Derivation of target structure for forests of Norway spruce vegetation zone in Slovakia

M. Moravčík

National Forest Centre – Forest Research Institute, Zvolen, Slovak Republic

ABSTRACT: Forests of the Norway spruce altitudinal vegetation zone occur on the upper limit of tree vegetation and they fulfil important ecological and social functions. A great part of these forests are man-made ones with changed age and spatial structure. The basic objective of the care of these forests is improvement or regeneration of their structure so that it will approach the structure of natural and primeval forests. Maximum fulfilment of their basic functions should be ensured in this way. Therefore following the analysis of our own empirical material the target structure of these forests was derived. Outlook target structure was derived so that it would correspond to the state of the most preserved forest ecosystems occurring in the spruce vegetation zone. Achievable target structure was defined for man-made forests with entirely changed structure.

Keywords: Norway spruce; target structure; naturalness class

Protective forests of the *Norway spruce* vegetation zone (*svz*) belong among forests with prevailing ecological and social functions. The aim of management in them is to achieve the state when maximal fulfilment of forest functions is ensured through their functionally effective stand structure, as well as regeneration, improvement or preservation of their self-regulating capability. Greguš (1989) stated that forests fulfil all required functions in the best way in the state corresponding to the state of natural stands not being affected by anthropic factors. The closer the structure of stand to the state of natural or primeval forest stands, the more are the forests capable of development through internal self-regulating processes.

Therefore it is necessary that forest management planning and forestry practices in forests with prevailing protective functions be based on the "naturalness" of forest. Especially this indicator "naturalness class" must be a decisive criterion for determining the need and urgency of management measures. With the aim of ensuring this approach in framework as well as in detailed forest management planning, the objectives of management, mainly target structure, were derived as some of the basic presuppositions.

Development and composition of natural forests were explored in the Carpathian Arc as early as in the thirties of the last century by Zlatník (1934, 1935, 1957, 1976). Meaningful and systematic research of management targets, with emphasis on target structure in forests of the *svz* in conditions of the Tatras National Park (TANAP), started in Slovakia in the sixties of the last century. Results of this research were used by Greguš (1969, 1998) to work out the concepts of forest management planning in protected forests of the TANAP. Furthermore, mainly these authors studied the forest structure in the *svz* in Slovakia: Faith and Grék (1975, 1978), Midriak et al. (1981), Korpeľ (1978, 1989, 1990), Turok (1990, 1991), Hladík et al. (1993), Korpeľ and Saniga (1995), Gubka (1996, 1998), Fleischer (1999), Moravčík et al. (2002). Among foreign authors dealing with issues of *Norway spruce* forest structure in relation to forest management and stability of forests I used the knowledge published mainly by these authors: Míchal (1983), Jurča et al. (1986), Korpeľ (in Ott 1995), Pretzsch (1998), Plíva (2000).

MATERIALS AND METHODS

The target structure of forests of the *svz* was investigated as a part of research on improving and objectifying the procedures of forest management in these forests with the aim to intensify the care of them. As all forests fulfil ecological functions in the best way in the state corresponding to the state of natural forests not affected by any anthropic effects, the basic objectives of management in the forests of the *svz* are preservation, improvement and restoration of functionally effective stand structure being similar to that of natural forests or primeval forests. Therefore it is proposed to base forest management planning in such forests and subsequently forestry practice as well in dependence on the actual state of their naturalness.

Due to the above-mentioned reasons it was important to work out the goals of management, when in addition to differentiated target tree species composition and target stocking the target structure was derived as well. For its derivation data on some indicators of spatial structure were used acquired by the analysis of our own empirical material and from literature. The mentioned empirical material was obtained in the framework of solving the scientific project *Research on Methods of Mountain Forest Management on the Principle of Sustainable Management* co-ordinated by the author of this paper. To derive the target structure of forests in the *svz* the following method was used:

Obtain and evaluate original empirical material from permanent research plots (PRP) established:
– in forests with different naturalness classes,
– in all significant groups of forest types and both altitudinal (upper and lower) zones within the *svz*; *lower zone* – within the altitude to 1,400 m and *upper zone* – at the altitude from 1,400 m up to timber line,
– in forests in those forest regions with significant occurrence of the *svz*.

Find out on PRP detailed data on natural conditions and stand conditions of the forests of the *svz* with the use of indicators being suitable to express the state of structurally differentiated forests.

Derive average values of the indicators of forest condition on PRP being classified according to aggregated degrees of naturalness and development stages.

Provide automated processing and assessment of the empirical material.

Selection of suitable indicators was the first inevitable step for working out the objectives of management and identification of the naturalness classes. The state of the stand structure of primeval and natural forests is characterised by a high degree of structural (age, diameter, height) variability and mosaic horizontal structure. Currently used indicators are not suitable to express such a structure. Therefore different ones were chosen that would serve for a description of such forests in the best way. The indicators are as follows:
– Degree of the variance of diameters as the indicator of diameter variability;
– Proportion of canopy level as the indicator of height variability;
– Ratio of crown length to tree height as the indicator of static stability;
– Slenderness quotient as the indicator of static stability;
– Stand texture to judge the horizontal structure and mosaic of stand clusters.

