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# Structural diversity and regeneration patterns of the Norway spruce (*Picea abies* (L.) Karst) dominated virgin forest in NNR Zadná Poľana

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**Abstract:** Saniga M., Balanda M., Pittner J., Kucbel S., Jaloviar P. 2013: Structural diversity and regeneration patterns of the Norway spruce (*Picea abies* (L.) Karst) dominated virgin forest in NNR Zadná Poľana. – *Beskydy*, 6 (2): 127–134

The paper analyzes the structural diversity of the spruce dominated old-growth forest in National Nature Reserve (NNR) Zadná Poľana on the series of three permanent research plots (PRP) with the area of 0.5 ha each. The height and diameter diversity as well as the spatial distribution were expressed using standard structural indices (Füldner's TH and TD index, Gini index, Clark-Evans index). Obtained results confirmed the low structural diversity regardless of the developmental stage of investigated forest. The extensive ungulate browsing retards the height growth of the subsequent tree generation and leads toward to the structural homogenization of the future forest stand.

**Keywords:** Norway spruce, diversity, developmental stage, natural forest

## Introduction

Natural nature reserve (NNR) Zadná Poľana with the area of 685.8 ha represents the most southern autochthonous Norway spruce ecosystems growing on the volcanic bedrock within the frame of western Carpathians.

Regarding the recent climate change, the poor tree species diversity seems to be one of crucial ecological weaknesses of mountain spruce forests (Holeksa 1982, Schmidt-Vogt 1991, Saniga 2005). Study of forests growing under mentioned climate conditions is of the great importance to sustainable management of mountain forests (Trepp 1981, Schütz 1989, Mayer, Ott 1991).

Basic knowledge dealing with the NNR Poľana was published in the work of Korpeľ (1989, 1995, 1996). Author described the lowest variability of the number of stems with dbh above 2 cm from among all investigated spruce natural forests in Slovakia. The variability of growing stock within the whole developmental cycle shows the same patterns as other natural spruce forests.

The evaluation of structural diversity of the spruce mountain forests is important, inter alia, from the point of view of disturbance processes.

First attempts for analysis of structural diversity were oriented on study of altitudinal on the structural pattern of spruce forests in NNR Babia hora (Vorčák 2004, Vorčák et al. 2006) and in NNR Nefcerka (Pittner, Saniga 2008).

The analysis of stem spatial distribution in NNR Babia hora using the index of Clark, Evans (1954) confirmed the similar results as obtained from the spruce forest in NNR Poľana (Holeksa et al. 2007). The course of index value change in relation to the altitudinal gradient was almost similar. The random stem distribution to nearly uniform distribution was confirmed for both investigated forests. However, the index value does not report any information about the tree height and diameter variation.

The complex index of Jähne, Dohrenbusch (1997) offered the additive knowledge about the structural diversity of spruce forest in NNR Babia Hora. Thought the usage of this index,

the authors Vorčák et al. (2006) found out that the structural diversity of forest in NNR Babia hora is continuously decreasing in relation to increase of altitude up to the altitude zone 1460 m. Here, the trend maintains the different course and the stand diversity is increasing. The spatial diversity in the altitude 1260 m is affected by the substantial admixture of rowan and significantly small-scale texture (0.0001–0.0002 ha) of developmental stages. In spite of this, Holeksa et al. (2007) did not state the same structural patterns in NNR Poľana. The author's results confirmed the homogenous spatial structure of investigated natural forest. Better ecological conditions, soil composition as well as the large-scale structure of developmental stages are the most likely the main causes of the recent state (Korpeľ 1995).

Diversity of the spruce protection forests expressed by structural indexes (Reineke index, Gini index, Shannon index, Clark-Evans index, Fuldner and Zenner index) was analyzed by Kucbel (2011). Author confirmed the suitability of listed indexes for the effective description of forest structure in spite of the high elaborateness of the data acquisition.

