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METHODOLOGICAL DEVELOPMENTS TO THE LONG TERM RESEARCH OF STAND STRUCTURE OF FOREST RESERVES

Thesis of doctoral (PhD) dissertation

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SOPRON
2012

Doctoral school: Roth Gyula Doctoral School of Forestry and Wildlife Management Sciences

Leader: Professor Dr. Sándor Faragó

Program: Ecology and diversity of forest ecosystems (E1)

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I. INTRODUCTION AND AIMS

The Hungarian Forest Reserve Programme was set off in the early 1990s. At the beginning, it focused on defining fundamental terms, setting up the forest reserve network, and creating conditions for protection. Prominent national research groups prepared plans and methodological proposals. At the same time, Hungary joined the COST Action E4 (Forest Reserves Research Network) to review forest reserve research in Europe and to clarify the terminology and harmonize research methodology. Based on the preliminaries in Hungary, and the Hungarian and COST E4 experiences, a book entitled “*The aims, strategies and methods of forest reserve research in Hungary*” (edited by Horváth and Borhidi, 2002) was written by a wide range of authors. The book determined the primary aims, strategies and methods of research, categorized forest reserves according the types and intensity of research conducted, and described each forest reserve briefly based on National Survey 2, 1998/99 (Horváth and Bölöni, 2002). Although it made the first move to define research sites and methods and to adjust them to each other, it failed to elaborate and harmonize the details.

Between 2003 and 2009, a devoted research team developed a general long-term sampling plan, elaborated a uniform technique for the survey of stand structure, regeneration and ground vegetation, adjusted and tested these methodological modules in the field, and discussed the experiences comprehensively. Present dissertation is linked largely to this joint work.

The aims of my thesis were:

- to present the methodological frameworks of the series of long-term surveys,
- to verify and document the method of double (combined) stand survey,
- to clarify the calculation of stem number per hectare and stand basal area based on the double (combined) survey, and
- to give a proposal for the method of stand structure assessment.

II. MATERIAL AND METHODS

Methods were tested in the forest reserves of Vár-hegy at Felsőtárkány, Hidegvíz-völgy, Kékes and Szalafő Őserdő, at the FOREST+n+e+t (ERDŐ+h+á+l+ó) sampling points. The great variety of the stands surveyed gives a fair representation of the stand types found in Hungarian forest reserves, which guarantees universality to our method and approach. Present paper is mostly connected to the survey and evaluation of the 90-ha Vár-hegy forest reserve. The core area is situated on the hill range of the Southern Bükk mountain between Felsőtárkány and Eger, occupying the peak, the ridge and the E-SE and W-SW slopes, and the upper part of the Csák-pilis area. The mass of the bedrock is Triassic grey lime and chert with layers of dolomite, white lime and red silica shale at places. The oak-hornbeam macroclimate is replaced by dry Turkey oak – sessile oak mesoclimate on southern slopes, and by beech mesoclimate on northern expositions. The soil is mostly colluvial and lessivated brown forest soil, or brown, red and black rendzina and rocky skeletal soils at extreme sites. The deciduous forest was regenerated mainly by sprout in 1870-80, and was abandoned about 30-50 years ago. At present, it comprises of age groups 20-30, 60-70 and 130-140 years, and one group older than 170 years near the ridge. The forest is dominated by sessile oak, Turkey oak, white oak and common ash with many mixing species. The trees form dry Turkey oak - sessile oak, fresh sessile oak – hornbeam, submontane beech, closed thermophilous oak, white oak scrub, and mixed rock woodlands and topforests. Owing to the oak decline in the 1980s and some sporadic thinnings, these abandoned stands have turned grove-like with a diverse stand structure: common ash, hornbeam and field maple are filling the gaps. The amount of game is incredibly high especially in winter, when they move down from higher regions of the Bükk mountains.

