ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 40-41, 2007, 123-133.

FOREST STRUCTURE STUDIES IN AGGTELEK NATIONAL PARK (HUNGARY)

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Összefoglalás – Vizsgálatunk célja a Haragistya-Lófej erdőrezervátumban a faállomány jelenlegi állapotának feltérképezése, és a 212 felhasznált mintapont kategóriákba sorolása volt. A vizsgálathoz az egyes mintapontokra kiszámítottunk néhányat a leggyakrabban alkalmazott szerkezeti és diverzitási mutatók közül. Megvizsgáltuk ezek térbeli eloszlását a mintaterületen, valamint egymással való kapcsolatukat. Kiválasztottunk négyet (Shannon index, variációs koefficiens, körlapösszeg/ha, állománymagasság) és ezek alapján hierarchikus klaszter-analízis segítségével csoportosítottuk a mintapontokat. Az eredmény alapján elmondható, hogy a faállomány-szerkezetet jelentősen befolyásolja a termőhely, különösen a domborzat.

Summary – Our measurements were carried out in the Haragistya-Lófej forest reserve, in Aggtelek karst. The aim of our investigation was to describe the present state of the forests in our study area and to define groups with the help of structural and compositional indices. We have chosen some of the most commonly used indices and calculated them for 212 plots. Out of these we chose a set that were not strongly correlated with each other while each described a range of other related variables. These were the Shannon Index, the coefficient of variation (dbh), the basal area/ha and the stand height. On the basis of these 4 variables we divided the area's forests in 6 classes. The groups are much affected by the production site; the role of elevation seems especially important. The buffer zone and the core area of the reserve also differ, especially in terms of tree size and distribution.

Key words: forestry, stand structure, Aggtelek National Park, karst, Haragistya

1. AIMS AND OBJECTIVES

The aim of designating forest reserves in Hungary was to provide places where research can be carried out in order to better understand the natural processes of forest ecosystems. (*Temesi,* 2002) Researching stand structure is one of the practical ways of approaching the concept of biodiversity, which has recently become increasingly important for stake-holders.

Generally speaking, diversity means the inner variability of the structures and elements of a system (*Haeupler,* 1982). Ecological diversity means the variability in the spatial and temporal patterns and the relationships of populations along with their structures. This diversity describes the physical structure deriving from the spatial distribution of species, age groups and growth forms (*Standovár and Primack,* 2001).

Besides being related to the diversity of the forest wildlife, stand structure can also provide an explanation to its spatial patterns. (*McElhinny et al.,* 2005) Analysing the patterns of stand-level structural and compositional indices has a great practical significance, the stand being the basis of forest management and thus the possibility of direct human interference is highest at that level. The knowledge of both spatial and temporal patterns may serve as a basis for sustainable management aiming to keep a broad range of forest goods and services. (*Spies,* 1998)

The forests of the karst plateau called Haragistya (Aggtelek Mts.) have been seriously affected by anthropogenic activity in the last centuries. After much of the area had been designated a forest reserve in the 1990's active forest management has declined. The aim of this study is to describe the area's forests by analysing the spatial distribution of some common structural and compositional indices. The present forest structure in the area is a result of long-term human impact and a spatially very varied natural environment. Thus, after examining the correlations we also define a set of basic indices suitable for categorising the sampling points. The resulting groups are then compared in terms of both production site and management history in order to understand the development of the area's forests.

2. MATERIALS AND METHODS

2.1. The study area

The Haragistya-Lófej forest reserve is situated in the north-western corner of Aggtelek National Park, surrounded by the Slovakian border. Except for a part of its buffer zone in the south, the area is under strict protection. The Haragistya bears all the hallmarks of a typical karst plateau; its surface is dry and highly varied, covered by series of dolines and dry valleys. The sample area is situated in the south-eastern part of the plateau (*Fig. 1*). Its main features are two N-S direction dry valleys (Hosszú-valley in the east and the other is referred to as Dry valley), two mountains (Mt. Ocsisnya in the west and Mt. Káposztás in the east) and a ridge between the valleys. The northern boundary is a series of dolines in E-W direction.

