

Development of the natural regeneration on sites with different level of the natural and antropogenous disturbance

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Abstract

Nowadays, between four and five thousand ha of declined forest in the Šumava National Park are as a direct consequence of bark beetle gradation, both on the German and Czech side of the border. The presented study was performed on 14 permanent regional research plots characterized by severe Norway spruce decline, which were used for a comparison of declined and vital forest. Observed spruce regeneration was currently sufficient (average number over 11000 saplings.ha⁻¹ in the vital stand and almost half of this number in the declined stand). A large number of seedlings in most of the vital stands (1.280–31.000 individuals.ha⁻¹), react actively under modified light and temperature conditions. Faster growth was reported on the declined plots, which led to the larger number of natural regeneration in the higher height classes. On the other hand, the age structure is influenced negatively in declined stands, because of the missing part of the youngest age class. These results indicate that present stands will likely to develop into more or less even-aged forest again, with the possibility of the similar situation happening in the future.

Introduction

The Šumava is an area of Central European Hercynian massive stretched on the border of Austria, Germany and the Czech Republic. The National Park (NP) Šumava (Bohemian Forest) Mts. was officially opened in 1990, covering the upland and forest area of 69.030 ha. Together with the

Bavarian National Park on the border with Germany and with buffering zone declared Protected landscape area (90.000 ha), it represents the largest protected area in Europe, with forest coverage of 66 %. This area contains mainly mountainous forests. Šumava ridges often reach altitude 1000-1100 m a.s.l.. The highest points are Javor (1457 m) and Roklan (1454 m) in Bavaria and Plechý (1378 m) on the Czech side (CHÁBERA, 1987). Called the “Green roof of Europe”, Šumava NP contributes greatly to the wild life conservation practices in Europe. It also contains rich water resources, glacial lakes, and high mountains covered by natural forests requiring strict protection. Its main mission is to protect and preserve unique natural areas, more or less undisturbed by man. It is also to preserve biodiversity and conservation areas for research and evolutionary processes. Šumava NP is also used for physical and spiritual recreation of human mankind. Until 1945, this region was relatively densely populated. After World War II, it became part of a military zone. Forests were just partly commercially exploited. The low population, lack of labor and forestry trends in the former Czechoslovakia resulted in the forested region of high natural value, but with extensive management. Extensive forestry practices and large bark-beetle calamities in 1860's-70's (JELÍNEK 1988) resulted in large clear-cuts, Norway spruce monocultures, introduced allochthonous ecotypes and even-aged stands. At present the majority of stands are over 120 years old (ZATLOUKAL 1998). Acid rain with high immission loads in the 80's, affected the soil properties of the mountain ecosystems. The forest stability was lowered as a result of nutrient losses (PASUTHOVÁ, LOMSKÝ 1998). Under these conditions, catastrophic wind storms hit the national park in 1980's, followed by slow removal of damaged wood. The neighboring Bavarian National Park in Germany was as a source of not processed wood and thus the cause of enormous gradation of *Ips typographus* L. and also other bark-beetle species (VÍNS 1999). Finally over four thousand ha of declined spruce forests was a consequence of these events.

The Šumava NP is divided into several zones. The park zoning helps to achieve the aims of the National Park: In zone I, all management is limited to the protection of natural processes. Zone I contains also “quiet areas”, established for the protection of ecologically rare parts of the park, mainly habitats of rare animals, sensitive to the presence of man. Zones II and III are dedicated to environmental management, education and additional non-profit activities. There is also the “buffer zone” for restricted management and the park protection on the border. Natural regeneration is one of the basic factors of management and future development of mountain forests in protected areas (TESAŘ and TESAŘOVÁ, 1996), including those declined during bark beetle calamity in the NP Šumava. The evaluation of natural regeneration potential and its vitality should be the basic for crucial for the differentiated management of the forest ecosystems in the NP zo-

nes II (55.890 ha). Zones I (8.800 ha,) are prevailingly left for natural succession, without any active human impact. Natural regeneration in the mountain zones have some specific problems, which are higher influence of climatic and microclimatic factors and which results in a longer periods between seed years (usually 8-14 years), a short vegetation period and low germinating ability of seeds (ŠERÁ et.al., 2000), slower growth of the seedlings and a higher possibility of their mortality due to e.g. frost, movement of snow cover during the spring, or game damages, or ground vegetation competition (VACEK, PODRÁZSKÝ 2003). Also the amount of coarse wood debris on the stand could be important; special ectomycorrhizal types are connected with this type of growth substrate and can improve seedlings germination and further growth (UHlíAROVÁ et al, 1999). In some cases of plots with low potential of natural regeneration, the management measures should be taken to prevent ecological and environmental damages - e.g. game damages reduction by fencing, replanting pioneer or missing climax species for improving unfavorable microclimatic conditions and measures for accelerating the succession. It helps to save functioning forest ecosystems and prevent some hardly reversible changes of the landscape (PODRÁZSKÝ et al., 1999). The aim of the presented article is to evaluate spontaneous potential of natural regeneration on representative research plots in the most affected area.

