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Original Research

Objective Evaluation of Forest Naturalness: Case Study in Slovak Nature Reserve

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Abstract

Our paper analyzes the naturalness of the forest in Babia Hora Nature Reserve, Slovakia, using an objective classification model based on predictive discriminant analysis. The partial indicators of forest naturalness in the model are: the arithmetic mean of the ratio between crown length and tree height, deadwood volume, coverage of grasses, coverage of mosses and lichens, the Clark-Evans aggregation index, and the coefficient of variation of tree diameters. The analysis of the model results revealed that the model was capable of distinguishing the parts of the reserve affected by natural disturbances and/or by past human activities. Hence, the classification model can be used as a supportive decision-making tool when adopting proper measures aimed at improving the actual state or decisions about changing the use of forests with evidently low natural values.

Keywords: natural forest, discriminant analysis, spatial analysis, classification model

Introduction

Concepts such as biodiversity and naturalness are frequently used in conservation [1], while naturalness is often considered to be one the most important criteria for assessing the conservation status of forest ecosystems [2]. It is often taken as a major tool used to support conservation management planning [2]. The significance of naturalness has been approved in many international schemes, e.g. it was included in the list of pan-European indicators of sustainable forest management [3].

Although there has been much debate on the definition of naturalness in scientific literature [4-7], naturalness is in general perceived as a condition that can persist over time in the absence of human intervention [7, 8]. Hence, the degree of naturalness representing its quantitative description indicates the intensity of human interventions, or the divergence of the ecosystem from the natural state [8, 9]. Within the scope of the MCPFE, three degrees of forest naturalness were distinguished: forests undisturbed by people, semi-natural forests, and plantations. Forests undisturbed by people are forests where natural processes and species composition remain natural to a considerable extent or have been restored. Semi-natural forests can keep certain natural characteristics allowing natural dynamics and biodiversity closer to the original ecosystem. Plantations represent man-made (artificial) forest communities that are completely distinct from the original ecosystem [3]. Similar scales that

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use a gradient from less to more natural systems with different numbers of naturalness degrees (3 to 10) are common in literature [8, 10-14].

The degree of forest naturalness is assessed on the basis of selected (compositional, structural, and functional) attributes [2], mainly: nativeness of species and genotypes, differentiation of stand structure (e.g. diameter frequency distribution, vertical and age structure, occurrence of deadwood and of natural regeneration of forests), as well as the existence and extent of human influence in particular forest ecosystems (e.g. existence of and methods of timber felling and forest re-establishment, soil preparation, presence of forest roads, recreational activities, grazing, forest damage) [13]. In general, indicators are divided into positive, i.e. those reflecting the natural status, and negative indicators, i.e. those reflecting human activity [10]. Overall naturalness is then obtained by considering and combining partial indicators of naturalness. An overview of existing assessment methods and scales can be found in, e.g., Machado [8], and in Winter et al. [15].

The number of selected parameters for the evaluation of naturalness differs between publications. Some authors use only one indicator, e.g. Pasierbek et al. [16] based their index of naturalness solely on tree diameter distribution. The most common approach of assessing naturalness is to analyze the naturalness of tree species composition [17-19]. Also, Šmídt [20] accounted for tree species composition, but in the assessment he also included forest structure. Because of the complexity of naturalness, Colak et al. [10] suggested using factor combinations instead of a single factor. Hence, recent works usually evaluate naturalness on the basis of several indicators. For example, Hepcan and Coskun [21] proposed an additive model for the calculation of total naturalness quality based on four indicators:

(1) remoteness from access
(2) remoteness from settlements
(3) biophysical naturalness (the degree to which the natural environment is free of biophysical disturbance due to human occupation and exploitation)
(4) uniqueness (occurrence of rare natural vegetation and/or physical characteristics)

Bartha et al. [2] suggested a complex assessment of forest naturalness by evaluating the naturalness of the composition and structure of a canopy layer, shrub layer, regeneration, and forest floor. Recently, Moravčík et al. [13] presented a classification model of forest naturalness degree for spruce forests in Slovakia with 6 partial indicators derived from tree, stand, and vegetation characteristics (tree diameter and height, crown length, deadwood volume, relative coverage of grasses, mosses and lichens, aggregation index by Clark and Evans [22]).

While most of the published studies focus on identifying reliable naturalness indicators [15] and suggesting an index, formula, or a model for expressing naturalness [8], in the presented study we aimed at applying an existing model of Moravčík et al. [13] in order to:

(1) examine the model performance outside the parameterization data set
(2) analyze the naturalness level of the forests in the Babia Hora Nature Reserve

Data

The data come from Babia Hora, situated in the northern part of Slovakia along the border with Poland. Babia Hora is an isolated mountain massif belonging to the outer Western Carpathian mountain range. In 1926, a nature reserve of an area of 117.6 ha was established to preserve the forest ecosystems, which was enlarged in 1974, and currently the area of the nature reserve is 503.94 ha [23]. The massif of Babia Hora consists of tertiary flysch rocks, mainly sandstones, marl, claystones, slate, and conglomerates. The soil types that occur in the area are raw soil, andosol, and podsol. The mean annual precipitation of the reserve is 1,600 mm, and the mean annual temperature is 2ºC. The nature reserve is located at an elevation ranging from 1,160 to 1,725 m above sea level. The forest stands are composed of Norway spruce (*Picea abies* (L.) Karst.) with a small admixture of rowan (*Sorbus aucuparia* L.) and silver fir (*Abies alba* Mill.) in the eastern part. Norway spruce contributes 99% of the stand basal area [24].