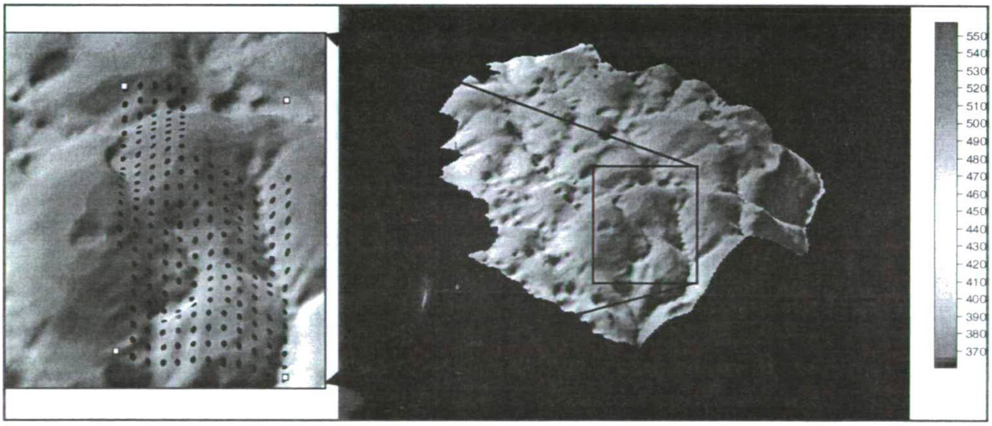

Fig. 1 The study area and the sampling points

The bedrock is rather homogenous; light grey limestone and dolomite of the Wetterstein Formation vary. However, in the bottom of hollows (dolines, valleys and slope curves) Cretaceous red clay sediments (*Jakucs,* 1977; *Beck and Borger,* 1999) have accumulated. The bedrock essentially defines soil type distribution; on the tops, ridges and slopes different types of hollow rendzina soils are characteristic while in the above-mentioned hollows deeper red clayey rendzinas and brown forest soils can be found. The development of the soil profiles is rather disturbed; traces of either erosion or accumulation appear in most cases.

The vegetation is a mosaic of dry thermophilous oak forests, dominated by *Quercus pubescens*, oak-hornbeam forests and beech-hornbeam forests in smaller patches in the valleys and on northern slopes. The most common species are *Carpinus betulus, Quercus petraea, Quercus pubescens, and Fagus sylvatica*, often accompanied by *Acer campestre* and *Sorbus torminalis (Fig. 2).*

According to the forest management plan made in 1993 the age of the forests in the sample area varies between 50 and 110. However, archive plans show slightly higher ages; according to these even the youngest forests have been regenerated in the mid-thirties and are therefore approximately 70 years old. The oldest forests can be found in the series of dolines in the northern parts of the study area (*Fig. 3*). Management activity mostly consisted of thinning. In some parts of the area, there's no written evidence of cuttings since 1935; much of the area has not been managed for the last 40 years. However in some sections thinnings took place in the 80's and the last cutting occurred in 1997 in a single section in the reserve's buffer zone (*Fig. 4*).

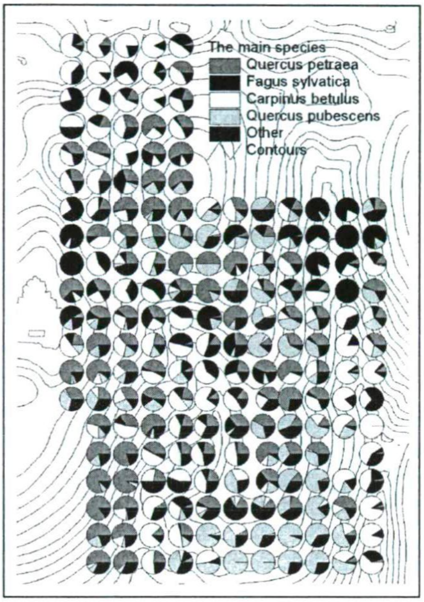

Fig. 2 The main species of the area

Fig. 3 The age of forests

2.2. Data and methods

We have started our measurements in the Haragistya-Lófej forest reserve in April 2006. We have recorded the position, diameter at breast height (dbh), species and social position (according to the Kraft-classification) of every living or dead tree exceeding a dbh of 5 cm or a height of 5 m in 10 m-radius permanent plots, situated in a 50 m-resolution grid. In the present study we use the data of 212 such plots. About half of these are situated in the core area of the reserve while the rest are in the buffer zone. No detailed measurement has been carried out in the area before; however there are available archive forest management plans dating back until 1935. The spatial resolution of these is rather lower than the variety of the karst surface and consequently that of the forest but still they represent a valuable information source concerning past management activities and the state of the forest.