Table 1. Criteria for the classification of stands by the naturalness classes (NC)

NC	Name	Signs of anthropic effect; signs of stand structure
A	Primeval forest	without any effect of human activity
B	Natural forest	appearance of primeval forest without obvious signs of anthropic activity, possible selective felling in the past, natural forests affected by natural disasters left to natural development are included as well
C	Semi-natural forest	natural tree species composition, altered spatial structure due to extensive human activity
D	Predominantly natural forest	natural signs predominate over anthropic signs
E	Slightly altered forest	forest with natural as well as anthropic signs, the latter ones prevail
F	Markedly altered forest	forests only with anthropic signs but of natural appearance
G	Completely altered forest	forest stand only with anthropic signs of its origin or formation

Table 2. Overview of aggregated naturalness classes and their classification by developmental stages

1 – primeval forests (A)	2 – natural and semi-natural forests (B, C)	3 – man-made forests (D, E)
11 – in the stage of growth	21 – in the stage of growth	34 – tending phase
12 – in the stage of optimum	22 – in the stage of optimum	35 – regeneration phase
13 – in the stage of disintegration	23 – in the stage of disintegration	–

Table 3. Classification of permanent research plots by natural and stand conditions

Forest region (*n*/%)						
35 – Veľká Fatra		37 – Poľana		46 – Nízke Tatry		47 – Vysoké Tatry
7/5.7		12/9.8		85/69.7		18/14.8
Group of forest types (*n*/%)						
SP, LP hd		AcP hd		FP hd		CP
84/68.9		22/18.0		9/7.4		7/5.7
Naturalness class (*n*/%)						
A	A/B	B	B/C	C	D	E
1/0.8	16/13.1	49/40.2	25/20.5	20/16.4	7/5.7	4/3.3
Altitude (*n*/%)						
Within 1,350	1,351–1,400	1,401–1,450	1,451–1,500	1,501–1,550	above 1,551	
14/11.5	21/17.2	29/23.8	32/26.2	19/15.6	7/5.7	

SP – *Sorbeto-Piceetum*, LP hd – *Lariceto-Piceetum* higher degree, AcP hd – *Acereto-Piceetum* higher degree, FP hd – *Fageto Piceetum* higher degree, CP – *Cembreto-Piceetum*

Practices usual for research were used to establish PRP (Šmelko 1985; Šmelko et al. 1996). Circular plots of the size 2–10 ares were established so that there would be at least 25 trees on each plot. The coordinates of PRP were laid in the field using a global positioning system (GPS).

To find out natural conditions we monitored on PRP exposure, slope, altitude, relief, geological parent rock, thickness and form of humus layer, surface skeleton, forest type, soil type and the soil was also sampled. To characterise the state of the forest stocking and canopy were monitored, basic mensurational parameters were taken and development stage and naturalness class were determined on each PRP. All trees were localised as regards position and visualised by means of Stand Visualisation System (SVS), version 3.36 (Mc Gaughey 2002). Then damage to trees, loss of assimilatory organs and social status were determined, crown length was measured and a necessary number of bores for age analyses was taken. Assimilatory organs were sampled for laboratory analyses. Ground vegetation was assessed as well as conditions for natural regeneration of Norway spruce and existing natural regeneration.

The classification of forests according to their naturalness was based on the categorisation according to Zlatník (1976), used also in the works of Korpeľ (1989), Greguš (1998), Fleischer (1999) and others (Table 1). Naturalness was evaluated as the rate of anthropic influence on the forest, starting with visual signs after management activities which are reflected in the tree species, spatial and age structure (Fleischer 1999). Each PRP was classified into one of the naturalness classes from A to G.

For the needs of framework and detailed planning less detailed classification of forests into aggregated naturalness classes was proposed on the basis of the results of the assessment of empirical material from 122 PRP, and it was complemented by the classification according to basic development stages defined by Korpeľ (1989) (Table 2).

An overview of the classification of 122 PRP according to natural and stand conditions under which they were established (forest region, group of forest

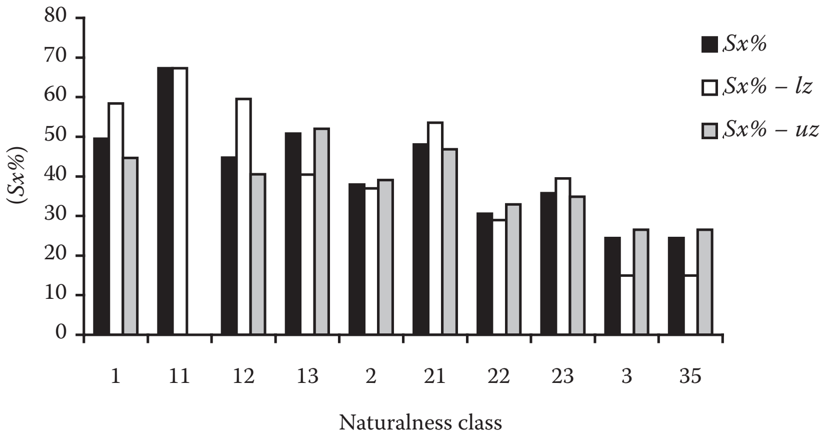

Fig. 1. Diameter variability by the naturalness classes and altitudinal zone

Table 4. Results of testing statistical significance of the differences in diameter variability