A new method of stand structure survey

We have developed a double (combined) survey method that is more universal than the one used for characteristic stand types in forest management planning. We had two reasons for doing so. On the one hand, the structure of natural (or becoming more natural) stands is much more diverse than that of production forests, which diversity has to be reflected in the sampling method as well[1]. On the other hand, a universal method can be used repeatedly without any further adjustment.

The new method of stand survey described in present thesis is a sampling method in which a given stand is characterized by the study and assessment of sampled trees. The rules, ways and parameters of the so-called double (combined) sampling, the details of the assessment of sampled trees, and especially the optimal combination of all these were discussed at eight meetings held between 2004 and 2009. The discussions and debates took place at the meetings of the Forest Reserve Scientific Advisory Council conducted by the author of present paper, with participating colleagues from the Institute of Ecology and Botany, Centre for Ecological Research of the Hungarian Academy of Sciences, the University of West Hungary, the Eötvös Loránd University, the Central Agricultural Office, the Hungarian Forest Research Institute, the Őrség National Park and the University of Szeged, and several other experts. During this period, the method and its upgraded versions were tested in the diverse stands of 4 forest reserves, which represented 9 of the existing 12 forest association types described by Bartha and Esztó (2001), and all the abandoned forest types described by Czájlik (2002). This work was carried out by 25 researchers and university students.

Experimental sample area and preliminary comparative methodological studies

The preliminary studies involved a complete stand survey carried out in a three-hectare sample plot of a typical, mixed, diverse oak stand in Vár-hegy forest reserve, and the GIS database of the survey (Aszalós et al. 2004). Four field survey methods (angle-count method, survey by circular plots, survey by concentric circular plots and angle-count method combined with strip sampling) were tested in twelve quarter-hectare units of the sample plot to compare their labour need and representativeness when evaluating the results. I used the GIS database for testing and evaluating further sampling method varieties and simulated surveys.

[1] Recording the diversity of stand structure reveals structure types, which would be overlooked when averaging the samples.

Sensitivity test of the double (combined) method using simulated data

Sensitivity tests are suitable for determining the method-dependence and reliability of the estimation of stem number per hectare (N) and stand basal area (G) parameters, in the interrelationship of a semi-natural stand and the sampling methods. I chose a forest stand (Hidegvíz-völgy forest reserve, Vitális & Zakariás 2006) with known species composition and a diverse structure. Using its tree species composition, mixture ratio and diameter distribution data, I created 25 one-hectare randomly structured virtual stands. In the centre of each stand I carried out double (combined) sampling (control), and set up two "what if..." series of experiments with 5, 15, 25, 35, 45 and 65 cm breast height diameter of randomly "planted" trees. In experiment "PLUSZ-18N", I increased the number of stems per hectare with 3% in every case. In this experiment I tested the estimation of stem number per hectare according to three different calculations: the so-called "VAGY" method (estimation of N based on subsamples of the circular sampling plot, estimation of G based on subsamples of the angle-count method), the "MX-ÁTLAG" method (based on the average of both subsample estimations) and the "MX2523" method. In experiment "PLUSZ-2G", I increased the stem basal area per hectare with 5% in every case. In this experiment I tested the estimation of stand basal area per hectare according to the same calculation methods: the so-called "VAGY" method, the "MX-ÁTLAG" method and the "MX2523" method. These experiments were used to examine divergences from the control, and to test the standard deviation of divergences along the series of diameters.

The use of multivariate statistical methods for the identification of stand structure types

I analysed the complete dataset of the 398 FOREST+n+e+t sampling points (SP) of Vár-hegy forest reserve. Of the 32 variables describing tree stand structure, 20 were used in further principal component analysis (PCA). The first six components proved to be significant and comprised 68% of the total variance. Their adequacy was tested with the so-called "random lambda" procedure. Using the component scores of the six PCA axes, cluster analysis was further used to define stand structures types. I used seven clustering methods on the distance matrix calculated from the data matrix of the 6 PCA axes' scores. Three of the classifications (single link, centroid and K-medians) yielded ambiguous results, but the complete link (CMP), the group average (AVG), the average link (MCQ) and Ward's minimum variance method (WRD) gave interpretable results. To find the optimal number of clusters (i.e. to decide where to cut the dendrogram), "silhouette" examinations were made. The outcoming results of the seven classifications (CMP-16, AVG-9, AVG-18, MCQ-13, MCQ-18, WRD-19 and WRD-26) based on the „silhouette" evaluation were summarized in a final, so-called consensus classification.