According to maintained results of presented scientific works we can state that the analysis of spatial distribution and diversity of spruce forests are very important for the better understanding of disturbance processes, however it should be performed on the plots with the area at least 0.1 ha.

The main aim of this paper is the analysis of the structural diversity and the identification of possible causes according to developmental stages on the plots with the area of 0.5 ha in the natural spruce forest in NNR Poľana.

## Methods

The well preserved Norway spruce natural forest in NNR Zadná Poľana represents the most valuable part of the biosphere reservation Poľana. The spruce ecosystems have maintained the character of natural forests due to their inaccessibility and later, since 1962, thanks to the strict preservation by law. The natural reservation is spread on the area of 685.84 ha with the buffer zone (82.1 ha). The natural nature reserve with strict fifth degree of nature protection belongs to CHKO Poľana and it is a part of the Poľana Biosphere Reserve since 1990. Due to the fact that the national nature reserve represents the most southern natural Norway spruce mountain forest located in the Carpathians and the only natural spruce forest growing on the vulcanite bedrock (pyroxenic andesites and tuffs), it is of high importance within the Slovak and European countries. In term of the phytogeography, the ecosystems in Poľana Mts. are under the impression of the pannonian climate. Mentioned fact has modified the many important growth processes of this spruce ecosystem what consequently resulted in some singularities when compared to other Slovak spruce mountain forests (ecological features of local ecotype of N. spruce and specific developmental cycle of natural forest).

Three permanent research plots (PRP) with the area of 0.5 ha each were established in the NNR, within the same altitudinal zone (1300–1350 m), in 1974. Each of these represents the different developmental stage. According to Korpeľ (1995) the PRP1 represented the advanced breakdown stage in time of its establishment, PRP2 the advanced optimum stage and the PRP3 advanced phase of the growth stage. All three research plots were set in the group of forest types *Acereto-Piceetum,* the most common forest type in the autochthonous spruce forests in orographic unit Zadná Poľana.

Data collection was performed in 2013. The historical data from forest inventory of research plots in 1974 were used for the purposes of comparative analysis of forest development in the time span of 40 years. After the renewal of PRP borders, the x, y positions of all tree individuals with diameter $d_{1.3} > 8$ cm were measured. Following biometric parameters were measured on the area of PRP (0.5 ha):

- Tree height (with accuracy to 0.5 m)
- Crown base height (with accuracy to 0.5m)
- Position and the volume of deadwood (according to Huber's formula)
- Crown projection(with accuracy to 0.1m)
- Trunk diameter $d_{1.3}$ (with accuracy to 0.001 m)

The vertical profile of investigated forest was divided into three vertical zones by dividing of upper tree height into three equal parts. Evidence of natural regeneration was performed on transects (700m$^2$) according to tree species and height category as follows:

- Seedlings up to 20 cm height
- Saplings 21–50 cm height
- Saplings 51–80 cm height,
- Young trees 81–130 cm height,
- Trees higher then 130 cm up to $d_{1.3} \leq 8$ cm

The relation between the tree diameter $d_{1.3}$ and tree height was approximated using the Korf's growth formula. Obtained dataset was processed and analyzed by Statistica 10.0 software. The statistical significance of structural shifts was tested by non-parametrical Komogorov-Smirnov (KS) test.

## Results

### Diameter and height structure

The information dealing with analyzed dendrometric parameters is displayed in Tab. 1 and in Fig. 1–3. The obtained production data correspond with the respectful developmental stage of the plot. The natural forest in advanced breakdown stage (PRP1) is typical by the lowest recorded average diameters, tree volume and basal area. The highest values of mentioned parameters were recorded in the optimum stage of spruce natural forest (PRP2).

Analysis of the diameter structure according to developmental stages confirmed the typical patterns of diameter distribution. There were no significant changes of diameter distribution recorded on any research plot during the 40 years of observation. The only significant decrease of tree abundance was observed in diameter category "up to 10 cm" in the growth stage and breakdown stage. This fact suggests to the discontinuity of regeneration processes during the investigated period.