In 2002, 57 permanent circular sample plots were established, each with an area of 0.05 ha (i.e. radius = 12.62 m) [24]. The plots are located at elevations from 1,173 m to 1,503 m above sea level, the latter representing the timberline in this region. The plots are equally divided between the three main developmental stages of virgin forests: stage of growth, optimum, and disintegration as defined by Korpeľ [23], i.e. each group consists of 19 plots (Fig. 1).

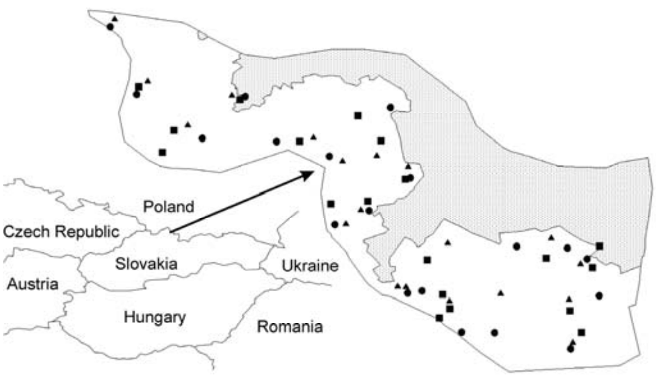

Fig. 1. Location of sample plots in the Babia Hora Nature Reserve (Zone A). Legend: ▒ – alpine meadows and stands of mountain dwarf pine (*Pinus mugo* ssp. *mugo* Turra), sample plots in the developmental stage of: ● – growth, ■ – optimum, ▲ – disintegration.

The natural conditions of each plot were described in the field by the following information: aspect, slope, elevation, topography, geological parent rock, the thickness and the form of humus layer, forest type, and soil type.

In each sample plot, every tree with diameter at breast height (1.3 m) greater than 7 cm was measured. The trees higher than 1.3 m but with the diameter at breast height below 7 cm were measured in the second concentric circle. Its radius was estimated directly in the field using the principle of optimum size of an inventory plot [25] defined as an area including 15 to 25 trees. If the radius of the second circle exceeded the radius of the first circle (i.e. 12.62 m), it was set to this value. For each tree, basic descriptive characteristics were determined, including tree species, position inside the plot (the azimuth and the distance from the centre), diameter at breast height (dbh), tree height, crown width, qualitative characteristics of crown and stem, etc.

Apart from the living trees, dead standing trees and coarse woody debris (lying stems and naturally formed stumps) with diameter above 7 cm were recorded. For dead standing trees, their tree height and diameter at breast height were assigned. In the case of lying dead wood, its total length and diameter at ½ of its length was measured, whereas for stumps only diameter at 0.3 m height was determined. In addition, the position of dead wood on the plot was described with the azimuth and the distance from the centre: in the case of lying stems both ends were aligned. The degree of deterioration (decay class) was assessed using the 8-degree (0-living trees, 8-almost entirely decomposed) scale proposed by Holeksa [26].

The ground vegetation was described in a smaller square plot of 5×5 m situated in the centre of the circle plot. Inside this plot, the phytosociological relevés were performed. The total vegetation coverage of all herbaceous species and the coverage of each species were estimated visually. The coverage of individual species was estimated with the varying accuracy from 0.1% to 5%, depending on their frequency. The names of species conform to [27].

Methods

Classification Model

Naturalness of forests in the selected area was evaluated using the model by Moravčík et al. [13]. The model was developed on the basis of statistical principles using an extensive database of spruce forests located in the 7th forest altitudinal zone (according to the classification of Zlatník [28]). It classifies forest ecosystems into one of three degrees of forest naturalness [29-30]:

1. Primeval forest – without any anthropic activity
2. Natural forest – with the appearance of a primeval forest with no obvious signs of anthropic activity, e.g. natural forests affected by natural disasters left to natural development, possible selective felling in the past, forests with natural tree species composition, but with altered spatial structure due to extensive human activity
3. Man-made forest – forests with anthropic and natural signs.

The model is based on predictive discriminant analysis [31]. It consists of three equations, each for calculating the score of one degree of forest naturalness. The examined plot is assigned such a degree of forest naturalness, for which the calculated discriminant score is a maximum. The partial indicators of forest naturalness that enter the model are: the arithmetic mean of the ratio between crown length and tree height (*AM_K*), the deadwood volume (*MOD*), the relative coverage of grasses (*PK_T*), the relative coverage of mosses and lichens (PK_M), the aggregation index (*CE*) by Clark and Evans [22], and the coefficient of variation of tree diameters (*CV_D1.3*). (For more details about the model see [13].)

