Structural diversity change and regeneration processes of the Norway spruce natural forest in Babia hora NNR in relation to altitude

J. Vorčák[1], J. Merganič[2], M. Saniga[3]

[1]*Forestry Trades School, Tvrdošín, Slovak Republic*
[2]*Forest Research Monitoring (FORIM), Sobrance, Slovak Republic*
[3]*Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovak Republic*

ABSTRACT: The research was focused on exploring the dynamics and forms of regeneration processes and structural diversity of the Norway spruce virgin forest in Babia hora NNR in relation to altitude. In each developmental stage 19 sample plots were established. The structural diversity was assessed by the indices proposed by Clark and Evans (1954), Füldner (1995) and Jaehne and Dohrenbusch (1997). Concerning the spatial distribution of the trees in the virgin forest no tendency to their clustering with the increasing altitude was found in the zones below 1,460 m. The influence of the altitude was confirmed in the zone above 1,461 m where the groups of "family spruces" are typical. Diameter differentiation was significantly higher in the growth stage. Evaluation of this attribute in terms of the altitude detected significant diameter differentiation at an altitude below 1,260 m in the growth stage. According to the Füldner index the virgin forest has generally medium differentiated diameter structure. According to the complex index by Jaehne and Dohrenbusch (1997) the differentiation of the virgin forest decreases with the ascending altitude up to 1,460 m, where the compact forest ends. Evaluation of the seedbed revealed that 46.2% of the naturally regenerated individuals were growing on mineral soil, 52.4% on dead wood and 1.4% on wind-thrown roots. Regarding the developmental stages 46% of the individuals were found in growth stage, 23% in optimum stage and 31% in breakdown stage.

Keywords: Norway spruce; virgin forest; structural diversity; natural regeneration

Natural Norway spruce forests in the 7th spruce forest vegetation zone serve as a laboratory for the observation of their structure and regeneration processes under changing ecological conditions. Mountain forests in the orographic unit Babia hora represent the remains of natural forests on the flysch bedrock. A major part of the virgin forests in this massif has become the object of legislative protection in the form of national nature reserve (NNR). According to Korpeľ (1989) the knowledge of the basic structural attributes of Norway spruce natural forests allows us to identify their stage with the maximum functional efficiency. In the process of investigating these issues the structural diversity of these forest ecosystems is of great importance. Its quantification and understanding can significantly contribute to the explanation of the complicated ecological problems such as calamities. The quantification of the diversity through the mathematic formulas allows us to evaluate this problem objectively and to better understand the relations of a given forest ecosystem. A remarkable part of their diversity is structural diversity, which according to some authors is defined as specific arrangement of the components in the system (Gadow 1999) or as their positioning and mutual connections (Heupler 1982 in Lübbers 1999). According to Zenner (1999) the structure can be characterized horizontally, i.e. the spatial distribution of the trees, and vertically in their height differentiation. Lübbers (1999) added the amount and form of dead wood to these attributes. Gadow and Hui (1999) defined the structure as spatial distribution, mutual position and height differentiation of the trees in a forest ecosystem. For the mathematic description and quantification of this issue the index methods (indices) are mostly used. The most famous for the description of the horizontal distribution of trees on the area of a stand is the index by Clark and Evans (1954), based on the relation between the real distance to the nearest neighbour and the expected distance in the Poisson forest, i.e. in a forest where the spatial distribution of the trees is random (Tomppo 1986).

Concerning different approaches, there are some indices that describe the differentiation of diameter, height and volume, respectively (Füldner 1995) or complex indices describing more components of the structural diversity (Pretzsch 1996, 1988; Jaehne, Dohrenbusch 1997; Zenner 1999; Lähde et al. 1999). By their help it is possible to add another hierarchical level of the stand diversity.

Regeneration processes in a Norway spruce natural forest are closely connected with the developmental stage and seedbed type. According to Korpeľ (1989), and Vorčák (2005) the amount of natural regeneration growing on dead wood increases with the altitude and most of it appears in the initial phase of the growth stage.

Analyzing the regeneration processes in the National Park Bavarian Forest Reif and Przybilla (1998) found that besides the dead wood as a seedbed light has an important influence on the Norway spruce seedling density. This was already been previously by Zierl (1972). The importance of the dead wood as a seedbed increases with the altitude of the Norway spruce natural forest. At the altitude above 1,400 m the dead wood represents the basic form of the seedbed (Mai 1999).

In Babia hora NNR Jaloviar (2006) discovered that the ratio between the Norway spruce seedling weight and their root system weight is twice higher on the dead wood than on the mineral soil. Holeksa (1998), who investigated the Polish part of the orographic unit Babia hora, found that the competition and presence of high plants especially the fern *Athyrium distentifolium* inhibited the germination process of Norway spruce seeds and that the regeneration mostly (60%) took place on decaying dead wood and wind-thrown roots.

The objective of the paper is to describe the structural diversity and regeneration processes on the basis of 57 research plots with the size of 500 m^2 that were established in various stages of the natural forest developmental cycle and at various altitudes.

STUDY AREA AND METHODS

Norway spruce natural forests of Babia hora were declared a nature reserve with the area of 117.6 ha in 1926, later the area was enlarged up to 503.94 ha under the name NNR Kotlina pod Babiou horou. The reserve is situated in the Oravské Beskydy Mts. in the cadastral unit Oravská Polhora on the slopes of W–SW aspect, in the altitude range 1,100–1,725 m. The bedrock is Magura-flysch and the most frequently represented soil types are podzolic Cambisols, Rankers and Podzols. Average annual temperature for the reserve is 2°C (for the vegetation period 6°C), average annual precipitation is 1,600 mm.