The diameter and height structure expressed by median values according to height levels is displayed on the Fig. 4. The highest variation showed the lower layer of the spruce forest in the advanced growth stage. The value of diameter variability was significantly lower in the growth stage. Considering the diameter structure of middle layer, the highest median

*Tab. 1: The basic stand parameters according to PRP and dbh class (PRP–permanent research plots, N–number, G–bazal area, V–volume, $m^3 \cdot ha^{-1}$)*

| Dbh class | PRP 1 | | | PRP 2 | | | PRP 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | G | V | N | G | V | N | G | V |
| 10 | 14 | 0.1 | 0.2 | 2 | 0.0 | 0.0 | 2 | 0.0 | 0.0 |
| 14 | 32 | 0.5 | 2.0 | | | | 6 | 0.1 | 0.3 |
| 18 | 32 | 0.8 | 3.9 | 6 | 0.2 | 0.7 | 18 | 0.5 | 2.6 |
| 22 | 24 | 0.9 | 5.6 | 2 | 0.1 | 0.4 | 8 | 0.3 | 2.3 |
| 26 | 14 | 0.7 | 5.1 | 2 | 0.1 | 0.7 | 6 | 0.3 | 2.9 |
| 30 | 16 | 1.1 | 7.7 | 4 | 0.3 | 3.4 | 18 | 1.3 | 12.0 |
| 34 | 22 | 2.0 | 16.1 | 10 | 0.9 | 7.8 | 12 | 1.1 | 10.2 |
| 38 | 20 | 2.3 | 21.0 | 12 | 1.3 | 14.2 | 8 | 0.9 | 10.5 |
| 42 | 14 | 1.9 | 17.7 | 8 | 1.1 | 14.3 | 24 | 3.5 | 42.2 |
| 46 | 18 | 3.0 | 30.7 | 10 | 1.7 | 24.6 | 20 | 3.3 | 40.5 |
| 50 | 8 | 1.6 | 14.4 | 22 | 4.4 | 58.7 | 12 | 2.4 | 29.4 |
| 54 | 14 | 3.2 | 35.0 | 18 | 4.1 | 51.6 | 30 | 7.0 | 88.8 |
| 58 | 10 | 2.6 | 30.1 | 20 | 5.3 | 73.0 | 22 | 5.7 | 66.2 |
| 62 | 8 | 2.4 | 23.6 | 18 | 5.5 | 74.7 | 20 | 6.0 | 82.1 |
| 66 | 14 | 4.8 | 52.4 | 26 | 8.9 | 124.1 | 16 | 5.5 | 67.5 |
| 70 | 4 | 1.6 | 19.3 | 20 | 7.7 | 112.6 | 14 | 5.3 | 71.7 |
| 74 | 10 | 4.3 | 44.8 | 12 | 5.2 | 71.8 | 2 | 0.8 | 10.1 |
| 78 | 12 | 5.8 | 63.3 | 8 | 3.8 | 54.2 | 6 | 2.8 | 37.5 |
| 82 | 2 | 1.0 | 8.0 | 6 | 3.1 | 46.6 | 6 | 3.2 | 39.3 |
| 86 | | | | | | | | | |
| 90 | | | | 2 | 1.3 | 18.9 | 2 | 1.3 | 16.9 |
| 94 | | | | 2 | 1.4 | 14.6 | 2 | 1.3 | 19.9 |
| Total | 288 | 40.7 | 400.9 | 210 | 56.3 | 767.0 | 254 | 52.8 | 653.3 |

