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Summary of Ph. D. thesis

The analysis of the spatio-temporal patterns of forest structure in Haragistya-Lófej forest reserve (Aggtelek Karst)

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1. INTRODUCTION, AIMS AND BACKGROUND

Due to their geographical location the natural vegetation in Hungarian karstlands is mainly mixed deciduous forest. There is still considerable forest cover in these areas therefore their past and present state is determined by forest management. As the forests in Europe in general, Hungarian forests also bear strong marks of previous forest management so little is known about their natural conditions or dynamics. Haragistya-Lófej forest reserve, situated on a karstic plateau of the Gömör-Torna Karst, is ideal for long-term studies; although in the past it was subject to very intense human impact, anthropogenic pressure decreased during the past few decades. Therefore the current processes work towards the development of a dynamic equilibrium.

The primary purpose of my forest structure studies in the reserve is to record the initial state after the abandonment, so that the resulting database serves as a baseline for long-term monitoring allowing a detailed examination of future changes. In the case of smaller areas stand structure can serve partly as an easily measureable surrogate for biodiversity and partly as a key variable in understanding the sources of biodiversity in the forest ecosystem. Studying structural elements at the stand level is also important because the stand is the basis of forest management; although an intervention affects all the components of the ecosystem, it is primarily aimed at the structure, which is directly and rapidly affected. Thus similar studies may provide useful lessons for a more natural approach in the handling of managed forests, which is currently a hot topic due to considerations of the other (not directly economic) functions of the forest.

In order to understand stand structural patterns it is necessary to know the processes affecting them. Despite the small size of the study area its topography, vegetation, and history are very heterogeneous (because of its karstic nature), so a further aim was to assess the importance of the natural and anthropogenic effects locally influencing forest structure. In order to do this, I collected and analysed historical data, carried out soil measurements and distinguished different habitat types using parameters calculated from a digital elevation model.

Aggtelek Karst is a transitional area with alpine, continental and sub-Mediterranean species occurring simultaneously therefore climate change would probably affect it heavily. Together with anthropogenic activity, it will affect long-term forest dynamical processes, therefore I found it important to analyse the climatic trends of the last 50 years, which define the current state of the stands and to look at my findings with regard to the ecological needs of the most important tree species of the area.

2. THE STUDY AREA

The study area is situated in the 'Aggtelek Mountains' geographical unit, which is part of the Aggtelek-Rudabánya Mountains. In the dissertation I use the name Haragistya to describe an approximately 10 km^2 area of the Silica plateau (located mainly in Slovakia) delineated on the basis of historical sources. I analysed the forest history data of the entire Haragistya plateau while my forest structure measurements were carried out in permanent plots in a smaller, 90-hectare area. Half of the plots are situated in the buffer zone of Haragistya-Lófej forest reserve while the other half in its core area.

The area's climate is cool, moderately humid continental, with an annual mean temperature of 8.9 ° C, and a mean annual precipitation of 620 mm. The mean temperature is -2.8 °C in January while 19.2 °C in July. The open karstic surface is mostly built of Wetterstein limestone and dolomite. Precipitation is the main (and in most places only) source of water on the plateau. The terrain is very diverse. The surface is mostly covered by different intrazonal soil types formed on the chalky bedrock (mainly shallow rendzinas or rocky soils). In the negative forms deeper colluvial soils and brown forest soils could also develop.

Aggtelek Karst belongs to the *Tornense* floristic area within the Northern Mountain Ranges (*Matricum*) district of the *Pannonicum* region. Due to its transitional nature its flora is very diverse even within a small area in which the spatial variability of the karstic microhabitats plays a major role. On the Haragistya plateau sessile oak-hornbeam forests (*Carici pilosae-Carpinetum*) are situated on the hilltops and northerly exposed slopes. The lower tops and southern slopes are characterised with xerothermic oak forests; Turkey oak-sessile oak (*Quercetum-petraea-cerris*) stands occupy the deeper soils while thermophilous oak forests (*Corno-Quercetum pubescenti-petraeae*) with a well developed shrub layer can be found on shallow soils. Extrazonal patches of submontane beech forests (*Melitti-Fagetum*) occur on the northern slopes and at the bottom of valleys. Ash-lime forests (*Tilio-Fraxinetum excelsioris*) appear in smaller patches (on the steep sides of larger dolines). Coniferous plantations occupy a larger area and meadows are also part of the overall picture.