Forest communities of the reserve are characterized by a high level of preservation of the original status and belong to three vegetation zones: 6th spruce-beech-fir, 7th spruce, 8th dwarf pine. From the groups of forest types *Fagetum abietino piceosum* (Fap), *Sorbeto-Piceetum* (SP) and *Mughetum* (M) are present. Among the tree species Norway spruce dominates, scattered occur rowan and sycamore maple and beech and Silver fir are scarce. Virgin forests of Norway spruce below the upper timberline change gradually into the dwarf pine and juniper stand. Norway spruce has a typical narrow crown form and its wood has very fine tree rings. The breaks and the drying-out of crown tops are very common. Above 1,500 m a.s.l. the crown canopy of the spruce stands is permanently open, the crowns reach down to the ground and the stems are considerably tapering.

Quantification of the structural diversity

For the research of the structure a stratified sampling performed in two levels was used. The first stratification level was the altitude divided into 4 altitudinal categories:

A – Norway spruce virgin forest below 1,260 m a.s.l.
B – Norway spruce virgin forest from 1,261 to 1,360 m a.s.l.
C – Norway spruce virgin forest from 1,361 to 1,460 m a.s.l.
D – Norway spruce virgin forest above 1,461 m a.s.l.

The second level for the location of the sample plots was the developmental stage of the virgin forest according to Korpeľ (1989).

In the first 3 altitudinal categories and in each developmental stage 5 sample plots were established. In the last altitudinal category 4 sample plots were established in each developmental stage. In each developmental stage of the virgin forest 19 sample plots were established. The size of each sample plot stabilized by GPS was 500 m^2.

Methods of the dendrometric attribute measurement

For the measurement the Vertex hypsometer, the calliper and the forest compass were used. From the sample plot centre the following dendrometric attributes were measured on the trees with dbh above 7 cm:
- tree height (m),
- height to the crown base (m),
- tree location in the grades from north (azimuth),
- distance of the tree from the sample plot centre (m),
- diameter at breast height (mm),
- crown width with the vectors x_1–x_4 according to the azimuth N, E, S, W (0.1 m).

The assessment of natural regeneration

The objects of the analysis were the individuals with the height below 130 cm, which were registered on 10 subplots each with the size of 1 × 1 m. The subplots were established on the circle with the radius of 6.2 m from the sample plot centre and spacing between the subplots equal to 36°. At the regeneration analysis the following four seedbed types for the assessed individuals were distinguished:
- mineral soil,
- wind-thrown roots,
- stumps (broken part of the tree) with the maximum height of 1.3 m,
- dead wood.

On the subplots 4 height categories (Korpeľ 1989) of the natural regeneration individuals were distinguished:
- individuals with the height below 30 cm,
- individuals with the height from 31 to 50 cm,
- individuals with the height from 51 to 80 cm,
- individuals with the height from 81 to 130 cm.

For the structural diversity analysis of the spruce virgin forest we used the aggregation index according to Clark and Evans (1954), diameter differentiation index according to Füldner (1995) and the complex index according to Jaehne and Dohrenbusch (1997).

Aggregation index R (Clark, Evans 1954)

The aggregation index was developed for the purposes of botanic and phytocoenologic studies. In forestry research this index was used very scarcely. Its importance increased with biodiversity and forest stand diversity studies. For the first time it was probably applied in the works of Pretzsch (1996) and Füldner (1995).

The aggregation index describes the horizontal distribution of trees using the relation of the mean distance between the reference tree and its nearest neighbour and the expected distance between them at the random distribution of trees in the stand. Mathematically it is defined as follows:

$$R = \frac{\frac{1}{n}\sum_{i=1}^{n} r_i}{0.5 \times \sqrt{\frac{Pl}{n}}} \qquad (1)$$

where: r_i – distance of tree i to the nearest neighbour,
n – number of trees on the sample plot,
pl – area of the sample plot (m^2).

Clark-Evans index R can theoretically range from 0 at maximum tree clustering to 2.1491 at the regular hexagonal distribution of trees. Index value equal to 1 means that the trees are distributed on the stand area randomly. The stands with the index value > 1 show the tendency to the regular distribution and the index values < 1 the tendency to the clustering.

For the practical use it is not enough to know the index value, i.e. whether the distribution is clustered, regular or random. In the nature most variables have a stochastic character and this index belongs to this type of variables. Therefore, it is important to know whether the difference between the calculated index value and the value expected at random distribution is significant (i.e. the level of significance). This fact can be tested as follows:

$$t = \frac{r_R - r_T}{\sigma_{rT}} = \frac{r_R - r_T}{\frac{0.26136}{\sqrt{n \times \frac{n}{Pl}}}} \qquad (2)$$

where: r_R – real distance to the nearest neighbour,
r_T – expected distance to the nearest neighbour,
σ_{rT} – standard error of mean for the expected distance to the nearest neighbour,
n – number of trees on the sample plot,
Pl – area of the sample plot (m^2).

If the calculated t-value is higher than 1.96 with 95% probability, we can state that the trees in the stand have a clustered or regular distribution according to the value of index R for the given stand.

Diameter differentiation index TM (Füldner 1995)

Tree differentiation is another important parameter of the structural diversity. It can be calculated from various tree attributes (diameter, perimeter, basal area, height, volume). Diameter is a commonly used attribute, because it is simple to measure. Füldner (1995) quantifies the differentiation by the following formula:

$$TM_i = \frac{1}{n}\sum_{j=1}^{n}(1 - d_{ij}) \qquad (3)$$

where: n – number of trees on the sample plot,
d_{ij} – the relation between thinner and thicker dbh in the analyzed neighbour tree pair.

The index values range from 0 to 1. The stands with small diameter differentiation have the index values near 0, while the stands with high diameter differentiation reach the index values close to 1.

