Different approaches to the classification of vertical structure in homogeneous and heterogeneous forests

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ABSTRACT: The paper shows difficulties in the evaluation of the forest status when considering forests with different height structure (uneven-aged forests). It is the main problem in categorizing such forests. Concerning the actual forest management conception in Slovakia, it is assumed that the area of forests with close-to-nature management system will increase. It leads to more structured forests, as for the tree species, age, height, as well as the spatial structure. The typical vertically homogeneous forests account for only 50% of all Slovak forests, according to results from the National Forest Inventory in Slovakia (NFI SR). During the processing of NFI data the stands were divided into 2 classes as follows: (*i*) vertically homogeneous stands, which are classified into nine growth stages; (*ii*) vertically heterogeneous stands, which are classified into two growth stages (lower and advanced), and stands in the process of regeneration. New approaches are not based on the visual subjective estimation of forest homogeneity, but on objective analyses of measured values from inventory plots (tree heights, diameters, and age). The paper shows a new approach to the classification of forest stands on an example of the variability of measured heights on inventory plots from NFI.

Keywords: height variability; forest status survey; NFI; structural classification

Structure is one of the basic forest characteristics. The structure represents a mutual arrangement of components next to each other or above each other. The structure can be considered from various aspects – most often as age structure, growth stage and tree species composition.

Classification of forest stands

The current forestry practice classifies forest stands mostly according to age, which seems to be the simplest. Stands are classified into even-aged groups – age classes (10-year interval or 20-year interval). The total number of age stages or classes is neither very high nor small (8–16). Forest stand classification according to the tree species composition seems to be more complicated at first sight, when we realize the total number of tree species in Central European forests (ca 60 species). When considering homogeneous forests the classification is simpler – forest stand is classified into a category which is clearly specified in advance.

Difficulties occur in heterogeneous stands – how to classify forests most effectively so that the classes would be the most homogeneous? Concerning the tree species mixture the forest types are used as a category in Slovakia. The problem is to define the number of forest cover types to cover all possible combinations occurring in the field. Thus, the management units of forest cover types were established, covering as much as 90 types (Lesoprojekt 2000). When considering the percentage ranging from 1 to 100% we could theoretically find 100^{60} exhaustive combinations as all possible tree species composition classes. Such classification is of course unclear in terms of information value.

The method of classification into homogeneous classes is used when considering the stand age of forests or its parts. Generally, it is performed according to the mean stand (or storey) age. Thus, the particular parts (storeys) of uneven-aged stands are separated from each other to be grouped into even-aged classes. The area of each storey is then calculated as a ratio of stand area with respect to the crop density. When the crop density of storey is higher than 100% (when the stand layers are overlapping), the area of all storeys is subsequently unnaturally reduced. Málek (2001) also described this problem in the Czech forest management. In addition, such an approach to classification does not offer enough information on the age structure of forest stands. Age variability is unknown. Naturally regenerated forest stands are grouped into the same class as even-aged stands planted during one year (for example a poplar plantation). There even occur one-storied forest stands which comprise the trees with 20-year age difference. The ratio of uneven-aged stands can only be estimated on the basis of the number of multi-storied stands. Nevertheless, two-storied stand can have higher age variability than three-storied stand. Furthermore, the cases when one-storied stand has high age variability exist (for example a high-mountain beech forest at an extreme site).

The clearcut silvicultural system was based on clear cutting a stand during one year. Classification according to the stand age seems to be suitable in order to monitor the balanced timber production. There arises a problem when the regeneration occurs under the parent stand. Thus the temporary uneven-aged forest stands, in which the storeys can be clearly distinguished from each other, originate. The problem is to divide the area (duplicity, unnatural reduction). The most difficult is to classify an uneven-aged (uneven-structured) forest stand. The selection forest which is partitioned into three storeys according to the current method of Forest Management in Slovakia is an example. But the stand is structured for a long time.

As the clearcut silvicultural system was changing toward the close-to-nature system, the area of uneven-aged forest stands was increasing. The regeneration period will be extended and regeneration will be stimulated. This will lead to more height structured forests. Such forest stands will be more resistant to many affecting factors. But it will also influence surveying methods.

Virgin forests are located on 5% of the total forest area in Slovakia. They create a basis for the study of interrelationships, vertical and horizontal structure. Many specialists dealt with the study of virgin forests on research plots and some information on structure and changes in its dynamics has been obtained so far (Korpeľ 1989; Saniga 1999; Merganič et al. 2003; Vorčák et al. 2006, and others).

