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Close to Nature Management in High-Mountain Forests of Norway Spruce Vegetation Zone in Slovakia

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1. Introduction

The Slovak Republic is one of the most forested countries in Europe. Forest covers about 20,000 km^2 (41%) of the total area of the country, a substantial part of which is occupied by the mountains of the Carpathian Arch (highest peak: Gerlachovsky Peak, 2655 m). Forests in Slovakia have commercial functions as well as functions of benefit to the public, for example: timber production, water management, soil erosion control, avalanche control, nature conservation, tourism, and aesthetic value. Many rivers that are important for neighbouring countries spring from the Slovak mountains; Slovakia is therefore sometimes called the roof of Central Europe.

The Slovak forests are classified according to dominating tree species into eight vegetation zones: 1. Oak (located on altitudes below approximately 300 m), 2. Beech–oak (about 200–500 m), 3. Oak–beech (300–700 m), 4. Beech (400–800 m), 5. Fir–beech (500–1000 m), 6. Spruce–beech–fir (900–1300 m), 7. Spruce (1250–1550 m) and 8. Mountain pine (over 1,500 m). One of the most important forest ecosystems in terms of benefit to the public is Norway spruce forests, located at an altitude of 1250–1550 m in the so-called Norway spruce vegetation zone (SVZ).

Mission of these forests is fulfilment of their important protective functions and specific social needs which govern also the way of their management. A substantial part of them are situated in protected territories pursuant to the Act on nature and landscape conservation in national parks or protected landscape areas. Thus forests of the SVZ fulfill in addition to ecological functions (water management, soil protective, avalanche control functions) also significant social functions, especially nature protective function and recreational function. By Greguš (1989) the mentioned forests with prevailing ecological and social functions fulfill in the best way all required functions in such a state, which corresponds to the state of stands not affected by human activity. The aim of management should be regeneration and preserving sustained forest existence with functionally effective stand structure of natural or primeval character with preserved self-regulating capabilities and good health condition. In this way the management and care about such forests is very effective as the treatments of manager are not required or they are minimal.

On the other side forest stands with substantially changed tree species, age and spatial structure, usually artificially established or disintegrating and disintegrated stands without natural regeneration cannot be retained for self-regulating processes without intervention. Required functionality can be secured in an acceptable time horizon only by means of reconstruction management measures with resultant creation of desired differentiated structure. In the forests with partially changed structure (semi-natural and natural) according to criteria of Zlatník (1976) only necessary correction measures should be carried out to direct their development toward target state.

According to Korpeľ (1990) we have only little experience with regulating the structure of forest stands with prevailing ecological and environmental functions, so there prevail considerable caution to complete passivity in this approach. Only few authors have been dealing with forest management of protection and special purpose forests in Slovakia. Because of such reasons, there is an urgent need for gathering of objective knowledge about the functionally desirable condition of these forests, patterns of their existence, development, risk factors that damage its stability and functionality as well as deepening the connections between forest management planning and work on patterns of dynamics of natural forests and nature friendly silviculture. This need led to the development of proposal presented in this paper focused on objectified practice of framework and detailed forest management planning depending on the degree of conservation of natural structure (naturalnee class) in forests with prevailing ecological or social functions.

The knowledge about the naturalness class of forest ecosystems is therefore of great importance. Its objective assessment is essential in the decision-making process dealing with forest utilisation and subsequent forest management. According to Hoerr (1993) and Schmidt (1997), naturalness is the most significant and widely applied criterion for the evaluation of nature conservation, and serves as a key tool in analyses and as a support in planning nature conservation measures. Unfortunately, the assessment of the forest naturalness class lacks the application of the complex objective procedures and methods not only in Slovakia, but also in other countries. This situation results from the facts that research has not provided the practice with any suitable methodological mechanisms that would enable its scientifically based and statistically provable determination. The same fact has been reported by Bartha and others (2006) who mentioned that in the last decades, a number of authors developed procedures for the assessment of forest naturalness. However, in all these schemes subjective elements have been included. The assessed values of the indicators depend partially on the expert judgement and partially on their estimation. In addition, the experts make decisions, which attributes are to be assessed and what their weight is. The classification of forest naturalness proposed by Zlatník (1976) for Slovakia is also primarily based on subjective expert evaluation of the extent of human influence on forests (Table 2).

In Slovakia, several authors dealt with the evaluation of forest naturalness using typological surveys (Šmídt 2002; Glončák 2007; Viewegh and Hokr 2003; Bublinec and Pichler 2001; Polák and Saxa 2005). These works are characterised by insufficiently complex evaluation of forest naturalness, since the authors primarily assess the suitability of tree species composition. For example, Glončák (2007) identified areas which require active management of forest ecosystems in protected areas by comparing real tree species composition with model using GIS tools. The disadvantage of this method is a high level of subjectivity needed for the development of the model of natural tree species composition. On the other hand, precise distribution of the values of naturalness of tree species composition in GIS environment is a practical advantage of this method. The proposal of the network Natura 2000 in Slovakia was based on the assessment of qualitative attributes of forest ecosystems using numerical quantifiers (Šmelko ex Polák and Saxa 2005; Šmelko and Fabrika 2007). However, this system assessed also features which were not directly connected to forest naturalness (e.g. forest health status, adverse external influences), and when evaluating the majority of attributes, artificial securing of forest status needed from the point of nature conservation was accepted. Hence, this system was more likely aimed at the assessment of nature conservation values than at naturalness of ecosystems.

Naturalness is also a pan-European indicator of sustainable forest management (SFM) belonging to the set of criteria and indicators for sustainable forest management (No. 4.3) proposed within the framework of the Ministerial Conference on the Protection of Forests in Europe (MCPFE (Ministerial Conference on the Protection of Forests in Europe) 2002). In this context, forests are divided into forests undisturbed by man, which encompass forests with least human interventions; modified natural forests, seminatural forests and plantations (productive and protective), which cover man-made (artificial) forests. According to the Global Forest Resources Assessment 2010 (FAO 2007), forests are distinguished into primary forests defined as naturally regenerated forests of native tree species with no clearly visible indications of human activities and with not significantly disturbed ecological processes; other naturally regenerated forests which are also regenerated naturally but the indications of human activities are clearly visible; and planted forests, where the trees established through planting or seeding prevail.

The degree of forest naturalness is assessed through various indicators, mainly: nativeness of species and genotypes, differentiation of stand structure (e.g. diameter frequency distribution, vertical and age structure, occurrence of deadwood, natural regeneration of forests and coverage of ground vegetation), as well as the existence and extent of human influence in particular forest ecosystems (e.g. occurrence of timber felling and forest re-establishment and the applied methods, soil scarification, existence of forest roads, recreational activities, grazing, forest damage). (e.g. McComb and Lindenmayer 1999; Müller-Starck 1996; Peterken 1996; Scherzinger 1996; Frank 2000). Some European countries assess forest naturalness at a sample plot level within the framework of their national forest inventories. However, such an assessment provides summary information on individual forest naturalness classes only at national or regional levels.

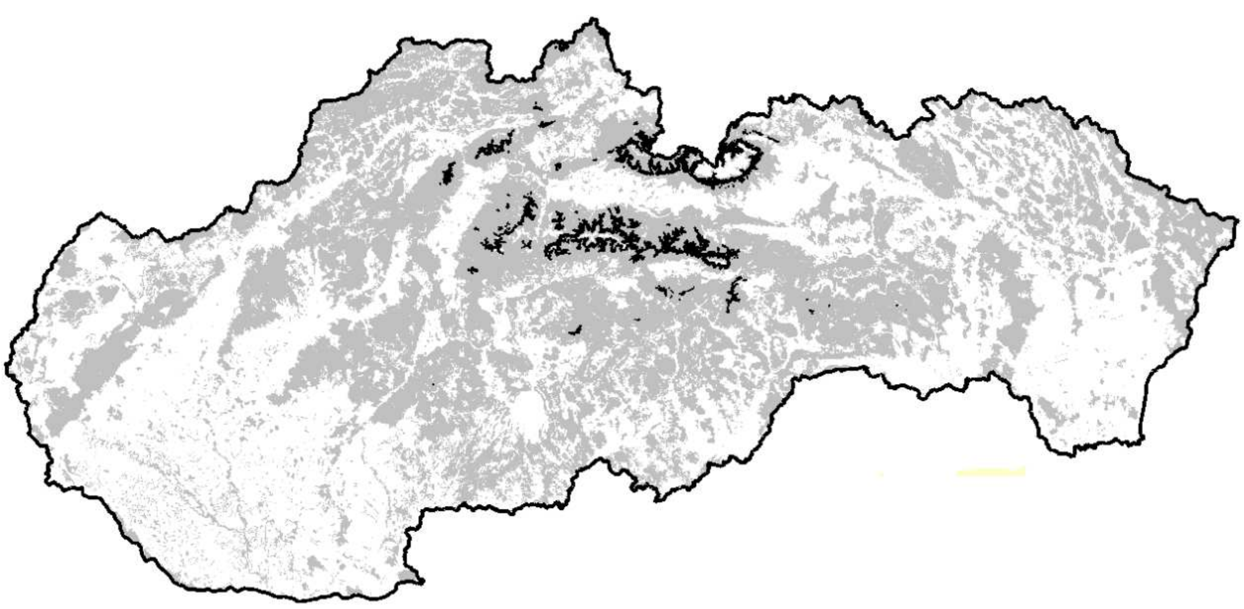
Since the assessment of forest naturalness is very demanding from the points of methodology, applied techniques and funding, its realisation is reasonable if this indicator is an essential element in a specific decisionmaking process. In forestry, forest naturalness is of the greatest significance in the decision-makings that deal with the designation of forests as protected areas, and as a tool for determination the need and the urgency of management (cultivation, tending) in such a way, which will secure the protection of biological diversity, ecological stability and other natural values in forest with prevailing ecological and social functions – protective and protected forests. For these purposes, it is required to perform detailed surveys of forest naturalness.

In contrast to the above-mentioned methods, our proposal (presented in this chapter) is based on more precise data gathering methods, it deals with exclusive relationship with forest naturalness, and allows to account for the specifications of particular biotopes. And above all, it presents the proposal of mathematical and statistical assessment, formulation and presentation of results. In this point the significance of this work has a great international value. It can be used as a basis for efficient application of differentiated methods of utilisation and subsequent forest management. It fits also for application of Assessment Guidelines for Protected and Protective Forests and Other Wooded Land in Europe (MCPFE 2003) which can be regarded as one tool for differentiated management of protected forests. In Guidelines, three classes of forests, in which biodiversity is the main management objective, were defined. Class 1.1 comprises the forests where no active direct human interventions can take place. In class 1.2, only minimum human interventions are permitted. Class 1.3 comprises the forests designated for biodiversity conservation through active management.

2. Characteristics and main problems of forests in the Norway spruce vegetation zone

In the SVZ, total annual precipitation ranges between 1000 and 1300 mm, mean annual temperature ranges between 2°C and 4°C, and the vegetation period lasts 70–100 days. The SVZ forests cover about 40,000 ha or 2% of the total forest area and are located in the central and northern parts of the country, some of them in national parks.

The original SVZ forests were made up mostly of sparse stands or groups of trees with Norway spruce as a dominant species. Some forests also have European larch, European beech, mountain ash, and individual stands of dense mountain pine. Silver fir, cembra pine, and sycamore maple can also be found. The most frequent forest type groups (original species composition before human influence) are *Sorbeto-Piceetum* (mountain ash-spruce) and *Lariceto-Piceetum* (Larch-spruce).



Similar forest types occurred in other European mountain ranges (e.g. Alpine and Carpathian regions in Romania, Ukraine, Poland, Austria, Germany, Switzerland, France and Czech Republic.

Fig. 1. Distribution of spruce vegetation zone over the area of Slovakia.

The age, diameter, and height structure of the forests in SVZ should be highly (horizontally and vertically) diversified to ensure the fulfillment of important ecological and social functions. Their static stability and the continuous influence of forest stand structure on forest functions are significant. Some authors (Korpeľ 1978, Turok 1990, 1991) stated that in spite of the existence of the trees that live to a greater age, the upper age of the mountain Norway spruce primeval forests is approximately 250 years. Almost identical forest types are spread over the whole Alpine and Carpathian region, less frequently they can be found also in other European mountain ranges (Palearctic habitat 42,21: Alpine and Carpathian subalpine spruce forests).