For better interpretation of the index his author suggested the 4-level scale of differentiation: small (0.0–0.3); average (0.3–0.5); big (0.5–0.7) and very big (0.7–1.0) differentiation. Some years later Aguirre et al. (1998) suggested to divide the *TM* index values into the 5-level scale in order to simplify the comparison of the stands as follows: low differentiation (0.0–0.2); medium differentiation (0.2–0.4); obvious differentiation (0.4–0.6); strong differentiation (0.6–0.8) and very strong differentiation (0.8–1.0).

Complex stand diversity index B (Jaehne, Dohrenbusch 1997)

For the evaluation of the general differentiation the index according to Jaehne and Dohrenbusch (1997) was used, which evaluates complex diversity at the forest stand level. The authors created the *B*-index consisting of four variables of stand structural diversity:
- Index of tree species composition (*A*),
- Index of vertical structure (*S*),
- Index of spatial distribution (*V*),
- Index of crown differentiation (*K*).

1. *Index of tree species composition (A)*

$$A = \log(N) \times (Z - Ma_{max} + Ma_{min}) \qquad (4)$$

where: N – number of tree species,
Z – control parameter, the authors suggest the value 1.5,
Ma_{max} – relative proportion of the most abundant tree species,
Ma_{min} – relative proportion of the least abundant tree species.

2. *Index of vertical structure (S)*

$$S = 1 - \frac{\sum_{i=1}^{n} BHD_{min}}{\sum_{i=1}^{n} BHD_{max}} \qquad (5)$$

where: n – number of measured trees (3 thickest and 3 thinnest trees),
BHD_{min} – dbh of the thinnest trees (cm),
BHD_{max} – dbh of the thickest trees (cm).

3. *Index of spatial distribution (V)*

$$V = \left(1 - \frac{\sum_{i=1}^{n} Ab_{min}}{\sum_{i=1}^{n} Ab_{max}}\right) \times f \times st \qquad (6)$$

where: n – number of measured distances (3 shortest and 3 longest distances between neighbour trees),
Ab – distance between trees (m),
f – correction for the stand density (in the pole-stage and older stands it can be omitted)

$$f = Y - \frac{1}{\frac{\sum_{i=1}^{n} Ab_{min}}{n} + \frac{\sum_{i=1}^{n} Ab_{max}}{n}}$$

st – factor considering coppice sprouts

$st = N_{250} \times 0.1 + 1$

N_{250} – n umber of coppice sprouts per 250 m^2,
Y – control parameter.

4. *Index of crown differentiation (K)*

$$K = \left\{1 - \log\left(\frac{\sum_{i=1}^{n} Ka_{min}}{n}\right)\right\} + \left(\frac{\sum_{i=1}^{n} Kd_{mix}}{\sum_{i=1}^{n} Kd_{max}}\right) \qquad (7)$$

where: n – number of selected trees (2 trees with the smallest and 2 trees with the largest crown diameter),
Ka_{min} – the smallest height to the crown base (m),
Kd_{min} – the smallest crown diameter (m),
Kd_{max} – the largest crown diameter (m).

5. *Complex stand diversity index (B)*

$$B = p \times A + q \times S + V + K \qquad (8)$$

where: A – index of tree species composition,
S – index of vertical structure,
V – index of spatial distribution,
K – index of crown differentiation,
p, q – factors of importance ($p = 4$, $q = 3$).

Jaehne and Dohrenbusch (1997) also offered the general evaluation of the stand diversity according to the *B*-index value:
$B \geq 9.0$ – very heterogeneous stand structure
$8.0 \leq B < 8.9$ – heterogeneous stand structure
$6.0 \leq B < 8.0$ – uneven stand structure
$4.0 \leq B < 6.0$ – homogeneous stand structure
$B < 4.0$ – monotonous stands.

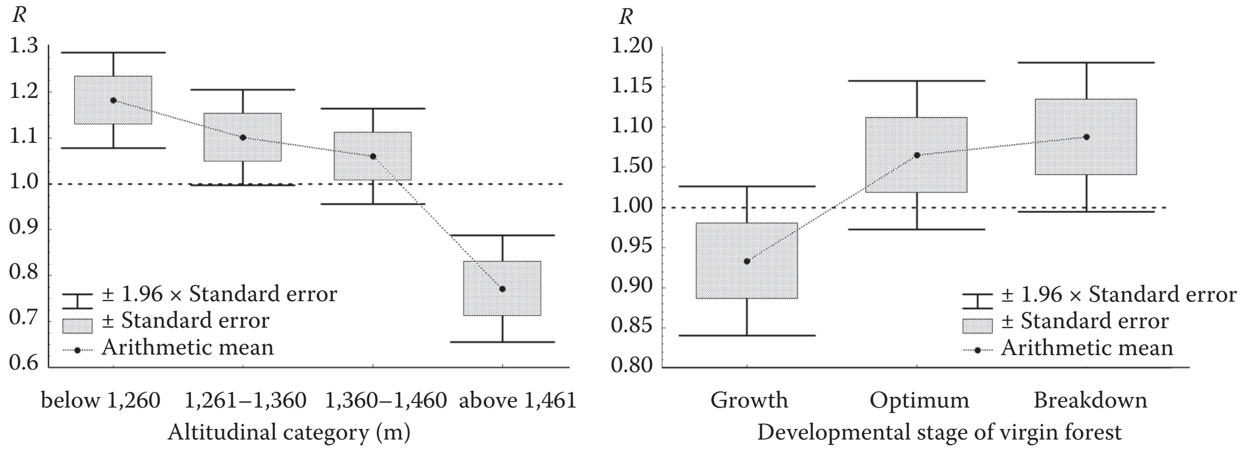


Fig. 1. The values of index *R* in individual altitudinal categories and developmental stages of the virgin forest

RESULTS

Structural diversity

The Norway spruce natural forest in Babia hora NNR is characterized by small-scale texture and high ecological stability. From the evaluation of its diversity on the basis of the aggregation index according to Clark and Evans (1954) we can state two substantial facts. The distances between the neighbouring trees show a tendency to clustering with increasing altitude regardless of the developmental stage. The trees with dbh above 7 cm have regular or random distribution at altitudes below 1,460 m, which is significantly changing to cluster distribution at an altitude above 1,461 m. This is due to the vegetative regeneration and the form of family spruces which create tree clusters (Fig. 1).