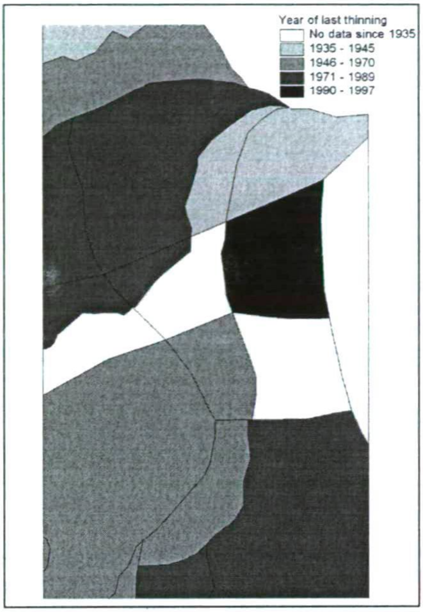

Fig. 4 Year of last thinning

In order to describe the present state of the forests we have chosen some of the most commonly used structural and compositional indices after *McElhinny et al.* (2005) and *Neumann and Starlinger* (2001) and calculated them for every plot. We looked at the spatial distribution in general and the upper and lower 10 % of the values in order to outline areas where the indices are extremely different from the expected value. In the case of the Cox Index, we used the categories defined by *Cox* (1971).

Structural indices: These indices mostly describe the diversity of forms in space. Some of the most typical indices included in this category are the diameter distribution, the number of tree species, the horizontal distribution of individuals and the vertical structure of the crown layer (*Dylla and Krätzner*, 1986). We have computed most of them including the living trees and the dead standing trees (snags), not taking into account the data of shrub species.

The number of stems/ha is a widely used measure of density (*Nagel*, 2001).

Average dbh: This index increases with age and in different forest types it was successfully used for discriminating successional stages (*McElhinny et al.,* 2005)

Standard deviation of dbh: This index is related to the presence of different-aged individuals in the plot and thus reflects naturalness.

Coefficient of variation (dbh): This index is calculated as the quotient of the standard deviation and the mean dbh.

Basal area/ha is a widely used index in forestry for expressing tree volume and biomass in an area.

The number and proportion of snags: The ecological importance of snags, apart from their effects on recruitment, is more similar to that of living trees than logs. Although seedlings in most cases cannot grow on the snag directly it offers favourable places for regeneration at the root collar (*Bauer,* 2002). In case of undisturbed forests the number of snags and their proportion can refer to the successional stage. However their main importance lies in their role as bird habitat; they are an important source of tree hollows (*McElhinny et al.,* 2005).

Stand height (modelled): In order to define stand height we used a height map derived from a Digital Terrain Model as described in *Zboray and Tanács* (2005).

Cox Index: This index serves to characterise the horizontal distribution of trees (*Cox,* 1971). It is calculated on the basis of smaller sample areas (in our case each 10 m circle was divided in 52 squares in a 2.5*2.5 m grid) as $K = s^2/x$ where s^2 is the variance and x is the mean of the sample plots. The Cox Index defines the proportion of usage within each sample plot and whether this value has a Poisson distribution. If it does, the distribution of the trees follows no pattern (*Fröchlich,* 1993). If it is not significantly different from 1, which means it does follow a Poisson distribution, then the trees are randomly distributed in the stand. If $K<1$ the pattern is regular while if $K>1$ the trees are aggregated. If K exceeds

5, the trees are highly aggregated (*Cox*, 1971). When calculating the Cox Index, we did not include shrub species, such as *Cornus mas*, *Cornus sanguinea*, *Crataegus monogyna*, *Crataegus laevigata* and *Coryllus avellana*.