In spite of significant ecological and social functions of these forest ecosystems, their actual condition is not favourable. Moravčík and others (2005) presented the following reasons of the current, not always favourable state of the forests:

- Natural conditions: the SVZ forests are situated at an elevation from approximately 1250 up to almost 1600 m above sea level on long and steep slopes; growing in shallow, skeletal, drying-out (mainly due to the climate change), and nutrient-poor soils; on the sites with high potential and real soil erosion; on remote and technologically inaccessible locations.
- Climatic conditions: extreme temperature, moisture, and wind conditions; frequent intensive precipitation with occurrence of storm rainfalls, which is in the last years intensified by the climate change; and short vegetation season (70 to 100 days).
- Another negative ecological factor significantly influencing the health of high-mountain forests is unfavourable climatic conditions (lack or unsuitable distribution of annual precipitation, temperature extremes, etc). Formerly, the Slovak high-mountain forests were considered to have sufficient precipitation and favourable soil moisture. However, recent studies showed a dramatic change in the water regime in mountain forest soils, especially in sparse spruce stands. Soil acidification and lack of soil moisture are considered the most negative factors — worsening, or on some sites even disabling, natural regeneration of high-mountain forests.
- Monitoring of forest health in certain areas within the SVZ showed that about 90% of SVZ forest can be considered to be affected by air pollution. A rise in ozone concentration with altitude has been proven within the SVZ. Furthermore, a significant decrease of soil pH values was recorded (0.5–1.0 unit since the 1960s). Although sulphur and nitrogen emissions were considerably reduced during the past two or three decades, these substances are still accumulated in the soils.
- Age, vertical and horizontal stand structure of a large proportion of these forests is altered and little/unsufficiently differentiated. This state is the result of the strong colonisation pressure and clear-cutting management in the past.
- A significant proportion of these stands are over-mature (average age 105 years), disintegrating or disintegrated; average stocking 0.63 is significantly lower than the target stocking (0.7).
- Influence of injurious agents. The forests of SVZ are exposed to a complex of negativelly influencing factors, particularly at the upper limit of their occurence. This refers to the influence of air pollution in conjunction with natural factors (insects, fungi, wildlife), with climatic effects (windthrows and snow breakage), and with the impact of tropospheric ozone.

- These forests have been seriously damaged by storms. Trees damaged by wind or physiologically weakened by climatic extremes create suitable conditions for bark beetle outbreaks. Whereas in the past such outbreaks occurred only up to 1000 m, presently this limit is at 1300 m and in certain areas even at the timberline. All these factors cause weakening or even collapse of forest ecosystems. Forest stands become sparse and fragmented. This phenomenon is most evident on mountain ridges at 1300–1600 m.
- Long-term tendency of leaving forests in SVZ without any treatments (since the first half of the last century), which was caused by the fact that their management was unprofitable if assessed solely from the point of management costs and returns obtained from selling the wood. Considering lower wood quality and long extraction distances, both tending and regeneration measures are loss-making.
- Lack of objective knowledge about the functionally desired state of forests in SVZ and about the regulation or management of the structure of the stands with prevailing ecological and social functions. This has resulted in considerable cautiousness or even in passivity in their management (Korpeľ 1989).
- The attitude of state administration of nature conservation and some organisations of nature conservationists, who support a so-called passive conservation, i.e. against any treatments of these forests regardless their altered origin and their actual state.

3. Objectives, materials and methods

The purpose of this scientific paper is to improve the practices of forest management and tending of forests with particularly ecological and social functions on the example of SVZ. It contains development of objectified processes of forest tending according to their naturalness. The primary instruments of systematic forest tending in Slovakia are models of forest management (Fig. 2) that determines for specific natural conditions and stand conditions: management targets, basic management decisions and forest management principles. Our primary objective was to develop differentiated models of forest management for conditions in SVZ forests with added differentiating measure – naturalness class, which has not been applied systematically in the models so far.

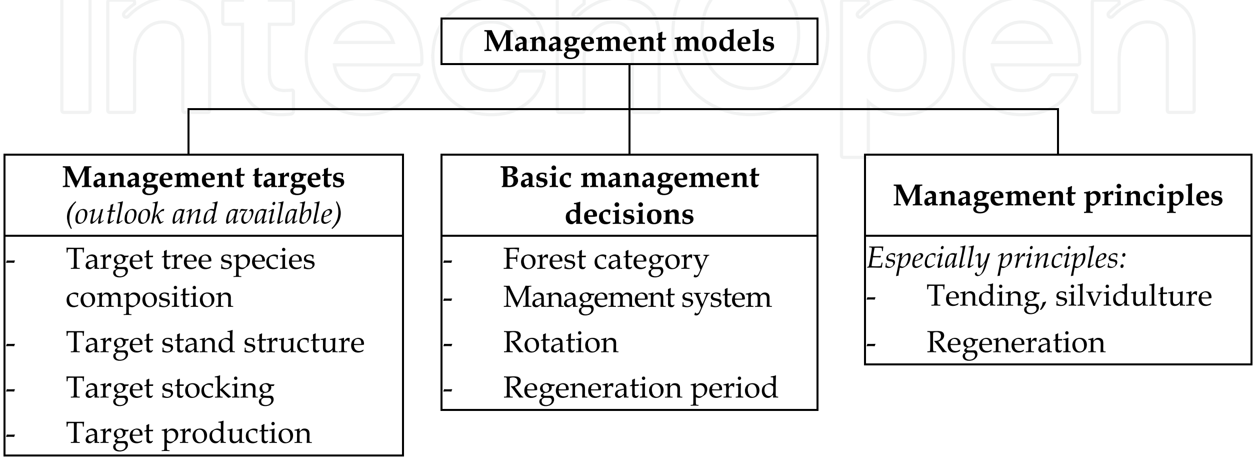


Fig. 2. Framework classification and content of management models.

For mentioned research we selected the SVZ ecosystem because of these reasons: 1) This forest community is very valuable but also vulnerable with significant ecological and social functions including nature-conservation functions. 2) Current condition of these forests (see previous section) is characterized by inappropriate structure of forest stands on a considerable part of them, exposure to harmful agents and adverse changes of the environment, which cause the urgent need to implement the measures to restore and improve their functional efficiency. 3) Because extensive national and international scientific activities have been carried out in the forests of SVZ (e.g. 4-year research project at the Zvolen Forest Research Institute dealing with methods for high-mountain forest management based on principles of sustainable development; S4C Initiative, Mountain Research Initiative, International Scientific Committee on Research in the Alps ISCAR).

Greguš (1989) formulated the general principles of forest management as follows: The mission of forest management should be: (1) achieving the maximum benefits from forest, (2) their permanent provision, (3) minimum risk, and (4) efficiency of providing these benefits. Once formalized these principles to the conditions of SVZ forests, in terms of the forest tending it is essential to achieve:

- The maximum observation of ecological and environmental functions, in particular through the functionally efficient forest stand structure, equivalent or approaching the state of natural anthropicly unaffected stands.
- Ensuring the permanent existence of the forest with good health condition and with corresponding forest stand structure according to which stands are capable of self-regulatory processes.
- Minimal risk of benefits in the given natural conditions through healthy, statically and ecologically stable forests with high-differentiated structure.
- Effectiveness of provision of benefits, through conservation and cultivation of natural forests to primeval forests with preserving their self-regulating features, which will reduce intervention of the forest manager to a minimum.

From the above-mentioned principles, the passive approach for SVZ forests with changed forest stand structure is unacceptable, respectively retaining them without the intervention (the self-development), because there is a risk of their subsequent destruction in large areas. The time horizon of the natural return into the stage of climax forest with the desired functionality through the stages of pioneer and intermediate forests is as a result of the passive approach unacceptable.

Proposing the methodology of solving the problem area was based on the following principles:

- Due to variety of natural conditions and the SVZ stand conditions, forest management models should be differentiated according to:
  - The naturalness class of forest stands (primeval forests, natural and semi - natural forests, man-made forests) and development stages of nature friendly forests.
  - Specific natural conditions characterized by present groups of forest site types (GFT) *Sorbeto-Piceetum* (SP) *Lariceto Piceetum* higher degree (LP hd) *Cembreto-Piceetum* (CP) *Acereto-Piceetum* higher degree (AcP hd) *Fageto Piceetum* higher degree (FP hd) and *Pineto-Laricetum* higher degree (PiL hd).

- Height zones of SVZ (lower zone – to an altitude of about 1400 m and high zone – from about 1400 m up to the upper limit of tree vegetation).
- With regard to the mission of SVZ forests, the basic objectives of management are the following: the target tree species composition, target stand structure and the target stocking.
- Available management targets should be proposed for man-made forests in which the target status can not be achieved during one rotation period.
- Identify the need and urgency of the implementation of forestry measures in forests with different naturalness.

To achieve planned objectives the following procedure was chosen:

- To obtain and evaluate own empirical material from the permanent research plots (PRP) established, so that:
  - each of the PRP represents a particular naturalness class,
  - PRP represents significant typological units: groups of forest site types and the both vertical zones (hight zones) (upper and lower) in SVZ,
  - they were etsablished in the forest areas with a significant presence of SVZ.
- To find a detailed information on natural conditions on PRP and on forest stand condition of SVZ forests using indicators appropriate for expression of condition of structurally differentiated forests – according to their naturalness.
- Deduce the average values of the indicators on forest condition in the PRP classified by the aggregated naturalness classes and development stages so that they could be used retroactively in forest management practice to identify the given forest types and to precise and add the existing management models.
- To use and to process data available from literature and documents of Forestry Information Centre.

We used data of detailed analysis of SVZ forest relized on the basis of data from 122 PRP and published knowledge from authors dealing with the issue of mountain forests as a background material to provide the above-mentiond activities. Empirical material was collected in PRPs by preferential and non-random sampling. The PRPs were established as circle plots of a size of 100-1,000 m^2 in order to meet the prerequisite that a minimum of 25 trees occur within each plot. The PRPs were localized using the global positioning system (GPS). The methodological intention was to establish PRPs in such a manner that detailed information about the natural and stand conditions (inclusive of forest naturalness) of forests in SVZ could be obtained. In the process of the methodology preparation, indicators suitable for the description of the state of structurally differentiated forests that were assumed to be related to the forest naturalness class were identified and proposed.

To find out natural conditions we monitored on PRP the status of these indicators: 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. 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 database system „*Mountainous Forests*" was constructed in MS Access 2000 for the processing and assessment of empirical material. An overview of the classification of 122 PRP according to natural and stand conditions under which they were established (forest eco-region, group of forest site types, naturalness classes and elevation) is given in Table 1.

<table>
<tr><th colspan="24">Aggregated naturalness classes, n / %</th></tr>
<tr><td colspan="9">Primeval forest</td><td colspan="9">Natural forest</td><td colspan="6">Man-made forest</td></tr>
<tr><td colspan="9">17/13.9</td><td colspan="9">94/77.1</td><td colspan="6">11/9.0</td></tr>
<tr><td colspan="9">Of it the stage of</td><td colspan="9">Of it the stage of</td><td colspan="6">Of it the phase of</td></tr>
<tr><td colspan="3">Growth</td><td colspan="3">Optimum</td><td colspan="3">Decline</td><td colspan="3">Growth</td><td colspan="3">Optimum</td><td colspan="3">Decline</td><td colspan="3">Tending</td><td colspan="3">Regeneration</td></tr>
<tr><td colspan="3">2</td><td colspan="3">9</td><td colspan="3">6</td><td colspan="3">32</td><td colspan="3">36</td><td colspan="3">26</td><td colspan="3">2</td><td colspan="3">9</td></tr>
<tr><th colspan="24">Forest eco-region, n / %</th></tr>
<tr><td colspan="6">Veľká Fatra</td><td colspan="6">Poľana</td><td colspan="6">Nízke Tatry</td><td colspan="6">Vysoké Tatry</td></tr>
<tr><td colspan="3">7/5.7</td><td colspan="3"></td><td colspan="3">12/9.8</td><td colspan="3"></td><td colspan="3">85/69.7</td><td colspan="3"></td><td colspan="3">18/14.8</td><td colspan="3"></td></tr>
<tr><th colspan="24">Group of forest site types, n / %</th></tr>
<tr><td colspan="6">SP, LP hd</td><td colspan="6">AcP hd</td><td colspan="6">FP hd</td><td colspan="6">CP</td></tr>
<tr><td colspan="6">84/68.9</td><td colspan="6">22/18.0</td><td colspan="6">9/7.4</td><td colspan="6">7/5.7</td></tr>
<tr><th colspan="24">Elevation (meters above sea level), n / %</th></tr>
<tr><td colspan="4">Up to 1,350</td><td colspan="4">1,351–1,400</td><td colspan="4">1,401–1,450</td><td colspan="4">1,451–1,500</td><td colspan="4">1,501–1,550</td><td colspan="4">1,551 and above</td></tr>
<tr><td colspan="4">14/11.5</td><td colspan="4">21/17.2</td><td colspan="4">29/23.8</td><td colspan="4">32/26.2</td><td colspan="4">19/15.6</td><td colspan="4">7/5.7</td></tr>
</table>

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

Table 1. Data structure with regard to natural and stand conditions.

