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THE ROLE OF FORESTS IN THE KARSTECOSYSTEM

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Összefoglalás: A növényzet összetételét és növekedését egy adott helyen a környezeti tényezők közötti kölcsönhatások határozzák meg. A magyarországi karsztterületek természetes vegetációja az erdő. Az erdődinamikai folyamatok, és az ezeket befolyásoló emberi tevékenység alaposabb megismerése hasznos eszköznek bizonyulhat a gyorsan változó, érzékeny karsztos ökoszisztémák kutatásában.

Abstract: The composition and growth rate of vegetation is defined by an interaction between the environmental factors and therefore can be considered a result of these interactions. In Hungarian karstlands the natural vegetation is forest. A better understanding of forest dynamics might prove a useful tool in the research of the fast-changing, sensitive karstecosystems.

Keywords: Forest, karstecosystem, tree growth, Aggtelek National Park

INTRODUCTION

The claim to understand the wider context of the karsts' environment only appeared in the last few years. Vegetation is one of the karstecological factors as described in *Kevei-Bárány* (2004). As such, it interacts with the other factors of the karstecosystem: it directly affects microclimate and soil and thus indirectly the whole system; meanwhile the composition and growth rate of vegetation is basically defined by the very same factors. The composition and growth rate of vegetation can be considered a product of the interaction between the karstecological factors therefore investigating these characteristics can lead to a better understanding of karst processes and provides a unique possibility of monitoring.

According to the natural vegetation map of *Soó et al.* (1999) the potential vegetation of Hungarian karstlands is mixed-stand deciduous forest. Despite the vegetation having been affected for centuries by human activity, the proportion of woodland in these areas is still relatively high as opposed to lower-elevation parts of the country (*Fig. 1*). In order to use this information in karst research, we need to develop a deeper knowledge of the natural dynamics of forests and the anthropogenic activities affecting them.

The extension and state of the forest today is defined by forest management which means silvicultural activity has an impact on the whole karstecosystem through changing the forest and the production site. The extensive use of wood as fuel or building material has been present in our mountain areas since the 15th century, but conscious forest management in Hungary started only in the late 19th century. Therefore a thorough knowledge of old forest management methods is extremely important because silvicultural practise defines the state and extension of a forest for centuries. Land owners and foresters have been interested in forest growth characteristics early on as their income depended on having the right type of forest at a specific production site. In some areas forest management plans date back to the early 20th century and besides tree volume data they provide complementary information on the species composition, soil and water balance of the production sites. Foresters' data and practical experience gathered over such a long period might be of help in understanding the ongoing processes of karstlands.

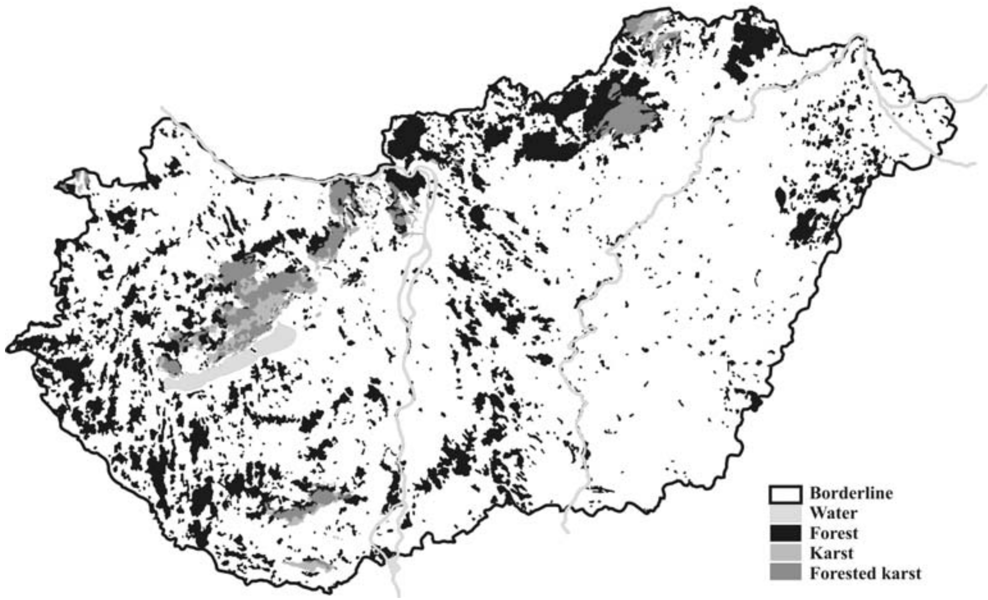

Fig. 1 The karst and forest areas of Hungary
(based on *Bárány-Kevei* (1987) and *National Forestry Service* (2001))