Compositional indices: according to *Kimmins* (1987) the notion of diversity should always include species diversity and dominance. Several indices were developed in order to measure diversity; these indices are considered to be very important indicators. Generally the diversity of a community is higher if the number of species is higher and the individuals are more equally divided between species. Only those indices are suitable to measure biodiversity that include both the number of species and the distribution of individuals among the species (*Mühlenberg*, 1993). From among these we chose the widely used *Shannon-Weaver* (1949) diversity index. The advantage of this index is that it takes into account both the number and evenness of the species. Its value is increased either by having more unique species, or by having a greater species evenness (*Pielou*, 1977).

$$Hsh = \sum_{i=1}^{n} pi \cdot \ln pi$$

Where p_i is the relative abundance of each species, in this case calculated as the proportion of the basal area of individuals of a given species to the total basal area of individuals in the plot and n is species richness. When computing the Shannon Index, we also included shrub species.

We then analysed the spatial distribution of each, using ArcView 3.3 software. We examined their relationship with the help of SPSS 11 software and defined a set of indices that were not strongly correlated with each other while each described a range of other related variables. These were the Shannon Index, the coefficient of variation (dbh), the basal area/ha and the stand height.

After choosing the appropriate indices the values were standardised and hierarchical cluster analysis was applied on the selected variables. 6 classes were created. We then examined each class in terms of site and management history to see the reasons behind their differences.

3. RESULTS AND DISCUSSION

3.1. The spatial distribution of the indices in the study area

The mean stem number/ha is 997. Generally this value is lower in the valleys and dolines where *Carpinus betulus* and *Fagus sylvatica* are the dominant species (*Fig. 5a*) and higher on the slopes. The low values of the valleys can partly be explained by former and still existing roads. Also these sections have not been thinned for 40 years in average. There are 3 areas with especially high values: a southeast-facing slope besides Hosszú-valley, the south-eastern slope of Mt. Ocsisnya and some scattered points on the east-facing slope of the upper part of Hosszú-valley. The year of last thinning in these 3 areas varies from 1986 to the 1950's. On the southeast-facing slopes the dominant species is mainly *Quercus pubescens,* accompanied by *Quercus petraea, Carpinus betulus, Acer campestre* and *Sorbus torminalis* (*Fig. 2*).

The mean dbh of the plots is 19.35 cm, the highest values appear on the north-facing slopes of Mt. Ocsisnya. (*Fig. 5b*) There the last production occurred in 1989. The dominant species are *Carpinus betulus* and *Fagus sylvatica*, along with *Quercus petraea,* accompanied by *Cerasus avium* and *Sorbus torminalis*. The dolines north of this area also hold relatively high values; this section was last thinned in 1964. Besides *Carpinus betulus* and *Fagus sylvatica, Tilia cordata* and *Ulmus glabra* can also be found. In the southern part, in the buffer zone of the reserve there are only a few small patches with high values; mainly in Dry valley.