3. Methods

For most of the work (unless otherwise specified) I used ArcGIS 9.1 software for the spatial analysis and MS Excel 2003 and PASW Statistics 18 for statistics and database building.

3.1. The review and analysis of forest history

In order to describe and analyse the era preceding the date of the first forest inventory (1934) I used information from the literature. For this period I mainly examined the general nature of earlier land use and the extent of anthropogenic impact. For the analysis of the forest use and species composition changes of the 20th century I used the available forest inventories from 1934 to 1993 (complete with data from 2003 for the forest structure study area). I georeferenced the forestry maps with the ERDAS Imagine 8.5 software package.

3.2. Climate trends between 1958 and 2008

I included the analysis of some climatic factors for the period between 1958 and 2008, as background factors of particular importance concerning changes in species composition. It is based on data from the Jósvafő meteorological station of the Hungarian Meteorological Service situated approximately 2 km south-southeast of the study area at 270 m above sea level. Besides the tendencies of annual mean temperature and precipitation I examined the values of Ellenberg's Climate Quotient. I distinguished periods of drought and humid periods using the Standard Precipitation Index (calculated using monthly precipitation data for 3-month base periods with SPI SL 6 software). I examined the annual number and magnitude of drought and humid periods for the 50 years.

3.3. Stand structure and species composition

Stand structure measurements were carried out from April 2006 till November 2007 in the 90-hectare study area described above. The position, dbh, species, crown class and other characteristics of trees and shrubs with a dbh exceeding 5 cm and/or 5 m of height were recorded in 361 10 m radius permanent plots situated in a 50x50 m grid. Characteristics of lying deadwood (length, diameter, species, decay state) were also recorded for every piece within the plot if its middle diameter exceeded 5 cm. In order to define stand height I used a height map produced automatically as the difference between a digital terrain model and a digital elevation model. Of the recorded data I calculated different compositional (e.g. diversity-related) and structural (horizontal and vertical, describing spatial distribution, size or quantities) indices for various groups of the measured individuals (e.g. trees and shrubs, living and dead individuals). In order to jointly analyse the structural indices I selected 7 variables related to naturalness. Handling the three main forest types (dry, open oak woods; mesophilous oak and beech) separately, I first tried to form groups using hierarchical cluster analysis and then characterise them with discriminant analysis. Then I classified the plots on the basis of their deviation from the means of the major forest types and thus created a 'naturalness value', which would be independent of species composition.

3.4. The relations of stand structure and the background variables describing stand history and site quality

I grouped the plots according to different criteria (forest types defined on site, based on species composition; site quality; stand age according to the forest inventory; last known period of use), and examined the similarity of the means of the different indices in the groups using the Mann-Whitney U-test. I analysed the relationship between the various (independently produced) groupings using contingency tables. χ^2 test was applied to find out whether there was a relationship, while I used the contingency coefficient to describe its strength.

The different measured and calculated values of the stands' structural and compositional characteristics were compared with the results of my soil investigations in a smaller part of the study area (parameters included soil depth; pH; organic matter, calcium and total N content) and various morphological, hydrological, and microclimatic parameters derived from a DEM. Spearman's rank correlation was applied for the comparison. I also examined the characteristic species on the different genetic soil types, and the distributions of terrain parameters in the different forest types.

3.5. The reconstruction of near-past dynamics

According to my hypothesis, if the proportion of tree species at a certain place changed in the near past the species composition of the living trees and shrubs would be different from that of the total population (including the live, standing dead and freshly fallen trees and shrubs). The latter thus serves as the model of a (fictional) earlier state. I compared the composition of the currently living individuals and the modelled earlier state for all forest types using χ^2 test, and also calculated the difference in the species numbers. In addition I examined the distribution of tree species across diameter groups and crown classes.