DATA AND METHODS

The article is a review of the role of vegetation in the karstecosystem and its relationship with the other system factors therefore it is mainly based on literature in the field of ecology and forestry. To provide local examples I also used GIS data derived from forest management plans of Aggtelek National Park from the year 2001 and some additional data from the National Forestry Inventory.

DISCUSSION

Functions of the forest ecosystem

Although there are no data available on the extension and attributes of forests in karst areas, a look at the two maps in *Fig.* 1 suggests that some of the largest continuous woodland in Hungary can be found in our karst mountains. The importance of forests in conservation and environment protection is well described by the fact that while the proportion of forested land in Hungary is only 19%, 49% of nationally protected areas are forested (*Exner and Jávor,* 2003).

Forests have several important functions. Some of these are gaining importance these days when the increasing human impact on nature becomes a major issue.

They play a significant part in balancing the nutrient and water cycle. In karst areas the latter function is even more important as karst rock types are water-soluble; this means there's an additional loss of water on the surface, due to infiltration into the rock base.

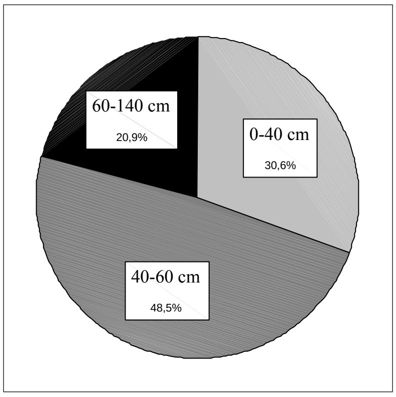

Fig. 2 The proportion of soil depth categories in the forests of Aggtelek National Park

Forests' role in erosion control was already recognised in the early 19th century (*Járási,* 1997) and protection measures were taken, with more or less success. Many forests owe their existence to the fact that karst soils are generally shallow and thus unsuitable for growing crops. *Fig.* 2 represents the proportion of soil depth categories in Aggtelek National Park.

Forests are the sole sources of wood, which is widely used as fuel, building material or paper. Forests growing on shallow karst soils do not, as a rule, provide quality wood. Karstlands being environmentally sensitive areas, their forests are often designated protection as primary function (*Fig. 3*). Wood production is limited or forbidden in such forests but they are valuable as habitat and places for recreation and tourism.

Last but not least, an equally important function of forests is to provide favourable conditions for maintaining their own continuous existence. One could argue whether this is ability or function but human interference disabling it often causes all the other functions to be temporarily or utterly disabled as well.

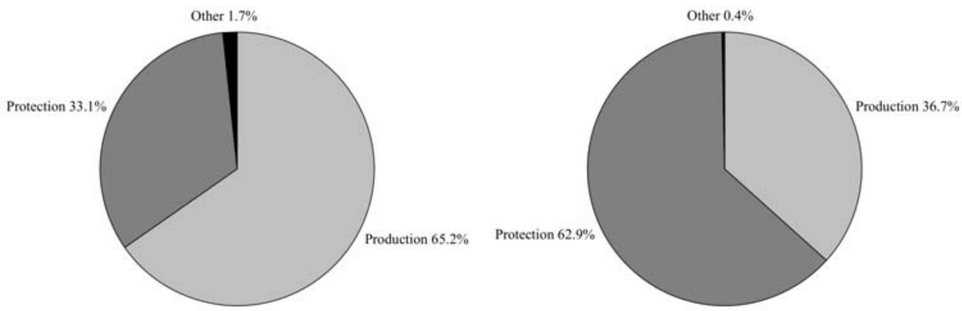

Fig. 3 Left: Primary function of the forests in Hungary in 2001 (*National Forest Inventory*, 2001)
Right: Primary function of the forests in Aggtelek National Park in 2001