The classification of forest into forest naturalness classes in each PRP in the field was based on the categorisation of Zlatník (1976) (Table 2). The assessed forest naturalness classes resulted from the detailed, though subjective evaluation of the forest status. Naturalness was assessed as a rate of human influence on a forest on the base of visual features that indicate human interventions (inclusive of forest management), which affect tree species, spatial and age structure (Fleischer 1999) of forests in SVZ. Each PRP was assigned one of forest naturalness class from the scale A to G (Zlatník 1976).

Forest naturalness classes (NC) by Zlatník (1976) were further aggregated into three degrees: Primeval forest, Natural forest, Man-made forest (Moravčík and others 2003; Moravčík and others 2005; Moravčík 2007a, b) prior to data processing. This was done due to insufficient number of plots in the degrees of the finer scale from A to G, and also from the reason of the need their practical application. The aggregated degrees of naturalness were complemented by the classification according to basic development stages defined by Korpeľ (1989) (Table 3).

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. Criteria for the classification of stands by the naturalness classes.

1 – primeval forests (A)	2 – natural and semi-natural forests (B, C)	3 – man-made forests (D-G)
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 decline	23 – in the stage of decline	–

Table 3. Overview of aggregated naturalness classes and their classification by development stages.

These development stages of naturalness classes 1 and 2 in SVZ can be characterized as follows:

- Stage of growth – this stage is characterized by the largest diameter, height and area (vertical and horizontal) differentiation of stands. Canopy is graded to vertical, with a significant participation of trees in the middle and lower layer. There is characterized high vitality of trees and slight tree mortality in upper layer. Smaller gaps as results of tree falling from the previous cycle or accidental death of a strong tree from a new cycle are rapidly canopying.

- Stage of optimum – due to a longer life than height growth, the forest adjusts in height despite the large all-age. The maximum growstock is reached. Characteristic is: small number of trees per area unit and loss of foliation. Construction of stand is graded in height
- Stage of decline – overaged trees in good health condition begin to die in numbers at the end of stage of optimum and the forest is getting to the stage of decline. Growing stock rapidly decreases due to mortality of numerous large trees and is distributed very irregularly. Squads and groups of trees from the old generation are altered by gaps or incoming forest regeneration. Individuals of natural regeneration from the end stage of optimum merge into a continuous regeneration. Usually, there is regeneration of climax (target) tree species, only after fast (calamity) damage also the regeneration of preparatory tree species.

Characteristics of the development stages of man-made forests in SVZ:

- Forests in a period of forest tending - Horizontal involved, even-aged mostly spruce stands in the growth phase of cultures, providing cultures, youg wood, pole young forest and pole mature forest that require forest tending interventions.
- Forests in the regeneration period – even-aged spruce stands in various stages of thinning, or even locally disrupted, in different ages and unstocked areas that require regeneration.

Considering the structure and the type of data stored in the database system ''Mountainous forests'', a number of indicators that were assumed to be related to a degree of forest naturalness were proposed. In total, 25 different indicators of naturalness of forest ecosystems in SVZ were quantified, while tree species diversity was represented with 10 indicators, and structural diversity with 15 indicators (Table 4a, 4b). Tree species diversity was quantified with five indices of species richness, two indices of species heterogeneity, and three indices of species evenness. The indices of species heterogeneity were calculated from the proportion of basal area of particular tree species from the total basal area in a sample plot. The indicators of structural diversity reflect the diversity of structural elements of a forest ecosystem in horizontal and vertical directions. From 15 proposed structural indicators, two characterise vertical diversity (number of tree layers determined on the base of the sociological position of trees, and ''*Arten Profil*'' (species profile) index (Pretzsch 1996), while horizontal diversity is quantified by an aggregation index (Clark and Evans 1954). The remaining structural indicators are relatively simple and easy to be quantified, and are also related to static stability, stand density, and site quality. The average ratio of crown length to tree height, and the average ratio of tree height to tree diameter were calculated from the trees ranked in 1st to 3rd sociological layers. The indicators describing the coverage of herbs, grasses, mosses and lichens, shrubs and subshrubs; the coverage of phases describing the conditions for natural regeneration (juvenile, optimal, senile); the coverage of natural regeneration were visually estimated in the field and are given in relative values (%) (Moravčík and others 2005).

Structural diversity			
Indicator	**Formula**	**Units**	**Reference**
Number of tree layers (*Z*)	$Z = j$	DIM	
Arten profil index (*A*)	$A = -\sum_{i=1}^{S}\sum_{j=1}^{Z} p_{ij} \cdot \ln p_{ij}$	DIM	Pretzsch 1996
Aggregation index (*R*)	$R = \frac{\frac{1}{M} \cdot \sum_{i=1}^{M} r_i}{0.5 \cdot \sqrt{\frac{M}{A}}}$	DIM	Clark and Evans 1954
Coefficient of variation of tree diameter (*CV_D1.3*)	$CV\_D1.3 = \frac{\bar{d}}{SD_d}$	%	Šmelko 2000
Coefficient of variation of height (CV_H)	$CV\_H = \frac{\bar{h}}{SD_h}$	%	Šmelko 2000
Average ratio of crown length to tree height (*AM_K*)	$AM\_K = \frac{\sum_{i=1}^{M} \frac{cl_i}{h_i}}{M}$	%	Šmelko 2000
Average height / diameter (*h*/*d*) ratio (*AM_HDR*) (Slenderness quotient)	$AM\_HDR = \frac{\sum_{i=1}^{M} \frac{h_i}{d_i}}{M}$	DIM	Šmelko 2000
Coverage of grasses (*PK_T*)	$PK\_T = p_i$	%	
Coverage of herbs (*PK_B*)	$PK\_B = p_i$	%	
Coverage of mosses and lichens (*PK_M*)	$PK\_M = p_i$	%	
Coverage of shrubs and subshrubs (*PK_K*)	$PK\_K = p_i$	%	
Coverage of juvenile regeneration stage (*PK_JS*)	$PK\_JS = p_i$	%	
Coverage of optimum regeneration stage (*PK_OS*)	$PK\_OS = p_i$	%	
Coverage of senile regeneration stage (*PK_SS*)	$PK\_SS = p_i$	%	
Coverage of natural regeneration (*PK_NR*)	$PK\_NR = p_i$	%	
Deadwood volume (*MOD*)	$MOD = \frac{\sum_{i=1}^{m} v_i}{A / 10000}$	m^3/ha	

Table 4a. Calculated indicators of structural diversity of forest ecosystems.

Tree species diversity				
Category	**Indicator**	**Formula**	**Units**	**Reference**
Species richness	Index N0 – living trees	*N0 = S*	DIM	Hill 1973
	Index N0 – mosses and lichens	*N0 = S*	DIM	Hill 1973
	Index N0 – shrubs and subshrubs	*N0 = S*	DIM	Hill 1973
	Index R1	$R1 = (S-1)/\ln(M)$	DIM	Margalef 1958
	Index R2	$R2 = S/\sqrt{M}$	DIM	Menhinick 1964
Species heterogeneity	Index λ	$\lambda = 1 - \sum_{i=1}^{S} p_i^2$	DIM	Simpson 1949
	Index H´	$H` = -\sum_{i=1}^{S} p_i \cdot \ln(p_i)$	DIM	Shannon and Weaver 1949
Species evenness	Index E1	$E1 = H`/ln(S)$	DIM	Pielou 1975, 1977
	Index E3	$E3 = (e^{H`}-1)/(S-1)$	DIM	Heip 1974
	Index E5	$E5 = ((1/\lambda)-1)/(e^{H`}-1)$	DIM	Hill 1973

Legende for Tables 4a and 4b:
S – number of species; M – number of individuals, number of living trees in a sample plot; m – number of deadwood individuals (stumps, lying deadwoood); pi – probability, proportion of ith species or category in a sample plot; pij– proportion of trees of ith tree species in jth stand layer; Z – number of layers – stories of the stand; ri – distance between ith tree and its closest neighbour (m); A – area of a sample plot (m2); d – tree diameter; SDd – standard deviation of tree diameters in a sample plot; cl – crown length; h – tree height; v – volume.

Table 4b. Calculated indicators of tree species diversity of forest ecosystems.

4. Results and discussion

4.1 Management targets

4.1.1 Target stand structure

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. The results of testing statistical significance of the differences in diameter variability, height variability, slenderness quotient, crown length (in %) between individual naturalness classes showed to be statistically significant (*) up to highly significant (**). But mostly no statistical significant differences were confirmed between individual altitudinal zones (lower zone – *lz* and upper zone – *uz)* in the same naturalness classes.

The objective is to achieve and keep the structure of forest stands with markedly differentiated age, diameter and height (horizontal and vertical), which ensures the fulfillment 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 of the forest stand life. A permanent effect of target structure mainly on soil protective function (soil erosion control, avalanche control) and water management function is desirable.

The threshold values of selected indicators for target stand structure were derived from data collected on the PRP classified in the 1st naturalness class (primeval forest). They characterize the most original SVZ forest stands and were therefore considered as a benchmark for the desired outlook stand structure. Primeval forests have 3 developmental stages—growth, optimum, and disintegration—characterized by adjusted average values of the following indicators: degree of diameter dispersion (to assess tree diameter variability); share of canopy level (to assess tree height variability); ratio between crown length and tree height, and tree height and tree diameter; and mosaic of stand clusters.

Indicator		**1st natural-ness class**	**Development stage (adjusted average values)**		
			Growth	**Optimum**	**Decline**
Tree diameter variability (Sx%)		50 ± 15	60	45	50
Degree of diameter dispersion		3	3	2–3	3
Tree height variability (Sx%)		40 ± 20	50	30	40
Share of canopy level (%)	Upper	55 ± 15	45	65	60
	Middle	25 ± 15	30	25	20
	Downer	20 ± 15	25	15	20
Crown length / tree height (%)		75 ± 10	80	75	75
Tree height / tree diameter (slenderness quotient)		0,6 ± 0,1	0,55	0,60	0,55
Texture: mosaic of stand clusters and groups of the area 0.5 hectare max.					

Table 5. Model of outlook target structure derived from the values of indicators of forest state on permanent research plots classified into the 1st naturalness class.

However, it will not be possible to reach the desired stand structure even in the next generation because of large areas of artificially formed stands where management has been neglected. The characteristics of a realistic (achievable) target stand structure were therefore derived from the data representing the 2nd degree of naturalness (natural forest).

Indicator		2nd natural-ness class	Development stage (adjusted average values)		
			Growth	Optimum	Decline
Tree diameter variability (Sx%)		35 ± 15	45	30	35
Degree of diameter dispersion		2	2-3	2	2
Tree height variability (Sx%)		30 ± 15	40	20	30
Share of canopy level (%)	Upper	65 ± 20	50	75	65
	Middle	20 ± 15	30	15	20
	Downer	15 ± 15	20	10	15
Crown length / tree height (%)		70 ± 10	75	67,5	72,5
Tree height / tree diameter (slenderness quotient)		0,6 ± 0,1	0,65	0,6	0,55
Texture: area form of structural types mixture (above 0,5 ha)					

Table 6. Model of achievable target structure derived from the values of indicators of forest state on permanent research plots classified into the 2nd naturalness class.