	(1)	(2)	(3)	(4)	(5)	(6)
NC 1 – *lz* (1)		0.002**	0.00002**	1	0.044*	0.000002**
NC 2 – *lz* (2)	0.002**		0.0001**	0.000002**	0.457	0.000002**
NC 3 – *lz* (3)	0.0002**	0.0001**		0.000002**	0.00003**	1
NC 1 – *uz* (4)	1	0.000002**	0.000002**		0.0002**	0.000002**
NC 2 – *uz* (5)	0.044*	0.457	0.00003**	0.0002**		0.000002**
NC 3 – *uz* (6)	0.00002**	0.000002**	1	0.000002**	0.000002**	

For Tables 4 to 7: NC – naturalness class, NC 1 – primeval forests, NC 2 – natural and semi-natural forests, NC 3 – man-made forests, *lz* – lower zone of the *svz*, *uz* – upper zone of the *svz*

types, naturalness classes including inter-classes A/B and B/C and altitude) is given in Table 3.

The database system *Mountainous Forests* was constructed in MS Access 2000 for the processing and assessment of empirical material from 122 PRP. To derive the target structure we used data from literature and the values of selected indicators of spatial structure obtained from the assessment of empirical material, namely from PRP classified into the highest naturalness class (primeval forests) for the derivation of outlook target structure and into the 2nd naturalness class (natural and semi-natural forests) for achievable target structure.

RESULTS AND DISCUSSION

Description of the spatial structure of forests of Norway spruce vegetation zone

Diameter variability

Forests classified as primeval forests with naturalness class (NC) 1 have the highest diameter variability (Fig. 1) and the variation quotient (S_x%) is 49.5%. Natural and semi-natural forests (NC 2) have lower diameter variability, about 38%, and the variation quotient is 24.4%. Within individual naturalness classes diameter variability differs in dependence on the development stage. Its highest values are in the stage of growth (67.3% in NC 1 and 48.1% in NC 2) followed by the stage of decline, when the variation quotient of diameters is 50.8% in NC 1 and 35.8% in NC 2, and finally by the stage of optimum with the lowest values of diameter variability in the 1st NC 44.7% and in the 2nd NC 30.5%. The same relationships between NC and development stages for diameter variability were recorded also within individual groups of forest types.

The results of testing statistical significance of the differences in diameter variability between individual NC and altitudinal zones (lower zone – *lz* and upper zone – *uz)* are presented in Table 4. We can conclude from the results that there are statistically significant (*) up to highly significant (**) differences between individual NC but no differences between altitudinal zones.

Height variability

The same conclusions as on diameter variability followed from the study of height variability (Fig. 2). The highest variability was recorded in primeval forests (38.3%) followed by natural and semi-natural forests (30.1%) and man-made forests with the value of variation quotient 17.8%. Equally the highest variability is in the growth stage, 62.5% in NC 1 and 39% in NC 2. The same results were obtained also within individual groups of forest types.

The results of testing statistical significance of the differences in height variability between individual

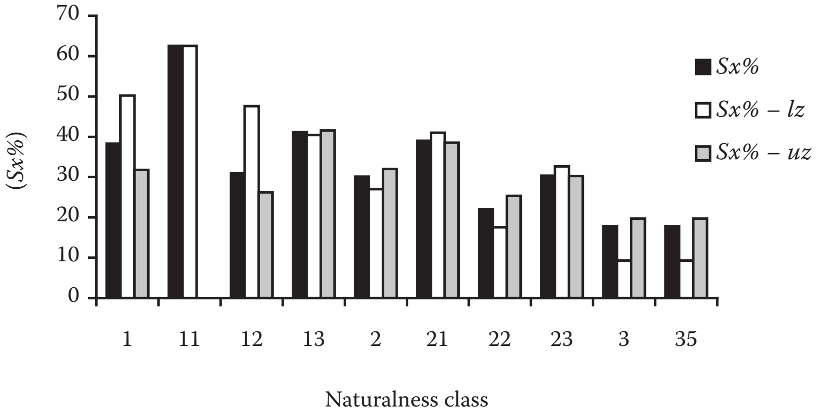

Fig. 2. Height variability by the naturalness classes and altitudinal zone

Table 5. Results of testing statistical significance of the differences in height variability

