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Forest Naturalness: Criterion for Decision Support in Designation and Management of Protected Forest Areas

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Abstract The article analyses the possibilities of developing an integrated indicator and a model of the assessment of forests naturalness using the data from the database of mountainous spruce forests situated in the Western Carpathians of Slovakia. The article presents two variants of such a model, one based on discriminant analysis, while the second one using an additive approach. The analysis of the data from mountainous spruce forests revealed significant indicators of forest naturalness degree: the arithmetic mean of the ratio between crown length and tree height, the deadwood volume, the coverage of grasses, the coverage of mosses and lichens, and the aggregation index. In addition, the coefficient of variation of tree diameters was included in the final model, since its presence in the model had a positive influence on the correctness of the classification of the forest naturalness degree. The correctness of the classification of the proposed discriminant model was 74.5%. For the additive model, the ranges of the values of the integrated indicator were defined for every degree of forest naturalness by taking into account the error ranges of the arithmetic mean values and the percentiles of the values in individual degrees of forest naturalness. The overall correctness of the classification with the additive model was 63.4%. In the second step, the scheme how to apply the classification model of the forest naturalness degree in the decision-making process of designating as a forest protected areas was proposed. In this scheme, the degree of forest naturalness is considered as a basic criterion for the determination of nature-conservation value of forest ecosystems. As further decision-making criteria we identified the possibility to restore, or the possibility to improve the naturalness of less natural forest ecosystems, which are designated as protected; the occurrence of the endangered species; and the occurrence of other natural values.

Keywords Indicators and models of forest naturalness · Evaluation of forest naturalness · Forest protected area · Decision-making support in forest utilisation

Introduction

Forest naturalness, or more precisely a degree of forest naturalness, is a significant indicator of the intensity of human interventions in forest ecosystems, i.e., it specifies the extent of human influence (Cluzeau and Hamza 2007). There exist a number of less or more detailed classifications of forest naturalness with a common feature that the scale begins with the forests in the original state representing the highest degree of forest naturalness and ends up with man-made forests (Welzholz and Bürger-Arndt 2004).

Naturalness is 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

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forests *undisturbed by man*, which encompass forests with least human interventions; *modified natural forests*, *semi-natural 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 degrees of forest naturalness 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 decision-making 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 in the second step that determine the need and the urgency of their management (cultivation, tending) in such a way, which will secure the protection of their biological diversity and/or of other natural values. For these purposes, it is required to perform detailed surveys of forest naturalness focusing particularly on such forest ecosystems which are the subject of decision-making processes whether they are to be declared protected areas or not.

In the case of protected forest areas, at least of those with the highest status of protection, one expects them to be very close-to-nature, with almost no human influence. It is assumed that only in such forests the natural developmental cycle, the adequate tree species composition, the age structure, and other components of forest naturalness have been preserved or have recovered. The maintenance and enhancement of these features should be the primary goal of nature conservation (Welzholz and Bürger-Arndt 2004; Bartha and others 2006).

From the perspective of nature conservation, the forests *undisturbed by man* are of great value, particularly if they are large compact forest areas. Such forests can serve as reference areas, where natural ecological processes can be studied; and can also contribute to the development of close-to-nature forest management methods (MCPFE 2007). In the conditions of Central Europe, such forests occur only scarcely and hence, are very precious. Owing to functioning natural ecological processes, they should be left to self-regulating processes without any human interventions.

Because of the above-mentioned reasons it is required to know the actual degree of forest naturalness in protected areas, and in the forest ecosystems, which have the potential for being protected, 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 forestland.

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 degree. 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 specific case of forest ecosystems located in a spruce altitudinal vegetation zone (hereinafter called SVZ).

