valuable areas. The increase of built-up areas entailed the intensification of fragmentation as well.

3. In order to specify the condition of stationary forest patches, I have used my own 12-point list taking into consideration the presence of anthropogenic influence, and I have conducted field surveys. Based on these results, I propose two areas for natural protection: Bolnoka Forest in Kerepes and Szár Hill Forest.

4. Regarding the settlements of Veresegyház, Szada, Gödöllő and Isaszeg, I have examined the extent of landscape dissection in the 1990s in order to characterise anthropogenity/naturalness according to the Bowen–Burgess Landscape Dissection Index. I have complemented the index with a new variable (population density) in order to make anthropogenity more accurately justifiable through statistics. Based on my analysis, I have established that the proportion of the so-called "landscape users" represents heavy stress in the case of wetlands and forests – areas that are the most sensitive from the perspective of nature conservation.

4. CONCLUSIONS AND RECOMMENDATIONS

Landscape changes in the Gödöllő Hills on the basis of historical maps

Based on the examination of the historical (military) and current maps of the past more than 200 years, it can be affirmed that significant changes have taken place, especially with respect to society's landscape-forming effect. This claim is also supported by Frisnyák's (2008) research (about the 18th–19th centuries in the Gödöllő Hills), who said that subsequent generations have created a cultural landscape in these hills.

There are three categories that can be distinguished according to the changing trends. The first category includes land use forms where we can see a clear increase, such as in the case of built-up areas: at the end of the 18th century, urban development was 0.62%, which leaped to 15.11% by the end of the 20th century. Growth was permanent, with no setbacks in any of the periods. The settlements of this micro-region began to be repopulated at the beginning of the 1700s. The economic development and repopulation of the area was greatly enhanced – in addition to the returning inhabitants – by the Slovaks coming from Upper Hungary (Frisnyák 2008). At the time of the "new beginning", there were only a couple of hundreds of people living in a settlement, whereas these towns – especially the ones in the metropolitan belt of the capital – have tens of thousands of inhabitants today. Over the past two centuries, essentially, the number of settlements has not changed. These towns have been constantly around, with a few minor exceptions (certain names have been modified, settlements have been consolidated, or parts of a settlement have become independent). The growth in the number of inhabitants also affects certain aspects of nature conservation as the latter is closely interrelated with the expansion of settlement and traffic infrastructure (construction of real estate, public buildings, industrial areas, railway lines and motorways). This further reinforces anthropogenic influence, and consequently leads to the reduction and fragmentation of undisturbed natural areas, diminishing the quality of the remaining areas.

The second category contains wetlands, meadows and pastures, and vineyards. These land use forms were characterised by a steady decrease due to the growing need for land (parallel to the trends described above). With the exception of vineyards, this led to a reduction in the size of lands that would have been potentially valuable from the perspective of nature conservation. The

shrinking of the size of lands covered by water is a phenomenon whose relevance is not restricted to the territory of the Gödöllő Hills – it is typical of other areas in Hungary as well (Tóth & Centeri 2008, Szabó et al. 2011). The increasing importance of agriculture and settlements has played a major role in that.

The third category includes those land use forms where there were changing, yet opposite trends in the period examined, in the case of forests and arable lands. The forest lands of Hungary – and of the Gödöllő Hills – have become larger over the past 90 years (Kovácsevics 2014). However, there is a significant difference between the proportions of forest cover in the country and in this micro-region: the forest cover of the Gödöllő Hills is nearly twice as high (approx. 21%) as the national average and is nearly 10% higher than the average of the North Hungarian Mountains (Fejes & Restyánszkiné Jaczkó 2013, Kovácsevics 2014).

By now, vineyards represent the smallest land ratio, having decreased from 3.08% at the end of the 18th century to 0.44%. The history of this micro-region used to be hallmarked by the wine-growing sector. Up until the end of the 19th century, some settlements even used to make their own wine (Galgóczy 1877b). The expansion of orchards and vineyards was greatly enhanced by the popularity of hobby plots and holiday homes in the 1970s and 1980s. The decline of their boom is most likely due to economic market growth – nowadays most people prefer to buy fruits and vegetables instead of producing them on their own.