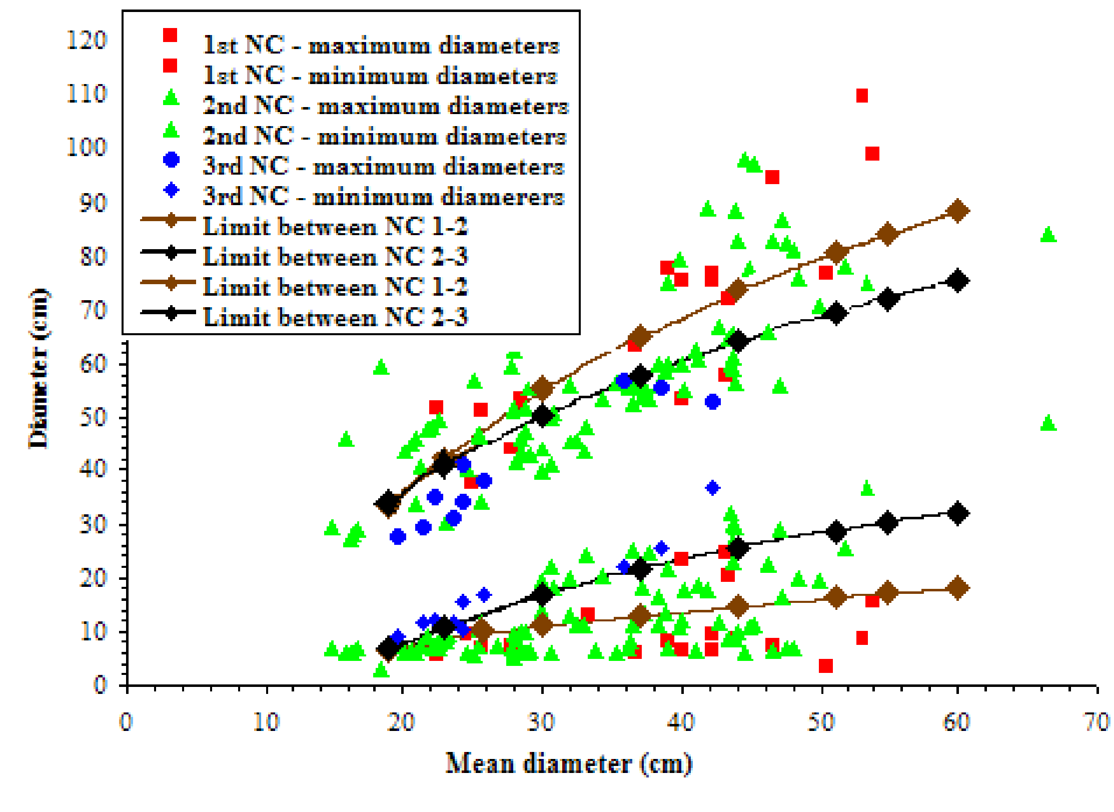


Fig. 3. Graph of diameter variance for Norway spruce in the SVZ in dependence on the naturalness classes.

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

4.1.2 Target stocking

As a rule stocking is defined as an indicator of the growth space utilization by a forest stand. Traditional way of its determination is the share of considered trees and the sum of considered trees and missing trees to the full stocking. According to Greguš (1976) target stocking is the stocking when the stand fulfils the determined functions in the best way. In commercial forests it is mainly production of wood and simultaneously fulfillment of other functions; in protective forests mainly fulfillment of publicly beneficial (ecological and social) functions (Midriak 1994). Greguš (1989) considered target stocking as an important component of management objectives especially because it informs us, though indirectly, but clearly about the fulfillment of desired functions and about the phase of regeneration. Especially by a change in stocking the manager can influence the development in forests. Derivation of target stocking is therefore a significant prerequisite to ensure professional care of forests, including those in the SVZ with the objective of achievement of their maximum functional utility. Assmann (1961) defined these concepts: optimum stocking with optimal stand basal area in which the forest stand produces maximum volume increment; maximum stocking with maximum stand basal area formed by living trees; critical stocking with critical stand basal area in which the forest stand still produces 95% of its maximum increment. In Slovakia mainly these authors dealt with issues related to target stocking: Halaj (1973, 1985), Faith and Grék (1975, 1979), Korpeľ (1978, 1979,1980), Šmelko et al. (1992), Korpeľ and Saniga (1993), Kamenský et al. (2002), Fleischer (1999), Moravčík et al. (2002).

Target stocking in the forests of the SVZ was derived on the basis of an original procedure as optimum stocking with harmonization of the requirements for the fulfillment of ecological functions, securing static stability and the existence of adequate conditions for formation and development of natural regeneration. To achieve this objective our own empirical material (122 PRP) was analyzed. Research was aimed at the investigation of relations between stocking and indicators (Table 4a) of static stability (slenderness coefficient and ratio of crown length to tree height), conditions for the formation and development of natural regeneration, coverage of natural regeneration and coverage of ground and non-wood vegetation in natural and semi-natural stands of the SVZ.

- *Ground vegetation* was found out as the percent of coverage of non-wood and shrubby vegetation on PRP; percent of coverage was determined in the groups: grasses, herbs, mosses and lichens, shrubs and semi-shrubs and total coverage.
- *Young regeneration and thicket* on PRP were found out as the percent of coverage by tree species in respective development stages; current year seedlings, natural seeding being high 50 cm, advance growth being high 1 m and thicket within diameter $d1.3 < 6$ cm were distinguished.

- Conditions for natural regeneration of the Norway spruce were evaluated according to Korpeľ (1990), Vacek et al. (2003) in three phases (juvenile, optimal and senile).
  - *Juvenile (early/premature) phase* – it is characterized by the almost closed canopy of stand with a marked microclimate buffering climatic extremes and by low coverage of ground vegetation. In the forests of the SVZ the soil is usually covered by a layer of forest floor, and low herbs and mosses with total coverage 30–40% prevail in the ground vegetation. The parent stand is capable to ensure natural seeding of the plot being regenerated by a sufficient amount of seeds that can germinate but the conditions of the stand environment are not suitable for the growth of natural seeding and formation of advance growth.
  - *Optimal phase* – it is characterized by the relatively open canopy, and thus by an increased access lof light, warmth and moisture to the soil surface. Climatic extremes are alleviated by the stand. Thin ground vegetation with prevalence of herbs over grasses occurs on the whole plot. In the forests of the SVZ this phase is frequently characterized also by the whole-area occurrence of mosses (more than 20%). Conditions of the stand environment enable the stages of germination, natural seeding, as well as advance growth on the same plot.
  - *Senile (late) phase* – it has the markedly open canopy of parent stand that enables almost a full access of light, warmth and moisture to the soil surface. In the dense ground vegetation grasses and high herbs prevail markedly. Ferns can be dominant in the stands of the SVZ at northern exposures as well. Conditions for the stages of seedling germination and their growth are not favourable any more. Providing there are natural seedlings or advance growth in the stand they can develop successfully.

Actual stocking on PRP was analyzed in the forests of the SVZ in relation to the degrees of naturalness classes, development stages, altitude and groups of forest site types. Average stocking on PRP established in primeval forests reached the value 0.61, in natural and semi-natural forests 0.62 and in artificial man-made forests 0.76. The lowest values of stocking were found in the decline stage (0.52 in NC 1 and 0.45 in NC 2). In the growth stage these values are 0.55 in NC 1 and 0.65 in NC 2. In the stage of optimum the values 0.69 and 0.72 were found. In average data on stocking there were not any statistically significant differences between stocking in the upper and lower altitudinal zone. Forests of the SVZ are permanently naturally open and thin by their appearance, towards the timberline the stands are thinner. Along the timberline they have a character of thin park forests.

In extreme site conditions the density of stands is lower. Trees in extreme conditions need a relatively greater growth area. Using the traditional way of stocking determination we estimate its value to be lower than 1.0 though it is frequently only the result of natural growth processes not influenced by man or injurious agents and its higher value under the given conditions (with regular spacing of trees) is not possible. In this case reduced clearing is unproductive clearing. Its reforestation is impossible. It is a part of the natural growth process and natural stocking of stands below the timberline also according to Assmann (1961).

Optimal stocking in the forests of SVZ was derived so as it would correspond in the best possible way to requirements for the fulfillment of ecological functions (soil protection, hydrological function), securing static stability and the existence of conditions for the formation and development of natural regeneration. It follows from the analysis of the relation between the ratio of crown length to tree height and stocking that with lower stocking the ratio is increasing, up to stocking about 0.7. Further drop of stocking is not reflected significantly in the increase in the ratio (Fig. 4).

It follows from the analysis of the relation between slenderness coefficient and stocking that with lower stocking the value of slenderness coefficient is lower as well. It drops to the value about 0.7. Further drop of stocking is not reflected significantly in the drop of the slenderness coefficient (Fig. 5).

It follows from the analysis of the relation between the conditions for natural regeneration and stocking that the most suitable combination of all three phases of preconditions for natural regeneration (juvenile, optimal, senile) is with stocking 0.7 (Fig. 6). At this value there are the most suitable conditions for the formation and development (advance) of natural regeneration as well as adequate coverage of ground and non-wood vegetation (Fig. 7).

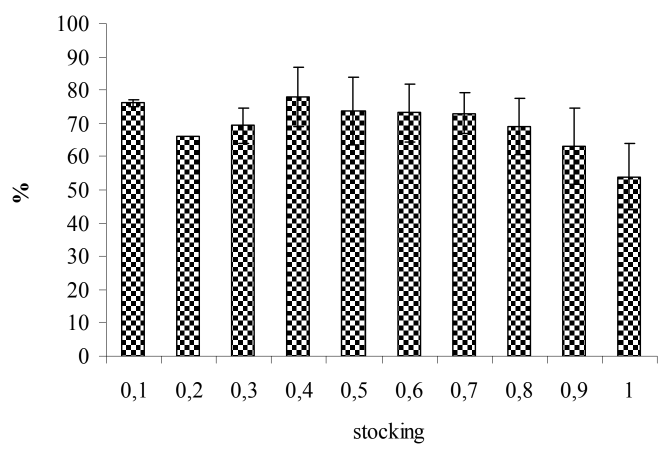


Fig. 4. A relation between the ratio of crown length to tree height (%) and stocking.

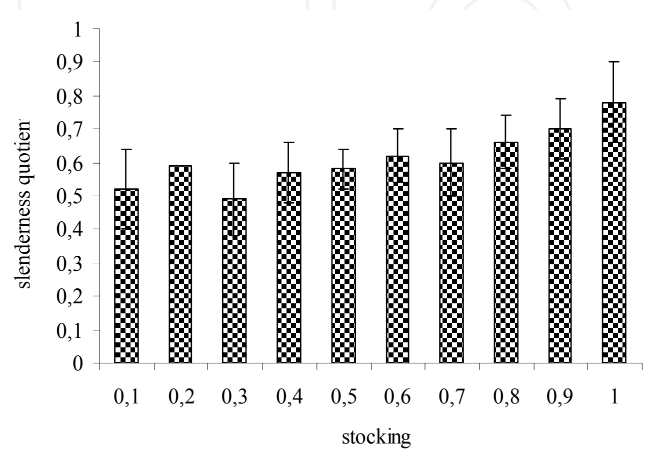


Fig. 5. A relation between slenderness coefficient and stocking.

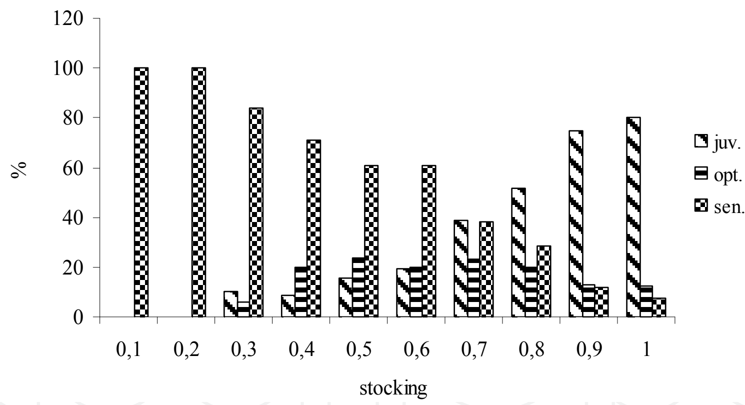


Fig. 6. A relation between natural regeneration phases (%) and stocking.