	(1)	(2)	(3)	(4)	(5)	(6)
NC 1 – *lz* (1)		0.00002**	0.000006**	0.333	0.068	0.761
NC 2 – *lz* (2)	0.00002**		0.798	0.0004**	0.000**	0.00001**
NC 3 – *lz* (3)	0.000006**	0.798		0.0002**	0.000**	0.00001**
NC 1 – *uz* (4)	0.333	0.0004**	0.0002**		0.007**	0.232
NC 2 – *uz* (5)	0.068	0.000**	0.000**	0.007**		0.105
NC 3 – *uz* (6)	0.761	0.00001**	0.00001**	0.232	0.105	

NC and altitudinal zones are given in Table 5. We can draw similar conclusions like from testing diameter variability. With some exceptions statistically highly significant differences between NC were confirmed, and the differences between altitudinal zones (*lz* and *uz*) within the same NC were not confirmed.

Slenderness quotient (ratio of tree height to tree diameter)

Slenderness quotient (Fig. 3) as a significant indicator of static stability shows the lowest values in primeval forests (0.59), something higher in natural and semi-natural forests (0.62) and the highest in man-made forests (0.73). From the point of view of development stage the lowest values of slenderness quotient were found in the stage of decline, namely 0.55 in NC 1 and 0.54 in NC 2, followed by NC 2 in the stage of optimum with the value 0.64 and the stage of growth with 0.65. In NC 1 the rank of the stage of optimum (0.63) and that of growth (0.57) is opposite compared to NC 2. Standard deviation illustrated in the given figure and in the table shows

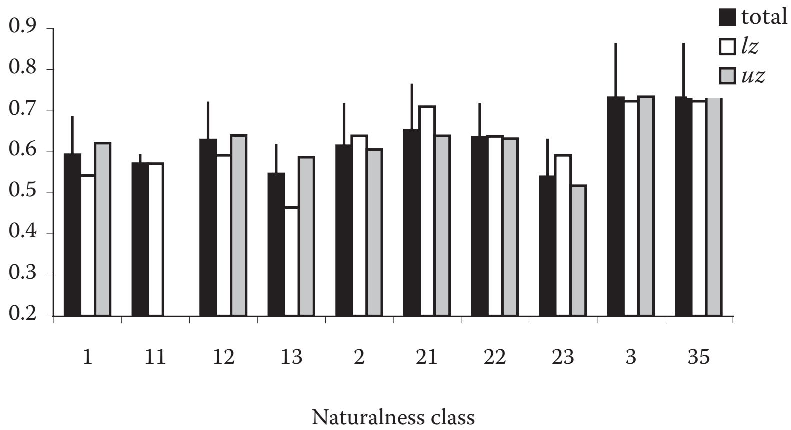

Fig. 3. Slenderness quotients by the naturalness classes and altitudinal zone

Table 6. Results of testing statistical significance of the differences in slenderness quotients

	(1)	(2)	(3)	(4)	(5)	(6)
NC 1 – *lz* (1)		0.0005**	0.00002**	0.730	0.017*	0.00002**
NC 2 – *lz* (2)	0.0005**		0.021*	0.0005**	0.349	0.00002**
NC 3 – *lz* (3)	0.00002**	0.021*		0.00009**	0.004**	0.999
NC 1 – *uz* (4)	0.730	0.0005**	0.00009**		0.073	0.000002**
NC 2 – *uz* (5)	0.017*	0.349	0.004**	0.073		0.00002**
NC 3 – *uz* (6)	0.00002**	0.00002**	0.999	0.000002**	0.00002**	

Table 7. Results of testing statistical significance of the differences in crown length (%)

	(1)	(2)	(3)	(4)	(5)	(6)
NC 1 – *lz* (1)		0.002**	0.00002**	1	0.044*	0.000002**
NC 2 – *lz* (2)	0.002**		0.0001**	0.000002**	0.458	0.000002**
NC 3 – *lz* (3)	0.00002**	0.0001**		0.000002**	0.00004**	1
NC 1 – *uz* (4)	1	0.000002**	0.000002**		0.0003**	0.000002**
NC 2 – *uz* (5)	0.044*	0.458	0.00004**	0.0003**		0.000002**
NC 3 – *uz* (6)	0.000002**	0.000002**	1	0.000002**	0.000002**	