If we evaluate the developmental stage of the virgin forest regardless of the influence of the altitude, it can be said that the trees in the growth stage have a tendency to clustering (R = 0.93) and the Norway spruce virgin forest in other stages has a random distribution of trees (R = 1.06 and R = 1.09, respectively).

Generally we can state that in the Norway spruce virgin forest in Babia hora NNR the altitude has no significant impact on tree clustering except the upper timber line, where this tendency is confirmed by the cluster or group distribution of family spruces due to the vegetative regeneration. A moderate tendency to tree clustering was confirmed in the growth stage as well.

Füldner's index *TM* was used for the analysis of the diameter differentiation of the trees in the spruce virgin forest (Figs. 2 and 3). If we evaluate the impact of the developmental stage of the virgin forest on the *TM* index value, the highest diameter differentiation can be found in the growth stage. The analysis of variance confirmed that T-value in the growth stage is significantly higher than in the breakdown stage (p = 0.0014). The differences of *TM*-index between optimum and breakdown stage were not confirmed meaning that their diameter differentiation is equal (Fig. 2).

The analysis of the diameter differentiation according to altitudinal zones and developmental stages of Norway spruce virgin forest (Fig. 3) revealed that only the virgin forest in the altitudinal zone below 1,260 m in the growth stage can be characterized as evidently diameter differentiated. In all other altitudinal zones in this developmental stage the spruce virgin forest is moderately differentiated (Fig. 3) according to the scale by Aguirre et al. (1998). Generally we can state that according to Füldner's *TM* index the Norway spruce virgin forest in the growth and optimum stage has mainly medium differentiated diameter structure except the altitudinal zone 1,361–1,460 m, where in the optimum stage the virgin forest has a single-storied structure with small diameter differentiation.

Interesting values were found by the description of structural diversity according to index B (Jaehne, Dohrenbusch 1997). Mean value of the B-index

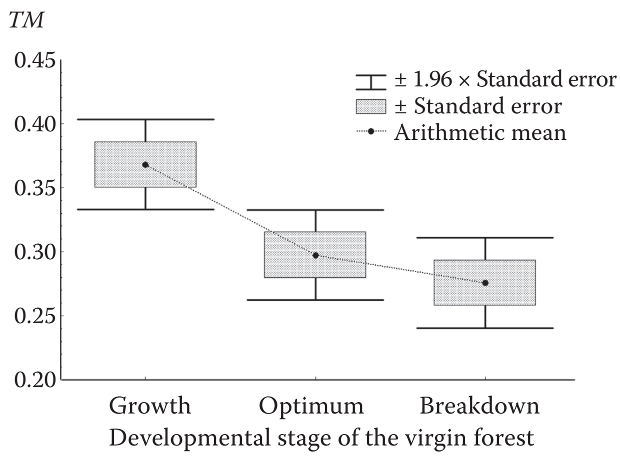
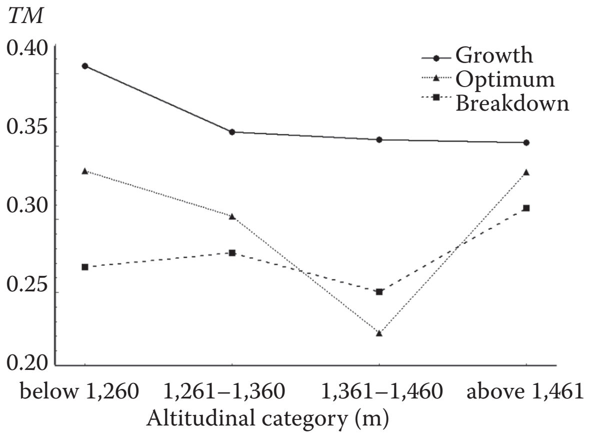


Fig. 2. The values of index *TM* in individual developmental stages of the virgin forest



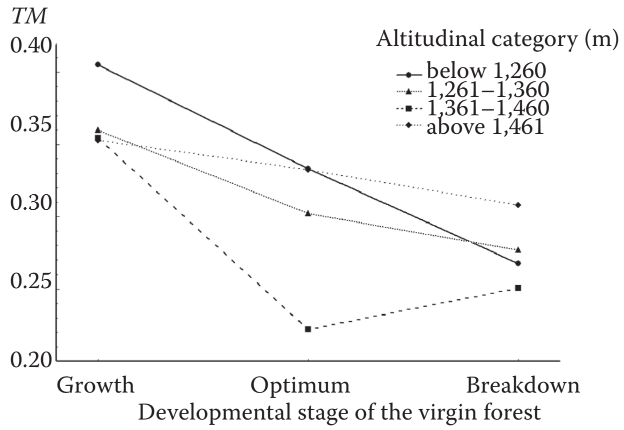


Fig. 3. Average values of index *TM* in individual altitudinal categories and developmental stages of the virgin forest calculated for the set of trees with dbh above 7 cm