We selected this type of ecosystems due to two reasons. First, this forest community is very valuable with significant ecological and social functions including nature-conservation functions (Korpeľ 1989). Secondly, extensive national and international scientific activities (e.g. S4C Initiative, Mountain Research Initiative, International Scientific Committee on Research in the Alps ISCAR) have been carried out in the forests of SVZ. During the scientific works performed in the years 1999–2002, a large amount of data suitable for solving our task was gathered, since the need for the research of naturalness of forest ecosystems was respected already in the process of data acquisition.

Materials and Methods

Database

The SVZ is the highest altitudinal vegetation zone (VZ) with forest and tree-like vegetation in Slovakia (Fig. 1). It

Fig. 1 Distribution of spruce vegetation zone over the area of Slovakia. 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); *Legend*: Boundary of the Slovak Republic, Forest stand area, Spruce vegetation zone

is situated above spruce-beech-fir VZ, in which typical well-grown management forests occur. Forests in SVZ reach smaller heights (at an upper zone line the trees are dwarfed), and have a character of protective forests. At higher altitudes, SVZ merges into mountain pine VZ. The SVZ is located at an elevation from 1,250 to 1,550 (1,600) m above sea level. Total annual precipitation is 1,100–1,600 mm per year. Vegetation season lasts from 70 to 100 days, and mean annual temperature is approximately 2–4°C.

Apart from Norway spruce (*Picea abies* (L.) K.), other tree species, namely rowan (*Sorbus aucuparia* L.), European larch (*Larix decidua* Mill.), Arolla pine (*Pinus cembra* L.), Sycamore (*Acer pseudoplatanus* L.), European beech (*Fagus sylvatica* L.), Silesian willow (*Salix silesiaca* Willd.), Carpathian birch (*Betula pubescens ssp. carpatica* Willd.), Great sallow (*Salix caprea* L.), and Dwarf mountain pine (*Pinus mugo ssp. mugo* Turra), also occur in these stands with a proportion of up to 30%, approximately. The age, diameter, and height structure of the forests in SVZ should be highly (horizontally and vertically) diversified to ensure the fulfilment of important ecological functions.

Almost identical forest types 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).

Empirical material was collected in permanent research plots (PRP) by preferential and non-random sampling. This sampling is common in ecological studies, which are mainly aimed at ecological gradients, because it covers a broader range of vegetation variability (Rolecek and others 2007). 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 occurr within each plot. The PRPs were localised 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 (Table 1). 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 degree were identified and proposed.

To assess and to characterise natural and stand conditions of PRPs, a lot of information was collected: forest type, soil type and crown closure were determined; basic mensurational parameters were measured; and the developmental phase and the degree of forest naturalness of the stand inside the PRP were assessed. Tree crown length was calculated as the difference between tree height and height to crown base. For age analysis, a required number of core bores were collected. The coverage of ground vegetation (grasses, herbs, mosses, lichens, subshrubs, and shrubs), the conditions for natural regeneration of spruce, and existing natural regeneration were also assessed.

In total, 122 PRPs were established. Table 1 presents the summary information about the data structure with regard to natural and stand conditions of the PRPs, in which they were established (forest eco-region, group of forest types, degree of forest naturalness, and elevation). As shown in Table 1, the category Natural forests having 94 sample plots is the most abundant, while the category of Man-made forests has the lowest frequency.

Classification of Forest Naturalness for Parametrisation of Classification Model

The classification of forest stands into degrees of forest naturalness was based on the categorisation of Zlatník (1976) (Table 2). The assessed degree of forest naturalness 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 degree of forest naturalness from the scale A to G (Zlatník 1976), which 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 due to the insufficient number of plots in the degrees of the finer scale from A to G. For further processing and evaluation of information from 122 PRPs, the database system "Mountainous forests" was created in the environment MS Access 2000.