Analysis of Forest Naturalness

Considering (1) the long-term conservation of forest ecosystems in the assessed nature reserve Babia Hora since 1926, and (2) the position of the forests on hardly accessible steep slopes, we made an a priori assumption that all sample plots represented naturalness degree 1, i.e. primeval forests.

The model classification was analyzed with the methods of contingency tables, ANOVA, and correlation analysis to identify the causes of the differences between the model results and our hypothesis. Spatial analysis and the zones of particular degrees of forest naturalness were derived by interpolating the discriminant scores of forest naturalness degrees of individual sample plots using the method of the nearest neighbours, which takes into account a specific number of the nearest points when calculating the value of the analyzed cell. In our case, the number of the nearest neighbors was set to 6 and the power, i.e. the exponent of the distance that controls the significance of the influence of the surrounding points on the value assigned to the cell that is being analyzed, was set to 3. For each cell of the raster, the interpolated discriminant scores were compared using the operation of Boolean expressions and conditional statements. The cell was assigned the degree of forest naturalness with the maximum value of the score.

Results

The classification model of forest naturalness derived by Moravčík et al. [13] classified 60% of sample plots to naturalness degree 1, i.e. to primeval forests (Table 1). From the remaining 40% of the plots, 21 plots were classified into naturalness degree 2, while only 2 plots were assigned naturalness degree 3.

Influence of Developmental Stages and Elevation on the Correctness of Classification

In the next step, we analyzed the reasons why not all plots were assigned degree 1 of forest naturalness as we assumed prior to analysis. First, we examined if the data indicated any trend with the developmental stage and elevation.

Table 1. Classification of the degree of forest naturalness in the Babia Hora Nature Reserve, Slovakia, performed by the classification model derived by Moravčík et al. [13].

Result	Number of sample plots	%
Incorrectly classified (classified into degrees 2 and 3)	23	40.4
Correctly classified (classified into degree 1)	34	59.6
Sum	57	100

Table 2. Classification of the degree of forest naturalness in the Babia Hora Nature Reserve, with the classification model derived by Moravčík et al. [13] distributed between the developmental stages. "Correct" represents classification of the sample plots into degree of forest naturalness 1 (primeval forests), and "incorrect" stands for the classification of the sample plots into degrees 2 and 3.

Developmental stage	Statistics	Incorrectly classified	Correctly classified	Sum
Disintegration	*n*	6	13	19
	%	31.6	68.4	100.0
Growth	*n*	9	10	19
	%	47.4	52.6	100.0
Optimum	*n*	8	11	19
	%	42.1	57.9	100.0
Sum	*n*	23	34	57
	%	40.4	59.6	100.0

Table 3. Classification of the degree of forest naturalness in the Babia Hora Nature Reserve, with the classification model derived by Moravčík et al. [13] distributed between the elevation categories. "Correct" represents classification of the sample plots into degree of forest naturalness 1 (primeval forests), and "incorrect" stands for the classification of the sample plots into degrees 2 and 3.

Elevation category	Statistics	Incorrectly classified	Correctly classified	Sum
Below 1,260 m	*n*	2	13	15
	%	13.3	86.7	100.0
1,260-1,360 m	*n*	5	10	15
	%	33.3	66.7	100.0
1,360-1,460 m	*n*	5	10	15
	%	33.3	66.7	100.0
Above 1,460 m	*n*	11	1	12
	%	91.7	8.3	100.0
Sum	*n*	23	34	57
	%	40.4	59.6	100.0

The result of Pearson Chi-square test ($\chi^2_{(2)}$ =1.02, statistical significance *p*=0.60) and the results presented in Table 2 show that the classification is not significantly affected by the developmental stage of the forest.

The following analysis revealed that the correctness of the classification significantly decreases with increasing elevation (Table 3), since in the first elevation category (i.e. below 1,260 m) 86% of the plots were classified to degree 1, while in the last elevation category (i.e. above 1,460 m) the model classified only 8% of the plots into the highest naturalness degree. In this case, the value of Pearson Chi-square test is high with $\chi^2_{(3)}$ =18.29, and the result is significant at 99% level.

Correlation with Input Variables

Next, we analyzed the correlation of the classification with the independent input variables. The coverage of grasses (*PK_T*) was found to have the greatest influence on the classification (R=-0.57) (Table 4). Significant correla-

Table 4. Correlation of independent variables in the classification model with the correctness of the classification (independent variables = f(binar[0,1] result of classification).

Correlation index	Independent variables in the classification model					
	AM_K	*MOD*	*PK_T*	*PK_M*	*CE*	*CV_D1.3*
R	-0.13	0.50**	-0.57**	0.48**	0.53**	0.20

AM_K – arithmetic mean of the ratio between crown length and tree height, *MOD* – deadwood volume, *PK_T* – relative coverage of grasses, *PK_M* – relative coverage of mosses and lichens, *CE* – aggregation index by Clark and Evans [21], *CV_D1.3* – coefficient of variation of tree diameters, **95% significance level

tion was also found between model performance and the aggregation index (*CE*), deadwood volume (*MOD*), and the coverage of mosses (*PK_M*) (Table 4). Fig. 2 shows that forest naturalness increases with decreasing coverage of grasses, increasing deadwood volume, increasing coverage of mosses, with the tendency toward regular distribution of trees, with increasing ratio between crown length and tree height and decreasing variation of tree diameters.