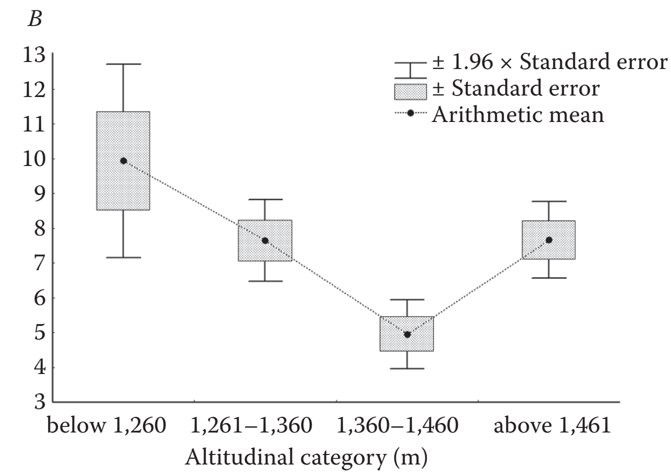
calculated for all developmental stages and altitudes of the spruce virgin forest reached 7.5, which ranks the virgin forest to the category of uneven structure. If we evaluate the average *B*-index with regard to increasing altitude, it reaches its highest value in the virgin forest in the zone below 1,260 m (*B* = 9.8) indicating heterogeneous structure. The high value of the index in the first altitudinal zone is caused by a high admixture of rowan and by gradual exchange of the virgin forest developmental stages on small areas. On relatively large parts of the virgin forest the phase of selection forest structure occurs. With increasing altitude the index declines to the value *B* = 4.9 at an altitude 1,361–1,460 m, which stands for the homogeneous stand structure. Increased values of the index *B* = 7.7 in the altitudinal zone above 1,461 m are due to the cluster or group distribution of the virgin forest at the upper timber line (Fig. 4).

While evaluating the influence of the virgin forest developmental stage on the diversity the highest value of the index *B* = 11.8 appeared in the advanced phase of the breakdown stage and in the initial phase of growth stage *B* = 11.5 (Fig. 5). According to the authors of the index this is a virgin forest with very heterogeneous structure. The lowest values of the index were found in the optimum stage, i.e. the virgin forest has homogeneous to monotonous structure.

On the basis of the complex examination it can be said that with increasing altitude the heterogeneity of the spruce virgin forest declines to the altitude 1,460 m, where the compact forest ends and the virgin forest changes its structure to clusters or groups, which causes the increase of the *B*-index value.

Regeneration processes

The regeneration process dynamics depending on the developmental stage of the virgin forest and the altitude is characterized in Table 1. From this table some relations are obvious. The evaluation of the number of individuals according to the altitude revealed lower values with the increasing altitude practically in all developmental stages of the spruce virgin forest (Table 1). The growth stage, which cre-



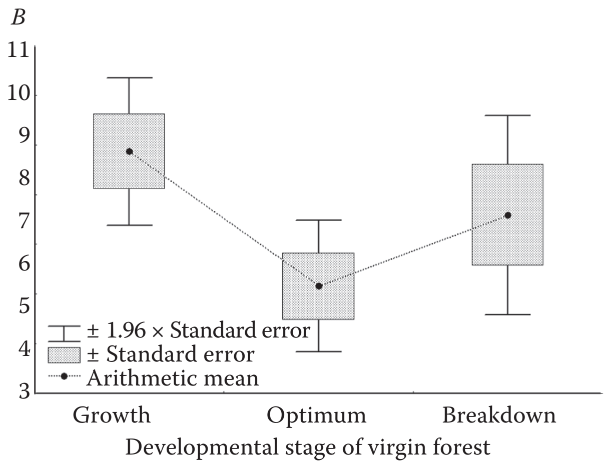


Fig. 4. The values of the complex index *B* in individual altitudinal categories and developmental stages of the virgin forest

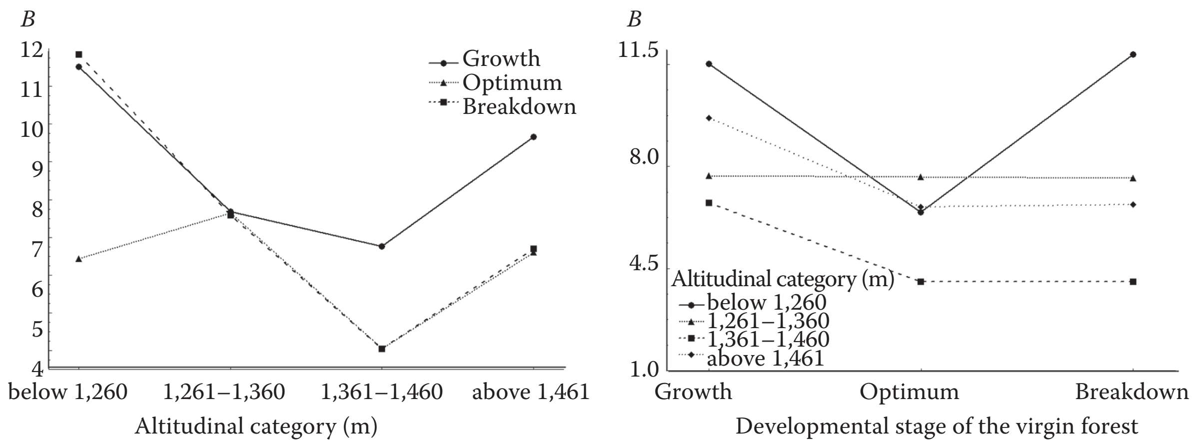


Fig. 5. Average values of the complex index *B* in individual altitudinal categories and developmental stages of the virgin forest

ates the best ecological conditions for the survival and growth of spruce seedlings, has the highest numbers of individuals of this tree species. A distinctive decrease occurred between the altitudinal zone below 1,260 m and the altitudinal zone 1,260 to 1,360 m, where the number of spruce individuals declined from the value 28,600 ha^{-1} to 7,333 ha^{-1}. A notable decrease was also registered between the altitudinal zone 1,361–1,460 m and above this limit. The difference was caused by a strong decline of the temperature gradient and change in the overall ecological profile of the virgin forest. At an altitude above 1,461 m, there is a lack of warmth as well as lower germination capacity of spruce, which causes its lower number and lower emergence of vegetative regeneration, which is the leading form of stand regeneration in this altitudinal zone.