Interactions between the forest and the other karstecological factors

Comparing *Fig. 4*, which presents the structure of the karstecosystem (*Keveiné Bárány,* 2004), with *Fig. 5*, that describes the interactions between environmental factors influencing tree growth, the similarity of the factor groups becomes evident. As it is the major system factors of the karstecosystem that directly define the state of the vegetation, the composition and growth rate of vegetation can be considered the result of the interaction between the karstecological factors. Therefore they can be used as an indicator of changes in the system.

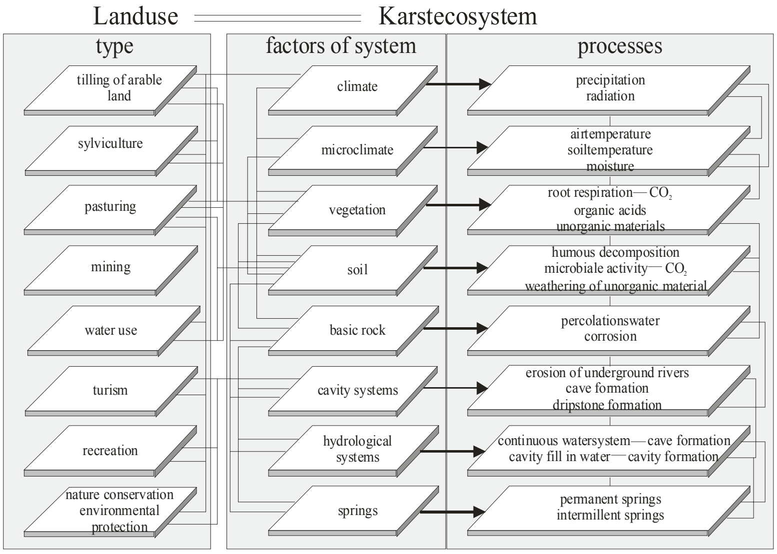

Fig. 4. The karstecosystem (*Keveiné Bárány*, 2004)

The generally shorter life cycle of herbaceous plants means that their species composition is quickly modified according to the changing environment. Meanwhile arboreal species adapt to changes by means of their genetic diversity and in stand by creating an optimal environment. Changes in the surrounding environment affect their growth and health, in extreme case their mortality or survival but changes in their species composition are much slower. General preferences and possible indicator roles of different plant species in Hungary have been thoroughly examined by *Zólyomi et al.* (1967) and *Borhidi* (1993) so this article concentrates on the possible role of tree growth rates in karst research.

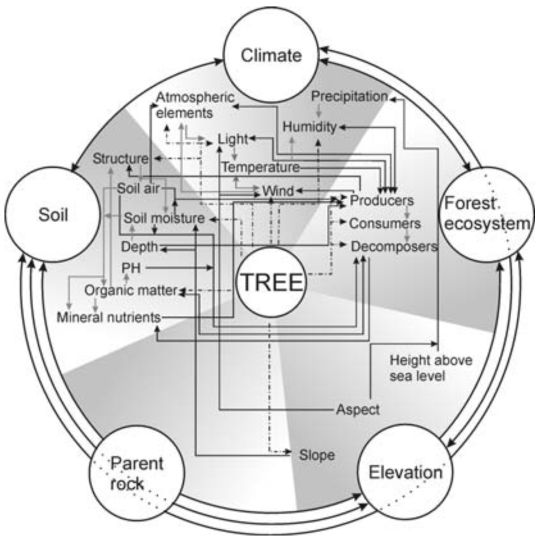

Fig. 5 The environmental factors affecting tree growth (original)

Both agricultural research and plant ecology extensively investigated the correlations between environmental factors and plant life. Direct observational approach did not usually bring success, because usually the actual outcome (survival, fatalities, growth rates, etc.) is a result of the interaction between the factors (*Grime,* 1991). So this kind of research often consists of the investigation of one factor within a controlled environment (*Füleky and Tolner,* 1999). The emphasis obviously lies on the preferences of crops and other cultivated plants; however, trees' and stands' responses to a range of environmental factors have also been studied. Yet, due to the wide range of environmental factors and their complex interactions, the resulting mechanistic detail is often difficult to translate into practical application (*Long et al.,* 2004).