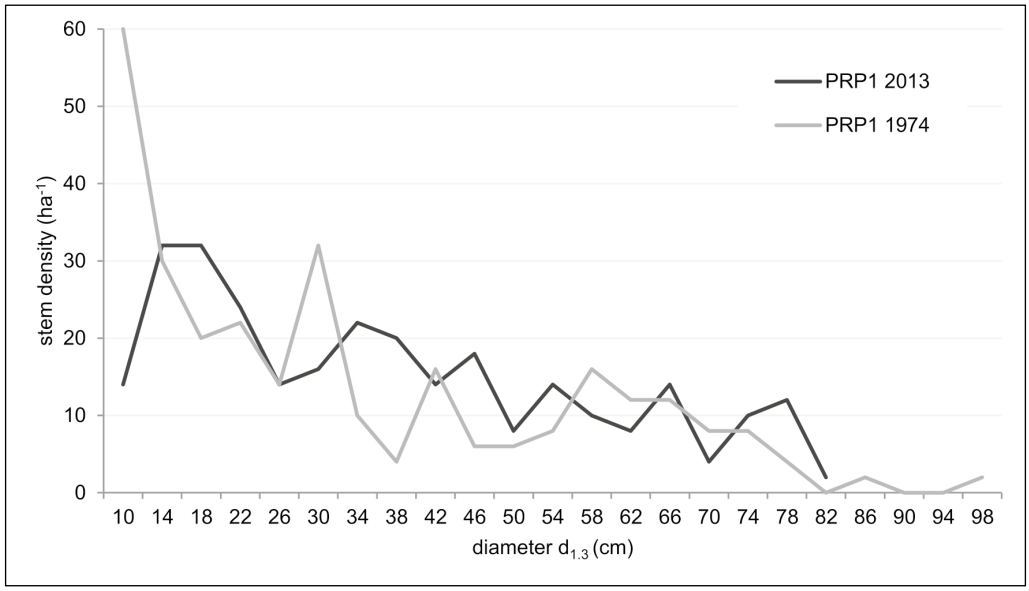


*Fig. 1: The diameter distribution of the recorded tree individuals on the PRP1 (advanced breakdown stage) during the period of 40 yr in NNR Poľana.*

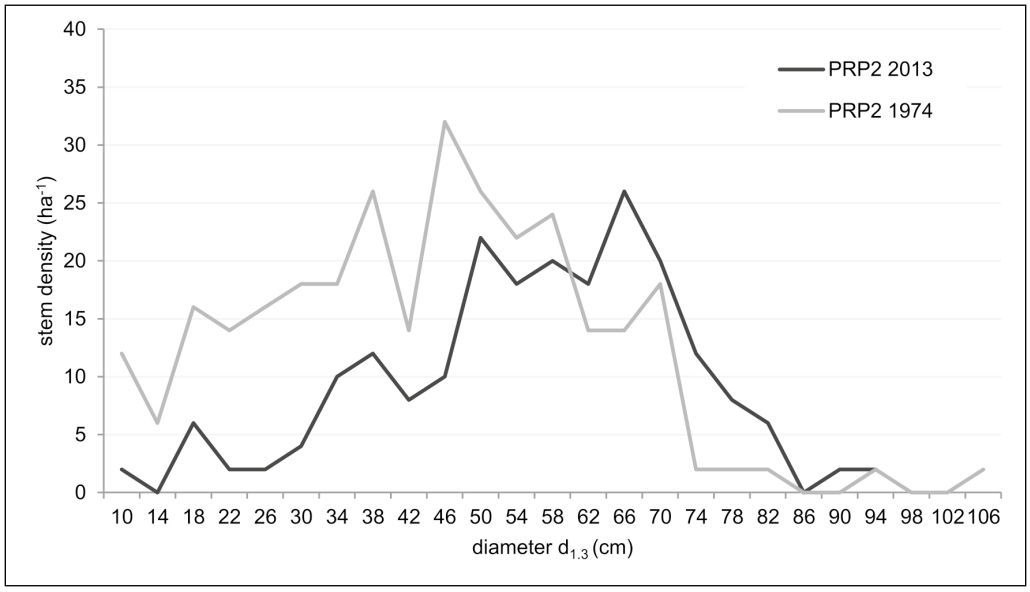


*Fig. 2: The diameter distribution of the recorded tree individuals on the PRP2 (advanced optimum stage) during the period of 40 yr in NNR Poľana.*