The optimum stage permanently has the lowest number of spruce individuals at all altitudes. This is due to unfavourable ecological conditions, above all to the lack of warmth, which is not able to heat up the seedbed at the existing crown canopy and thus to start the germination process to a larger extent. The other reason is the smaller volume of dead wood as the basic form of the seedbed (Table 1). Compared with the optimum stage the breakdown stage has a higher density of spruce regeneration in all altitudinal categories because of better ecological conditions and the presence of a higher amount of dead wood.

Generally we can state the Norway spruce virgin forest has a relatively long time period that is appropriate for the generation exchange below the altitude 1,460 m. In the higher altitudinal zone the vegetative natural regeneration prevails.

Table 1. Tree species structure of natural regeneration (trees/ha) per altitudinal category and seedbed type

Developmental stage	Tree species	Altitudinal category (m a.s.l.)				Total per stage
		below 1,260	1,261–1,360	1,361–1,460	above 1,461	
Growth	spruce	28,600	7,333	6,000	250	11,444
	rowan	3,000	2,667	333	0	1,778
	total	31,600	10,000	6,333	250	13,222
Optimum	spruce	8,400	2,600	1,400	250	3,316
	rowan	8,800	800	800	250	2,789
	total	17,200	3,400	2,200	500	6,105
Breakdown	spruce	22,000	3,200	2,000	750	7,050
	rowan	1,800	1,600	0	250	900
	total	23,800	4,800	2,000	1,000	7,950
Total per altitudinal category	spruce	19,667	4,563	2,643	417	7,193
	rowan	4,533	1,750	357	167	1,807
	total	24,200	6,313	3,000	583	9,000

Table 2. Tree species structure of natural regeneration (trees/ha) per altitudinal category and seedbed type

Seedbed type	Tree species	Altitudinal category (m a.s.l.)				Total per seedbed
		below 1,260	1,261–1,360	1,361–1,460	above 1,461	
Soil	spruce	8,000	1,625	715	0	2,737
	rowan	3,400	1,500	357	83	1,421
	total	11,400	3,125	1,072	83	4,158
Wind-thrown roots	spruce	67	125	0	0	53
	rowan	0	250	0	0	70
	total	67	375	0	0	123
Lying dead wood	spruce	10,667	2,250	1,286	333	3,824
	rowan	466	0	0	83	140
	total	11,133	2,250	1,286	416	3,964
Stumps	spruce	867	563	642	83	561
	rowan	733	0	0	0	193
	total	1,600	563	642	83	754
Total per altitudinal category	spruce	19,600	4,563	2,643	417	7,175
	rowan	4,600	1,750	357	166	1,825
	total	24,200	6,313	3,000	583	9,000

For the conservation of the virgin forest and the generation exchange the question of its seedbed is very important (Table 2). According to the evaluation of the numbers of spruce and rowan individuals growing on the particular seedbed, the most of the individuals were registered on dead wood (logs and stumps) 52.4%. On the mineral soil 4,158 ha on average were recorded, which means 46.2%. If we evaluate the relation between the seedbed type and altitude, an interesting fact appears regarding the wind-thrown roots. The higher number of regenerated individuals on this seedbed in the altitudinal range 1,261–1,360 m suggests that there is a higher amount of wind-thrown trees there. On the other side, with the increasing altitude the proportion of the naturally regenerated individuals of spruce on dead wood grows. In the last altitudinal zone the regeneration on this seedbed type represented even 86% of the individuals.

The importance of dead wood increases if we evaluate the relation between the area proportion of the seedbed type and the amount of natural regeneration (Table 3). Although the mineral soil as a seedbed type constitutes 94.4–97.8% of the area, the number of the regeneration individuals on this seedbed type decreases with the altitude. On the other hand, the area of the lying dead wood declined with the increasing altitude to 2%, and 0.8% at an altitude above 1.61 m. If we consider the seedbed types that are connected with the tree component of the virgin forest (stumps,

Table 3. Proportion of seedbed types for regeneration in the total examined area per altitudinal category (m²/%)

Altitudinal category (m a.s.l.)		Seedbed type			
		soil	wind-thrown roots	lying dead wood	stumps
Below 1,260	(m²)	9,433.7	0.3	527.2	38.8
	(%)	94.34	0.00	5.27	0.39
1,261–1,360	(m²)	9,533	0.9	437.2	28.9
	(%)	95	0.01	4.37	0.29
1,361–1,460	(m²)	9,784	0	199.2	16.8
	(%)	97.80	0	2	0.20
Above 1,461	(m²)	9,914.7	0	79.5	5.8
	(%)	99.10	0	0.80	0.10
Total	(m²)	9,666.2	0.6	310.7	22.5
	(%)	96.66	0.01	3.11	0.23

logs, wind-thrown roots), their area represented 3.34% while the proportion of the regeneration growing on them was 53% of the number of individuals.

DISCUSSION AND CONCLUSIONS

The evaluation of the structural diversity using only one index can lead to incorrect conclusions. If we evaluate the tree distribution of the Norway spruce virgin forest on the basis of the aggregation index according to Clark and Evans (1954), our results confirm the findings from the Norway spruce natural forest in Poľana NNR (Holeksa et al. 2006). The changes in the index values in relation to altitude are also nearly the same in this explored object. Both spruce virgin forests appear to have random or moderately regular distribution of the trees on the area of the virgin forest. However, this index says nothing about the range of tree diameters and heights, or about other dendrometric attributes.