Table 1 Data structure with regard to natural and stand conditions

Degree of forest naturalness, *n*/%

Primeval forest			Natural forest			Man-made forest	
17/13.9			94/77.1			11/9.0	
Of it the stage of			Of it the stage of			Of it the phase of	
Growth	Optimum	Disintegration	Growth	Optimum	Disintegration	Tending	Regeneration
2	9	6	32	36	26	2	9

Forest eco-region, *n*/%

Veľká Fatra	Poľana	Nízke Tatry	Vysoké Tatry
7/5.7	12/9.8	85/69.7	18/14.8

Group of forest side types, *n*/%

SP, LP sup	AcP sup	FP sup	CP
84/68.9	22/18.0	9/7.4	7/5.7

Elevation (meters above sea level), *n*/%

Up to 1,350	1,351–1,400	1,401–1,450	1,451–1,500	1,501–1,550	1,551 and above
14/11.5	21/17.2	29/23.8	32/26.2	19/15.6	7/5.7

Table 2 Criteria for the classification of stands by the naturalness classes

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 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

Proposal of Indicators of Forest Naturalness for Classification Model

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 3).

Tree species diversity was quantified with five indices of species richness, two indices of species heterogeneity, and three indices of species evenness (Table 3). 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

Table 3 Calculated indicators of naturalness of forest ecosystems

Tree species diversity					Structural diversity			
Category	Indicator	Formula	Units	Reference	Indicator	Formula	Units	Reference
Species richness	Index N0—living trees	$N0 = S$	DIM	Hill (1973)	Number of tree layers (Z)	$Z = j$	DIM	
	Index N0—mosses and lichens	$N0 = S$	DIM	Hill (1973)	Arten profil index (A)	$A = \sum_{i=1}^{S}\sum_{j=1}^{Z} P_{ij} \ln P_{ij}$	DIM	Pretzsch (1996)
	Index N0—shrubs and subshrubs	$N0 = S$	DIM	Hill (1973)	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)
	Index R1	$R1 = (S - 1)/\ln(M)$	DIM	Margalef (1958)	Coefficient of variation of tree diameter ($CV\_D1.3$)	$CV\_D1.3 = \frac{\bar{d}}{SD_d}$	%	Šmelko (2000)
	Index R2	$R2 = S/\sqrt{M}$	DIM	Menhinick (1964)	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)
Species heterogeneity	Index λ	$\lambda = 1 - \sum_{i=1}^{S} p_i^2$	DIM	Simpson (1949)	Average height/diameter (h/d) ratio (AM_HDR)	$AM\_HDR = \frac{\sum_{i=1}^{M} \frac{h_i}{d_i}}{M}$	DIM	Šmelko (2000)
	Index H′	$H' = -\sum_{i=1}^{S} p_i \cdot \ln(p_i)$	DIM	Shannon and Weaver (1949)	Coverage of grasses (PK_T)	$PK\_T = p_i$	%	
Species evenness	Index E1	$E1 = H'/\ln(S)$	DIM	Pielou (1975) and (1977)	Coverage of herbs (PK_B)	$PK\_B = p_i$	%	
	Index E3	$E3 = (e^{H'} - 1)/(S - 1)$	DIM	Heip (1974)	Coverage of mosses and lichens (PK_M)	$PK\_M = p_i$	%	
	Index E5	$E5 = ((1/\lambda) - 1)/(e^{H'} - 1)$	DIM	Hill (1973)	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	

S number of species; M number of individuals, number of living trees in a sample plot; m number of deadwood individuals (stumps, lying deadwoood); p_i probability, proportion of ith species or category in a sample plot; p_{ij} proportion of trees of ith tree species in jth stand layer; Z number of layers—stories of the stand; r_i distance between ith tree and its closest neighbour (m); A area of a sample plot (m^2); d tree diameter; SD_d standard deviation of tree diameters in a sample plot; cl crown length; h tree height; v volume

coverage of natural regeneration were visually estimated in the field and are given in relative values (%) (Moravčík and others 2005).

Classification Model of a Degree of Forest Naturalness

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 degree of forest naturalness.