MATERIAL AND METHODS

Data from Inventory Plots (IP) acquired during the National Forest Inventory in 2005–2006 (NFI) were used. The data were collected according to the methodology of Šmelko et al. (2006). 1,419 IPs with the basic area of 500 m^2, which met a criterion for the forest definition in terms of NFI methodology, were established. When the different parts (forest/non-forest area boundary, forest/area temporarily without forest, different stand age, and different growth stages) within IP were recognized, the IP was divided into two or more parts (subplots) to be more homogeneous only when its area was 50 m^2 and more. Thus 1,105 IPs covered by trees (78%) were not divided into subplots, 159 IPs uncovered by trees (11%) were not divided either and the remaining IPs (11%) were divided into more homogeneous subplots.

The data which were directly measured as well as the data only estimated were taken to be analyzed. Measured data were: breast-height diameter (dbh) and height of all trees on IP. Information on the age of selected trees within IP and on stand age was obtained (increment cores, counting annual rings on stumps, counting branch whorls at young coniferous species, expert estimation, and information from forest management plans). The mean age for each plot (or subplot, storey) and for tree species was estimated on the basis of this information. In uneven-aged forest stands the estimation of mean age was very difficult.

In terms of the vertical structure of stand the stand storey (tree layer) could be recognized. Stand storeys are even-aged parts of stand which can be clearly distinguished from each other. The stand storey is a set of trees the crowns of which create a separate layer differing from another layer in height and age (minimum of 20 years). To distinguish a storey the canopy density has to be minimally 20%. Each IP (subplot) was included in one of the vertical structure classes, which are as follows (Table 1): (a) one-storied; (b) two-storied; (c) three-storied; (d) multi-storied and (e) selection forest stands. To make it simpler the aggregation was applied: (a) one-storied; (b) two-storied; (c) three-storied forest stands. Basic statistics such as mean and standard deviation of tree height on all IPs were computed.

Aim of study

The aim of the study was to find a method for objective quantification of selected characteristics of stand structure using measured parameters on the example of height structure. Expert estimation of

Table 1. Height and diameter variability in estimated classes of vertical structure in Slovak forests

Class of vertical structure	Regeneration	Number of IPs n	Ratio	Height variability	Height SD	dbh variability	dbh SD
				(%)			
One-storied	No	413	35.2	23.1	10.9	34.3	10.8
Two-storied		247	21.1	33.5	12.2	46.0	14.2
Three-storied		24	2.1	38.3	14.8	53.2	13.4
Multi-storied		36	3.1	33.3	8.7	41.9	11.0
Selection		10	0.9	38.4	7.3	50.9	11.9
One-storied	Yes	122	10.4	20.4	10.0	32.4	10.6
Two-storied		194	16.6	27.2	14.2	39.2	17.2
Three-storied		88	7.5	33.5	15.8	46.6	15.4
Multi-storied		30	2.6	30.9	14.2	50.2	19.8
Selection		3	0.3	21.8	5.3	40.8	15.2
Total		1,167	100				

SD – standard deviation, dbh – diameter at breast height

these characteristics is used in current practice. In homogeneous forest stands the classification is quite simpler than in heterogeneous ones.

The objective assessment of homogeneity rate should be the basis for classification.

RESULTS

In storied stands the area of each storey is calculated as a ratio of total area in relation to canopy density of the particular storey. Such a stand is subsequently divided into even-aged categories when summarized. The result is a histogram (representation of growth stages), but without any information on the forest structure (Fig. 1 – a part of conventional classification). Structural characteristics are subjectively estimated.

During the processing of NFI data the conventional categorization was proved as inappropriate. A different approach was applied: even-aged one-storied stands were grouped into age classes and growth stages. Three classes for uneven-aged stands (in which the age difference between structural elements is 20 years) were drafted out: (A) uneven-aged