4. Results

4.1. The review and analysis of forest history

4.1.1. Concerning anthropogenic influences prior to the 20th century indirect (agro-terrace traces, soil characteristics, geographic names, historical descriptions) or direct (military maps) sources indicate that *the area was subject to very intensive use at least since the Middle Ages*, and was not always used as a forest (rather possibly as orchard or arable land, later as pasture) (Tanács et al. 2006, Tanács et al. 2007a). Permanent forest cover can be assumed from the mid-1800s but the stands were probably grazed, sparse coppices. While the diverse geological, geomorphological features have probably always insured a varied forest cover, the different anthropogenic interventions (affecting habitat, species composition and the site as well), further increased this, therefore by the 20th century, the spatial variability of the vegetation became very high.

4.1.2. *The last period of intensive land use* determining the current stands *took place in the first half of the 20th century*, when the majority of the stands were clear-cut. After this period larger amounts of wood were only extracted in the 1970s and 1980s (through thinnings). The stands earlier situated along frequently used paths became peripheral after the Trianon Treaty in 1920; therefore *coppice stools had a key role in the regeneration processes following the clear-cuttings*. The initial management works were skipped or started late due to a lack of resources. Artificial propagule input only occurred later, from the 1950's but even then mostly conifers (*Pinus nigra, Pinus sylvestris, Picea abies*) were planted in the northern part of the plateau (Tanács et al. 2006, Tanács et al. 2007a).

4.1.3. Conifers were planted in the north until the 1970's. Larger amounts of wood were only extracted in the 1970s and 1980s (through thinnings).

Following the foundation of Aggtelek National Park in 1985, then the designation of Haragistya-Lófej forest reserve in 1993 (which now includes a large part of the plateau), *direct anthropogenic impact ceased* (Tanács et al. 2006, Tanács et al. 2007a). *Currently, the most influential anthropogenic factor* (indirectly) affecting the processes of the core area of the reserve *is the high number of game*. Natural dynamics, at least concerning regenerative processes, have declined from the 1970s and 1980s (just like in other areas of the national park); *chances of regeneration and the function of gap dynamics are limited*.

4.1.4. At the end of the 1700s, the dominant species in the forests of the area were oak (probably sessile oak, or downy oak) and beech. *According to the data of the first forest inventory* available from the area (from 1934) *most of the stands* then already *consisted of sessile oak and hornbeam*, with some beech and trembling aspen in the south (downy oak was not distinguished). *The major changes* reflected in the archive inventory data *are a steady growth of the area of pine plantations* in the north (until the 1970s), *the slow expansion of beech to its potential sites* in the southern parts (on dolomitic bedrock), and *the spreading of hornbeam* from the 1980s. The plantations and the expansion of the above species typically occurred at the expense of sessile oak (Tanács et al. 2006, Tanács et al. 2007a). Besides a possible species selection during the thinning procedures, the oak decline of the 1980's may also have contributed to the retreat of the latter species.

4.2. Stand structure and species composition

4.2.1. *The species composition of the study area is still dominated by sessile oak and hornbeam* forests, along with terrain-dependent habitat mosaics of beech and downy oak dominated stands, mixed with other tree species (varying in type and numbers). Forest types with special history or site requirements only appear in small-sized patches (e.g. birch or lime-dominated patches related to dolines) (Tanács 2007, Tanács et al. 2010).

4.2.2. *The species distribution of snags* (including shrubs, calculated on the basis of stem number) *is different from the distribution of live trees and shrubs*. Sessile oak, downy oak, hornbeam, and juniper (as an indicator of stand history) dominate. Differences between the distributions are forest type dependent (Tanács 2007, Tanács et al. 2010).

4.2.3. *The horizontal structural indices describing size* (e.g. diameter at breast height and its statistics), *or quantity* (timber volume, stem number, basal area), *show a marked difference between the northern and southern part*, which can be explained partly with differences in the site and partly with age. Of the vertical indices, *stand height strongly reflects surface morphology*: the highest forests can be found on the deeper soils accumulated in the negative forms where growth is also stimulated by the competition for light (Tanács et al. 2007b).

4.2.4. *The volume of lying deadwood* is on average 21.89 m^3/ha, which *corresponds to the values of managed forests*, but some of the sampling points show values similar to those of natural or near-natural stands. This quantity currently depends on the local dynamical phenomena due to the similar age of the stands, and previous treatment – the death of a single tree may significantly increase the amount. The species distribution of logs more or less follows the species composition of the study area but the three most common species are followed by pioneer, light-demanding species, now rare among the living individuals.