Factors affecting tree growth and vegetation composition

Fig. 5 is a simplified description of the relationship between factors affecting tree growth. The drawing and the commentary is based on *Tompa* (1975), *Botkin* (1993), *Debreczeni* (1999), *Láng* (2000a, 2000b) and *Simon* (2000). I formed five classes of factors: parent rock, elevation, soil, climate and biosphere. Each class interacts with the others on a global and a local level. In the drawing global interactions are described by the surrounding arrows. Though these essentially define the environment and the possibilities of plant life, the really important relationships work out on a local level, represented by the arrows within the circle. I did not include the anthropogenic factor in the drawing because despite affecting each of the factors, human activity doesn't influence the way of their interactions. Hydrology could be viewed as a sixth class but the different parts of the hydrological cycle are closely related to the existing factor groups and were consequently defined as their part.

Climatic factors

Temperature affects tree growth by changing the rates of enzyme reactions and so it defines the rates of photosynthesis. By defining humidity it affects the rate of transpiration. High soil and air temperature dries the soil and leads to drought effects on trees (*Botkin,* 1993). Heat increases transpiration and if the rate of transpiration exceeds the rate of photosynthesis for a longer time, the tree will perish (*Láng,* 2000a). The thermal characteristic most commonly used to describe the temperature preferences of different species is the heat sum. Extreme temperature conditions and their temporal distribution are also of major importance (*Tompa,* 1975). Temperature is essentially defined by the amount of available light. Forests affect temperature by limiting the amount of available light and changing wind speed and direction.

Sunlight provides the energy needed for the evaporation of water and makes possible its transport from the roots to the leaves (*Botkin,* 1993). It is the basis of photosynthesis so it directly affects the rate of plant growth. The available amount of light defines temperature which in turn defines transpiration. The need for light varies with species and age; geographical position and quality of the production site also affects the light tolerance ability of plants (*Tompa,* 1975). The available amount of light is defined by the amount of solar radiation and exposition (elevation). Forests directly affect the amount of available light by shadowing the ground with their canopy.

Many atmospheric elements affect tree growth. Oxygen is the source of energy for all biological processes, needed for plant transpiration while atmospheric CO_2 is the main source of organic matter production (approximately 50% of the trees' dry matter consists of C – *Tompa,* 1975). An increase in CO_2 concentration increases the rate of assimilation. Oxygen is a product of photosynthesis while CO_2 that of transpiration so their local concentrations are directly affected by the type and structure of the forest. Nitrogen is a basic structural element of organic compounds, it plays a vital role in the formation of protein and thus the amount of available nitrogen significantly affects growth rate. Too high N-concentrations lead to a decrease in yield and quality (*Debreczeni,* 1999). Most of the nitrogen comes from the atmosphere and becomes available to plants through biochemical fixation by bacteria. Certain plants (i.e the *Fabaceae*) form symbiotic relationships with these so the presence of these plants results in higher soil nitrogen concentrations in their environment. Thus the amount of available nitrogen depends on the type of vegetation cover and the presence of nitrogen-fixing bacteria as well as the amount of nitrates settling from the atmosphere. Other elements (S for example) settling from the atmosphere can have either negative or positive effect on growth, mostly depending on the amount (*Debreczeni,* 1999). The concentrations of atmospheric elements are defined by the air movements, the quality and structure of the soil, modified by the type and structure of the vegetation cover.

Precipitation basically defines the water amount available to plants, even though it is humidity and the water content of the soil that actually influence tree growth. Water is essential for photosynthesis (as the source of hydrogene in primary organic matter production) and transpiration; it is the medium for biological processes within and outside of living organisms (*Simon,* 2000). It is water that enables plants to keep their cells in turgid state; it provides the means for element transport within the tree and facilitates the intake of nutrients (*Tompa,* 1975). The climate and the elevation define the amount of precipitation.