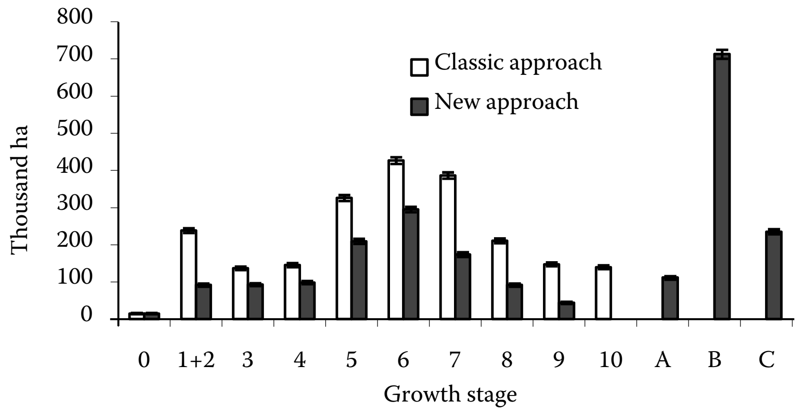

Fig. 1. The area of growth stages for even-aged (0–9) and uneven-aged (A–C) forest stands in the SR
Even-aged stands: 0 – clearing, 1+2 – natural seeding, advance growth, young plantation, 3 – thicket, 4 – small pole stage, 5 – pole stage, 6 – small-sized large – diameter stand, 7 – medium-sized large – diameter stand, 8 – large-sized large – diameter stand, 9 – very large-sized large – diameter stand
Uneven-aged stands: A – inferior mixed growth stage, B – advanced mixed growth stage, C – regenerated stand

younger stands (maximum age of the oldest tree in inventory plot is up to 60 years or top diameter at breast-height is up to 20 cm), (B) uneven-aged older stands (maximum age of the oldest tree in inventory plot is over 60 years or top diameter is over 20 cm), and (C) typical two-storied regenerated stands, where a parent stand is above its regeneration and each storey has a homogeneous vertical structure in contrast to preliminary groups. It would also be possible to draft out new categories for all age classes or growth stages, but in our opinion this would be rather chaotic.

Noticeable results have been revealed which have brought objective information on the real status of forests in terms of age, height and diameter structure. Uneven-aged forest stands are not grouped along with even-aged stands into the same classes. The total area of forest stands (along with areas with temporarily removed trees) is 2.17 ± 0.02 mil. ha. Nevertheless, the older uneven-aged stands occur on one fourth of the total forest area in Slovakia. Even-aged stands can be found on 50% and stands in the process of regeneration on 10% of the total forest area in Slovakia. These facts point out to the good condition of forests in terms of close-to-nature forest management. There is a potential for increasing the area of uneven-aged forests.

The above-mentioned approach to the classification of uneven-aged forest stands is a suitable and precision method for surveying the actual status of forest structure (heterogeneity). But one of its disadvantages is that only estimations are used. Another disadvantage is less information on the structure homogeneity within the age classes. The new classes are wide and high variability of characteristics can be found within them.

As an objective characteristic the coefficient of variance calculated from measured data was proposed to be used. The coefficient of variance of height to show height variability and coefficient of variance of diameter to show diameter variability were applied. The problem is when we want to assess age variability because of less information on stand age. Therefore the age structure is not dealt with in this paper. The estimation of vertical structure (subjective) is compared with height variability, which is calculated from measured trees. Only trees with diameter at breast height of 7 cm and more were included in the analysis. Furthermore, IPs with the number of trees 10 and more were included. Thus, 1,167 IP/subplots were included in analyses.

The average variability ranging from 23% (± 11% standard deviation) in one-storied stands up to 35% (± 16% standard deviation) in selection and three-storied stands was revealed. As only the trees with diameter of 7 cm and more were included, there could be higher variability in those stands where the trees up to 7 cm in breast height occur. Therefore, in the following analysis the IPs where the number of such trees was not sufficient to distinguish a storey were excluded. Variability for classes with regeneration and without regeneration is calculated separately. For more information the diameter variability within the classes is presented.

After excluding IPs where the trees of diameter at breast height up to 7 cm occur, the real variability was shown. Average height variability of 23% (± 11%) in one-storied stands, 33% (± 12%) in two-storied stands, 38% (± 7%) in three-storied and 38% (± 15%) in selection stands was found out. Diameter variability is higher than height variability and is as much as 35% in one-storied stands and over 50% in three-storied stands.