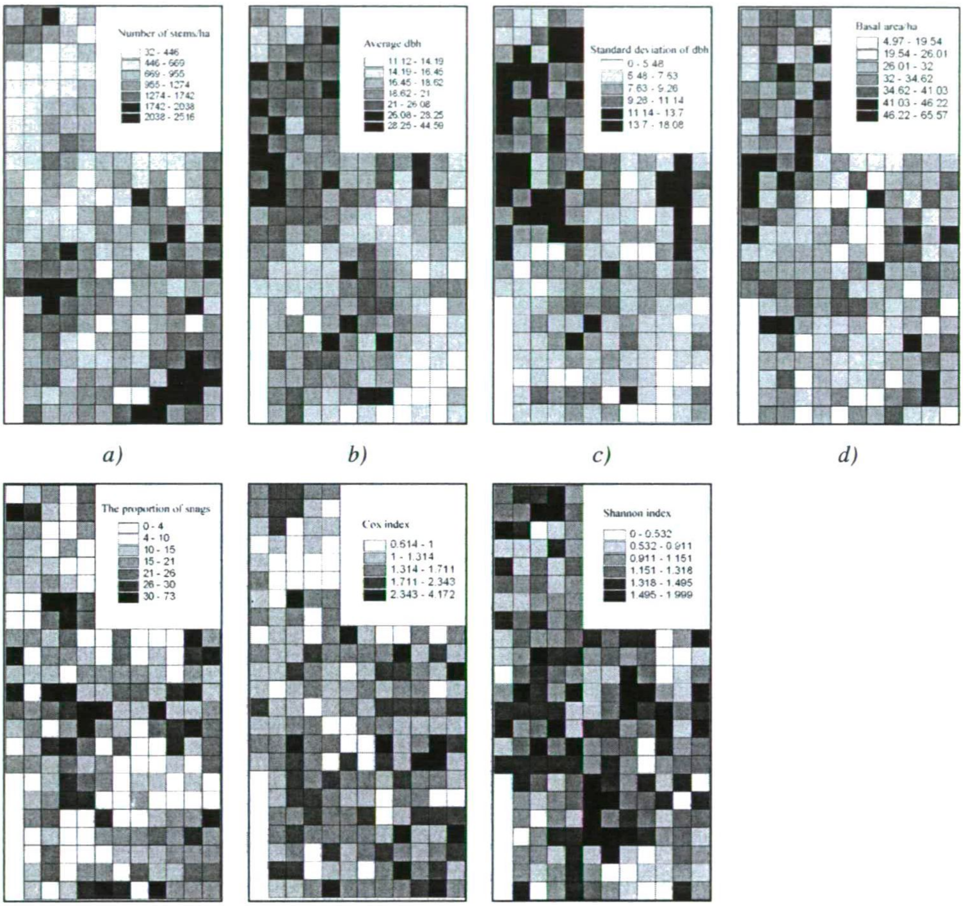

Fig. 5 The spatial distribution of structural and compositional indices in the study area

The mean value of the dbh standard deviation in the area is 8.82 cm. The sampling points with small values are all situated in the buffer zone; their dominant species are usually *Quercus* species with *Carpinus betulus, Sorbus torminalis, Acer campestre* and *Fraxinus excelsior*. The areas with higher values are situated in the core area, mainly on north- or west-facing slopes or ridges (*Fig. 5c*) where *Quercus petraea, Carpinus betulus* and *Fagus sylvatica* dominate the crown layer along with *Tilia platyphyllos*, *Quercus cerris* and *Cerasus avium.*

The mean basal area/ha (*Fig. 5d*) in the study area is 30.64 m^2. This index shows high values mainly in the northern part of the area and the saddle between Mt. Ocsisnya and

Káposztás where *Quercus petraea* and *Carpinus betulus* are most frequent. The basal area is also high on the east-facing slope in the northern part of Hosszú-valley (*Fagus sylvatica*) and the southern part where *Quercus pubescens* and *Carpinus betulus* dominate. Small values characterise the reforesting clearings on the ridge south of Mt. Káposztás. Average values occur in the sampling points dominated by *Carpinus betulus* in the bottom of the valleys.

The proportion of snags in the sampling points is rather varied (*Fig. 5e*); there are no major consistent patches. The mean of the sampling points is 16.78%. There are 3 areas with higher values: the south-east-facing slopes of Mt. Ocsisnya, a small patch west of Mt. Káposztás and the northern part of Hosszú-valley. This value is very small (0-10%) on the ridge south of Mt. Káposztás and the slope north of it. These sampling points are usually characterised by a varied species composition, mainly with *Carpinus betulus, Fraxinus excelsior* and *Quercus petraea.*

Examining the spatial distribution of the Cox Index (*Fig. 5f*) in the study area we found no sampling points with a very high aggregation value (K<5). Most of the area is characterised by an average level of aggregation while on the north-facing slopes of Mt. Káposztás the horizontal distribution of the trees is regular. The characteristic species in these stands are *Carpinus betulus, Fagus sylvatica* and *Quercus petraea* and the last thinning occurred in 1989. The same tendency can be seen in the middle parts of Dry valley, in a stand with the same species, last thinned in the 1960's.

The Shannon Index (*Fig. 5g*) shows a high variability in the area. However, highest are its values on the north-facing slope of the northern dolines, on the saddle between Mt. Ocsisnya and Káposztás, in the southern part of Dry valley and the middle part of Hosszú-valley. These forests have not been managed in the last 40-60 years and the high diversity reflects that well. We found the lowest values in the *Fagus sylvatica*-dominated northern part of Hosszú-valley, the *Quercus pubescens*-dominated southern slopes of Mt. Káposztás and in the northern dolines.