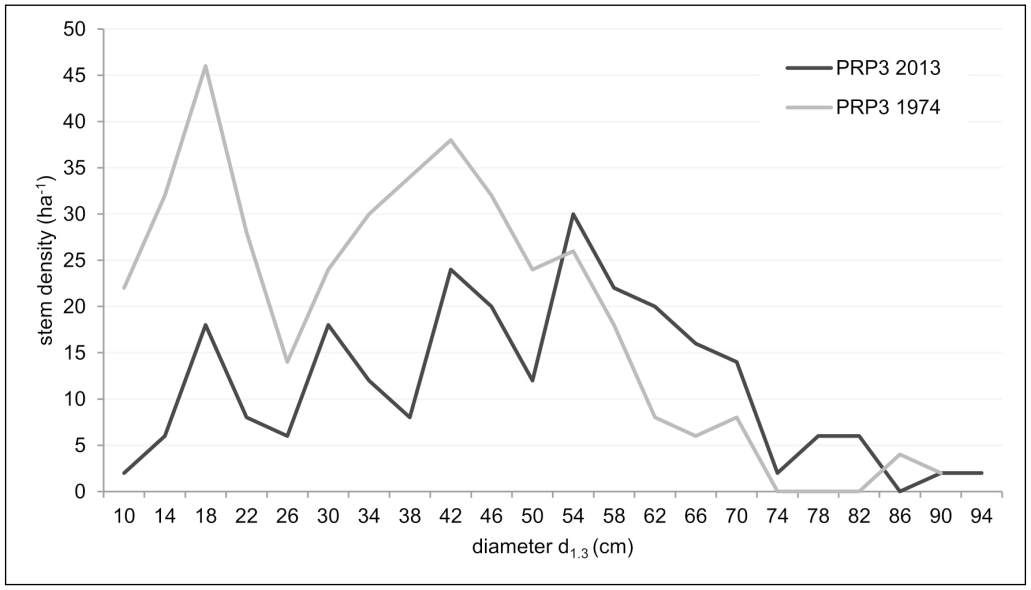


*Fig. 3: The diameter distribution of the recorded tree individuals on the PRP3 (advanced growth stage) during the period of 40 yr in NNR Poľana.*

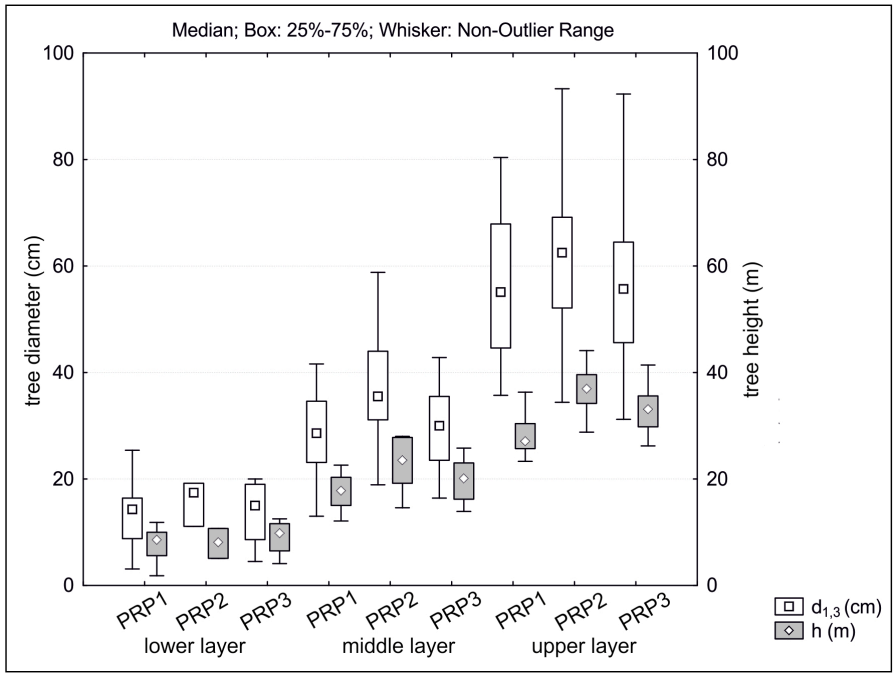


*Fig. 4: Diameter and height structure of the Norway spruce natural forest in respective developmental stages in NNR Poľana.*