4.2.5. *The amount of lying and standing deadwood and the diversity of decay classes were key factors in defining the naturalness groups* (created with the hierarchical cluster analysis of selected structural indices, 2-3 for every major forest type) in the dry oak, hornbeam-oak and beech forests as well. Besides these vertical diversity played an important role in the dry oak forests whereas the diversity (species and size) of standing (dead and live) trees separate the groups in the beech forests.

4.2.6. The classification based on the differences of the selected indices at the plots from their means calculated for the major forest types proved useful in separating plots with more or less natural structure. With the applied procedure I managed to eliminate the effects of species composition, and it allowed a comparison between the different (major) forest types, although the results are valid only locally.

4.3. The relations of stand structure and the background variables describing stand history and site quality

4.3.1. *Morphological categories* describing the site (combined with aspect) *show a significant, but moderate relationship with the distribution of forest types* (defined in the field by their species composition). However the histograms of the various morphological parameters calculated from the DEM of the area strongly overlap between the different forest types. There are some forest types of which the spatial location cannot be explained with natural factors only.

4.3.2. *A (weak) relationship between soil properties and the relative frequencies of species* (calculated based on the stem number of live individuals) *could only be shown in some cases*, which corresponds to previous findings in the literature. *Soil depth proved the most important of the investigated 7 soil characteristics* – its correlations highlight the two extremes i.e. beech, which is dominant on the deeper soils, downy oak and cornel, dominating on shallow soils.

4.3.3. Among the parameters derived from the DEM clearly the complex features such as potential sunshine duration and radiation (describing the microclimatic conditions), and the convergence index are most strongly linked to the species composition. Since these show the strongest correlation with soil depth as well, in absence of soil data they can be used as proxy in similar sites in similar studies.

4.3.4. Forest types are significantly associated with both background variables chosen to characterise human impact. This suggests that the spatial patterns of forest types and species composition are not only determined by the terrain and the site conditions, but management history as well. The current spatial distribution of tree species can therefore change even without further influences (e.g. another human intervention, climate change, etc.) in the future.

4.3.5. *The relationship of horizontal structural indices describing size or quantity with the age groups* (the means of 100-120 year-old stands are significantly higher than those of the younger stands) *as well as the lower species diversity of the middle age group* (80-100-year-old forests) *suggest a kind of turning point in the dynamics around the age of 90-100*. This is supported by the observation that the strength of the relationship between the stem number of standing dead trees and the total stem number is different for each age group – the difference depends on forest type.

4.3.6. *Few of the single structural indices can be linked to the last period of use*. However, the *naturalness categories* created on their basis *show a significant relationship with this particular background variable*. The *naturalness categories are also related to the distance from remaining* (still used) *roads*.

4.3.7. The distribution of forest types over the age groups suggests that the *thermophilous oak forests represent the initial phase of spontaneous regeneration processes in the most extreme sites of the study area* (in some places meadows still occupy some of their potential sites). The oak forests interspersed with large seed trees preserve memories of former grazing whereas unmixed hornbeam stands characterizing the 80-100-year age group are probably the results of single emergency extractions.

4.4. The reconstruction of near-past dynamics

4.4.1. *The presence of dead junipers* even in stands currently dominated by beech is an important sign when trying to reconstruct past dynamical processes. Besides the gradual closure of the forest canopy it also *suggests* *a similar initial state* (open woodland pasture with a few seed trees) even *in currently very different stands* (Tanács 2007, Tanács et al. 2010).

4.4.2. Since there is no evidence of plantation using native species in the available inventories and management archives the *current diversity may be the result of the different speed and nature of the succession processes*. On the deeper soils of concave slopes and negative forms the struggle for light may have defined species composition from the beginning, while on the convex slopes and positive forms the soil eroded by previous use and, indirectly, the microclimatic conditions may have become determinant.