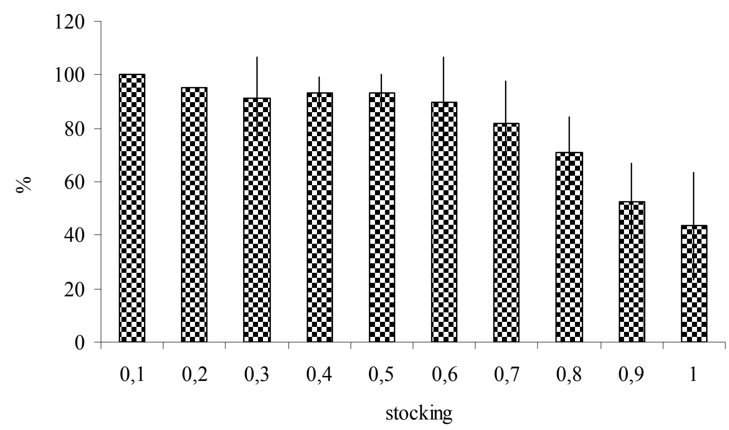


Fig. 7. A relation between ground and non-wood vegetation coverage (%) and stocking.

The optimum values of stocking with regard to the state of evaluated indicators are for stocking 0.7 or 0.7+. It follows from this finding that on average target stocking is about 0.7 for the forests of SVZ. It can differ slightly in dependence on the altitudinal zone or group of forest site zones. More significant differentiation can occur in dependence on the development stage but the objective of the care of forests of SVZ is to prevent the occurrence of the development stage "decline" on large areas. It is a desirable permanent (continuous) effect of this indicator of stand structure on forest functions. We can consider the given stocking rounded to 0.7 as Assman's natural stocking of the stands of SVZ below the timberline being evaluated by a practical manager with a traditional attitude. The values of stocking lower than 0.7 but within 0.7 determine the area share to complement or regenerate the stand.

4.1.3 Target tree species composition

Norway spruce has an absolute dominante in autochtonous stands of SVZ. It is the only tree species, which bears the harsh and extreme existential conditions of this vegetation zone. Therefore, spruce is the doninant tree species in current stands. Current tree species composition in groups of forest site types does not differ from the desired target tree species composition (such as in the sixth vegetation zone, or in other); on the contrary, it is very similar in the main tree species.

In neighbour lower sixth vegetation zone in the original stands of individual forest site type groups tree species as spruce, fir and beech (possibly along with other coniferous and broadleaved tree species such as pine, larch, sycamore maple, ash, elm) formed various mixtures. Currently, tree species composition is altered in a large part of these forests. It consists of spruce monocultures and often is different compared to desired target diverse tree species composition. This has led to introduction of the so-called achievable tree species composition into forest management planning (achievable target), which reflects the current, altered tree species composition and it disintegrates (into the phases) the complex process of a desired target status into shorter periods, respectively to the possible achievable change in the current rotation period. This process is not necessary in SVZ with respect to closely existing and target tree species composition.

Table 7 shows the target tree species composition for groups of forest site types of SVZ. Selection and shares in forest site type groups is based on the original tree species composition as introduced by Zlatník (1956, 1957, 1959). There is an expected arborescent growth of spruce, in LP also of larch and swiss pine. Other tree species may have a height of a tree or shrub, according to altitude and locality conditions of a specific site. Desirable are all original, also rarely growing shrub tree species. Representation of mixed tree species can be provided by permanent, constant cluster and individual natural regeneration, or filling, in the emerging stand spaces.

Forest site type groups	**Target tree species composition, %**	**Detailed specification considering the height degree**
SP	Spruce 70 – 90, rowan, Silesian willow, betula carpatica, sallow, dwarf pine 10 – 30	In the higher degree towards the upper forest limit (which is mostly irregular and continuous), dwarf pine should be more applied in tree species composition for a continuous transition to 8. vegetation zone.
LP hd	Spruce 70 – 90, larch, swiss pine, rowan, rowan, Silesian willow, betula carpatica, sallow, dwarf pine 10 – 30	In the higher degree towards the upper forest limit (this has a continuous transition), individually and cluster mixed swiss pine, larch and dwarf pine should be more applied in tree species composition.
AcP hd	Spruce 70 – 90, sycamore maple, rowan, beech, Silesian willow, dwarf pine 10 – 30	Beech can be applied in a lower degree (referring to 6. vs), there is a lack in higher degree, to apply more dwarf pine towards the upper forest limit.
FP hd	Spruce 70 – 90, beech 0 – 10, white beam, rowan, larch, Silesian willow, dwarf pine 10 – 30	Beech mainly in a lower degree, there is a lack in higher, to apply more dwarf pine towards the upper forest limit.
PiL hd	Larch, dwarf pine, spruce, fir, pine, white beam, Silesian willow (individual tree species on rocks and cliffs)	Small areas of extreme localities of different tree species composition.

SP – *Sorbeto-Piceetum*, LP hd – *Lariceto-Piceetum* higher degree, AcP hd – *Acereto-Piceetum* higher degree, FP hd – *Fageto*
Piceetum higher degree, PiL hd - *Pineto-Laricetum* higher degree.

Table 7. Target tree species composition by groups of forest types and height degree.

4.2 Basic management decisions

Basic management decisions in the Slovak forest management practice concern forest category (forests: commercial, protective, special purposes), silvicultural system (clear-cutting, shelter-wood, selective cutting), rotation, and regeneration period.

4.2.1 Functional focus

In terms of significance of SVZ forests when carrying out the environmental and social functions, their current categorization as protective forests is correct and there is no need to change it. Highly functional potential in providing natural and protective functions is in many cases seen in their declaration as a special purpose forests.

4.2.2 Rotation period (non-production rotation maturity)

The derivation of rotation period in SVZ forests was based on rotation maturity of the main tree species – spruce, life of forest stands and functions that are provided by these forests. Rotation period in protective forests results from their ability to carry out the required functions and it should not be higher than life of forest stands. Life of forest stand is deemed as the maximum age to which the stand retains in the given tree species composition and structure the character of canopy forest, not weedy by foreign species of forest phytocoenoses, preventing the forest regeneration.

These principles were the basis for evaluating the backround material with aim to derivate the rotation perion of SVZ forests. If the rotation period does not to exceed the life of forest stand, it must be determined in the age before the onset of stage of decline, i. e. at the end of the stage of optimum. Because the life of man-made stands is shorter due to faster culmination of growth processes compared to stands growing under cover of parent stand (Pliva, 2000), we researched the life of stand with regard to naturalness classes. We selected among the PRP those that are characterized by natural, semi-natural and man-made forests. Forest stand in a stage of optimum were set apart in and natural and semi-natural forests. Despite the fact that in different locality conditions (group of forest site types), altitude and forest area the life of stands may be different, in the framework feature of rotation period are these differences negligible. Therefore, we suggest differentiating the rotation periods only generally by aggregated naturalness classes.

Rotation period should be seen as a benchmark variable set near the maximum life of stands in natural and semi-natural forests. Maximum age of stands in the stage of optimum in these forests is about 180 to 210 years, so we recommend indicating the rotation period at the age of 200 years. Rotation period is only symbolic in the forest stands with a structure corresponding to the state of primeval forests with preserved self-regulatory process and should be close to the maximum physical age of the main tree species – spruce. Based on literature data and own findings, we suggest indicating the age of 250, respectively 300 years in these best-preserved SVZ forests. In man-made forests with the density 0.7 to 1.0 can be found the oldest stands mainly in the age of only 100 to 110 years. There were found no stands of age that exceeded 150 under the given stages of density. Man-made stands in age over 150 years can be usually found only in the advanced stage of decline. Based on these findings, we proposed to indicate the rotation period at maximum of 150 years in man-made forests.

4.2.3 Regeneration period

Stand structure in SVZ forests should be improved, we should prevent its levelling and create conditions for natural regeneration. It is therefore necessary to maintain the current practice of applying a continuous regeneration period in natural and semi-natural forests, when applying the fine methods and regeneration felling of shelter management method, in particular special purpose selection. In man-made forests, which are intended to restructure to more nature friendly forest types, we should bear in mind with respect to the largely neglected forest tending and difficult natural conditions the early onset, low intensity and slow process of regeneration. Therefore, there is also a well-founded application of a continuous regeneration period. The advantage of a continuous regeneration period is that it allows carrying out interventions with aim to improve the functional efficiency of stands and promotion of forest regeneration any time. An excception from these introduced processes are stands with poor health condition and high degree of threat, often thinned and weedy. Felling-regeneration procedures can not be applied in these stands that require a long-term regeneration periods.

4.2.4 Silvicultural methods

The aim of forest management in SVZ forests is to maintain or achieve such condition of stands, when they can carry out the best of the desired ecological and social functions and are able to exist and evolve through their internal self-regulatory abilities, without or with minimal human intervention. In natural and semi-natural forests of SVZ with partly altered structure, this status can be achieved by applying the finest forms and regeneration felling of shelterwood system, mainly special purpose selection. Selection system can be used only in stands with selection structure. The current state of man-made stands does not allow using special purpose selection. Their reconstruction requires using group, respectively marginal shelterwood cutting which will enable to achieve structurally differentiated stands.

Intensified management use of SVZ

In the issue of use of SVZ forests can be noticed an effort to enforce the passive protection by some interested groups of nature protection. However, there are also proponents of more intensive management use, for example Mráz (2001). In assessing the requirements of more intensive management use, we were looking for conjunction between the limit attributes of production capacity of stands and the need to meet the primary protection functions. The suitability of stands for their management use is limited by locality conditions, relief characteristics (slope, sceleton, regularity of micro-relief), transport accessability and an acceptable height stand quality. Locality conditions in SVZ are expressed by five groups of forest site types (SP, LP hd, AcP hd, FP hd, PiL hd). We should exclude from economic use all those forest site types in groups of forest site types FP and PiL becasue of terrain condition resulting from the following conditions:

- Slope should not exceed 40%, in larger slope there is an increased need to realize the soil protection functions, especially erosion and in higher altitudes also avalanche functions.
- Soil and surface sceleton should not exceed 50% for potential management use. SVZ forests are situated on hard sceleton soils. Sceleton directly affects also production capabilities of the site that decrese in greater representation of the sceleton.
- Forests used for the production of wood requires more management measures, so there should be regular slopes with an balanced gradient of slope and micro-relief should not be bouldered or rised.
- With regard to the possibility of use the ecological techniques and technologies, it is essential to provide accessibility to the given localities. This is essential requirement also in terms of preventing the subsequent damage to stands and soil.
- An important indicator of the possibility of management use of stands is the middle height, respectively the absolute height quality. Hančinský (1972) Stands in SVZ groups of forest site types SP, LP a AcP are considered to be possible economically used when they achieve the absolute height quality 24-25 m. Vološčuk (1970) In AcP and its bottom limit in the absolute height quality. According to our results, it could be from the absolute height quality of 24 m. According to this reason, potential economic conditions for management use can be limited by altitude up to about 1400 m, because there is a significant decrease of height quality over this limit and cluster stan structure with a loose canopy.
- With regard to the above conditions and requirements, these forest site types are potential for the management use:
  - 7106 – fertile rowan spruce wood - SP, LP hd
  - 7401 – fertile maple spruce wood – AcP hd
  - 7404 – irrigated maple spruce wood – AcP hd

Based on the analysis of natural, stand and economic conditions of SVZ forests, we concluded that these forests could be increasingly used for timber production after fulfilling the following conditions and criteria:

- They must be situated on forest site types with the potential of economic use (7106, 7401, 7404), indicated by acceptable absolute height quality of 24 meters or more.
- They must be located in the lower zone of SVZ, up to approximately 1400 m.
- They must meet criteria of micro-relief, limited to a maximum allowable slope up to 40% and the proportion of soil and surface skeleton up to 50%.
- They must be accessible by transport and there must be created such conditions for a minimum damage to stands and soil.
- There shall be no deterioration in carrying out the primary ecological and social functions.
- To assign particularly stands with lower naturalness class for intensified economic use (man-made, respectively natural forests).

4.3 Management principles

Until recently, mountain forests were rather domain of natural scientists. With regard to the inefficiency of their management from the momentaly short-term view, they apply a conservative approach. They were retained to self-development regardless of their structure and closely related stability. Reducing of vitality and decline of mountain stands, however, drew the attention of foresters. Extreme climatic and soil conditions along with an unstable structure, which is a natural consequence of the lack of silviculture treatment, create from mountain forests complexes with a low resistance to stress factors and a high probability of catastrophic decline. In cases where this process has already begun, remedial measures are extremely difficult to apply from a technical and economic point of view. Using an appropriate silviculture measures may lead to growing of stands with significantly differentiated structure, which substantially increases their stability. Implementation of silviculture measures under these conditions is very difficult mainly due to their "un-profitability", unaccessability of stands and discrepancies between forestry legislation and environmental legislation.