*Tab. 2: Diameter structure of investigated Norway spruce natural forest according to tree layers and PRP in NNR Polana (calculated per 1 ha).*

| Plot | Layer | Stem number | % | $d_{1.3} \pm sd$ | Variation koef. |
|---|---|---|---|---|---|
| PRP1 | lower | 72 | 25.0 | 13.3 ±6.0 | 45.1 |
| | middle | 98 | 34.0 | 29.7 ±9.8 | 33.0 |
| | upper | 118 | 41.0 | 56.9 ±13.6 | 23.9 |
| | total | 288 | 100.0 | 35.2 ±21.2 | 60.1 |
| PRP2 | lower | 6 | 2.9 | 15.9 ±4.3 | 26.7 |
| | middle | 36 | 17.1 | 38.2 ±13.8 | 36.1 |
| | upper | 168 | 80.0 | 61.3 ±11.9 | 19.4 |
| | total | 210 | 100.0 | 56.1 ±16.4 | 29.3 |
| PRP3 | lower | 20 | 7.9 | 13.7 ±6.0 | 43.7 |
| | middle | 54 | 21.3 | 31.9 ±12.1 | 38.0 |
| | upper | 180 | 70.9 | 56.5 ±12.6 | 22.4 |
| | total | 254 | 100.0 | 47.1 ±19.1 | 40.6 |

*Tab. 3: The values of selected structural diversity according to developmental stage of natural forest.*

| | Structural indices | | | |
|---|---|---|---|---|
| | Fuldner TD | Fuldner TH | Gini index | Clark-Evans |
| PRP1 | 0.436 | 0.396 | 0.250 | 0.998 |
| PRP2 | 0.332 | 0.286 | 0.121 | 0.998 |
| PRP3 | 0.389 | 0.332 | 0.176 | 1.025 |

deviation was observed in the optimum stage, while the variation of tree diameters in growth stage and breakdown stage was almost the same. Within the upper layer, the highest variability of spruce diameters was recorded in optimum stage. The lowest median value with tight variation span was observed in advanced breakdown stage. The height structure of the analyzed spruce forest showed significantly lower level of variability.

The structure of stems diameter according to tree layers expressed by arithmetic mean and variation coefficient confirmed the abovementioned statements.

The lowest variability of such parameter was traced to upper layer in all developmental stages, while the differences among the respective developmental stages weren't significant.

Structural diversity of analyzed natural forest was described by usage of selected structural indexes. Fuldner's index that characterizes diameter (TD) and height (TH) structure showed the low level of structural diversity, regardless of the developmental stage (Tab. 3). The similar knowledge was confirmed by the values of Gini's coefficients. The values of Clark Evans index (CE) point on the random distribution of stems on the researched plots. Obtained values of structural indexes confirmed the significant homogeneity of spatial structure of analyzed Norway spruce natural forest.

## Regeneration processes

The dynamics of natural regeneration of the Norway spruce that creates the skeleton species of analyzed ecosystem is presented in Tab. 4.

Regarding the data listed in Tab. 4, we can observe the continuous shift of spruce cohorts towards the category "up to 80 cm". The other developmental stages showed the low outgrowing of spruce individuals to higher categories. Moreover, the total abundance of spruce samplings is very low. We can observe the obstruction in the developmental shift of spruce individuals to the higher height categories. The main reason of actual case could be the most probably the intensive grazing by wild ungulates what was first time stated back to the 1974. Mentioned fact creates serious obstruction in the successful