4.4.3. In certain forest types *the χ^2-test showed a significant difference between the species composition of living trees* (based on stem number) *and the past species composition modelled* on the basis of the stem number of all the individuals (including live trees, snags and logs) in the plot. In beech-hornbeam forests the differences suggest a recent increase in the proportions of beech and hornbeam. In hornbeam-sessile oak forests the difference is probably caused by the higher proportions of oak species (especially downy and sessile oak) in the modelled past, and possibly the expansion of hornbeam, but the difference is much smaller compared to the total number of trees examined than in the case of the hornbeam-beech stands (Tanács et al. 2010).

4.4.4. The possibility to analyse regeneration processes is limited due to the 5-cm diameter limit applied. The low number of young (crown class=6) trees, the diameter distributions of the main species and general observations from the area during the work make it clear that *regeneration processes have been limited for a while*. Shoots still play a significant role but are no longer dominant. *The four most common species among the young individuals are all shade-tolerant* (at least at young age), but field maple and wild service only appear where beech has not yet become dominant in the upper canopy. Where this is the case, other species could not recently regenerate. In mesophilous sessile oak-hornbeam forests the young trees are mostly hornbeams, or field maples. In the dry, open oak forests the species composition of young trees is more varied, and sometimes (downy) oak also appears, although the proportions of wild service and field maple are higher (Tanács 2007, Tanács és Bárány-Kevei 2010).

4.4.5. Of the two main processes directly influencing the species composition *mortality is clearly* the *dominant* one, *resulting in a decrease of species diversity, and a reduction in spatial aggregation*. Even omitting the data of juniper 42,3% of the sampling plots have at least one species among the dead individuals which cannot be found among the live trees or shrubs in the plot. However, new species (compared to the older living trees) appear among the young trees only in 14% of all the plots. In most cases they are wild service or field maple.

4.5. Climate trends between 1958 and 2008

4.5.1. Annual mean temperature shows an upward trend from the beginning of the 1980s. No apparent change is detectable in the annual precipitation sums in the examined period. The Standard Precipitation Index calculated using monthly rainfall data for 3-month base periods shows that from the 1980's onwards, the number and magnitude of drought have increased whereas the opposite is true for humid periods. From the 2000's, the latter trend seems to ease, which in turn results in both extremes subsequently occurring (Tanács és Bárány-Kevei 2010, Tanács 2011).

4.5.2. *Ellenberg's Climate Quotient indicates the transitional nature of the area (between oak- and beech-dominated forests)*, slightly favouring oak. Although years in favor of oak are more common, the climatic characteristics apparently provide the necessary conditions for beech to occur in negative forms and on northern slopes and to re-occupy its potential sites. This is supported by the fact that beech did not retreat even during the droughts of the 1980s and 1990s. *The expansive nature of beech regeneration processes confirms that the current occurrence and* *patterns of this species are not (or not entirely) the result of limiting environmental factors but the former direct and indirect anthropogenic influence*. The observed phenomena again draw attention to the fact that the current area of beech in Hungary does not necessarily indicate the potential boundaries of this species, therefore calculations and scenarios based on its current occurrence could be misleading. In terms of potential climate alterations the survival of beech stands near their xeric limit could be significantly affected by local site conditions (Tanács 2011).

PUBLICATIONS DIRECTLY USED FOR THE DISSERTATION

TANÁCS, E., SZMORAD, F., KEVEI-BÁRÁNY, I. (2006): A Haragistya (Aggteleki-karszt) erdeinek története [The history of the forests on the haragistya plateau (Aggtelek Karst) – in Hungarian]. In: A III. Magyar Földrajzi Konferencia kiadványkötete.

TANÁCS, E. (2007): Erdőszerkezeti vizsgálatok a Haragistya-Lófej erdőrezervátumban [Forest structure studies in haragistya-Lófej forest reserve – in Hungarian]. In: Tavaszi Szél konferenciakiadvány. Műszaki, tudományok, élő és élettelen természettudományok. pp.

TANÁCS, E., SZMORAD, F., KEVEI-BÁRÁNY, I. (2007a): A review of the forest management history and present state of the Haragistya karst plateau (Aggtelek Karst, Hungary). Acta carsologica 36. pp. 441-451.

TANÁCS, E., SAMU, A., BÁRÁNY-KEVEI, I. (2007b): Forest structure studies in Aggtelek National Park (Hungary). Acta Climatologica Et Chorologica Universitatis Szegediensis 40-41. pp. 123-133.