Humidity affects the rate of evaporation and transpiration; it is defined by the amount of precipitation, and modified by evaporation from the canopy (interception) and the transpiration of plants (*Simon,* 2000).

Besides affecting temperature and the atmospheric concentration of different elements, wind plays an important part in the reproduction processes of many trees. It helps the spreading of these species and thus has a major role in natural reforestation. Strong winds may distort trees or even cause windfall; the leaf cover of the forest floor or the surface air with higher CO_2 concentrations (essential for photosynthesis) can be flown away (*Tompa,* 1975). Wind also increases the rate of transpiration by affecting humidity. Macroclimatic conditions and the elevation essentially define wind speed and direction. However, forest cover can significantly modify both.

Elevation

As elevation defines a lot of the other factors its indirect effects on growth are of major importance. Aspect defines microclimate. The steeper the slope, the greater the angle of radiation and consequently the temperature's higher. On steep slopes, a greater amount of water is lost as runoff and therefore less is available for plants; also the soil profile is less deep and nutrients are washed out. The stability of the slope directly affects the possibility of plant colonisation; meanwhile the presence of vegetation enhances slope stability. Parent rock and climate basically define elevation and vegetation cover also affects it to a lesser extent.

Parent rock

Parent rock does not directly influence tree growth (except under very special conditions) but it defines soil, elevation and hydrological conditions and thus should be included in the model.

Soil

Apart from physically limiting the size of roots the depth of the soil profile affects the water and heat balance of soils. This soil characteristic depends on the parent rock, the climate, the original material and the elevation.

Soil structure affects soil air and moisture; compressed soil acts as physical obstacle to the roots (*Tompa,* 1975). Soil structure is affected by the vegetation cover, and microbial activity.

Soil air is essential for microbial and root transpiration. Its oxygene concentration affects microbial activity and thus defines mineralization processes. Vegetation affects soil air by root transpiration and by modifying the soil structure.

Though precipitation basically defines the water amount available to plants, soil moisture is of primary importance. Additional water may become available by subsurface runoff or through upward capillary action. Water may be lost through percolation, runoff or evaporation from the soil. Soil moisture is defined by soil structure, precipitation and slope; it is also affected by the plants taking up water, which is eventually transferred to the atmosphere by transpiration from the leaves (*Botkin,* 1993).

The pH value of a soil defines nutrient availability for plants. In extreme cases toxic materials normally not available to plants become uptakeable (*Láng,* 2000b). Forest plants modify the pH of a soil by providing organic matter of different quality. So the pH of a soil basically depends on the type of parent rock, climate but it's also influenced by the type of vegetation cover.

Organic matter positively influences soil properties. Its quantity depends on the available dead material and the intensity of microbial activity.

Mineral nutrients are needed for the production of different molecules in living organisms. Each plant species needs different amounts of these so their presence affects species composition. According to *Grime* (1991), besides having a dominant effect on the quality and quantity of phytomass, they also control the rates of both cyclical and successional vegetation change. The different concentrations of these elements in different plant species affect the nutrient content of the soil after the death and decomposition of the plant. Thus the nutrient content of the soil is defined by parent rock, elevation and the type of vegetation cover.

The forest ecosystem

Only plants are capable of primary organic matter production so they are the producers, the basis of the food pyramid. All the plants in a forest are each other's competitors in the contest for resources; meanwhile they continuously form their environment, which in turn leads to a constant dynamic change in the composition of the vegetation. Some plants have a direct effect on others by emitting material that prevents their reproduction but mainly they affect each other indirectly by defining the amount of available light and the nutrient content of the soil.

On the higher levels of the forest food web consumers upkeep the nutrient cycle, define plant species composition and the soil structure; they play a vital role in the reproduction of certain tree species. Some (i. e. mycorrhizal fungi, nitrogen-fixing bacteria, etc.) living in symbiotic relationship with plants provide a critical linkage between the plant root and soil and thus enable them to tolerate environmental stresses better. A propagation of primary consumers (i. e. *Ips typographus, Lymantria dispar*, etc.) often results in the destruction of large forested areas. Such events are partly natural and partly due to the selective removal of parts of the forest food web. Some consumers are species-specific while others polyphag, nevertheless it is the vegetation composition that essentially defines the presence of consumer species.