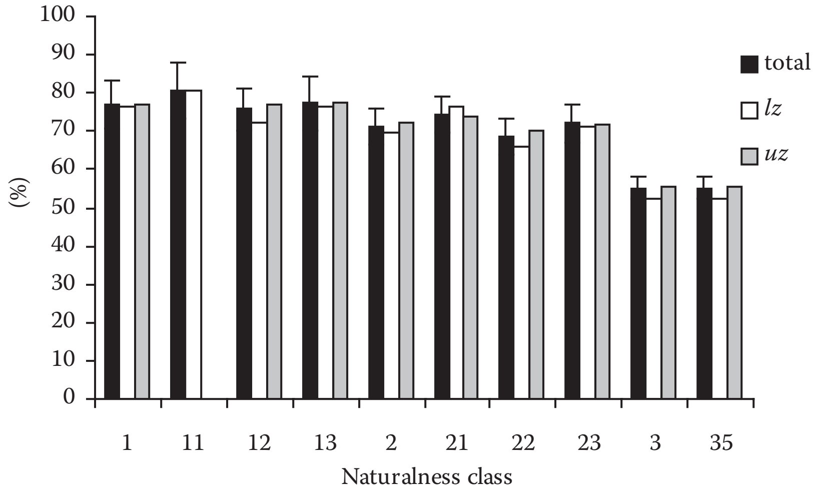

Fig. 4. Crown length (%) by the naturalness classes and altitudinal zone

relatively high variability of the values, on average ± 1 tenth.

We can see from the results of testing the differences in slenderness quotient (Table 6) that except for one case (between StP 1 and StP 2 in the upper zone) statistically significant and highly significant differences between NC were confirmed. In the case of slenderness quotient within the same NC we did not confirm any differences between altitudinal zones.

Ratio of crown length to tree height (crown length in %)

The same conclusions as for slenderness quotient are drawn for crown length (%) (Fig. 4). The most favourable values of crown length (%), on average 76.9% were found in NC 1; in NC 2 it is 71.5% and in NC 3 only 55.1%. From the viewpoint of development stages the highest value was found in the stage of growth (NC 1: 80.6%, NC 2: 74.3%), then in the stage of decline (NC 1: 77.3%, NC 2: 72.1%) and finally in the stage of optimum (NC 1: 75.8%, NC 2: 68.6%). The highest variability given by standard deviation was found in NC 1 (6.2%), followed by NC 2 (4.7%) and NC 3 (2.9%). In testing the differences in crown length (%) in Table 7 statistically highly significant and significant differences between NC were confirmed in all cases. Not even in the case of crown length were the differences between altitudinal zones within the same NC confirmed.

Proportion of canopy levels

Fig. 5 and the following table present an overview of the proportions of canopy levels by individual NC and their development stages. The most favourable composition of all three canopy levels was found in primeval forests (58.7%, 21.3% and 20%), followed by natural and semi-natural forests (63%, 21% and 16%), while it was the least favourable in artificial forests (88.7%, 5.8% and 5.5%). In primeval, natural and semi-natural forests the highest proportion of the second and third level was found in the stage of growth (29.3% and 24%; 27.8% and 20%), then in the stage of decline (21.2% and 22%; 16.5% and 15.6%) and finally in the stage of optimum (20.9% and 17.4%; 16.3% and 11%).

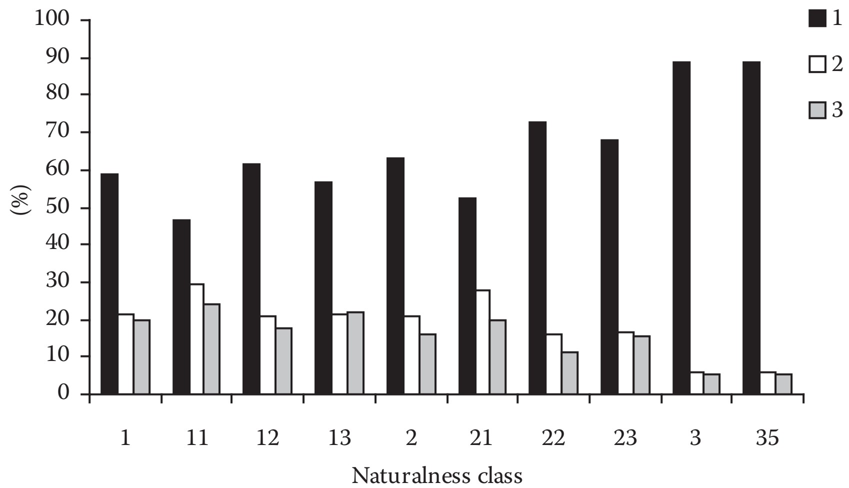

Fig. 5. Proportions of canopy levels by the naturalness classes

Table 8. Model of outlook target structure derived from the values of indicators of forest state on permanent research plots classified into the 1st naturalness class

Indicator		Naturalness class 1 primeval forests	Developmental stage		
			growth	optimum	disintegration
Diameter variability (Sx%)		50 ± 15	60	45	50
Degree of diameter variance		3	3	2–3	3
Height variability (Sx%)		40 ± 20	50	30	40
Share of canopy levels (%)	1	55 ± 15	45	65	60
	2	25 ± 15	30	25	20
	3	20 ± 15	25	15	20
Crown height (%)		75 ± 10	80	75	75
Slenderness quotient		0.6 ± 0.1	0.55	0.60	0.55
Texture (ha)		mosaics of stand clusters and groups of the area 0.5 ha max.			