A more detailed analysis of the relationship between the model classification and the coverage of individual herbaceous species revealed significant differences in the coverage of *Avenella flexuosa* (L.) Parl. (grass) and *Polytrichum formosum* Hedw. (moss) (Fig. 3). The coverage of *Avenella flexuosa* (L.)/Parl. is lower in the plots classified to degree 1 than in the remaining plots assigned degrees 2 or 3. On the contrary, the coverage of *Polytrichum formosum* Hedw. is greater in the plots classified to naturalness degree 1. Another visible, though insignificant difference can be seen in the case of *Vaccinium myrtillus* L., which has greater coverage in the plots assigned degree 1 (Fig. 3).

Since in general, a herb layer reacts to canopy closure and the age of a tree layer, we also examined if these factors also affect model classification. This analysis did not detect any significant differences between the groups of the plots assigned naturalness degree 1 and degrees 2 and 3 – either in stand age or in canopy closure. Similarly, no significant influence of aspect, slope, and aboveground rockiness was detected on the classification of forest naturalness degree.

Spatial Analysis

The output of spatial analysis (Fig. 4) shows that plots classified to naturalness degrees 2 or 3 are located in one of the three parts of the reserve:

(1) near the bottom boundary of the nature reserve
(2) around the upper timberline
(3) in the eastern part of the nature reserve, while the eastern part of the reserve is the largest area that was classified into lower naturalness degree than expected.

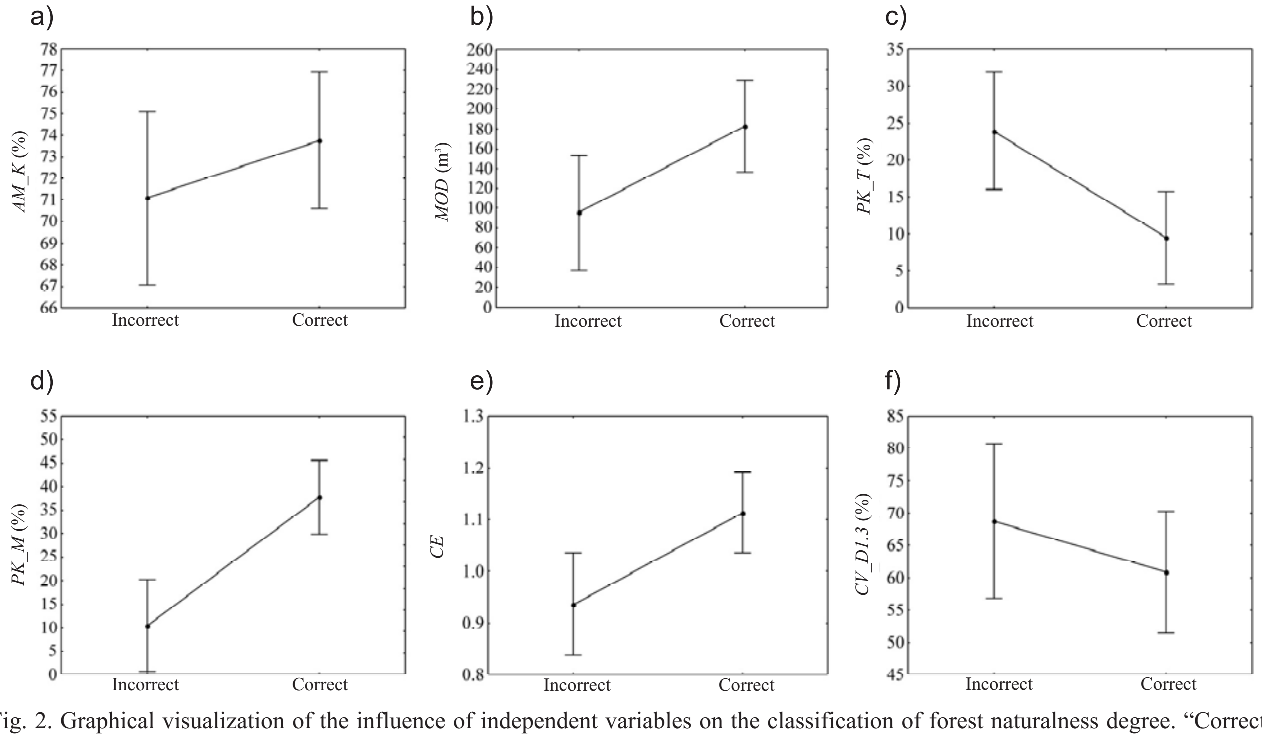

Fig. 2. Graphical visualization of the influence of independent variables on the classification of forest naturalness degree. “Correct” represents classification of the sample plots into degree of forest naturalness 1 (primeval forests), and “incorrect” stands for the classification of the sample plots into degrees 2 and 3. (a) *AM_K* is the arithmetic mean of the ratio between crown length and tree height, (b) *MOD* is the deadwood volume, (c) *PK_T* is the relative coverage of grasses, (d) *PK_M* is the relative coverage of mosses and lichens, (e) *CE* is the aggregation index by Clark and Evans [21], and (f) *CV_D1.3* is the coefficient of variation of tree diameters.