Landscape stability in the Gödöllő Hills

I have set up a system of categories (an 11-grade scale) in order to describe landscape stability and examine its changes, which has helped me to take into consideration aspects of nature conservation, i.e. which has identified the direction of these changes. Based on that, I have concluded that in the past 200 years, stability has remained above 50% (with the exception of the EOV topographic survey in 1989). It was the greatest in the most recent period (between the EOV survey and the CLC50 survey), but the time elapsed between these two surveys was much shorter than in the other cases.

Regarding stability, in the periods compared, arable lands and forests have always been among the three most stable land use forms, as intensively cultivated areas and areas that deserve special attention with respect to nature conservation. These two stable land use forms are similar in that they both constitute extensive and contiguous parts of the landscape; fragmentation is not characteristic of them.

Similarly to the Gödöllő Hills, the growth of forest-covered areas could be detected lately in other parts of the country as well (Antal et al. 2010, Tóth & Centeri 2008, Zagyvai 2008). The area of forests has increased. Forests can be considered stationary habitat patches, but their structure still gives reason for concern. Forests are often not characterised by quasi-naturalness.

By the 1950s, so-called "spoiled forests" became more and more dominant, so hundreds of hectares of such forests were cut down each year. Reforestation was the easiest to perform with exogenous species, so black locust (false acacia), eastern black walnut, Ailanthus and black pine trees were planted (Fekete & Varga 2006).

Concerning changing, non-stable patches, it can be affirmed that "wetlands", "hobby plots, orchards, vineyards" and "meadows and pastures" showed the least stability. There was an especially significant change in the case of the most sensitive wetlands. If we look at the directions of change, most of these areas came under cultivation as arable lands, or were converted into meadows and pastures.

Wetlands are increasingly reduced in area; the remaining wetlands respond sensitively to any change, and their rehabilitation is a lengthy process. The EU's Water Framework Directive is aimed at the conservation and improvement of the condition of surface waters and groundwater, which, in many cases, can be achieved through the cooperation of several countries (Http2). Wetlands react sensitively to climate change as well, for instance, to flash floods that have become more and more frequent these days, and which play a major role in the intensification of gully erosion.

Stationary patches, which have maintained their original function, but not necessarily their structure, deserve special attention from the perspective of nature conservation.

The delineation of stationary patches can confirm the result of the stability survey, namely that forests are not only the most stable, but also the most decisive land use forms with respect to permanence. The Gödöllő Hills Landscape Protection Area has been set up along the extensive forests of the territory. The conservation of the forest patches was enhanced by the fact that these forests used to play a special role as royal pastures and hunting areas. As a condition of Hungary's adhesion to the European Union, Natura 2000 areas have also been designated. The latter territories (stationary forest patches) have proved to be a favourable addition to the already protected areas. 40% of Hungary's forests are now under protection, including Natura 2000 areas (Kovácsevics 2014). A significant proportion of stationary forest patches are located in the Gödöllő Hills Landscape Protection Area, which means that landscape change has been more moderate within the area than outside of it.

Completing the quantitative examination with field surveys, I have come to the conclusion that out of those forest patches that are not currently under protection, two could be proposed for protection (to be confirmed by further examinations). These two suggested forest lands are Bolnoka Forest and Szár Hill Forest at Kerepes.

Landscape intensity in the Gödöllő Hills

Regarding the quasi-natural (wetlands, forests, and meadows and pastures) and anthropogenic (built-up/residential areas, arable lands, hobby plots, orchards and vineyards) categories, it can be stated that the location of these habitat patches is increasingly dominated by fragmentation and anthropogenity.