Table 9. Model of achievable target structure derived from the values of indicators of forest state on permanent research plots classified into the 2nd naturalness class

Indicator		Naturalness class 2 (natural and semi-natural forests)	Developmental stage		
			growth	optimum	disintegration
Diameter variability (Sx%)		35 ± 15	45	30	35
Degree of diameter variance		2	2–3	2	2
Height variability (Sx%)		30 ± 15	40	20	30
Proportion of canopy levels (%)	1	65 ± 20	50	75	65
	2	20 ± 15	30	15	20
	3	15 ± 15	20	10	15
Crown height (%)		70 ± 10	75	67.5	72.5
Slenderness quotient		0.6 ± 0.1	0.65	0.6	0.55
Texture (ha)		area form of structural types mixture (above 0.5 ha)			

Age composition

Fig. 6 presents an overview of average age and age variability of the forests of the *svz* according to the naturalness classes and development stages. The highest average age was found in NC 1 (191 years). The oldest stands, more than 250 years old, were in the stage of decline in NC 1. In natural and semi-natural forests the average age closely exceeds the limit of 150 years (153). In the stage of optimum and decline we found the age of stands more than 200 years only occasionally. The average age reached 159 years in the stage of optimum and 169 years in the stage of decline with standard deviation 29 or 23 years. The average age of PRP in man-made forests is about 125 years.

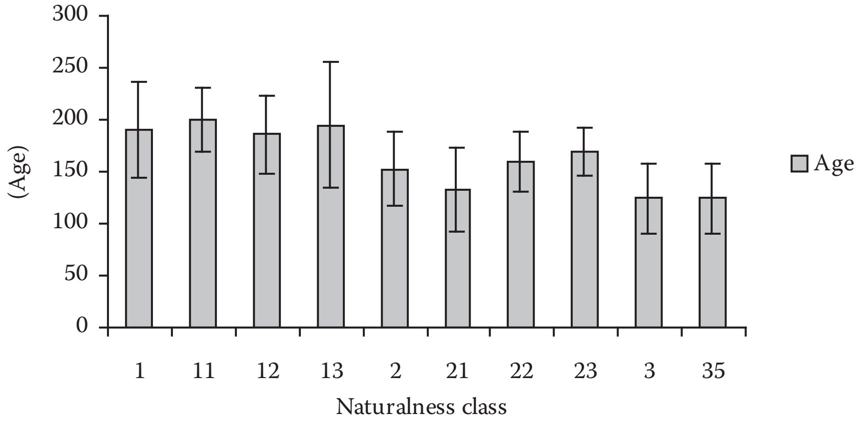

Fig. 6. Age compositions of the stands of the Norway spruce vegetation zone by the naturalness classes