*Tab. 4: Natural regeneration according to tree species and developmental stages in NNR Poľana in 2013 (calculation per hectare).*

| Species | up to 20 | 21–50 | 51–80 | 81–130 | 131–$d_{1.3} \leq 2.0$ | 2.1–4.0 | 4.1–8.0 | Total | % |
|---|---|---|---|---|---|---|---|---|---|
| | **PRP1 (cm)** | | | | | | | | |
| *P. abies* | 1136 | 500 | 227 | | | 6 | 12 | 1881 | 27.3 |
| *S. aucuparia* | 2682 | 2136 | 136 | | | | | 4954 | 72.0 |
| *A. pseudoplatanus* | 45 | | | | | | | 45 | 0.7 |
| *F. sylvatica* | | | | | | | 2 | 2 | 0.0 |
| Total | 3863 | 2636 | 363 | | | 6 | 14 | 6882 | 100.0 |
| % | 56.1 | 38.3 | 5.3 | | | 0.1 | 0.2 | 100.0 | |
| | **PRP 2** | | | | | | | | |
| *P. abies* | 536 | 357 | 36 | | | | | 929 | 32.5 |
| *S. aucuparia* | 607 | 821 | 357 | | | | | 1785 | 62.5 |
| *A. pseudoplatanus* | | 71 | 71 | | | | | 142 | 5.0 |
| Total | 1143 | 1249 | 464 | | | | | 2856 | 100.0 |
| % | 40.0 | 43.7 | 16.2 | | | | | 100.0 | |
| | **PRP3** | | | | | | | | |
| *P. abies* | 179 | 71 | | 36 | | | 2 | 288 | 8.6 |
| *S. aucuparia* | 1678 | 964 | 286 | | | | | 2928 | 87.1 |
| *A. pseudoplatanus* | 36 | 71 | 36 | | | | | 143 | 4.2 |
| *F. sylvatica* | | | | | | | 4 | 4 | 0.1 |
| Total | 1893 | 1107 | 321 | 36 | | | 6 | 3363 | 100.0 |
| % | 56.3 | 32.9 | 9.6 | 1.1 | | | 0.2 | 100.0 | |

continual change of developmental stages what was previously confirmed by the diameter distributions in the breakdown stage and growth stage.

## Discussion

The structural diversity of spruce natural forest in NNR Poľana is significantly lower when compared to NNR Nefcerka and Kotlov Žľab (Korpeľ 1993, Vorčák et al. 2006, Pittner, Saniga 2008). The research in NNR Nefcerka revealed that the spruce natural forest in the growth stage creates the selection structure. This structure is used for the development of model of the selection forest growing in the high-mountain vegetation belt. The high structural diversity reflects the small-scale texture of developmental stages. The continual and dynamic natural regeneration is necessary for the maintaining of such level of diversity (Vorčák 2004).

The structural diversity of investigated natural forest in NNR Poľana is very low in all developmental stages. Obtained results confirmed the findings of previous studies (Korpeľ 1995, Saniga 2005, Saniga et al. 2007). The long lasting (at least 40 years) perturbation of natural regeneration lead to the height and diameter homogenization of this spruce forest. The high density of red deer browsing the most part of spruce saplings is considered to be the crucial factor causing the disturbance in natural regeneration and prevents the successful outgrowing of spruce individuals to the height categories above 80 cm. Such process doesn't allow the continuous developmental shift of young spruces to the lower layer. Under recent conditions, we expect the extensive breakdown of this ecosystem with consequent development through the processes of secondary succession in the so-called large developmental cycle (Schmidt-Vogt 1991, Korpeľ, Saniga 1995).

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## References


Clark, Ph. J., Evans, F. C. 1954: Distance to nearest neighbour as a measure of spatial relationships in populations. *Ecology*, 35(4): 445–453.

Holeksa, J. 1982: *Rozpad drzewostanu i obnovienie svierka a struktura i dynamika karpackiego boru gornoreglowego* [Breakdown of forest ecosystems and natural regeneration of spruce, structure and dynamics of pine forest ecosystem]. Monographie botanicae 82, Lodz, 212 pp.