Füldner's index *TM* pointed to the tendency of certain diameter differentiation especially in the spruce virgin forest below the altitude 1,260 m. This index was not used in the analysis and evaluation of the structural diversity of the spruce virgin forest in Poľana NNR.

The complex index according to Jaehne and Dohrenbusch (1997) completed the information about the structural diversity of the Babia hora spruce virgin forest. The values of this index confirmed the decline of the structural diversity with the increasing altitude up to the altitudinal zone 1,460 m. Above this limit its values are increasing again. The heterogeneous forest structure as one of the highest diversity levels at an altitude below 1,260 m is caused by a high admixture of rowan and gradual exchange of the developmental stages on small areas (200–400 m^2). Such diversity was not confirmed in the spruce virgin forest in Poľana NNR (Holeksa et al. 2006), where the virgin forest has a monotonous structure. The reasons for this status are better ecological conditions, soil conditions and a large-scale character of the developmental stages in this virgin forest.

The regeneration processes of Norway spruce and rowan in this orographic unit confirmed that rowan as an admixture in this forest ecosystem created appropriate ecological conditions for the regeneration of Norway spruce. In all developmental stages of the virgin forest the number of individuals of both tree species decreases with the increasing altitude. Similar results were reported by Holeksa (1998) from the Polish part of the orographic unit Babia hora and from the orographic unit Poľana as well (Holeksa et al. 2006). Concerning the seedbed types the results confirmed that 53% of spruce seedlings emerged on dead wood and 47% on mineral soil, while the proportion of dead wood was only 3.34%. These results correspond almost entirely with the results of Holeksa (1998). At an altitude above 1,460 m the natural regeneration on dead wood represented 86% and on the mineral soil only 14%. This result confirms the data presented in the paper of Mai (1999).

References

AGUIRRE O., KRAMER H., JIMÉNEZ J., 1998. Strukturuntersuchungen in einem Kiefern-Durchforstungsversuch Nordmexikos. Allgemeine Forst- und Jagdzeitung, *169*: 213–219.

CLARK P.J., EVANS F.C., 1954. Distance to nearest neighbour as a measure of spatial relationship in populations. Ecology, *35*: 445–453.

EICHRODT R., 1969. Über die Bedeutung von Moderholz für die natürliche Verjüngung im subalpinen Fichtenwald. Beihefte zur Schweizerischen Zeitschrift Forstwesen, *45*: 122.

FÜLDNER K., 1995. Zur Strukturbeschreibung in Mischbeständen. Forstarchiv, *66*: 235–240.

GADOW K., 1999. Waldstruktur und Diversität. Allgemeine Forst- und Jagdzeitung, *170*: 117–121.

GADOW K., HUI G., 1999. Modelling Forest Development. Amsterodam, Kluwer Academic Publisher: 213.

HOLEKSA J., 1998. Rozpad drzewostanu i odnowienie swierka a struktura i dynamika karpackiego boru gornoreglowego. Monographie botanicae Lodz, *82*: 210.

HOLEKSA J., SANIGA M., SZWAGRZYK J., 2006. Altitudinal variability of stand structure and regeneration processe in a subalpine spruce forest of the Poľana Biosphere reserve, Central Slovakia. European Journal of Forest Research, *125* (in press).

JAEHNE S., DOHRENBUSCH A., 1997. Ein Verfahren zur Beurteilung der Bestandesdiversität. Forstwissenschaftliches Centralblatt, *116*: 333–345.

JALOVIAR P., 2006. Vybrané morfologické parametre koreňov prirodzenej obnovy smreka na moderovom dreve a minerálnej pôde v NPR Babia hora. Beskydy, *19* (in press).

KORPEĽ Š., 1989. Pralesy Slovenska. Bratislava, Veda: 332.

LÄDHE E., LAIHO O., NOROKORPI Y., SAKSA T., 1999. Stand structure as the basis of diversity index. Forest Ecology and Management, *115*: 213–220.

LÜBBERS P., 1999. Diversitätsindizes und Stichprobenverfahren. Universität Freiburg: 101.

MAI W., 1999. Über Ammenstämme im Gebirgswald. LWF aktuell 18. Freising.

PRETZSCH H., 1996. Strukturvielfalt als Ergebnis Waldbaulichen Handels. Allgemeine Forst- und Jagdzeitung, *167*: 213–221.

PRETZSCH H., 1998. Structural diversity as a result of silvicultural operations. Lesnictví-Forestry, *44*: 429–439.
REIF A., PRZYBILLA M., 1998. Regeneration der Fichte in den Hochlagen des NP Bayerischen Wald. Allgemeine Forstzeitschrift/Der Wald, *8*: 400–403.
TOMPPO E., 1986. Models and methods for analysing spatial patterns of trees. Communicationes Instituti Forestalis Fenniae, *138*: 65.
VORČÁK J., 2005. Štrukturálna diverzita vybraných horských lesov Oravských Beskýd a Západných Tatier vo väzbe na ich ekologickú stabilitu. [Dizertačná práca.] Zvolen, TF: 135.
ZENNER E., 1999. Eine neue Methode zur Untersuchung der Dreidimesionalität in Waldbeständen. Universität Freiburg: 11.
ZIERL H., 1972. Der Hochwald. [Dissertation.] Hamburg und Berlin, Verlag Paul Parey: 80.