Both plots that were assigned naturalness degree 3 were situated near the bottom boundary of the nature reserve (Fig. 4).

To examine the reasons why the mentioned parts of the reserve were classified into the degrees of naturalness 2 and 3, we performed the spatial analysis of the assigned degree of forest naturalness with regard to independent variables that enter the classification model (Figs. 4a-f). The results show that the areas assigned the degree of naturalness 2 are characterized by greater coverage of grasses (Fig. 4a), lower values of Clark-Evans aggregation index (Fig. 4d), lower amount of deadwood (Fig. 4c), and lower coverage of mosses (Fig. 4b). The degree of forest naturalness 3 was assigned to the areas around the plots, with very low ratios of crown length to tree height (Fig. 4e).

Discussion

Assessing the level of naturalness on a quantitative base is quite rare [8], although such an approach allows a more objective analysis of the ecosystem condition. The model applied in the presented work is an objective tool, since the quantification of naturalness is based on the values of partial indicators, which were selected by a thorough statistical analysis [13]. Our validation of the model performance revealed that the model is capable of classifying forest naturalness well, since 60% of the examined plots in Babia Hora were classified into the expected degree of forest naturalness 1 (primeval forests). From a purely statistical point of view, the remaining 40% of the plots represent incorrect classification, but from the perspective of assessing the naturalness of the nature reserve, the result can also indicate that some parts of the protected reserve have been affected by human-induced disturbances.

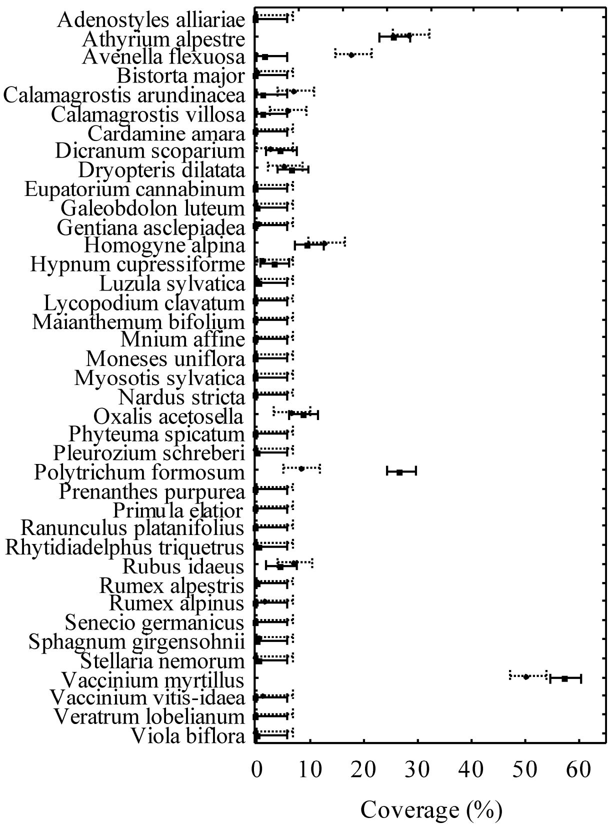

Fig. 3. Analysis of the coverage of herbaceous species in relation to the classification of the degree of forest naturalness. Legend: Degrees of forest naturalness 2 and 3: ● – arithmetic mean, ⌶ 95% confidence interval, degree of forest naturalness 1 (primeval forests): ■ – arithmetic mean, ⌶ 95% confidence interval.

In a number of mountain ranges in Europe, agricultural activities across elevation zones up to the natural alpine meadows located above the timberline have been occurring for centuries [32]. Hence, the model classification should be analyzed with regard to the history of the area, because the reconstruction of the historical development is necessary in order to understand the current situation [14, 33]. However, reliable written historical records about past management are often missing [34] or insufficient. In such cases, an objective diagnostic tool that is able to perform a thorough analysis of the ecosystem condition would help us identify the areas with altered values of naturalness. Therefore, the analysis of the model output was performed with regard to available historical information and findings published elsewhere to reveal if the applied model is able to identify the parts with lower values of forest naturalness.