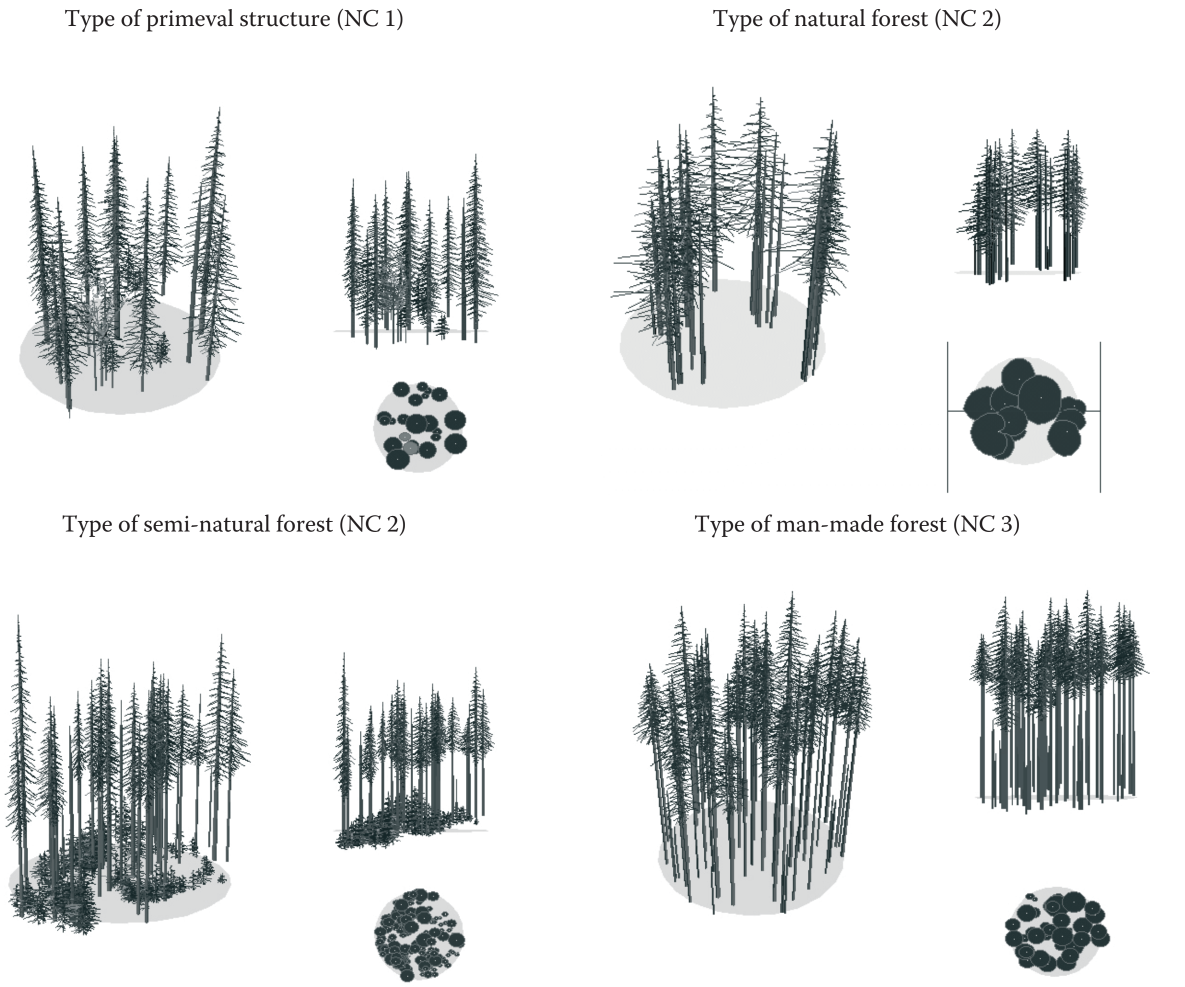

Fig. 7. Examples of some types of forest stand structure in the *svz*

Derivation of target structure

The objective is the structure of forest stands with markedly differentiated age, diameter and height (horizontal and vertical), which ensures the fulfilment of their significant protective (ecological and social) functions. Static stability of these forest stands is of primary importance. Their target structure is not connected with a single moment from the life of stands. A permanent effect of target structure mainly on soil protective function (soil erosion control, avalanche control) and water management function is desirable.

The assessment of empirical material of 122 PRP was based on these principles with the aim to determine the target structure of forests of Norway spruce *vz*. Those PRP that showed the highest class of naturalness were selected and assessed by means of suitable indicators. The following table presents equalled (rounded) average values of these indicators, including their ranges whose values are given by rounded values of standard deviations of individual indicators. Data given for NC 1 and its development stages (Table 8) characterise on average the state of the most preserved forest stands of the *svz* in this country and therefore we can consider them as a model of outlook target structure of stands under given natural conditions.

Due to neglected silvicultural care in the past in a substantial part of the forests of the *svz*, being currently in the stage of decline, it will not probably be possible even in the following generation to reach the structure corresponding to the structure of primeval forests. For such forests as well as for even-aged dense forests with low differentiated structure with neglected tending it is substantiated and necessary to define the achievable target structure that can be expressed by characteristics of structurally less differentiated forest stands, i.e. stands with lower naturalness class (natural and semi-natural forests). With this aim and by the same procedure as used in the derivation of characteristics of the state of primeval forest stands the indicators of stand structure on PRP classified into NC 2 were evaluated (Table 9).