Received for publication March 10, 2006
Accepted after corrections May 10, 2006

Zmena štrukturálnej diverzity a regeneračné procesy smrekového prírodného lesa v NPR Babia hora v závislosti od nadmorskej výšky

J. Vorčák[1], J. Merganič[2], M. Saniga[3]

[1]*Stredné odborné učilište lesnícke, Tvrdošín, Slovenská republika*
[2]*FORIM Sobrance, Slovenská republika*
[3]*Lesnícka fakulta, Technická univerzita vo Zvolene, Zvolen, Slovenská republika*

ABSTRAKT: Výskum bol zameraný na zistenie dynamiky a formy regeneračných procesov a štrukturálnej diverzity smrekového pralesa v NPR Babia hora v závislosti od nadmorskej výšky. V jednotlivých vývojových štádiách bolo založených zhodne 19 pokusných plôch. Pri posudzovaní štrukturálnej diverzity boli použité rôzne indexy (Clark, Evans 1954; Füldner 1995; Jaehne, Dohrenbusch 1997). Pokiaľ sa týka rozmiestnenia stromov v pralese, nepotvrdil sa vplyv nadmorskej výšky na zhlukovatenie stromov až vo výškovom rozpätí nad 1 461 m, kde sa jedná o skupinové zoskupenie rodinných smrekov. Hrúbková diferenciácia bola štatisticky významne väčšia v štádiu dorastania. Pri hodnotení tohto znaku z hľadiska vplyvu nadmorskej výšky sa významná diferenciácia potvrdila v nadmorskej výške pralesa do 1 260 m v štádiu dorastania. Celkovo na základe Füldnerovho indexu možno konštatovať, že prales má stredne diferencovanú hrúbkovú štruktúru. Na základe komplexného indexu (Jaehne, Dohrenbusch 1997) možno súdiť, že rozrôznenosť pralesa klesá so stúpajúcou nadmorskou výškou do výšky 1 460 m, kde končí kompaktný les. Vyhodnotením klíčneho lôžka bolo zistené, že 46,2 % jedincov obnovy sa nachádzalo na pôde, 52,4 % na moderovom dreve a 1,4 % sa vyskytovalo na kopčekoch po vývratoch.

Kľúčové slová: smrek; prales; štrukturálna diverzita; prirodzená obnova

Výskum bol zameraný na zistenie dynamiky a formy regeneračných procesov a štukturálnej diverzity smrekového pralesa v NPR Babia hora, nachádzajúceho sa v nadmorskej výške od 1 190 m do 1 482 m. Analýza sa vykonala v 4 výškových rozpätiach do 1 260 m, 1 261–1 360 m, 1 361–1 460 m a nad 1 460 m n. m. diferencovane podľa vývojového štádia pralesa (Korpeľ 1989) na 57 kruhových skusných plochách s výmerou 500 m². Kritériom pre rozdelenie na výškové zóny po 100 m bolo výškové rozvrstvenie pralesa. V jednotlivých štádiách (štádium dorastania, štádium optima a štádium rozpadu) bolo založených zhodne 19 pokusných plôch. Plochy boli stabilizované systémom GPS.

Pre posudzovanie a vyhodnotenie štrukturálnej diverzity boli použité rôzne indexy (Clark, Evans 1954; Füldner 1995; Jaehne, Dohrenbusch 1997).

Pokiaľ sa vykonala analýza rozmiestnenia stromov, potvrdil sa vplyv nadmorskej výšky až vo výškovom rozpätí nad 1 460 m, kde vegetatívna obnova má vplyv na skupinové (zhlukové) rozmiestnenie stromov cez proces rodinných smrekov. Smrekový prales v ostatných výškových zónach má náhodné rozmiestnenie stromov (obr. 1).

Pri posúdení hrúbkovej diferenciácie stromov na výskumných plochách hodnotenej Füldnerovým indexom sa potvrdil štatisticky významný rozdiel pralesa v štádiu dorastania (obr. 2). Faktor nadmorskej výšky a jeho vplyv na tento znak štruktúry pralesa bol štatisticky významne potvrdený v nadmorskej výške do 1 260 m v štádiu dorastania (obr. 3). Komplexnou analýzou pomocou tohto indexu bolo potvrdené, že prales v celom výškovom rozpätí má stredne diferencovanú hrúbkovú štruktúru.

Komplexná štrukturálna diverzita hodnotená indexom autorov Jaehne a Dohrenbusch (1997) hovorí o tom, že rozrôznenosť pralesa klesá so stúpajúcou nadmorskou výškou do výšky 1 460 m, kde končí kompaktný les (obr. 5). Priemerná hodnota zistená pre celú rezerváciu (B = 7,5) zaraďuje smrekový prales medzi porasty s nerovnomernou výstavbou, výškovo diferencované. Najvyššia hodnota bola zistená v štádiu rozpadu 11,8 a v štádiu dorastania 11,5 v nadmorskej výške do 1 260 m (obr. 5). V tejto výškovej zóne ide o štruktúru pralesa s veľmi rôznorodou výstavbou.

V otázke prirodzenej obnovy (jedince do výšky 1,30 m) bol zistený poznatok, že vo všetkých štádiách vývojového cyklu smrekového pralesa ich počet klesá so stúpajúcou nadmorskou výškou (tab. 1).

Vyhodnotením vplyvu klíčneho lôžka na početnosť prirodzenej obnovy bolo zistené, že 46,2 % jedincov sa nachádzalo na minerálnej pôde, 52,4 % na moderovom dreve a 1,4 % sa nachádzalo na kopčekoch po vývratoch (tab. 2). Na druhej strane plošný podiel pôdy reprezentoval 96,66 % a moderové drevo len 3,11 % (tab. 3). Možno konštatovať, že moderové drevo je zásadný komponent z pohľadu typu klíčneho lôžka pri regeneračných procesoch tohto smrekového pralesa.

Corresponding author:

Prof. Ing. Milan Saniga, DrSc., Technická univerzita vo Zvolene, Lesnícka fakulta, T. G. Masaryka 24, 960 53 Zvolen, Slovenská republika
tel.: + 421 455 206 234, fax: + 421 455 332 654, e-mail: saniga@vsld.tuzvo.sk