The two plots classified into degree 3 of forest naturalness are situated at the bottom boundary of the nature reserve (Fig. 4), which can indicate that forest management applied in the neighboring management forests outside the nature reserve has affected their development. A closer look at the characteristics revealed that the amount of deadwood in these plots was lower when compared with the surrounding plots (Fig. 4c). This fact can suggest that the development of the bottom part of the reserve could have been influenced by the extraction of deadwood. Such management has been quite common in nature reserves, because coarse woody debris has often been perceived as a threat to the health of stands [16]. In general, protection status does not seem to ensure exclusion of human impact from the protected areas, as also Uotila et al. [34] revealed that in Fennoscandia 33% of the protected forests have been influenced by man documented by the signs of light selection felling, or slash-burn cultivation. Nevertheless, deadwood characteristics are common attributes used for assessing forest naturalness [15, 35], since the difference between managed and unmanaged forests is in most cases notable [36, 37]. In our case, lower deadwood volume was also recorded in the two parts of the reserve at the bottom boundary and the eastern part of the reserve, all assigned degree 2 of naturalness (Fig. 4), which had been affected by windthrow in 1955 (documented in aerial photographs from that period, not shown here). The windthrown timber was extracted from these parts, which reduced deadwood volume and affected forest naturalness assessment.

In addition, the analysis of independent parameters revealed that both plots classified to naturalness degree 3 were also characterized by low values of the ratio between crown length and tree height (*AM_K*), (Fig. 4e). The low values of this parameter can indicate that ecological conditions (mainly humidity and temperature) of these locations approximate the production optimum of spruce (i.e. species production is at its maximum, [38]). At such locations, forest stand density is higher, which causes self-pruning of trees and, hence, shorter crowns [39].

At the upper timberline, the majority of the plots were classified into the degree of forest naturalness 2, mainly because of higher coverage of grasses, particularly of *Avenella flexuosa* (L.) Parl. (Fig. 4g), but also because of lower values of the aggregation index (Fig. 4d), suggesting that forest stands situated at the upper timberline have an aggregated structure. Considering the position of the plots at the upper timberline and the historical development above the timberline in the past, there are two possible explanations for why the model classified the plots at the timberline into a lower degree of forest naturalness than originally hypothesized.

On one side, trees at the upper timberline are naturally aggregated into small groups [40, 41], which is a typical feature of forest stand development at such locations without human impact. According to Holeksa and Cybulski [42], openings in the forest canopy are typically structural elements of subalpine spruce forests, when on the Polish side of Babia hora the authors found that gaps cover 34% of the examined area. Hence, higher coverage of grasses can occur naturally due to the permanently released canopy of these stands.