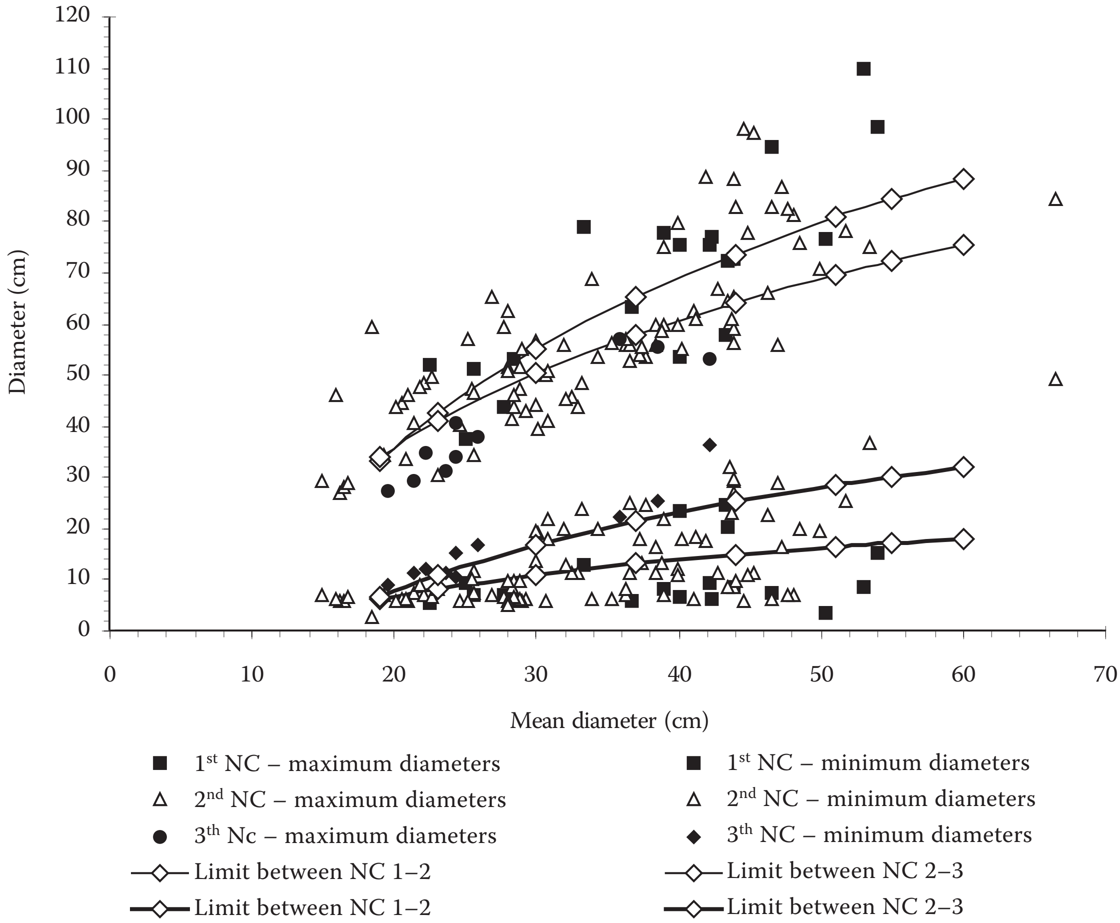

Fig. 8. Graph of diameter variance for Norway spruce in the *svz* in dependence on the naturalness classes

General characteristics of target structure is given in Table 10. Examples of some types of forest stand structure are illustrated in Fig. 7.

Derivation of degree of diameter variance

To simplify the evaluation of diameter variability it is possible to use the degree of diameter variance as a practically usable indicator. In dependence on the mean diameter given on *x* axis the values of minimal and maximal diameter (*y* axis) of each PRP were illustrated. Minimal and maximal values of diameters were separately equalled graphically for all three naturalness classes. Equalling was made by means of logarithm curves. As the obtained curves represented only average values for the naturalness classes, the curves of limit values between the 1st and 2nd naturalness class, and the 2nd and the 3rd naturalness class were put between them. In this way 4 limit curves were constructed (Fig. 8) determining the variances of diameters for all three naturalness classes. The highest degree of variance 3 corresponds to the 1st class of naturalness, the 2nd degree of vari-

Table 10. General characteristics of target structure

Target structure of forest stands
● The aim is the structure, markedly differentiated as regards age, diameter and height (horizontally and vertically), which ensures the fulfilment of significant ecological functions of forests of the Norway spruce vegetation zone
● The aim is irregular gradual structure of stands, where in mosaic alter trees of different age, diameter and height as well as maturity and clusters of trees, or groups with favourable indicators of static stability; with higher altitude the trees have good branching and branches are gradually set lower, while in the upper zone (above 1,400 m) trees grow mostly in clusters
● Static stability and appropriate stocking of these stands is important as well
● Continuous (permanent) effect of stand structure on forest functions is desirable

ance corresponds to the 2nd class of naturalness and the lowest degree of variance 1 corresponds to the 3rd class of naturalness.

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Odvodenie cieľovej štruktúry lesov smrekového vegetačného stupňa na Slovensku

ABSTRAKT: Lesy smrekového vegetačného stupňa sa nachádzajú na hornej hranici stromovej vegetácie a plnia významné ekologické a sociálne funkcie. Veľkú časť z nich tvoria umelo založené lesné porasty so zmenenou vekovou a priestorovou štruktúrou. Základným cieľom starostlivosti o tieto lesy je zlepšenie alebo obnova ich porastovej štruktúry tak, aby sa približovala štruktúre prírodných lesov až pralesov. Takto by sa malo zabezpečiť maximálne plnenie ich základných funkcií. Preto sa na základe rozboru vlastného podkladového materiálu odvodila cieľová štruktúra. Výhľadová cieľová štruktúra sa odvodila tak, aby zodpovedala stavu najzachovalejších lesných ekosystémov, nachádzajúcich sa v smrekovom vegetačnom stupni. Pre umelo založené lesy s úplne zmenenou štruktúrou sa nadefinovala dosiahnuteľná cieľová štruktúra v rámci ich aktuálneho obnovného cyklu.

Kľúčové slová: smrek obyčajný; cieľová štruktúra; stupeň prirodzenosti

Corresponding author:

Ing. Martin Moravčík, CSc., Národné lesnícke centrum – Lesnícky výskumný ústav, T. G. Masaryka 22, 960 92 Zvolen, Slovenská republika
tel.: + 421 455 314 180, fax: + 421 455 314 192, e-mail: moravcik@nlcsk.org