Description of the stand structure types of Vár-hegy forest reserve

In order to characterize the stand structure types obtained from the consensus classification, I applied graphical descriptive statistics to describe stratification, stem number in the diameter classes, the mixture ratio of the most relevant 15 woody species according to stem number and stand basal area, and the spatial pattern of the types examined. Stand structure types were characterized textually as well.

III. RESULTS

The vertical structure model of the forest

We have adapted the vertical stand structure model recommended by COST E4 (Hochbichler et al. 2000) and have slightly modified it owing to the method of ground vegetation survey and canopy schematization. Consequently, all lying dead wood, and all the woody shoots of live or dead trees or shrubs reaching or exceeding 5 cm of diameter at breast height (DBH) are considered as part of the stand structure. The canopy is treated as either one- or two-layered (upper and lower canopy). Thinner living woody shoots (DBH < 5 cm) reaching heights of 130 cm or more are regarded as shrub layer. Woody shoots between 50 cm and 130 cm of height are taken for regeneration. All herbaceous plants, and the woody shoots not exceeding a height of 50 cm are considered ground (herb) layer. This model is applicable in more than 90% of the core areas of forest reserves in Hungary.

The concept of elementary forest dynamic unit and the method of sampling

What could the ”functional” stand units of a natural tree stand be? What could the size of the smallest stand patch be where the structures and processes to be examined can occur? It is determined primarily (but not exclusively) by gap dynamics in Hungary. Consequently, the smallest possible stand unit of forest dynamic processes is determined by the dimension of the range of gap dynamic processes (but not the gaps themselves), which is approximately a stand with a radius of 1-1.5 times the dominant tree height. Evidently, it is the dimension of gap formation and of its ecological impacts. Of course, such a unit may not be torn away from its environment, the forest stand, without destroying its function; its functioning can only be examined in extensive stands. This special stand size, which cannot be delineated precisely, is named an “elementary forest dynamic unit”, and is considered a forest stand of 0.1-0.5 ha in Hungary. Sampling was carried out right in this dimension. Each sample represents the current state of a local tree stand. The temporal data series of every sample may describe an elementary forest dynamic episode, where considerations should be made of the stochastic processes, the environment or site, the forest historical patterns and their interfering transitions. Neighbouring local patches of the same type can make up one homogeneous stand. Thus, sampling is principally aimed at describing elementary forest dynamic units, which makes the “a posteori” identification of higher level units possible as well.

Stand dynamic and ecological observation network of natural forests

The purpose of the stand dynamic and ecological observation network of natural forests (FOREST+n+e+t) is to support the planned, started and currently running long-term monitoring (HTV) and further interdisciplinary researches in forest reserves

- with the economical and effective use of our resources,
- providing a common infrastructure,
- along a wide spatial range,
- for decades.

Every network is set up and used within the frameworks of the HTV research project. The surveys and researches are carried out at the nodes of the network (sampling points (MVP)), in the following interrelated basic survey topics:

- tree stand structure module (MVP FAÁSZ)
- soil mapping (MVP TALAJ)
- regeneration and shrub layer survey (MVP ÚJCS)
- ground vegetation survey (MVP ANÖV)

The effective utilization of field infrastructure is supported by scientific and documentation-information services.