<table>
<tr><th>Aggregated Naturalness Classes / Forest Type Groups</th><th>Forest category</th><th>Management system</th><th>Rotation, year</th><th>Regeneration period, year</th></tr>
<tr><td colspan="5">1 – Primeval forests</td></tr>
<tr><td>SP, LP, AcP, FP hd, PiL hd</td><td>Protective</td><td>Retained for self-regulating processes without intervention</td><td>Symbolic 250 – 300</td><td>Permanent natural regeneration</td></tr>
<tr><td colspan="5">2 – Natural forests</td></tr>
<tr><td>SP, LP, AcP, FP hd</td><td rowspan="2">Protective</td><td>Shelterwood system</td><td rowspan="2">200</td><td rowspan="2">Continuous</td></tr>
<tr><td>PiL hd</td><td>Retained for self-regulating processes without intervention</td></tr>
<tr><td colspan="5">3 – Mand-made forests in reconstruction</td></tr>
<tr><td>SP, LP, AcP, FP hd</td><td>Protective</td><td>Shelterwood system</td><td>150</td><td>Continuous</td></tr>
<tr><td colspan="5">Forests of the SVZ determined for more intensive commercial expolitation</td></tr>
<tr><td>SP, LP (7106), AcP (7401, 7404)</td><td>Protective</td><td>Shelterwood system</td><td>120 – 130</td><td>50 – 60</td></tr>
</table>

Table 8. Review of chosen basic management decisions in Norway spruce vegetation zone.

The aim of management in protected forests, including SVZ forests is not the quantity of production as in production forests, but the quality of stands, expressed by target tree species composition, target structure, target stocking and other indicators. It is necessary to focus primarily on use and direction of natural forces towards a low need for additional energy in all phases of management, from establishment through tending and regeneration of stands. Therefore we also propose to differentiate the management principles for the stands with various naturalness classes and development stages. Moreover procedures must be also differentiated with regard to health condition, static stability and the state of natural regeneration of forest stands. From this aspect only preserved forest stands or their parts with parameters corresponding to primeval forests including stand texture, which should be by Plíva (2000) formed of a mosaic of stand clusters, groups and small stands with the area the most 0.5 ha can be retained for self-regulating processes.

Predisposition of mountain forests to forming large-scale horizontal structure Korpeľ (1989, 1995) considers a significant risk factor. Mayer & Ott (1991) state that immediately as there appears a tendency of formation of one-layered stand the spruce stand can be maintained in the state of optimal functional effectiveness only by permanent silvicultural tending. Based on the results of owns research as well as experience from abroad Korpeľ (1990) also notes that high effective differentiated structure cannot be maintained in the altitude below 1400 m for a longer period without intentional silvicultural-logging treatments (with except for extreme soil conditions). He also says there is little experience with regulating desirable structure of stands with prevailing protective (ecological) functions and therefore a very careful almost passive attitude prevails in this field. Korpeľ (1980) evaluated the development and structure of Slovakian natural spruce forests in the SVZ. In the stage of optimum one-layered, height-balanced structure with horizontal canopy is being formed in these forests with long lasting (about 100 years) low resistance potential against wind. Due to fear of weakening the stands are left their natural development frequently, which is ended by calamity.

Due to the mentioned reasons we propose to carry out in the forests with partially altered structure (natural and semi-natural forests) if necessary inevitable correction measures to direct their development towards target state. By KORPEĽ (1980) the most effective and least risky are regulatory treatments through so called purposeful selection felling in advanced phase of growing up or in the initial phase of optimum. Purposeful selection must be aimed at increasing (maintaining) individual stability of trees. Shelterwood regeneration should start in advance on small areas in clusters or groups or in small cleared gaps. The procedure is similar to slow natural disintegration / declina but going on in still resistant stand. In Norway spruce natural forests, where development stages and structurally different parts of stand interchange in a mosaic on plots smaller than 1 ha, regulatory silvicultural-felling treatments are not urgent (especially treatments similar to regeneration felling).

Later when there are still suitable conditions for the germination of seed, survival and growth of spruce seedlings (prior to old-age phase of the conditions of natural regeneration) it is purposeful by Korpeľ (1980) to try to start intentional regeneration. Trees with reduced stability (intermediate with short crown) are removed and the most stable trees as bearers of stand resistance are preserved. By cutting of instable trees concentrated into clusters or groups an irregular regeneration elements rise. It is desirable to use permanently silvicultural and regeneration opportunities for creating strongly differentiated structure of stands and improvement of their static stability, mainly in lower part of the SVZ within the altitude about 1400 m. A great individual stability of trees is conditioned by slow decline of individual trees and thus markedly small-scale regeneration and small area forest texture (Korpeľ 1992). By Míchal (1995) the greater is the area of optimum stage with one-layered stands, little differentiated what concerns height and diameter the faster is their decline and on the greater area. In opposite to that markedly uneven-aged groups decline slowly on a small area.

The difference between actual value of stocking lower than 0.7 and stocking 0.7 determine area proportion to complement or regenerate the stand providing the area has continuous round shape, not very elongated, of minimally 300 m^2, e.g. 17x18 m, 20x15 m etc., which appears as a marked stand gap after missing trees. Fleischer (1999) states he found only for the plot with area 300 m^2 more stable progress of natural regeneration. In this sense also Saniga (2000) give the area of 200-300 m^2 as sufficient also for larch. He states the best conditions for natural regeneration are in the stands with stocking about 0.7 without herbaceous cover (herbs and mosses occur only sporadically). In some places there are small plots with almost 50 about two-year old spruce seedlings per m^2 but the conditions for survival are not suitable and therefore seedlings die (insufficient heat and light).

In structurally altered forests it is impossible to secure in an acceptable time horizon required functionality through retaining the forests for self-regulating processes. Therefore there must be applied reconstruction management measures according to actual state in forest stands with substantially altered age and spatial structure, formed usually as a result of artificial regeneration or in declining and declined stands without natural regeneration. A principal shortcoming is late time of regeneration and state of advanced decline of stands without securing regeneration. In such cases the regeneration can be realized only through artificial or combined regeneration; however only stands with little differentiated age and spatial structure are again created in this manner.

With all this in mind, we propose to plan and carry out any measures in these forests only on the basis of their actual "naturalness" class, which has to be the decisive criterion for determining the urgency of proposed measures. Additional criteria should include an assessment of static stability, natural regeneration, health condition, and stocking, as an indicator of fulfilment of ecological functions (mainly soil and water protection). Basically, it can be stated that the forest stands classified in the 1st naturalness class can be left as is. In such stands, natural regeneration usually fully corresponds to the actual stand structure, and both static stability and health condition are excellent. Forest stands that do not meet these criteria—mostly man-made, even-aged, vertically and horizontally little-differentiated forests, but also natural forests with various development stages whose natural regeneration ability is insufficient—require concrete measures. These measures can be classified according to the degree of urgency, based on the forest's actual status.

Better management of high-mountain forests SVZ will also require building a comprehensive net of forestry roads that are ecologically adapted to the terrain. It will be necessary to adapt all forestry activities in these forests to ecological standards and to introduce the most recent techniques and technologies. Clear-cutting is forbidden in the SVZ and has been fully replaced by shelter-wood and selection (purposefull) systems. On sites with deteriorated soils, recovery measures such as area-wide application of dolomitic limestone by airplane or helicopter, addition of dolomitic limestone and NPK fertilizers in holes, or application of mulching cloths when planting will create suitable growth conditions for subsequent forest stands.

Generally, natural regeneration is preferable. However, on certain sites tree species diversity will be enhanced by planting desired tree species. Mixed stands (especially of Norway spruce, European beech, silver fir, Scots pine, sycamore maple, European larch, and mountain ash) will gradually substitute pure spruce plantations, thus enhancing the ecological stability of the forests (including resistance to ongoing climatic change). The health status of forests and occurrence of harmful agents will continue to be monitored. In the field of forest protection, preventive methods will be given preference over suppressive methods.

4.3.1 Need and urgency of management measures

On the basis of the status of stand structure indicators, the conditions and the state of natural regeneration, static stability, health condition as well as after considering the requirements and conditions being given in basic management decisions and the management targets the manager will decide about the need and urgency of management measures with applying the management principles. The manager will decide whether the stand or its part requires a concrete management measure as well as about the degree of the urgency of management measure based on the fact how the state of stand corresponds to the criteria listed in following table.

Forest stand or its part doesn´t require any measures	*Forest stand or its part requires measures in the 1st degree of urgency (within 3 years)*
1st naturalness class Static stability – excellent Health condition – excellent Natural regeneration – fully corresponding	3rd (2nd) naturalness class Static stability – unsatisfactory Health condition – caduceus or died forest Natural regeneration – slight or minimal
Forest stand or its part requires measures in the 2nd degree of urgency (within 10 years)	*Forest stand or its part requires measures in the 3rd degree of urgency (postponable)*
3rd or 2nd naturalness class Static stability – satisfactory Health condition – mediumly declined Natural regeneration – slight or minimal at the age of forest less than 50 years under rotation	2nd (3rd) naturalness class Static stability – good Health condition – slightly declined Natural regeneration – slight or minimal at the age of forest more than 50 years under rotation

Table 9. Criteria for determination of the need and urgency of the measures.

Stand or its part will be classified into respective naturalness class on the basis of evaluation of diameter and height variability (especially by means of the degree of diameters dispersion and the share of canopy level – Fig. 3 turned into table), crown length and stand texture. Age range may be as an auxiliary indicator. In the following tables (10, 11) are given orientation values of the indicators. They can be used as an aid for assignment of the aggregated naturalness class and development stages of the 2nd NC of respective forest stands or their parts. The values listed in the following tables were derived from empirical material of 122 PRP.

Indicator		**Aggregated naturalness classes**		
		1	**2**	**3**
Degree of diameters dispersion		3	2	1
Share of canopy level; %	1	55 ± 15	65 ± 20	90 ± 10
	2	25 ± 15	20 ± 15	5 ± 5
	3	20 ± 15	15 ± 15	5 ± 5
Crown length; %		75 ± 10	70 ± 10	55 ± 10
Stand texture; ha		> 100	40 – 100	< 40
Age range; years		< 0,2 – 0,5	> 0,5	> 0,5

Table 10. Values of chosen indicators of forest status in naturalness classes 1, 2 and 3.

Indicator		Development stages of naturalness class 2		
		21	22	23
Degree of diameters dispersion		2-3	2	2
Share of canopy level; %	1	50 ± 20	75 ± 15	70 ± 15
	2	30 ± 15	15 ± 10	15 ± 10
	3	20 ± 15	10 ± 5-10	15 ± 10
Crown length; %		75 ± 10	67,5 ± 7,5	72,5 ± 7,5

Table 11. Values of chosen indicators of forest status in development stages of naturalness class 2.