3.2. Relationship between the different indices

According to the one-sample Kolmogorov-Smirnov test, the basal area/ha, the proportion of snags in the plots, the coefficient of variation, the Shannon Index and the stand height have a normal distribution. *Table 1* shows their Pearson correlations. *Fig. 6a* shows the relationship between dbh-related indices and stem number/ha. The well-known allometric relationship between stem number and mean dbh can be clearly seen. There is also a positive non-linear relationship between mean dbh and diameter standard deviation, which shows that in the older forests gap dynamics have started and the originally even-aged stands are turning into uneven-aged ones. Since the coefficient of variation shows a positive linear relationship with the standard deviation of dbh it can be used to express naturalness among the variables chosen for the classification. It is also correlated to the proportion of snags in the plots.

Fig. 6b shows the relationship between snag characteristics, basal area/ha and stem number/ha. Out of these variables we have chosen basal area/ha to include in the classification. We have added stand height since it reflects site quality, being related to soil depth. To a lesser extent, it also refers to the species composition (*Fig. 6c*). It is positively correlated with the proportion of *Fagus sylvatica* in the plot and negatively with the proportion of *Quercus pubescens. Fig. 6d* shows that there is no correlation between the finally chosen four variables: the Shannon Index, the coefficient of variation (dbh), the basal area/ha and the stand height.