Holeksa, J., Saniga, M., Szwagrzyk, J., Dziedzic T., Ferenc S., Wodka M. 2007: Altitudinal variability of stand structure and regeneration in the subalpine spruce forests of the Poľana biosphere reserve, Central Slovakia. *European Journal of Forest Research* 126: 303–313.

Jahne, S., Dohrenbusch, A. 1997: Ein Verfahren zur Beurteilung der Bestandesdiversität. *Forstw. Centralblatt*, 116: 333–345.

Korpeľ, Š. 1989: *Pralesy Slovenska* [Virgin forests in Slovakia]. VEDA, Bratislava, 332 pp.

Korpeľ, Š. 1993: Dynamika smrekového lesa v Západných Tatrách na príklade ŠPR Kotlov žľab [Dynamics of the spruce natural forest in Western Tatras on the example of NNR Kotlov Žľab]. *Zborník prác o Tatranskom Národnom Parku, 33*: 193–226.

Korpeľ, Š. 1995: *Die Urwälder der Westkarpaten*. G. Fischer Stuttgart, Jena-New York, 310 pp.

Korpeľ, Š. 1996: *Zákonitosti formovania štruktúry, vývoj a produkčné schopnosti a autoregeneračné procesy v prírodných lesoch smrekového vegetačného stupňa* [The patterns of the structure creation, development and production patterns and regeneration processes in the natural spruce forests]. ZS LF TU Zvolen, 76 pp.

Korpeľ, Š., Saniga, M. 1995: *Prírode blízke pestovanie lesa* [Close-to-nature Silviculture]. UVPLH, Zvolen, 158 pp.

Kucbel, S. 2011: *Štruktúra porastov a regeneračné procesy vo vysokohorských ochranných lesoch Nízkých Tatier* [Stand structure and regeneration processes in high-mountain protection forests in Low Tatras]. TU, Zvolen, 120 pp.

Mayer, H., Ott, E. 1991: *Gebirgswaldbau-Schützwaldpflege*. Fischer-Verlag, Stuttgart-New York, 587 pp.

Pittner, J., Saniga, M. 2008: A change in structural diversity and regeneration processes of the spruce virgin forest in Nefcerka NNR (TANAP). *Journal of Forest Science*, 54 (12): 545–553.

Saniga, M. 2005: Štruktúra a regeneračné procesy smrekového pralesa NPR Zadná Poľana [Structure and regeneration of the spruce natural forest in NNR Zadná Poľana]. *Acta Facultatis Forestalis*, XLVII: 175–186.

Saniga, M., Holeksa, J., Szwargrzyk, J. 2007: Štrukturálna diverzita smrekového prírodného lesa v národnej prírodnej rezervácii Zadná Poľana [Structure diversity of the spruce natural forest in national nature reserve Zadná Poľana]. *Biosferická rezervácia Poľana po pätnástich rokoch*: 115–119.

Schmidt-Vogt, H. 1991: Naturnahe Waldwirtschaft. In: Wilhem-Wilhem-Munker-Stiftung (ed.) *Beitrage zur Lebensqalitat, Walderhaltung und Umweltschutz, Gesundheit, Wandern und Heimatpflege*, Heft 31, 56 pp.

Schütz, J. Ph. 1989: *Der Plenterbetrieb*. ETH, Zürich, 54 pp.

Trepp, W. 1981: Das Besondere des Plenterns im Gebirgswald. *Schweiz. Zeit für Forstwessen* 132: 87–95.

Vorčák, J. 2004: Význam moderového dreva pre regeneračné procesy smrekového prírodného lesa v supramontánnom stupni NPR Babia hora [Importance of coarse woody debris for regeneration of the spruce natural forest in the high-mountain level of NNR Babia hora]. *Beskydy*, 17: 143–148.

Vorčák, J., Merganič, J., Saniga, M. 2006: The structural diversity change and regeneration processes of the Norway spruce natural forest in NNR Babia hora in relation to altitude. *Journal of Forest Science*, 52: 399–409.