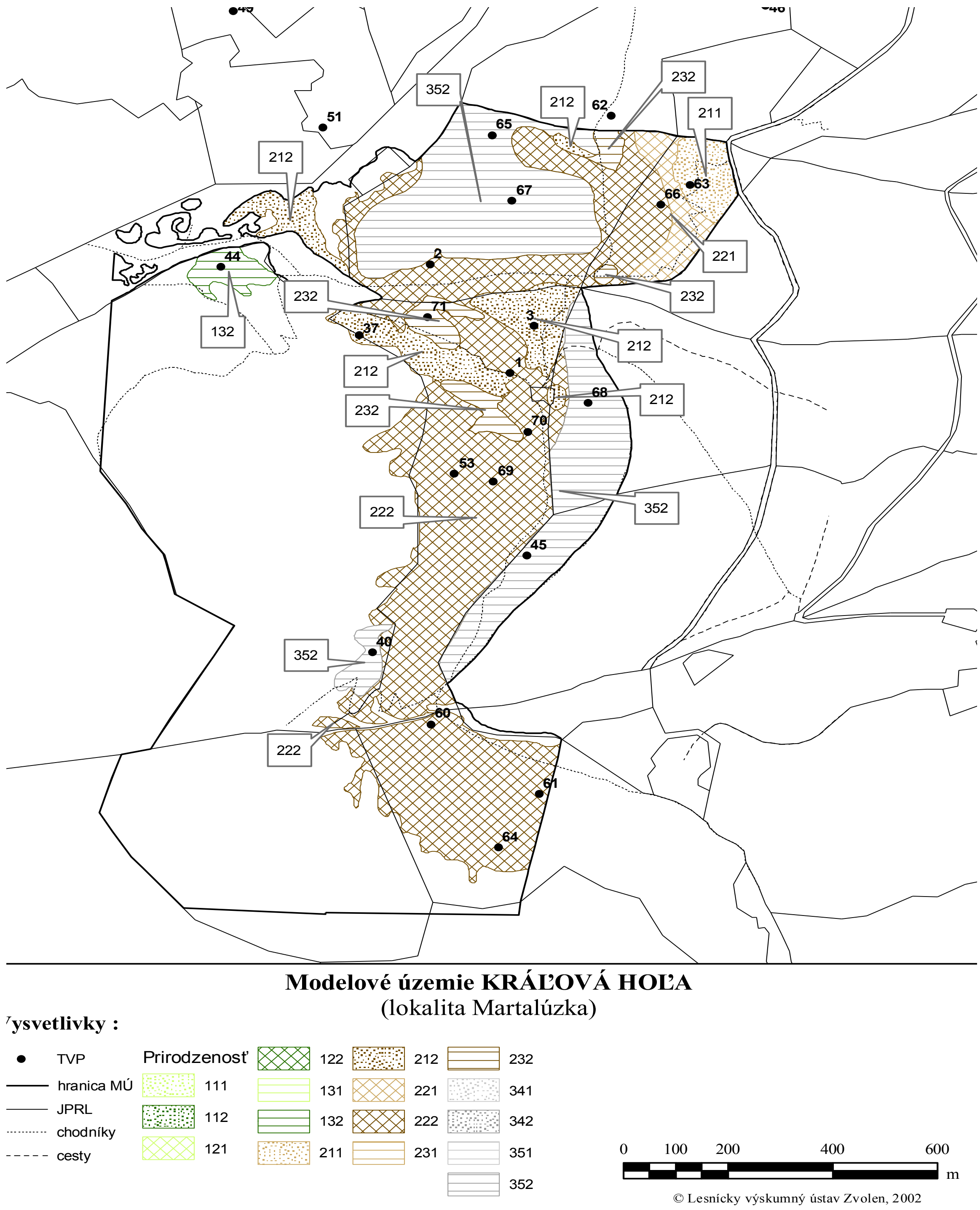
The evaluation of static stability (Konôpka, J., 2002) will be made on the basis of the value of slenderness coefficient, which will be calculated as the proportion of tree height and tree diameter $d_{1,3}$ multiplied by 100. Slenderness coefficient of the stand or its part will be determined as mean value of slenderness coefficients found on respective standpoints. The assessment will be done in four degrees in the dependence on mean diameter and yield class.

Yield class	Degree of static stability	Slenderness coefficients by mean diameter, cm						
		10	15	20	25	30	35	40
≤ 16	1-excellent	0,63	0,60	0,57	0,55	0,52	0,49	0,46
	2-good	0,64-0,73	0,61-0,70	0,58-0,67	0,56-0,64	0,53-0,61	0,50-0,58	0,47-0,55
	3-suitable	0,74-0,82	0,71-0,79	0,68-0,76	0,65-0,73	0,62-0,70	0,59-0,67	0,56-0,64
	4-unsuitable	0,83	0,80	0,77	0,74	0,71	0,68	0,65
18-22	1-excellent	0,67	0,65	0,63	0,60	0,58	0,55	0,53
	2-good	0,68-0,77	0,66-0,74	0,64-0,72	0,61-0,69	0,59-0,67	0,56-0,64	0,54-0,62
	3-suitable	0,78-0,86	0,75-0,83	0,73-0,81	0,70-0,78	0,68-0,76	0,65-0,73	0,63-0,71
	4-unsuitable	0,87	0,84	0,82	0,79	0,77	0,74	0,72
≥ 24	1-excellent	0,68	0,66	0,64	0,62	0,61	0,59	0,57
	2-good	0,69-0,78	0,67-0,76	0,65-0,74	0,63-0,72	0,62-0,70	0,60-0,68	0,58-0,67
	3-suitable	0,79-0,87	0,77-0,85	0,75-0,83	0,73-0,81	0,71-0,79	0,69-0,77	0,68-0,76
	4-unsuitable	0,88	0,86	0,84	0,82	0,80	0,78	0,77

Table 12. Criteria for evaluation of static stability by mean diameter and site classess.

Health condition (Konôpka, J., 2002) is being evaluated according to the damage by identifiable injurious agents (wind, snow, frost, bark beetles, fungal diseases, it means rots, damage by game) and the evaluation of the state of crown, it means the loss of assimilatory organs. Co-dominant and dominant trees are evaluated by means of 5 degree scale – excellent or slightly disturbed, moderately disturbed, heavily disturbed, very heavily disturbed and dying or died stand.

In the assessment of the state of natural regeneration (Jankovič, 2002) actual state of natural regeneration will be estimated and on the basis of actual spatial and age structure of the stand or its parts there will be determined percentage of the area where natural regeneration should occur. It follows from the comparison of actual and required state of natural regeneration that the state being evaluated can be fully corresponding – suitable in 91-100 %, sufficient – 61-90 %, average – 41-60 %, weak – 11-40 % and minimal within 10 %. Only natural regeneration being in accordance with regeneration tree species composition is taken into account.



Explanation notes: 1st number – naturalness class, 2nd number – development stage, 3rd number – altitudinal zone.

Fig. 8. Example of forest distribution by naturalness classes and developmet stages in Nature Reserve of Martalúzka.

5. Classification model of a forest naturalness class

Because of the above-mentioned reasons it is required to know the actual forest naturalness class in the forest ecosystems since it can be taken as an objective criterion for decision-making about forest use and consequently about forest management (Hoerr 1993; Schmidt 1997). This is a generally applicable requirement and a need for achieving the optimal and the most effective use of forests. Hence, our goal was to prepare and propose a generally applicable method for the derivation of an integrated indicator and a model of forest naturalness class. Our requirement was to obtain unit values of the indicator and the variability of such a magnitude, that the differences between the individual degrees of forest naturalness would be significant. In order to examine the practical applicability of the proposed method, it was developed for a case of forest ecosystems located in SVZ.

Two variants of the classification model of forest naturalness were proposed, one based on the principles of discriminant analysis, while the second one uses an additive approach to derive the integrated indicator of the forest naturalness class. The discriminant model is derived as an application of multivariate statistical analysis, so-called predictive discriminant analysis (Cooley and Lohnes 1971; Huberty 1994; StatSoft 1996; Merganič and Šmelko 2004). Its role is to classify the sampling unit on the base of several quantitative variables into one of the pre-defined qualitative classes, in our case into one of the three forest naturalness classes. Using the data from the database, three discriminant equations were derived, each for one class of forest naturalness. These discriminant equations serve for the classification of an evaluated forest stand into one of the three forest naturalness classes. Secondly, we proposed an integrated indicator of forest naturalness class. This indicator belongs to complex indicators that combine several diversity components into a single value (Merganič 2008). The indicator is based on an additive approach, while the partial components are given in real measurement units. Mathematical formula of the integrated indicator of the forest naturalness class (IISP) is as follows:

$$IISP = ID_1 + ID_i + \ldots ID_n$$

where ID partial indicator of the forest naturalness class.

5.1 Data adjustment to meet the needs for the derivation of the classification model of the forest naturalness class

The relation between a diversity indicator and an area, for which the indicator was assessed, is known from a number of theoretical and practical studies. Due to the varying area of our sample units, we tested the relationship between the values of the partial indicators of forest naturalness and the area of the sample plot. The analysis revealed that 9 indicators (R1, R2, the average ratio of crown length to tree height, the average ratio of tree height to tree diameter, coverage of herbs and grasses, coverage of juvenile and senile phases and deadwood volume per hectar) had a significant relationship with the plot area ($p<0.05$). This result is logical and is mainly coupled with the effect of the development stages. The significant influence of the development stage on the indicators of forest naturalness was found in 16 out of 25 cases. Since the plots were distributed among the development stages, the varying area of the sample plots should not have a negative influence on subsequent analyses and on the creation of the classification model of the forest naturalness classes. On the contrary, the estimates of the average values and the variation of the indicators derived from tree data (the average ratio of crown length to tree height, aggregation index atc.) are even more representative, since they always represent a similar group of trees (approx. 25 trees).

Numbers of the PRP in individual forest naturalness classes, as well as the numbers of the plots in individual development stages (growth, optimum, decline) within the naturalness classes are imbalanced. Due to this and the above-stated facts, it was required to equalise the number of the sampling units in individual development stages and in individual forest naturalness classes. The missing plots were added by random replication of the existing sample plots using bootstrap technique (Chernick 2008; Yu 2003) until the number of the plots in the most abundant development stages was reached in other stages, too. In this way, the numbers of the plots in less abundant development stages and 1st, 2nd, and 3rd naturalness classes were set to 9, 36, and 9 plots, respectively.

Subsequently two different variants of the integrated complex indicator and the model of the forest naturalness class were proposed, one as a discriminant model, while the other one as an additive model.

Discriminant Model

From a great number of the examined combinations of the indicators (Table 4a, 4b), the best results of the correct classification of the forest naturalness class were obtained using the combination of the following six indicators: the arithmetic mean of the ratio between crown length and tree height (AM_K), the deadwood volume (MOD), the coverage of grasses (PK_T), the coverage of mosses and lichens (PK_M), the aggregation index (R), and the coefficient of variation of tree diameters (CV_D1.3). The general formula of the final discriminant model looks as follows:

$$\text{Discriminant score } j = AM\_K \cdot b_{j1} + MOD \cdot b_{j2} + PK\_T \cdot b_{j3} + PK\_M \cdot b_{j4} + R \cdot b_{j5} + CV\_D1.3 \cdot b_{j6} + b_{j7}$$

where: J = 1st to 3rd forest naturalness class.

The classification of the forest naturalness class is performed in several steps. First, the discriminant score of each naturalness class (1–3) is calculated from the particular discriminant equation using the real values of the partial indicators. An evaluated location, a stand, or in our case a sample plot, is assigned such a forest naturalness class, for which the calculated discriminant score is a maximum.

Forest naturalness class	Correct classification in %	Degree of forest naturalness according to the model			
		1	2	3	Total
		Number of plots			
1	85.2	23*	4	0	27
2	68.5	15	74*	19	108
3	94.4	0	1	17*	18
Total	74.5	38	79	36	153

** indicates the cases with correctly classified forest naturalness class.*

Table 13. Classification matrix of the discriminant model.

The results of the classification matrix of the parameterisation data set are presented in Table 13. As can be seen in this table, the overall correctness of the classification of the forest naturalness class using the proposed discriminant model is 74.5%. The highest probability of correct classification is in marginal classes (classes 1 and 3), while the lowest probability is in the middle class (class 2, 68.5%).

Following Table 14 presents the statistical characteristics of the model. According to the values of Fischer F and Wilks' Lambda statistics we can, with 99.9% probability, say that the proposed discriminant model is highly significant. The Willks' Lambda can be interpreted in the following manner: if its value is close to 0, the model is appropriate; if, on the other hand, the value approaches 1, the model is not suitable. The partial Lambda values given in the third column of Table 13 provide us with the information about the contribution of each independent variable to the discrimination of the dependent variable. Five out of six selected indicators are significant, which means that their contribution to the discrimination of the forest naturalness class is significant. Although the sixth indicator, the coefficient of variation of tree diameters, was insignificant, its presence in the model improved the classification. The indicators AM_K and MOD have the largest influence on the discrimination of the forest naturalness class.