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 degrees of forest naturalness. Using the data from the database, three discriminant equations were derived, each for one degree of forest naturalness. These discriminant equations serve for the classification of an evaluated forest stand into one of the three degrees of forest naturalness.

Secondly, we proposed an integrated indicator of forest naturalness degree. This indicator belongs to complex indicators that combine several diversity components into a single value. 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 degree of forest naturalness (*IISP*) is as follows:

$$IISP = ID_1 + ID_i + \ldots ID_n \tag{1}$$

where *ID* partial indicator of the degree of forest naturalness

Data Adjustment to Meet the Needs for the Derivation of the Classification Model of the Degree of Forest Naturalness

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 developmental stages. The significant influence of the developmental stage on the indicators of forest naturalness was found in 16 out of 25 cases. Since the plots were distributed among the developmental 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 degree of forest naturalness. 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).

As can be seen in Table 1, the numbers of the plots (PRP) in individual degrees of forest naturalness, as well as the numbers of the plots in individual developmental stages (growth, optimum, disintegration) within the naturalness degrees are imbalanced. Due to this and the above-stated facts, it was required to equalise the number of the sampling units in individual developmental stages and in individual degrees of forest naturalness. 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 developmental stages was reached in other stages, too. In this way, the numbers of the plots in less abundant developmental stages and 1st, 2nd, and 3rd degree of naturalness were set to 9, 36, and 9 plots, respectively.

Results

Two different variants of the integrated complex indicator and the model of the degree of forest naturalness 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 (see Methods for the list), the best results of the correct classification of the degree of forest naturalness 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_D*1.3). The general formula of the final discriminant model looks as follows:

$$\begin{aligned}\text{Discriminant score}_{\,j} = {} & AM\_K \cdot b_{j1} + MOD \cdot b_{j2} + PK\_T \\ & \cdot b_{j3} + PK\_M \cdot b_{j4} + R \cdot b_{j5} \\ & + CV\_D1.3 \cdot b_{j6} + b_{j7}\end{aligned} \tag{2}$$

where: *J* 1st to 3rd degree of forest naturalness

The values of the regression coefficients in individual discriminant equations are given in Table 4.

The classification of the degree of forest naturalness is performed in several steps. First, the discriminant score of each naturalness degree (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 degree of forest naturalness, for which the calculated discriminant score is a maximum.

The results of the classification matrix of the parameterisation data set are presented in Table 5. As can be seen in this table, the overall correctness of the classification of the degree of forest naturalness using the proposed discriminant model is 74.5%. The highest probability of correct classification is in marginal classes (degrees 1 and 3),

Table 4 Values of regression coefficients of the derived discriminant model

Partial indicator of a degree of forest naturalness	Regression coefficient	Degree of forest naturalness		
		1	2	3
Arithmetic mean of crown length/tree height ratio (*AM_K*) [%]	b_1	1.2521	1.1154	0.9108
Deadwood volume (*MOD*) [m^3/ha]	b_2	0.0306	0.0139	0.0058
Coverage of grasses (*PK_T*) [%]	b_3	−0.0290	0.0070	0.0059
Coverage of mosses and lichens (*PK_M*) [%]	b_4	0.1708	0.1132	0.0693
Aggregation index (*R*)	b_5	36.7123	33.5378	30.8615
Coefficient of variation of tree diameter (*CV_D*1.3) [%]	b_6	−0.0348	−0.0615	−0.0723
Absolute coefficient	b_7	−73.8718	−57.0578	−40.3190

while the lowest probability is in the middle class (degree 2, 68.5%).

Following Table 6 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 5 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 degree of forest naturalness 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 degree of forest naturalness.