The double (combined) method of tree stand structure survey

The SP FAÁSZ method is made up of the following modules: 1) general description of forest stand, 2) sampling of local tree stand (MX2523), and 3) survey of lying dead wood. For the estimation of the relevant attributes of stand structure (e.g. tree species composition, diameter distribution, stand basal area) a sample population has to be selected from the tree stand. The survey of stand structure is done by combining the method of circular sampling plot with fixed radius with the angle-count sampling method. This makes sampling universal and representative, and at the same time low-cost, easy-to-learn and clearly reproducible. The use of circular sampling plot ensures that a part of the total area is sampled and that thinner stems standing densely or in groups are represented appropriately in the sample. The angle-count method is more sensitive to the dominant, thick, scarcely distributed trees even in stands of highly different tree stand structures. Owing to the greater distance of bigger trees, the angle-count method counterbalances any spatial micro-heterogeneity originating from patchy patterns. The combined method has two essential parameters: the radius of the permanent circular sampling plot (8.92 m) and the multiplication factor “k” (2) of the angle-count method, which means that about 10% of an area can sampled at a sampling density of 4 MVP per hectars. The double (combined) sampling, i.e. the selection of trees to be sampled, is done easily in practice: all trees standing at 8.92 m horizontally from the sampling point or nearer have to be measured, together with the more distant, larger trees that fall within the angle-count with the multiplication factor 2.

Evaluating the results of the double (combined) survey method

In the double (combined) or MX2523 method, the sample population of trees is made up of two complementary subsamples. One is the group of trees *less* than DBH

25.23 cm, which fall within the sample by the circular sampling plot method (n_{mk}), the other is the group of *trees equal to or more* than DBH 25.23 cm, which fall within the sample by the angle-count method (n_{sz}). Consequently, both the stem number per hectare (N) and the stand basal area per hectare (G) parameters have to be added.

$$N = N_{mk} + N_{sz} \text{ (stem/ha), and } G = G_{mk} + G_{sz} \text{ (m}^2\text{/ha)}$$

In the subsample taken with the circular sampling plot (n_{mk}), the area of the circle, i.e. the sampling area is 250 m^2, and the results standardized to hectare are calculated by multiplying the subsample by 40.

$$N_{mk} = 40 \cdot n_{mk} \text{ (stem/ha), and } G_{mk} = 40 \cdot g_{mk} \text{ (m}^2\text{/ha)}$$

that is,

$$N_{mk} = \sum_{i=1}^{n_{mk}} 40 \text{ (stem/ha), and } G_{mk} = \sum_{i=1}^{n_{mk}} d_i^2 \cdot \pi / 1000 \text{ (m}^2\text{/ha)}$$

In the subsample taken with the angle-count method (k = 2) (n_{sz}), the results standardized to hectare are calculated with the multiplication factor and the variable sampling area, which depends on diameter, that is

$$N_{sz} = \sum_{j=1}^{n_{sz}} (d_j \cdot 0.353553)^2 \cdot \pi \text{ (stem/ha), and } G_{sz} = \sum_{j=1}^{n_{sz}} 2 \text{ (m}^2\text{/ha)}$$

Finally, the stem number per hectare is:

$$N = \sum_{i=1}^{n_{mk}} 40 + \sum_{j=1}^{n_{sz}} d_j^2 \cdot 0.392699 \text{ (stem/ha),}$$

and the stand basal area per hectare is:

$$G = \sum_{i=1}^{n_{mk}} d_i^2 \cdot \pi / 1000 + \sum_{j=1}^{n_{sz}} 2 \text{ (m}^2\text{/ha),}$$

where „d”

is the diameter of sampled trees at breast height, in cm.