On the basis of this analysis the top limit of height variability to determine a one-storied stand was proposed to be as much as 25%. The problem is to find a level of variability to distinguish two- and three-storied stands from each other. The overlapping of height variability of two- and three-storied stands points out to unclear and subjective

Table 2. Classes of vertical structure in Slovak forests according to calculated height variability

Classes of vertical structure	Number of IP *n*	Ratio	Height average variability (%)	Height SD (%)	dbh average variability (%)	dbh SD (%)
One-storied	570	48.6	17.0	5.1	31.4	10.5
Low varying tree heights	304	25.9	29.5	2.7	40.8	10.0
Highly varying tree heights	300	25.6	45.3	9.8	53.3	14.7
Total	1,174	100.0	27.4	13.2	39.4	14.7

SD – standard deviation, dbh – diameter at breast height

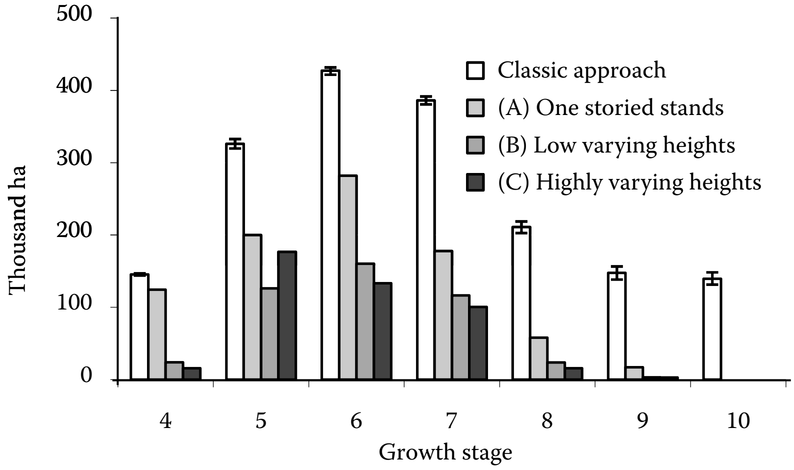

Fig. 2. The area of growth stages in Slovak forests according to conventional classification and classification on the basis of height variability

4 – small pole stage, 5 – pole stage, 6 – small-sized large–diameter stand, 7 – medium-sized large–diameter stand, 8 – large-sized large–diameter stand, 9 – very large–sized large – diameter stand

estimation and distinguishing the stand storeys. Distinguishing between two- and three-storied stands seems to be less important. Therefore, we propose to group the stands only into one-storied (A), stands of less varying tree heights (with height variability between 25 and 35%; B) and stands of highly varying tree heights (with height variability more than 35%; C).

The results of height structure assessment according to the above-mentioned methodology are as follows (Table 2):

The percentage of one-storied stands (A: average height variability of trees with dbh 7 cm and more is 17%) is as much as 49%, stands of less varying tree heights (B: average height variability of trees with dbh 7 cm and more is 30%) 26% and stands of highly varying tree heights (C: average height variability of trees with dbh 7 cm and more is 45%) 26%. These results are similar to subjective estimation (it shows good estimations) and bring information on the real height variability.

The following Fig. 2 shows a comparison between the conventional and proposed method. It contains only growth stages from small pole stage (4) because the younger growth stages are composed mainly of trees with dbh less than 7 cm. IPs were grouped into particular growth stages according to mean diameter.

The proposed method allows to find out the area or representation of growth stages similarly like the conventional approach as well as to evaluate height or other variability (diameter, age) – (Fig. 2). To make it easier the three-stage scale (A: one-storied, B: less varying, and C: highly varying tree height stands) was chosen, but it is possible to modify the scale if necessary.

We can see the height homogeneity in the small pole growth stage, where the stands with low height variability are dominant. Younger growth stages, which were only estimated during the NFI, occupy a smaller area than those determined on the basis of measured diameter. On the other hand, older growth stages occupy a larger area than those determined from measured diameter. When estimated, the tendency is to take into account the large-sized trees to determine a growth stage.

The area of the particular growth stages as well as the area of stands according to height structure classes can be deduced from the figure.

CONCLUSION

A new approach to the classification of homogeneous and heterogeneous forest stands on the example of height structure is presented in this paper. The objective determination on the basis of measured quantities (height, diameter, age) is applied to avoid a subjective estimation which requires the calibration of specialists. Objective determination is needed for the monitoring of changes during a time period. The more objective and the more precise the information, the better the detection of changes.

The advantage of this approach lies in easily and objectively (precisely) measured parameters in a selected group of trees. The number of such trees should be sufficient to comply with the representative variability of parameters.

This approach was applied to a database which represents the status of Slovak forests. In contrast to the conventional approach, approximately 50% of all forests are one-storied with average height variability 17%; about one-fourth are stands of less varying tree heights with average height variability 30%, and the rest are stands of highly varying tree heights with average height variability 45%. This supports the results from surveys which have been performed up to now that in terms of height structure the Slovak forests have a heterogeneous structure.

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