Based on settlement and traffic infrastructure, the Gödöllő Hills are among moderately fragmented areas. About 10% of the micro-regions belong to this group (Csorba 2005). Regarding the size of the population and the expansion of built-up areas, I have concluded that an urbanised area is starting to emerge along the central axis of the Hills (Veresegyház–Erdőkertes–Szada–Gödöllő–Isaszeg), and the urbanisation process manifests itself the most spectacularly in the case of the first four settlements. The intensification of urbanisation is a trend that characterises not only Hungary, but other European countries as well, and not only in the more urbanised territories in the west, but also in Greece, for instance (EEA 2015, Eurostat, 2018).

If we take a look at the individual settlements, it can be stated that ever since the 1980s, the ratio of built-up areas has been above 10% in Veresegyház, Szada and Gödöllő according to the EOV survey whereas it surpassed 25% according to the CLC50 survey (except in Isaszeg).

The changing land use is also confirmed by the Bowen–Burgess Landscape Dissection Index (LDI): in both periods examined, wetlands as well as hobby plots, orchards and vineyards showed a high level of fragmentation – though the latter category was not registered by the CLC50 survey due to the map's scale. Furthermore, it can be observed that the least fragmented patches of the micro-region were forests and arable lands.

In order to show the intensification of social presence, I have complemented the Bowen–Burgess Landscape Dissection Index with a new variable. In my opinion, this addition may be possible or necessary where, on the one hand, the population has clearly grown over the past 10-20 years, and on the other, where we are dealing with a suburbanised region located in the metropolitan zone of a major city, possessing favourable geographical features with respect to its location and traffic. In the case of the Gödöllő Hills, both conditions apply. First, the number of inhabitants has been growing since the 1990s in the four settlements examined, especially in Veresegyház which had 6,373 inhabitants in 1990 versus 15,998 inhabitants in 2011. Second, these are all settlements situated close to the capital, at a 31-40 km distance.

In order to express the stress caused by the growing population on the natural environment, I have referred to a relative indicator, population density, which shows the anthropogenic stress per area unit. The thus re-calculated index (the so-called landscape stress index) has also

confirmed that the growing population poses the biggest stress on wetlands and forests, i.e. on patches that deserve special attention from the perspective of nature conservation.

Recommendations

1. In order to correct the errors of land cover map series owing to the map's scale, I suggest the elaboration of a central guideline, with a special focus on the identifiability of the factors causing changes in the increasingly fragmented nature conservation areas.
2. With the help of the 11-grade scale that I have applied, the direction of changes is easy to follow, so I recommend the application of this scale for the elaboration of the long-term development plans of settlements. The scale may offer information about the reduction of areas that are sensitive (valuable) from the perspective of nature conservation, the direction of changes, and it may provide help in establishing the extent of changes.
3. Analysing the stability may be useful during the planning process of applying for protection for areas belonging to certain settlements. The creation of a puffer zone around patches identified as stable is also worth considering so that land subdivision and urban development for various (industrial or real estate) purposes do not take place adjacent to these stable patches.
4. The 12-point list may be suitable for assessing anthropogenic influence in other cases as well, as it describes forest patches in more detail from the perspective of nature conservation. I have recommended two areas for protection: Bolnoka Forest at Kerepes and Szár Hill Forest. The Bolnoka block (an approximately 26-hectare land northeast of the urban zone of Kerepes) has been classified as quasi-natural. In my opinion, this is where further examinations and a potential reclassification of the forest patches should be initiated. In order for an area to be placed under protection, additional (botanical and zoological) examinations must be carried out that may confirm or further narrow down the shape and extension of the lands proposed for protection.
5. I recommend the further expansion of the 12-point list and the elaboration of a related scoring system.
6. During the interpretation of one of the most important land use conflicts (the stress imposed on public roads due to a growing population, increasing urban development, etc.), the application of the landscape stress index may reveal what sort of environmental stress these factors will mean for a region and its valuable areas from the perspective of nature conservation, so I recommend its use during the planning of territorial development.

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