In order to explain the classification graphically, the canonical analysis was applied to the data set. Figure 2

Table 5 Classification matrix of the discriminant model

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

[a] Indicates the cases with correctly classified degree of forest naturalness

Table 6 Statistic characteristics of the discriminant model

Discriminant model			
Number of variables: 6			Number of groups: 3
Wilks’ Lambda: 0.43676			$F_{(12,290)} = 12.401$***
Input variables			
Indicator	Wilks’ Lambda	Partial Lambda	$F_{(3,935)}$ 95%**, 99.9%***
Arithmetic mean of crown length/tree height ratio (*AM_K*) [%]	0.587	0.744	24.944***
Deadwood volume (*MOD*) [m^3/ha]	0.491	0.889	9.062***
Coverage of grasses (*PK_T*) [%]	0.469	0.932	5.314**
Coverage of mosses and lichens (*PK_M*) [%]	0.465	0.940	4.608**
Aggregation index (*R*)	0.458	0.953	3.580**
Coefficient of variation of tree diameter (*CV_D*1.3) [%]	0.442	0.988	0.862

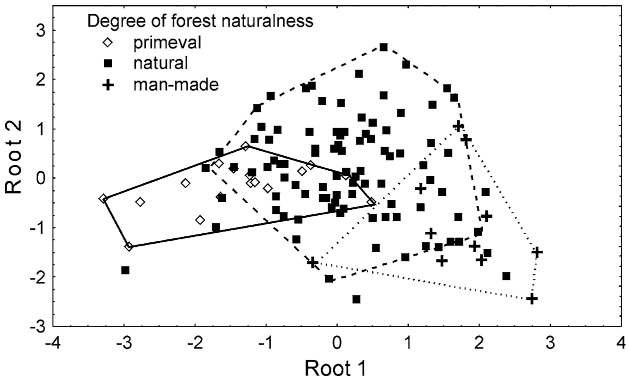

Fig. 2 Graphical interpretation of the classification of forest naturalness degree with the discriminant model using canonical analysis; *Legend*: Degree of forest naturalness: primeval, natural, man-ma

shows the position of the groups of the sample plots with the same degree of forest naturalness and their approximate borders. From this figure it is obvious that the marginal categories of naturalness degrees have the highest probability of correct classification because their overlap with the neighbouring class is the smallest.

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_D*1.3).

The significance of the model was tested by single-factor analysis of variance. The analysis revealed significant differences between the average values of *IISP* of the degrees of forest naturalness (the whole model $F_{(2,\ 150)} = 21.849$***, Tukey test). Figure 3 presents the graphical interpretation of the model. The range of *IISP* values was divided between the degrees of forest naturalness using the weighted approach, taking into account the error ranges of the average values of *IISP* and the percentiles of the values in every degree of forest naturalness. 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.

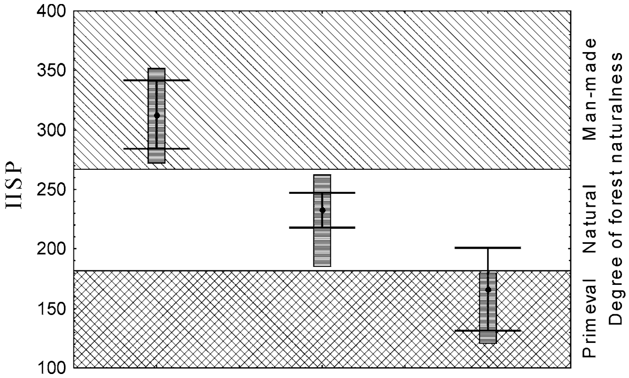

Fig. 3 Intervals of the integrated indicator of forest naturalness (IISP) specified for the three degrees of forest naturalness (primeval, natural, man-made forests); *Legend*: percentile 26–74% = 48% of values, 95% confidence interval (1.96′ standard error), mean

The correctness of the model classification was determined on the base of the categorisation of individual plots into the degrees of forest naturalness. The overall correctness of the classification using *IISP* is 63.4%. The individual degrees of forest naturalness 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 degree. 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 degrees of forest naturalness. 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.