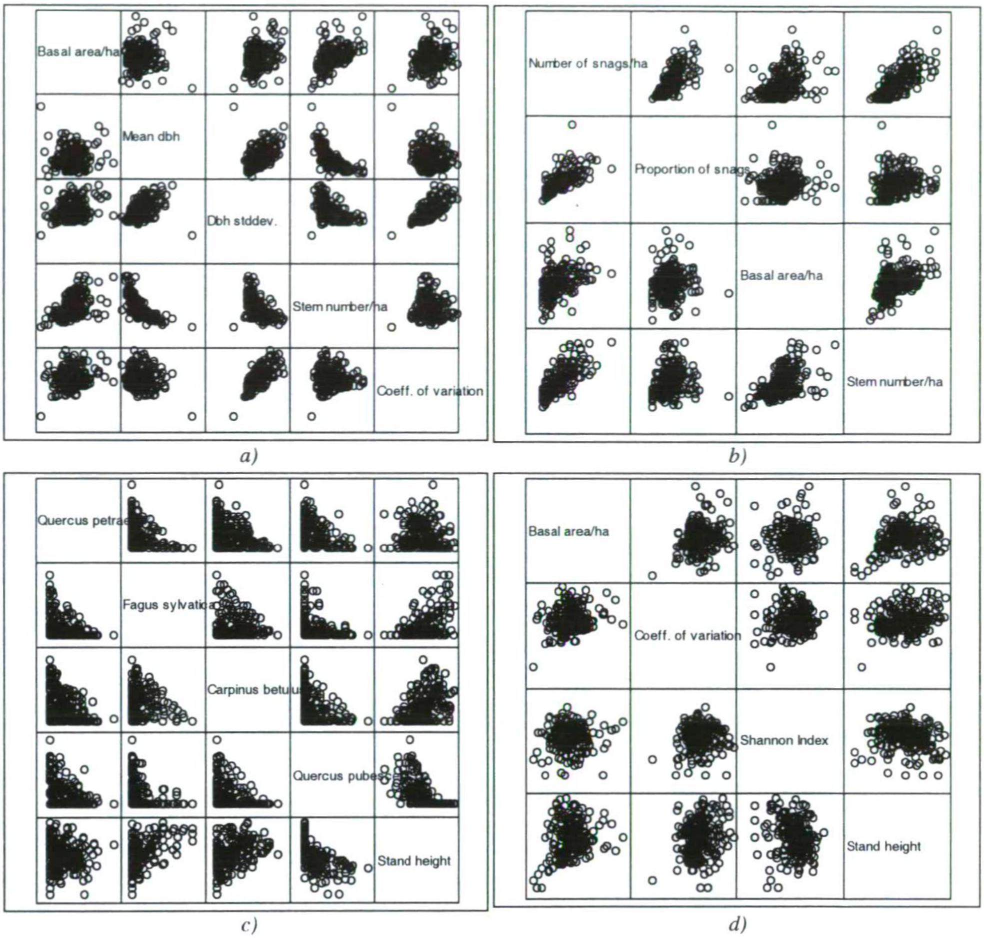

Fig. 6 Scatterplots of structural indices

Table 1 Pearson correlations of the variables with normal distribution

	B. area/ha	P.of snags	Coeff. of variation	Shannon Index
Basal area/ha	1			
Proportion of snags	0.099	1		
Coefficient of variation	0.186**	0.575**	1	
Shannon Index	0.020	0.031	0.031	1
Stand height	0.226**	0.071	0.193**	-0.188**

**Correlation is significant at the 0.01 level (2-tailed).

Fig. 7 shows one possible result of the hierarchical cluster analysis. In this case we used squared Euclidean distance and between-groups linkage. Choosing the optimal classification method will need further investigation; however this version summarizes the result of the individual indices and also our field experiences well. Comparing the location of the sampling points in each group to the boundaries of forest management units and the contours it seems that the groups are distributed mainly according to the production site and not so much according to management history. However by defining the age of the forests and the species composition, the latter also plays an important part in forming the present structure.

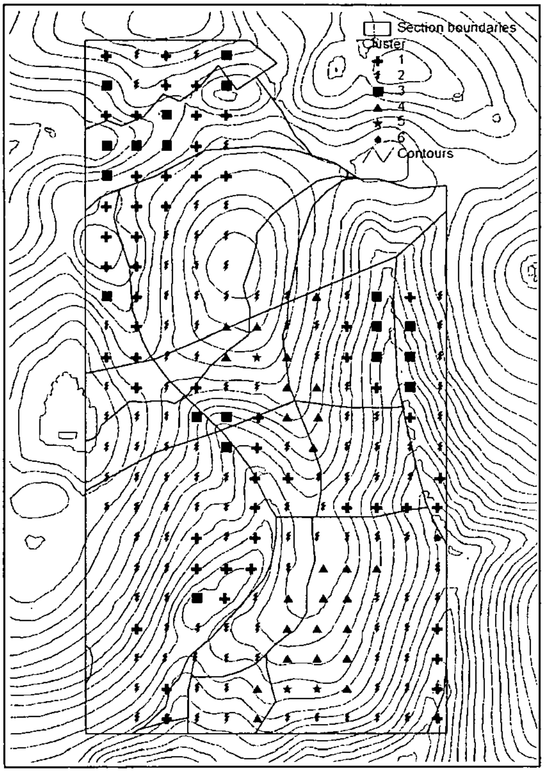

Fig. 7 The groups identified by the cluster analysis

Fig. 8 shows the boxplots of some chosen indices in the 6 categories. Group 1 is mainly situated on the lower parts of slopes along the valleys and is characterised by the dominance of *Quercus petraea* and *Carpinus betulus.* All the indices show rather high values, although never the highest. Stand height is about 22 meters. Group 2 is situated on the (mainly east-facing) slopes and includes the sampling points with the highest species diversity. Mean stand height is about 15 m but the basal area/ha is rather high, possibly because of a high stem density. The coefficient of variation (and consequently the diversity of age groups) is rather low. Group 3 represents the points in the older forests in the north and the valley heads, mainly dominated by *Fagus sylvatica.* The coefficient of variation is highest in these areas and the basal area is also rather high. The horizontal distribution of trees is close to regular while species diversity is rather lower. The average stand height is about 25 m. Group 4 is mainly situated on the ridge south of Mt. Káposztás, and the most characteristic species is *Quercus pubescens.* These stands generally show lower values; average stand height is around 10 m and both basal area and coefficient of variation are low. Species diversity however is very high and the stands are moderately aggregated. Group 5 represents the clearings in the ridge, so basal area is very low at these points and species diversity is not too high either. *Quercus pubescens, petraea* and *robur* dominate these points. A high median of the coefficient of variation refers to the natural reforestation processes occurring at these points. Group 6 consists of a single point in Hosszú-valley with rather low values in the case of all the indices, except height.