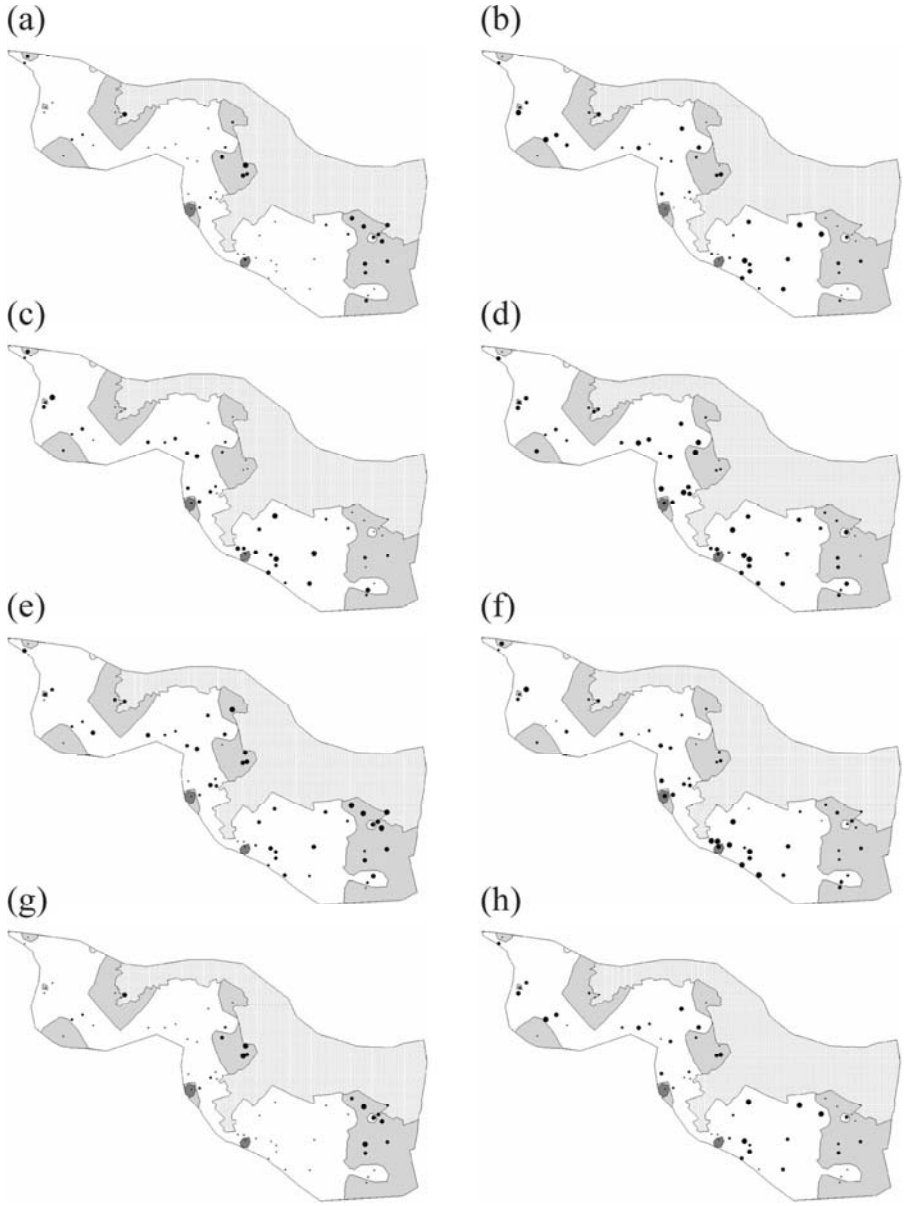

Fig. 4. Spatial analysis of the relationship between the independent variables in the classification model and the model classification: (a) coverage of grasses, (b) coverage of mosses, (c) deadwood volume, (d) Clark Evans index [21], (e) ratio of crown length to tree height, (f) coefficient of variation of diameters, (g) coverage of *Avenella flexuos*a (L.) Parl., (h) coverage of *Polytrichum formosum* Hedw. Legend: – alpine meadows and stands of mountain dwarf pine (*Pinus mugo* ssp. *mugo* Turra), • ● the size of the point indicates the value of the independent variable (low – high), – degree 1 of forest naturalness, – degree 2 of forest naturalness, – degree 3 of forest naturalness.

On the other hand, in Babia Hora alpine meadows above the timberline were utilized as pastures for cattle and sheep until 1974 [41]. According to historical documents, 320 sheep and 100 head of cattle grazed there 50 days per year. In addition, Trnka [41] reported that forest stands of mountain dwarf pine (*Pinus mugo* Turra ssp. *mugo*) above the timberline were burnt and cut in order to extend the pastures. This was a general practice in mountainous areas of Babia Hora until the middle of the 19th century [32]. Hence, higher coverage of grasses can also result from the past management above the timberline, as also Liira et al. [37] found that forest management indirectly increased the proportion of grasses by opening the forest canopy. The positive reaction to gap creation was reported e.g. for *Calamagrostis villosa* (Chaix) J.F.Gmelin [43-45]. In our case, *Calamagrostis villosa* and *arundinacea* have a higher but insignificant coverage in the areas assigned naturalness degree 2 (Fig. 3).

Other grass species, such as *Avenella flexuosa* (L.) Parl., *Nardus stricta* L., and *Luzula sudetica* Willd./Schult., etc., are known to create permanent natural grass communities above the timber line in Central Europe [46]. Based on the study of the sub-alpine grassland, Semelová et al. [47] reported that *Avenella flexuosa* (L.) Parl., *Nardus stricta* L., and *Deschampsia caespitosa* L./P.Beauv. have been predominant since 1786, and hence are recognized as long-term living species creating long-term stable grasslands. On the other hand, Krahulec et al. [48] found that the cessation of grazing resulted in higher coverage of tall herbs and grasses, and hence in decreased species richness. The areas that had been grazed for centuries have been degrading, and after the abandonment of grazing, such plots were colonized by species that are not nutrient demanding, *Avenella flexuosa* (L.) Parl. being one of them [49]. However, since our earlier study revealed that in Babia Hora phytosociological communities were spatially homogeneous with no significant differences between developmental stages [50], we presume that the permanently released canopy and the aggregated structure of forest stands are natural preconditions for higher coverage of grasses at the upper timber line. This is in accordance with Pyšek [43] and Glončák [51], who reported that grass species *Calamagrostis villosa* (Chaix) J.F.Gmelin and *Avenella flexuosa* (L.) Parl., respectively, are typical understorey species of natural spruce forests.

The largest area classified into degree 2 of forest naturalness is located in the eastern part of the reserve (Fig. 4). Similarly to the timberline, the plots in this part are characterized by the great coverage of grasses (Fig. 4a), even at lower elevations. In the past, the trail for the cattle and sheep led through this part of the reserve to the pastures above the timberline, which could have affected phytosociological communities. However, since the analysis of our data has not detected higher coverage of ruderal species in this part (Fig. 3), which become abundant after the cessation of grazing [42], we presume that the higher proportion of grasses was not caused by the passage of animals in the past, but by windthrow in 1955, which was followed by timber extraction, as such disturbances are known to have a positive effect on the coverage of grasses, e.g. *Calamagrostis villosa* (Chaix) J.F.Gmelin [43-45, 52].

In the parts classified into naturalness degree 1, we detected significantly higher coverage of *Polytrichum formosum* Hedw. (Figs. 3 and 4h), as well as higher coverage of *Vaccinium myrtillus* (Fig. 3). *Polytrichum formosum* Hedw. is a representative of bryophytes, which are often used as indicators of old-growth forests [54-55]. It is a moss species with the size comparable to small vascular plants [44], which indicates fresh-to-moist soils [49]. This corresponds well with the conditions of the examined reserve characterized by high precipitation amount [53]. The study of synusiae in Babia Hora massif performed by Holeksa [44] revealed that *Polytrichum formosum* Hedw. played a considerable role in the field-layer, while its frequency in gaps was smaller than under the forest canopy.