Discussion

Strengths and Weaknesses of the Approach

As we already stated in the introduction, the knowledge about the degree of 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. 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 degree of forest naturalness 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 in protected areas 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.

In Slovakia, the proposal of the network Natura 2000 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. The final proposal of the network Natura 2000 is currently widely criticised, partly also for insufficient consideration for forest naturalness.

In contrast to the above-mentioned methods, our proposal 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.

The developed 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 degrees of forest naturalness 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.

It is important to realize, that some important indicators of forest naturalness, such as preservation of original genetic diversity or preservation of original gene pool of main tree species, are not included in the model. It is mainly due to low availability of necessary data and extremely demanding methods of their gathering. Therefore, in case of having "natural stand structure", our method can evaluate forest stands established from the planting stock of non-native provenance. However, in reality, such cases should be rare, because the formation of natural stand structure is time-consuming and complicated, and majority of artificially planted forests had not enough time to develop to this state. Yet, old forest stands established from non-native planting stock and tended with methods imitating natural processes, could the model evaluate as natural. To summarise above mentioned, the inclusion of an indicator related to the gene pool of main tree species would improve the model, but limited availability of needed data makes this improvement just theoretical at the moment.

In Slovakia, 57.1% of forests are currently included in any type of the protected areas within the national and/or European network of protected areas (Moravčík and others 2008). The proportion of their area has been growing continuously in spite of the fact that current protected areas cover to a great extent altered forest ecosystems, where the restoration of natural biodiversity is not feasible or requires active management.

Nevertheless, there exists a group of supporters of passive nature conservation, who promote self-regulation also of the forest ecosystems with a very low degree of forest naturalness. Such an approach results in a large-scale breakdown causing the destruction of the protected element, the creation of hardly reforestable clearings, and the decrease of the required functional effectiveness of these forests.

Due to these reasons, we present the proposal for objective evaluation of the degree of forest naturalness in such a way that can be used as a basis for efficient application of differentiated methods of utilisation and subsequent forest management. Assessment Guidelines for Protected and Protective Forests and Other Wooded Land in Europe (MCPFE 2003) 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.

According to Greguš (1989), any forests can fulfil required functions best in such conditions, which correspond to the status of forests not influenced by humans. The better the approximation of such an untouched forest stand structure, the more likely it is that the forest is able to develop solely by means of its own self-regulating processes. Therefore, the basic goal of the classical concept (close-to-nature) of forest silviculture should be the preservation, enhancement, or restoration of the functionally effective forest stand structure similar to natural and primeval forests. This goal is inter alia of great economic importance, since it gives a manager the possibility to diminish the treatments to minimum, and to meet the required goals very efficiently and with minimum negative influences on nature and environment. In this context, the proposed assessment of forest naturalness has good preconditions for its application in the process of determining the need and the urgency of management measures in the scope of developing more efficient close-to-nature forest silviculture.

Application Areas

Application of the Classification Model in the Decision-Making Process About the Designation and Management of Forest Ecosystems in the Spruce Vegetation Zone (SVZ)

As we already stated in the introduction, currently there are no objective and widely applied methods for the determination of the degree of forest naturalness and for the decision-making whether the forest can or cannot be designated as a protected area. In this decision-making process, the naturalness degree is the most significant criterion. Hence, we suggest using the proposed methodology of the integrated indicator of forest naturalness in order to determine this degree of forest naturalness. The majority of scientists who deal with this issue recognise the close relationship between the degree of forest naturalness and the nature-conservation value of forest ecosystems. This knowledge is reflected in all relevant documents that deal with the assessment of protected forest areas. Owing to this, the degree of forest naturalness has a clear position in the decision-making process about the designation of the forest ecosystem a protected area. The higher its naturalness indicated by the degree of naturalness is, the more legitimate it is to designate it as a protected area. Apart from that, there tends to be the rule that the increasing naturalness of the ecosystem increases the degree of its protection. The forest ecosystems in the closest-to-nature state are the most precious, and in addition, they are also the most capable of existing by means of their own intrinsic regulating processes. Due to this, these ecosystems should be protected to the highest degree.