Decomposers break down dead organisms and thus define the nutrient content of the soil. Decomposer activity is affected by the soil properties, especially soil air and the amount of organic matter.

The need for different resources is species-related and besides the necessary amount, temporal distribution is also of importance. All the factors are highly varied both in a temporal and spatial sense and there's no general definition of their relative importance because even this changes over time and space. Easiest to detect are the effects caused by the abundance or lack of one factor, if all the others are available in sufficient quantities (*Füleky and Tolner,* 1999).

Similarly to ecologists (although driven by economic interests) foresters have also long been involved with the research of environmental factors affecting tree growth. Based on their field experience and long-term observations (without much knowledge whatsoever of the processes leading to the result of their observation) they also realised it was not the factors or any of their attributes that defined plant growth but it was a result of the interaction between them (*Járó,* 1972). They named the site-specific result of this interaction production capacity. In the 19^{th} century 6 productivity classes were defined which summarize the quality of the production site as a single index. The relationship between yearly tree volume increment and these productivity classes was verified with statistical methods a century later by *Bán* (1996). Of the wide range of factors a few have been selected that have a critical influence on tree growth and are also easy to measure or define in the field: genetic and physical soil type, depth of soil profile, height above sea level, slope, aspect, water excess and climate. (The latter describes average humidity of the site at 2 pm in July). These attributes of the production site are included in forest inventories and management plans, refreshed once every decade. Thus, these management plans provide valuable historical data and, to a limited extent, can be used for long-term monitoring purposes.

Tree growth as an integrator of the karstecological processes

The relationships described above suggest that besides examining the vegetation composition, measuring tree growth rates might prove an important tool in monitoring the karstecological processes as these rates provide information on the operation of the whole system. *Long et al.* (2004) argue that tree leaf area is the best integrator of the ecological processes affecting resource capture and carbon assimilation. However, in the case of Hungarian karsts the use of tree height and complementary field diameter measures would also be recommended because such data are available for the last 50 years for every forest stand and could be used as reference. According to *Botkin* (1993) tree growth is basically '*the net accumulation of organic matter and is therefore the difference between the amount of new organic matter produced by the leaves and the amount used by the rest of the living tissues'*. His fundamental growth equation expresses tree volume as proportional to the square of the diameter times the height. Volume could be replaced with either the diameter or the height as they are directly proportional. Diameter is easy enough to measure in the field but tree height data can be more simply acquired en masse using remote sensing techniques (*Bán*, 1996). Using Digital Surface Models created from air photography negatives enables digital tree height measurement with an accuracy of approximately 1-1.5 m (*Zboray and Tanács,* 2005). Using old photos time series can be created especially that additional information (species, age, and productivity class of the stand) indispensable for the analysis is available in the forest inventories. There are also empirical relationships defined for age, height, diameter and volume for each economically important species in every productivity class.

Forest management and its effects on forests – the example of Aggtelek Mountains

The use of forest growth as an indicator of changes is limited by the fact that at present there are no natural forests left in Hungary. Species composition, age structure and health conditions are all defined by forest management practices which aim to maximise quality wood production and, in order to achieve this, to ensure the dominance of certain tree species.

The history of forest management throughout Europe can be basically divided in two main periods: the age of forest use, and recently, the age of conscious forest management. However, the extension or reduction of woodland area has always been a function of landowners and their momentary economic interests (*Járási,* 1997). Throughout history regulations and laws could only influence forest use if they actually triggered economic interest.

In the Aggtelek area the period of simple forest use lasted from the appearance of humans till the beginning of the 19th century. It was mainly a period of deforestation; forest products (timber, herbs, berries, acorn, etc.) were gathered and used without any care for replacement and regeneration. Some species, like for example sessile oak (*Quercus petrea*), mostly characteristic of later successional stages, provided quality wood, represented higher value and were therefore widely used. After being cut down, frequent grazing prevented their natural regeneration and their place was taken by less seeked-out species with a better ability to tolerate disturbance and grazing (*Járási,* 1997; *Bartha,* 2001). This period defined the possibilities of forest management later so today's processes have their roots in the changes that occurred in these historical times.