Universality, sensitivity, robustness and low costs

The double (combined) sampling method, i.e. method MX2523 can be used in various stand structures effectively owing to its double nature. Some extreme examples from the databases of the Hidegvíz-völgy (HVV) and Vár-hegy (VÁR) surveys are: VÁR Ja-070, N=117 stem/ha, G=28.0 m^2/ha – beech stand; VÁR Kb-014, N=2860 stem/ha, G=30.6 m^2/ha – white oak scrub; HVV 04-07, N=435 stem/ha, G=38.1 m^2/ha – mixed beech stand; HVV 03-08, N=106 stand/ha, G=9.2 m^2/ha – stand with large gaps. The angle-count component adapts well to a range of higher diameters and more sparse population characteristic to large trees, while the permanent circular sampling plot component reduces the possibility of error arising from the random pattern of thinner trees to minimum. The combined sampling method and its analysis according to MX2523 integrate the assets of the two methods, and are therefore “universally” applicable to Hungarian forests. The sensitivity of the method is ensured by the fact that sampling points are fixed in the field and repeated surveys have to be carried out at the same points. The sensitivity tests “PLUSZ-18N” and “PLUSZ-2G” have shown the perceptibility of minor changes (+3% in stem number, and +5% in stand basal area) within the total range of diameters. Our method is considered “robust” in a sense that it does not exaggerate the presence of thinner or thicker trees in the sample, as opposed to other methods. Further, while the employment of the double (combined) method achieves optimal representativeness (at least 10-15 trees in a sample), it incurs low costs (20 or 26 trees on average per sample in the randomly simulated examples of Vár-hegy and Hidegvíz-völgy), as was confirmed by comparison with similar systems (Albrecht 1990, Althoff et al. 1993, Brang et al. 2008, Burrascano et al. 2008).

Proposed scheme for the assessment of stand structure types

The following attributes of stand structure were found to be relevant in determining the types: variables of vertical structure (cover of layers, gap extent, stand height); stem number per hectare and stand basal area, which characterize density and tree volume; variables describing the mixture ratios of the principal tree and shrub species; the relative frequency distributions of diameter classes that reflect the diameter distribution of live trees and shrubs. The 6 significant components of the principal component analysis explained 68% of the total variance, based on the initial 20 variables of stand structure. These components formed basis for further classifications. The “best” classification was achieved with the consensus clustering of the results of several classifications. This procedure turned the multidimensional description inherent in the data into easily interpretable stand structure types. Depending on the interpretation of the data, the clusters may mean either structure types or transitional stages. I integrated ordination and classification methods, their combination was found to be an effective and recommendable tool to determine stand structure types in forest reserves, especially in mixed stands.

The stand structure types of Vár-hegy forest reserve

Based on the analysis of 396 SPs of the Vár-hegy FOREST+n+e+t, 17 characteristic stand structure types or groups could be marked off (two more types were represented only once or twice). Consensus classification has separated the major forest types (ranging from white oak to beech) and further stand structure categories within them, which can be interpreted as forest dynamic units. In grove (or thinned) fresh oak-hornbeam habitats, gaps are filled chiefly by hornbeam, common ash and field maple, and there is a mixed white oak - Turkey oak type displaying similar dynamics, under drier conditions. In several stands, the increased amount of light due to thinning is utilized by a completely closed shrub layer of cornelian cherry under both dry and fresh conditions, while transitions to Turkey oak and white oak stands are also apparent. Other stands, however, are dominated by the ground layer (“grassy oak stand”). Several types are uncommonly mixed, some are dominated by ash. The closed, fresh oak - hornbeam and submontane beech stands are in a state of growth, while smoke tree - white oak scrublands on extreme expositions and dry sites seem to be stagnant.

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IV. MOST IMPORTANT SCIENTIFIC OUTCOMES

- Introduction of the term "*elementary forest dynamic unit*", and clarification of sampling concept.
- Set up, testing and description (shared outcome) of the "FOREST+n+e+t" – stand dynamic and ecological observation network of natural forests, as a consensus research methodology.
- Testing, detailed description and evaluation of the double (combined) method of stand structure survey (shared outcome).
- Finding the optimal algorithm for the evaluation of double (combined) survey data; the description, application and evaluation of the method "MX2523".
- Elaboration and testing of a multivariate methodological scheme; presentation of results to establish stand structure types.
- Establishment and description of the stand structure types of Vár-hegy forest reserve.

V. RELATED PUBLICATIONS

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