SUMMARY

In general we can conclude that there are several well-identifiable groups of sampling points in the Haragistya-Lófej forest reserve; the groups are much affected by the production site; the role of elevation seems especially important. The buffer zone in the south and the core area of the reserve also differ especially in terms of tree size and distribution. From several widely used structural and compositional indices we managed to define a set that were not strongly correlated with each other while each described a range of other related variables. These were the Shannon Index, the coefficient of variation (dbh), the basal area/ha and the stand height. On the basis of these 4 variables we divided the area's forests in 6 classes, which can later be used in the analysis of changes.

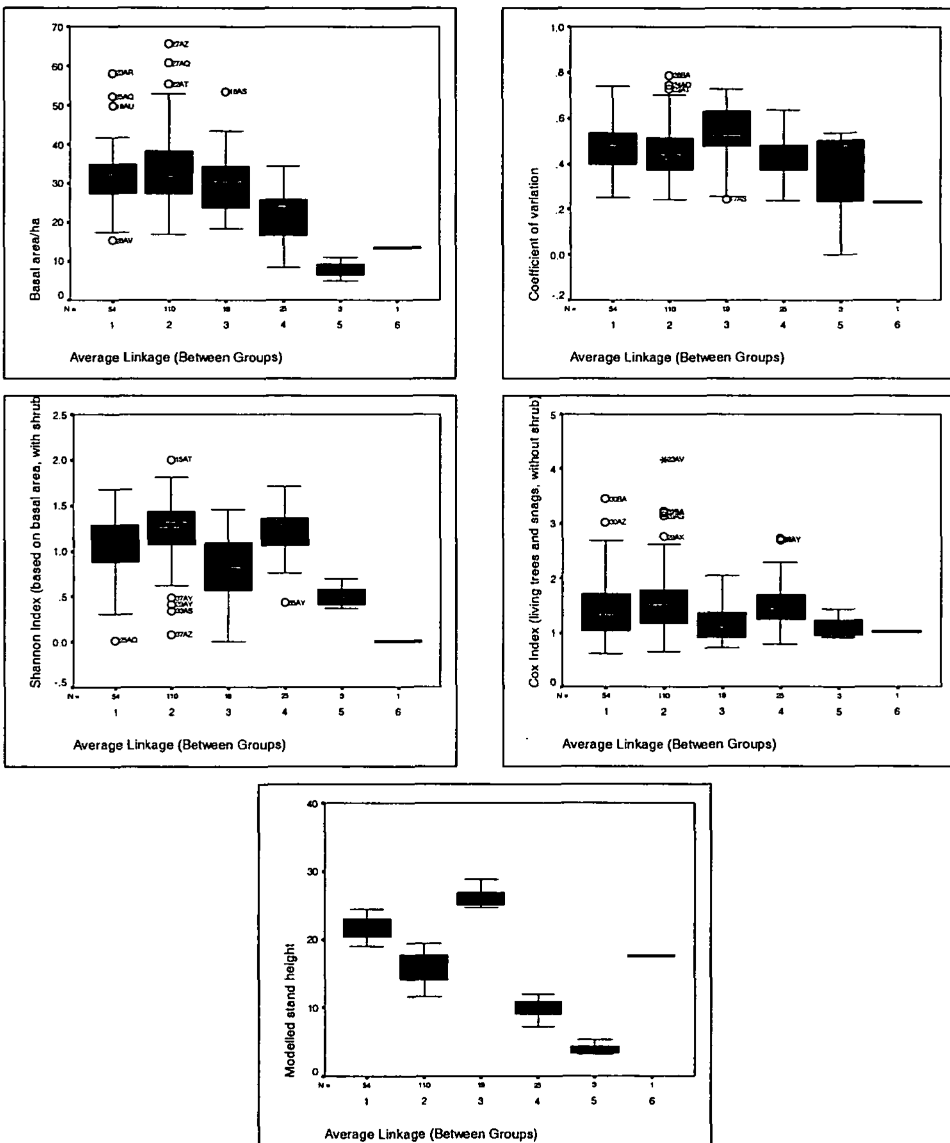

Fig. 8 Structural indices in the groups

Acknowledgments – The research was funded by the Hungarian Scientific Research Fund OTKA/T048356). The authors express their thanks to Ferenc Szmorad, from Aggtelek National Park, for his help in this research and the geography students of the University of Szeged, who helped our field work.

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