The period of transition from forest use to forest management lasted more than a century. Despite the need for sustainable management being recognised, there was no significant change in the actual silvicultural practices because of the unfavourable macroeconomic environment. The first half of the 20th century included two world wars and a global economic crisis. Hungary lost most of its forests; the forests left often meant the only income to their owners (*Járási*, 1997). The current age construction (*Fig. 6*) clearly shows that this period almost finished off the last remnants of forests in the Aggtelek area. After the world war, political changes resulted in the forests being taken into state management and a new era began. Regeneration works immediately started in order to satisfy the wood claim of post-war reconstruction.

In an ideally managed forest, there could be no distinction made between final harvest and regeneration, but the forest cover should be (at least on a large scale) continuous, both in space and time (*Sódor and Temesi,* 2001). But forest management methods were invented to handle a significantly disturbed ecosystem. Forests have their own responses to handle these disturbances – secondary succession (*Standovár*, 2000). In the Aggtelek area, it was the spreading of hornbeam (*Carpinus betulus*) that prevented irreversible erosion and the final disappearance of forests from large areas in the early 20th

century (*Gencsi and Vancsura*, 1992; *Járási*, 1997). Today's high proportion of hornbeam in the area's forests is the witness of earlier forest use (*Fig. 7*).

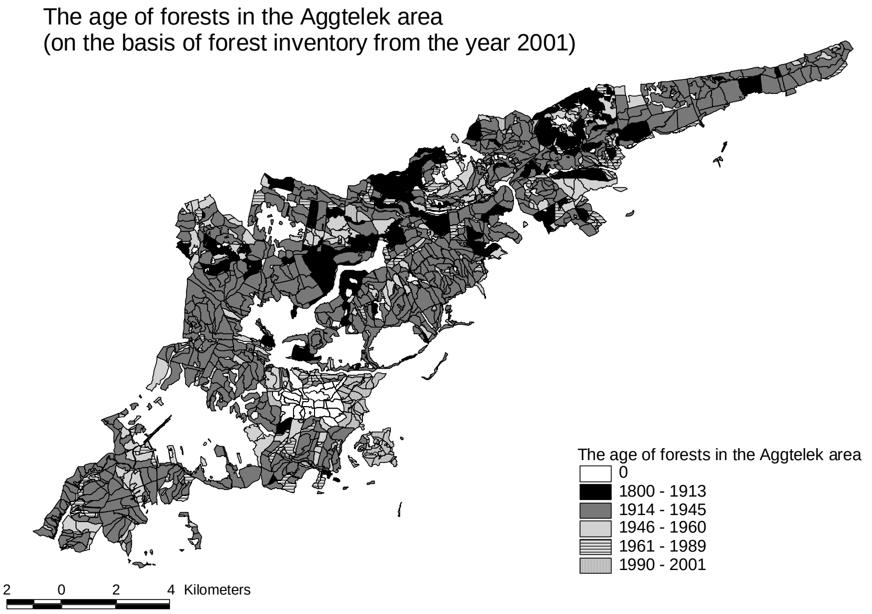

Fig. 6 Year of plantation – the age of forests in Aggtelek National Park

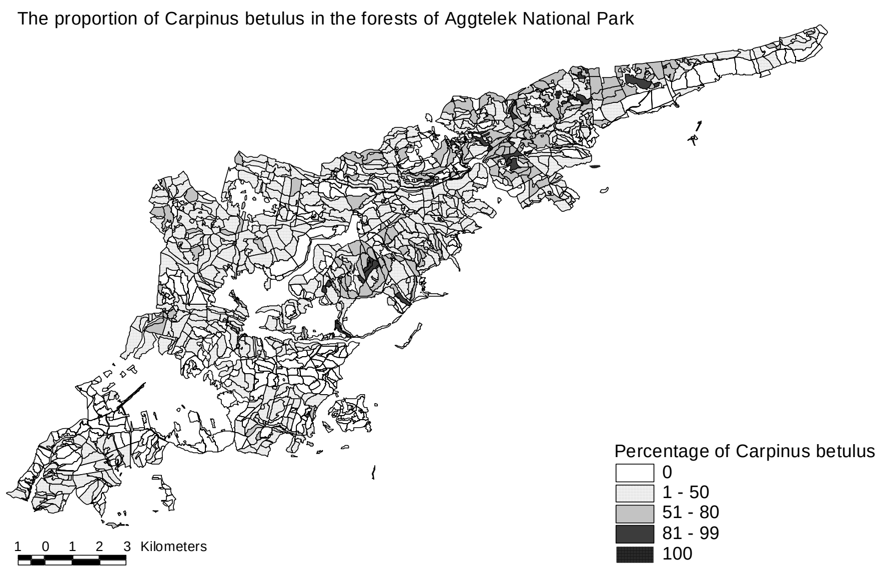

Fig. 7 The proportion of hornbeam (Carpinus betulus) in the forests of Aggtelek National Park

However, the claim for wood has always been too great to allow waiting centuries for the formation of another climax association. Felling cycles were and are much shorter than the lifetime of most tree species and this leads to frequent anthropogenic disturbance. According to *Long et al.* (2004) stand regeneration practices are usually intended to create conditions that favour early dominance by one or more desired species. In the Aggtelek area, it would be long-lived, slow-growing deciduous tree species (mostly oak species) which provide the most valuable wood. However, as *Grime* (1991) argues, '*non-equilibrium systems encourage plant species with high potential growth rates. (...) Under the impact of increasing habitat disturbance and eutrophication, the composition of vegetation is becoming more dependent upon the rates at which nutrients are captured and less upon the capacity to tolerate particular nutrient limitations'.