Similarly, *Vaccinium myrtillus* L. is one of the most important elements of the field-layer in a subalpine spruce forest in all developmental stages [44, 51], although its coverage in gaps is reduced due to the intensive growth of other species, in the region of Babia Hora *Athyrium distentifolium* Tausch ex Opiz [44]. Higher coverage of *Vaccinium myrtillus* L. in plots with naturalness degree 1 is in accordance with the findings of other authors. For example, Chovancová and Križová [45] reported the prevailing occurrence of *Vaccinium myrtillus* L. in the plots unaffected by windstorm as well as in the windthrown plot left to self-development, while their coverage of *Vaccinium myrtillus* L. was significantly higher than in the plot subjected to timber extraction. Likewise, Uotila [56] observed the negative effects of cutting and management on the coverage of *Vaccinium myrtillus* L.

Proposal of Model Application in Decision-Making of Forestry Policy

The 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 [57]. Its significance is also confirmed by the fact that it has been recognized as one of the pan-European indicators of sustainable forest management and of Global Forest Resources Assessment.

In forestry, the assessment of forest naturalness is of the greatest significance in decision-making processes that deal with the use of particular forestland from the point of their nature-conservation functions, e.g. with the designation of forests as protected areas [10]. Nowadays, 57.1% of forests in Slovakia belong to protected areas within national and/or European networks [58], and their size has been growing continuously. However, current protected areas also include altered forest ecosystems, where the restoration of natural biodiversity is not feasible or requires active management. Hence, naturalness is an important feature in the process of determining the need and the urgency of active management (cultivation, tending) with the aim to secure the conservation of their biological diversity and/or of other natural values. For these purposes, detailed surveys of forest naturalness are required primarily in those forest ecosystems that are being considered to be declared protected areas.

Since in general close relationships between the degree of forest naturalness and the nature-conservation value of forests is recognized, the incorporation of this indicator in decision-making processes dealing with the designation, conservation, and management of forest ecosystems is inevitable. The higher the naturalness of the forest ecosystem, the more legitimate it is to designate it as a protected area. At the same time, higher naturalness of ecosystems should logically result in a higher level of their conservation. Obviously, primeval forest ecosystems are the most precious as they represent the natural state, and are also the most capable of surviving through their own self-regulating processes. Hence, such ecosystems should be protected to the highest degree.

Coupling the applied classification model with the spatial analysis in the GIS environment as presented in our work (Fig. 4) allows distinguishing the areas of the analyzed region that meet and those that do not meet the criteria of naturalness. A similar approach has been applied in several works [12, 19] that analyzed the naturalness of landscape on the basis of vegetation maps processed in a GIS environment. Such a spatial analysis can be used as a remarkable support tool in the decision-making process about how to manage the region, or its parts. If the classification reveals lower naturalness of the examined region or its major part, other reasons for its conservation need to be identified, e.g. the existence of endangered species or the occurrence of other natural and nature-conservation values [59]. Moravčík et al. [13] suggested a decision-making scheme for the designation of protected areas that accounts for these indicators. If the areas of lower naturalness are significant from any of these points, they should be protected by applying the management that will ensure both the conservation of the area and the conservation of other values, e.g. the existence of endangered species. In such cases, active management and appropriate conservation measures should be directed to these areas with the aim to justify the need for their protection, and to analyze and validate the possibility of their effective reconstruction to a close-to-nature state. The effect of the applied measures can be examined by performing the monitoring of the area based on the principles of sampling assessment, which enables the analysis of the statistical significance of the changes in forest ecosystems.

Conclusions

Naturalness of forest ecosystems is considered to be one of the most important criteria for assessing their conservation status. It is usually quantified by the degree of naturalness that indicates the intensity of human impact. However, the estimation of the degree of forest naturalness is a complex task within which a number of different attributes should be accounted for. The classification model proposed by Moravčík et al. [13] and applied in the presented paper classifies forest ecosystems into one of the three degrees of forest naturalness:

(1) Primeval forest
(2) Natural forest
(3) Man-made forest

The model was capable of classifying independent data from the Babia Hora Nature Reserve, since 60% of the plots were assigned naturalness degree 1. Only two plots, i.e. 3.5%, were classified into degree 3 due to very low ratios of crown length to tree height and lower deadwood amount. The plots designated naturalness degree 2 are characterized by greater coverage of grasses, lower amount of deadwood, and lower coverage of mosses than those in naturalness degree 1. Further analysis of the results of the classification model in combination with the spatial analysis detected that the values of these characteristics could have been influenced by abiotic factors (windthrow), and/or human interventions (grazing, extraction of deadwood) in past.

Our paper documents how the classification model can be used in combination with spatial analysis in a GIS environment in order to distinguish the areas that meet and do not meet the criteria of naturalness. The classification model itself, and the spatial analysis of its results, can considerably support the decision-making process dealing with management of the examined area.

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