Apart from naturalness, the declaration scheme also accounts for the conservation of endangered species according to the Convention on Biological Diversity. If threatened species survive in unnatural ecosystems, it is required to conserve also these ecosystems by applying such a management that secures their preservation and consequently also the preservation of endangered species. A similar approach is applied in the case of *other natural values*. If, from any reasons, an ecosystem with a lower degree of forest naturalness is considered to be designated as a protected area, the necessity to protect it should be thoroughly explained, and the possibility to reconstruct it to a closer-to-natural forest ecosystem should be analysed and validated.

Following the above-stated facts, the decision-making process about the designation a protected forest area can be visualised as presented in Fig. 4.

Although this decision-making algorithm is generally valid, there exist several exceptions. It can happen that also ecosystems with a high degree of forest naturalness can disappear, since their conservation is in an unfavourable state. On the other hand, some unnatural ecosystems with a great nature conservation value, which do not require any management for their maintenance, can also exist. Such cases are, however, exceptional, and do not negate the given connections and relations between the degree of forest naturalness of forest ecosystems, their nature-conservation values, and eventually the necessity of the differentiated measures to be realised by a man with the aim of maintaining their stability. In the decision-making process of designating protected areas in such specific cases as described above, it is required to reach a consensus, based on objective justification, on the designation of less natural areas as protected, or on the application of inevitable correction measures in order to improve the condition of forests ecosystems that are natural to a high degree, but are disappearing.

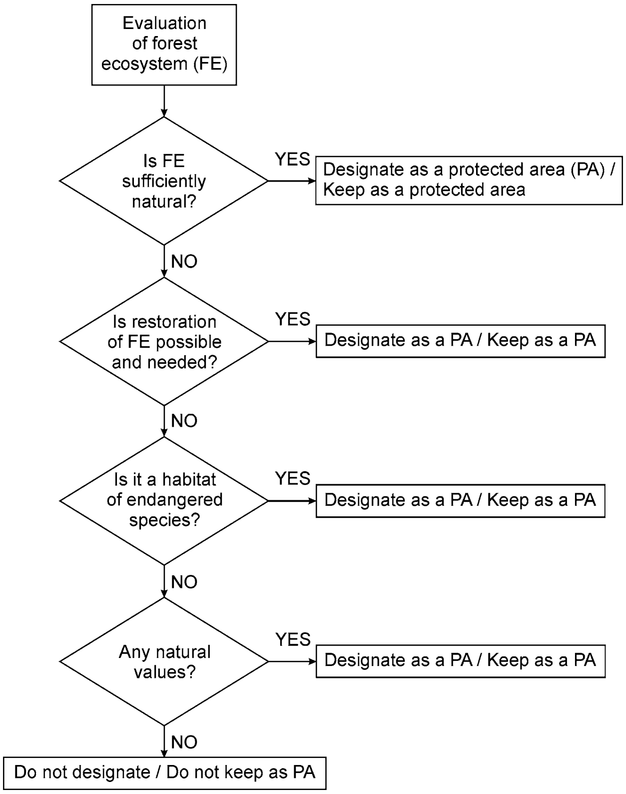

Fig. 4 Decision-making process about the designation as a protected forest area

Conclusion

The presented methodology for the evaluation of forest naturalness on the base of the selected indicators of tree species and structural diversity is an objective tool that can support decision-making process concerning the use of particular forest ecosystems for biodiversity conservation within the scope of nature and landscape conservation. It can not only contribute to the knowledge of the actual state of forest naturalness in protected areas, but can also provide decision-makers with the support in taking right actions aimed at enhancing the state, or in deciding to change the use of forests with low natural values (naturalness, biodiversity). 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.

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