* These conditions do not favour the above mentioned species. To resolve this contradiction modern forest management chose to even more drastically interfere with the forest ecosystem. Faster-growing, undemanding, often coniferous foreign species were planted to shorten the felling cycle or to reforest sites affected by erosion. Site preparation after clear-cutting often included harrowing, which completely removed understory vegetation. Some species were considered harmful or simply useless and consequently often removed along with their specific fauna. That decreased both structural and species biodiversity which in turn led to the weakening of the ecosystem's self-regulating function. In today's profit-orientated management, drastic forest treatment methods vary from clear-cutting to the extensive use of chemicals in order to control competing vegetation and consumer fauna. Such interferences cause the natural processes of forests to become homogenous (*Standovár,* 2000). Managed forests do not interact with the other factors of the karstecosystem anymore, rather one-sidedly affect them. The removal of the forest cover results in extreme temperature fluctuation in the dolines (*Keveiné Bárány,* 2004) which in turn limits reforestation. Wood production directly affects the nutrient cycle by removing nutrients stored in the trees (especially in case of coppice woods) and indirectly by increasing surface runoff which in turn increases erosion and washes out nutrients from the soil. Modifying species composition changes soil properties; non-native coniferous forests cause a decrease in pH that modifies the availability of nutrients and toxic material (*Berki*, 1999).

These are just a few examples of the effects of silvicultural practice on forests and their environment; but through the relationships shown in *Fig. 5* any kind of human interference affects each factor of the karstecosystem. Thus, when trying to investigate forest dynamics and their relationship with the environment, it is essential to take into account the forest management practices of the study area.

CONCLUSION

In this article I reviewed the relationship between the karstecological factors partly to represent the complexity of their interactions and partly to demonstrate how easily the whole system can be affected through modifying one single factor: the vegetation. In Hungarian karstlands the natural vegetation is forest. Forests have several important functions which may gain special significance in areas as environmentally sensitive as the karsts. However, the forest ecosystem has been affected by human interference for centuries, so in trying to better understand the functioning of the karstecosystem, it is essential to know the methods of forest management and their possible impact.

The forest ecosystem affects and is affected by the other factors, consequently its composition and growth rate can be considered a dynamic result of their interactions (modified by human impact). Herbaceous plant composition reacts quickly to environmental changes while changes in arboreal species composition are rather slower; however, tree growth rates can also provide information on these changes. Tree growth rates can be described by – besides other methods – a yearly volume increment which can be defined by diameter and height measurements. Besides being simple and cheap these measurements have the advantage of being comparable to unique historical data in forest inventories and management plans and are thus suitable for conducting investigations of long-term environmental change.

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