TANÁCS, E., SZMORAD, F., BÁRÁNY-KEVEI, I. (2010): Patterns of tree species composition in Haragistya-Lófej forest reserve (Aggtelek Karst, Hungary). In: Barančoková, M., Krajčí, J., Kollár, J., Belčáková, I., (Eds.). Landscape ecology - methods, applications and interdisciplinary approach. Institute of Landscape Ecology, Slovak Academy of Sciences, Bratislava, pp. 767-780.

TANÁCS, E., BÁRÁNY-KEVEI, I. (2010): Patterns of tree species composition and their relation with climate and past forest management in Haragistya-Lófej forest reserve (Aggtelek Karst, Hungary). In: Ostapowicz, K., Kozak, J., (Eds.) Conference Proceedings of the 1st Forum Carpaticum, Integrating Nature and Society Towards Sustainability. pp. 64-65.

TANÁCS, E. (2011): Temperature and precipitation trends in Aggtelek Karst (Hungary) 1958-2008. Acta Climatologica Et Chorologica Universitatis Szegediensis 44-45. *IN PRESS*

PUBLICATIONS RELATED TO THE TOPIC OF THE DISSERTATION

BARTA, K. **TANÁCS, E.** SAMU, A., BÁRÁNY-KEVEI, I. (2009): Hazai rendzinák megfeleltetése a WRB nemzetközi talajosztályozási rendszerben [*Correspondances of Hungarian rendzina soils to the WRB international soil classification system* – in Hungarian]. Agrokémia és talajtan 58/1 pp. 7-18

KEVEI-BÁRÁNY, I., **TANÁCS, E.** (2006): Changes in the conditions of forest cover in Hungarian karstic mountain regions (case study from Aggtelek Mountains). In: Martin F. Price (Ed.) Global change in Mountain Regions. Sapiens Publishing pp. 246-247.

TANÁCS, E. (2005): The role of forests in the karstecosystem. Acta Climatologica Et Chorologica Universitatis Szegediensis 38-39. pp. 143-156.

TANÁCS, E., KEVEI-BÁRÁNY, I. (2005): A karsztökológiai adottságok és az erdőgazdálkodás kapcsolatának vizsgálata az egyes fafajok termőhelyi preferenciái alapján, aggteleki példán [*The relationship between karstecological conditions and forest management, based on the site preferences of species. Case study from Aggtelek Karst* – in Hungarian]. Karsztfejlődés 10. pp. 343-361.

TANÁCS, E., BARTA, K. (2006): Talajvizsgálatok a Haragistya-Lófej erdőrezervátum területén [Soil studies in Haragistya-Lófej forest reserve – in Hungarian]. Karsztfejlődés 11. pp. 235-251.

TANÁCS, E., KEVEI-BÁRÁNY, I. (2006): Terepmodellből származtatott famagasság-térkép felhasználhatóságának vizsgálata karsztos területen [*An investigation of the usability of a stand height map derived from a DEM in a karstic area* – in Hungarian]. Tájökológiai Lapok 4. pp. 291-300.

TANÁCS, E., SZMORAD, F., KEVEI-BÁRÁNY, I. (2006): A review of the forest management history and present state of the Haragistya karst plateau (Hungary). In: Sustainable management of natural and environmental resources on karst, Postojna 2006 – abstracts of presentations and short articles.

TANÁCS, E., BARTA, K., JÁRMI, R., KISS, M., KEVEI-BÁRÁNY, I. (2007): A talajtulajdonságok és a faállomány kapcsolata a Haragistya-Lófej erdőrezervátum területén (Aggteleki-karszt) [*The relationship of soil properties and forest structure in Haragistya-Lófej forest reserve (Aggtelek Karst)* – in Hungarian]. Karsztfejlődés 12. pp. 225-241.

ZBORAY, Z., **TANÁCS, E.**, KEVEI-BÁRÁNY, I. (2007): The accuracy and possible uses of a stand height map derived from a digital surface model, 2007. In: Proceedings of the ForestSat 2007 Conference (CD), Nov. 5-7 Montpellier, France.