<table>
<tr><td colspan="5">Discriminant model</td></tr>
<tr><td colspan="3">Number of variables: 6</td><td colspan="2">Number of groups: 3</td></tr>
<tr><td colspan="3">Wilks' Lambda: 0.43676</td><td colspan="2">$F_{(12,290)}$= 12.401***</td></tr>
<tr><td colspan="5">Input variables</td></tr>
<tr><td>Indicator</td><td>Wilks' Lambda</td><td>Partial Lambda</td><td colspan="2">$F_{(3,935)}$ **95%, ***99.9%</td></tr>
<tr><td>Arithmetic mean of crown length / tree height ratio (AM_K) [%]</td><td>0.587</td><td>0.744</td><td>24.944</td><td>***</td></tr>
<tr><td>Deadwood volume (MOD) [m^3/ha]</td><td>0.491</td><td>0.889</td><td>9.062</td><td>***</td></tr>
<tr><td>Coverage of grasses (PK_T) [%]</td><td>0.469</td><td>0.932</td><td>5.314</td><td>**</td></tr>
<tr><td>Coverage of mosses and lichens (PK_M) [%]</td><td>0.465</td><td>0.940</td><td>4.608</td><td>**</td></tr>
<tr><td>Aggregation index (R)</td><td>0.458</td><td>0.953</td><td>3.580</td><td>**</td></tr>
<tr><td>Coefficient of variation of tree diameter (CV_D1.3) [%]</td><td>0.442</td><td>0.988</td><td>0.862</td><td></td></tr>
</table>

Table 14. Statistic characteristics of the discriminant model.

In order to explain the classification graphically, the canonical analysis was applied to the data set. Fig. 9. shows the position of the groups of the sample plots with the same forest naturalness class and their approximate borders. From this figure it is obvious that the marginal categories of naturalness class have the highest probability of correct classification because their overlap with the neighbouring class is the smallest.

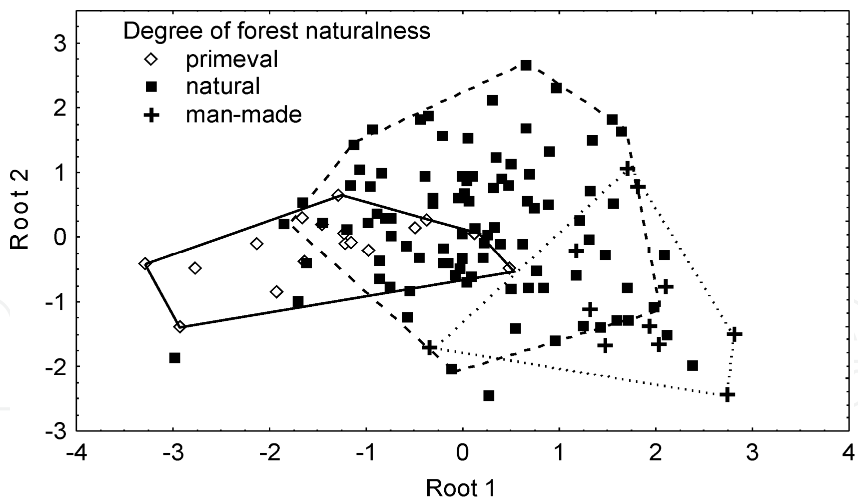


Fig. 9. Graphical interpretation of the classification of forest naturalness class with the discriminant model using canonical analysis.

Additive model

The partial indicators in the additive model are the same as in the discriminant model, i.e. the arithmetic mean of the ratio between crown length and tree height (AM_K), the deadwood volume (MOD), the coverage of grasses (PK_T), the coverage of mosses and lichens (PK_M), the aggregation index (R), and the coefficient of variation of tree diameters (CV_D1.3). The significance of the model was tested by singlefactor analysis of variance. The analysis revealed significant differences between the average values of IISP of the forest naturalness class (the whole model $F(2, 150) = 21.849^{***}$, Tukey test). Figure 10. presents the graphical interpretation of the model. The range of IISP values was divided between the forest naturalness classes using the weighted approach, taking into account the error ranges of the average values of IISP and the percentiles of the values in every forest naturalness class. The objects, e.g. the stands, with the IISP values exceeding the value of 267 represent primeval forests; the IISP values in the range from 182 to 267 indicate that the forests are natural, while the values of IISP below 182 classify the objects as man-made forests.

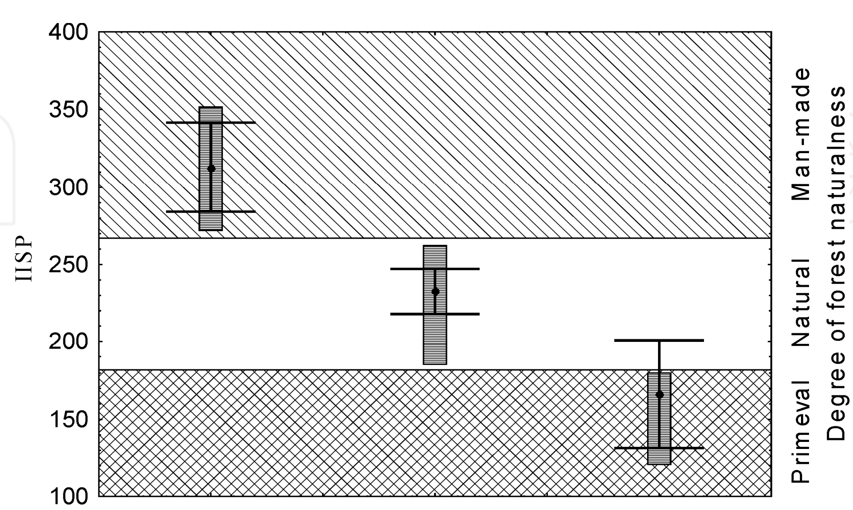


Fig. 10. Intervals of the integrated indicator of forest naturalness (IISP) specified for the three degrees of forest naturalness (primeval, natural, man-made forests); Legend: ▤ percentile 26–7 74% = 48% of values, ⌶ 95% confidence interval (1.96 × standard error).

The correctness of the model classification was determined on the base of the categorisation of individual plots into the forest naturalness class. The overall correctness of the classification using IISP is 63.4%. The individual forest naturalness classes 1, 2, and 3 were correctly classified in 74%, 56%, and 89% of cases, respectively.

Comparison of the models

The results of the classification of the forest naturalness degree indicate that both variants of the classification model have a similar probability of the correct classification of the assessed object into the forest naturalness class. The discriminant model behaves better, since its probability of correct classification is by approximately 11% higher than the probability of the additive model. Higher efficiency of the discriminant model is evident mainly in the proportion of correct classifications in 1st and 2nd forest naturalness classes. From the point of practical applicability, the additive model is simpler to use, but considering the current capacity of computers, it is also not difficult to apply the discriminant model in the form of a small computer program.

6. Conclusion

Because of enhancing requirements of public which are laid on forests the area of forests with prevailing social and ecological functions has been increasing in the last decades. Their important parts are forests in spruce vegetation zone. Therefore it is important to achieve status in which maximum fulfilment of mentioned functions through permanent existence of stable and healthy forest with corresponding stand structure is secured. Regeneration, improvement or maintenance of self-regulating ability of such forests should be essential. From these reasons forest management planning and subsequently also forestry operation should come out from appraisal and assessment of the class of natural structure conservation in carrying out of management measures. Naturalness class as indicator of natural structure conservation has to be a decisive criterion for determining need and urgency of the respective management measures.

For ensuring this approach there were chosen the most suitable indicators for quantification of stand structure status in primeval and natural forests which are characteristic with considerable degree of age, spatial, diameter and height diversity. Further there was collected and evaluated vast experimental material with objective of derivation of management targets – mainly target stand structure, target stocking and target tree species composition and criteria on identification of the basic naturalness classes – primeval forests, natural forests and man-made forests. The experimental material was collected in different natural, site and stand conditions from 122 permanent research plots in all significant groups of forest site types and altitudinal zones in the scope of spruce vegetation zone. Outcomes resulting from the evaluated experimental material confirmed statistically significant differences of forest status in various naturalness classes and actual development stages.

For needs of frameworking planning there were worked out: *differentiated tree species composition* by groups of forest site types and more detailed by altitudinal zones in the scope of spruce vegetation zone; *outlook target structure* derived following results of the primeval forests analysis and *available target structure* derived following results of the natural forest analysis and *target stocking* which was derived as optimum stocking on the basis of harmonising the requirements for fulfilment ecological functions, ensuring static stability and conditions for natural regeneration. The most suitable status of mentioned requirements was observed in stocking 0,7. There were derived differentiated rotation periods in dependence on the naturalness classes: 150 years for man-made forests, 200 years for natural forests and 250-300 years for primeval forests. However in primeval forests it is understood merely as a symbolic rotation period resulting from life-cycle of Norway spruce in respective natural preconditions. There were also identified the natural, site and stand preconditions of spruce vegetation zone in which forest stands could be utilised for more intensive commercial exploitation.

Likewise as the management targets and the basic decisions also management principles are differentiated in dependence on the naturalness classes. Basically it can be stated that only forests classified in the first naturalness class (primeval forests) can be left without any measures. In such stands concerning their structure, natural regeneration, health conditions self-regulating processes are usually in progress. Forest stands that do not meet these criteria – mostly man-made, even-aged, vertically and horizontally little-differentiated forests, but also natural forests with various development stages whose natural regeneration ability is insufficient – require concrete reconstruction measures. These stands can not be left for self-regulating because there is not possible to secure their required utility in acceptable temporal horizon.

Further there were proposed procedures for finding out and evaluating the forest status. They include the indicators and classification systems of evaluating the stand structure, status and conditions of natural regeneration, static stability, health conditions, determining the naturalness classes and evaluating ecological stability. Listed data are important for determining the need and urgency of respective measures.

Antoher very important outcome of this research is elaboration the methodology for the evaluation of forest naturalness on the base of the selected indicators of tree species and structural diversity. As we already stated, the knowledge about the naturalness of forest ecosystems is of great importance. Its objective assessment is essential in the decision-making process dealing with forest utilisation and subsequent forest management. Further more forest naturalness is the most significant and widely applied criterion for the forest evaluation from the viewpoint of nature conservation, and serves as a key tool in analyses and as a support in planning nature conservation measures. The currently proposed methodology, if applied within the practical forest management, can lead to the improvement of ecological stability of forests and landscape. Although the approach has already included several aspects of forest naturalness, it can be further enhanced by taking into account other components, e.g genetic diversity. The coupling of the model with statistical inventory and GIS tools can enable the creation of detailed maps of naturalness of forest ecosystems. Such information can further improve planning and practical application of nature conservation measures.

The developed classification model is easily applicable in practice and its application does not require intensive material and technical background. The applicability of the model for the classification of the forest naturalness classes has already been successfully tested on independent data (see Merganic and others 2009). **The method is applicable outside SVZ**

or even outside Slovakia. In any other conditions, appropriate indicators of forest naturalness need to be selected, data need to be gathered, and the model needs to be re-parameterised. The coupling of the model with statistical inventory and GIS tools can enable the creation of detailed maps of naturalness of forest ecosystems. Such information is important for planning as well as for practical application of nature conservation measures. The model is a powerful tool for objectifying the assessment and the evaluation of the development of forest ecosystems within monitoring schemes.

7. Acknowledgments

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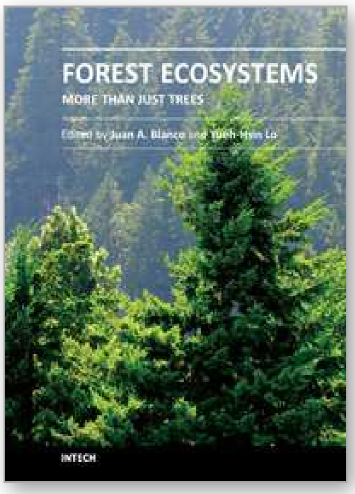

Forest Ecosystems - More than Just Trees
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The common idea for many people is that forests are just a collection of trees. However, they are much more than that. They are a complex, functional system of interacting and often interdependent biological, physical, and chemical components, the biological part of which has evolved to perpetuate itself. This complexity produces combinations of climate, soils, trees and plant species unique to each site, resulting in hundreds of different forest types around the world. Logically, trees are an important component for the research in forest ecosystems, but the wide variety of other life forms and abiotic components in most forests means that other elements, such as wildlife or soil nutrients, should also be the focal point in ecological studies and management plans to be carried out in forest ecosystems. In this book, the readers can find the latest research related to forest ecosystems but with a different twist. The research described here is not just on trees and is focused on the other components, structures and functions that are usually overshadowed by the focus on trees, but are equally important to maintain the diversity, function and services provided by forests. The first section of this book explores the structure and biodiversity of forest ecosystems, whereas the second section reviews the research done on ecosystem structure and functioning. The third and last section explores the issues related to forest management as an ecosystem-level activity, all of them from the perspective of the �other� parts of a forest.

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