Methods

The 14 permanent research plots (PRP) were established in the Forest districts of “the Modrava” and “the Plechý” area, in sampling I. and II. zone of the NP Šumava (PODRÁZSKÝ, 1997). The altitude of the plots varies between 1120-1370 m, precipitation 900–1380 mm per year, the average annual temperature is 3,5 -5 °C, the length of annual vegetation is 98–120 days, the bedrock is biotitic granite partly combined with gneiss, the soil is mainly podzolic soil of a ranker or a humic type. The plot differences occur due to differences in the slope gradients, the exposition and the water regime on the different plots (Table 1).

The plots are distributed basically in 4 localities:

- Plots Mo 1, 4, close to Modrava (49°N, 13°30'E), on the slope under Studená Mt., with vital, partly endangered stands. So far, relatively scarce bark beetle sanitation since 2002–3 has been done on this plot.
- Plots Pl 18-20 on Plechý Mt. (48°05'N, 13°50'E) and plots Tr 1–3 close to this locality, in the saddle between Plechý and Trojmezná Mt. These are vital stands, with scarce bark beetle sanitation since 2004–5.

· Plots Py 1-3 in Pytlácký roh locality in the Modrava area, with declined mature trees since 1996-8. Thick grass cover and abundant log breakage are typical for this plot.

· Plots Lu 1-3 on the slope of Velka Mokrůvka Mt. at the end of Luzen valley, also close to Modrava, with declined stands since 1996. This plot is also affected by abundant log breakage.

Plots Py1-3 and Lu1-3 are in the area of a former large scale bark beetle calamity in 1870's, so this stands are relatively even-aged, possibly with allochthonous ecotypes.

As a "vital stands" (for the Fig 1,2 results) are considered these with undamaged mature trees and canopy corresponding to the site and stand age - Mo 1,4; Pl 18-20; Tr 1-3. As a "declined stands" are considered Lu 1-3; Py 1-3.

Tab. 1: Site characteristics of the particular plots

Plot	Forest type	Altitude m.a.s.l	Exposition	Stand age	Canopy %	Moss cover%	Herbal cover%	Dominant herbs
Mo1	8N3	1140	E slope 60°	143	45	100	60	Vaccinium
Mo4	8R1	1120	flat	130	45	70	95	Vaccinium/Calamagrostis
Pl 18	7N3	1250	SE, slope 25°	200	40	20	85	Dryopteris/Vaccinium
Pl 19	8Y2	1300	SE, slope 40°	160	45	45	95	Vaccinium
Pl 20	8Y2	1370	Flat top	160	45	30	95	Avenella, Dryopteris
Tr 1	8Y2	1300	NW, slope 5%	190	45	75	95	Avenella, Dryopteris
Tr 2	8Y2	1300	NW, slope 5%	190	40	70	95	Luzulla, Dryopteris
Tr 3	8Y2	1300	NW, slope 5%	190	55	75	85	Avenella, Dryopteris
Lu1	8K3	1220	W slope 20°	160	0	30	95	Calamagrostis
Lu2	8Y0	1260	W slope 30°	175	3	70	95	Calamagrostis
Lu3	8Y0	1300	W slope 45°	175	0	70	95	Calamagrostis
Py1	8S1	1230	N slope 25°	160	0	5-10	95	Calamagrostis
Py2	8S1	1260	N slope 30°	160	0	20	95	Calamagrostis
Py3	8 Y0	1220	N slope 25°	160	0	20	95	Calamagrostis

Note: The forest type- 1st number means altitudinal vegetation zone (8- spruce), 2nd letter means soil characteristics: N-exposed acid stony site, Y-extreme skeletal site, S-moist and nutrient site, R-peat stand Canopy-canopy cover of mature trees layer, Plots Mo 1, 4; Pl 18-20; Tr1-3 - vital stands with occasional bark beetle sanitation. Plots Lu 1-3; Py 1-3 - plots with mature tree layer declined since 1996.

The herbal cover on the particular plots depends mainly on the canopy and humidity of the site. The main species are following: *Vaccinium myrtillus*, *Calamagrostis villosa*, *Avenella flexuosa*, *Anthyrium distentifolium*. The species of lower abundance are: *Trientalis europea*, *Homogyne alpine*, *Oxalis acetosella*, *Lycopodium annotinum*, *Maianthemum bifolium*, and on the declined plots *Chamaerion angustifolium*. In the highest elevations, the main species are *Polytrichum formosum*, *Dicranum scoparium*, *Sphagnum* sp. The area of each of the plots is 50 x 50 m and they are used for a complex forest ecosystem study, including the natural regeneration dynamics. Its first evaluation was performed in 1997 (PODRÁZSKÝ 1997). For the natural regeneration assesment, transects of 5 x 50 m were drawn through these plots. The basic characteristics of the regeneration were determined as follows: the space structure, i.e. its location on transects, the height structure - regeneration trees were divided into the height categories sorted by 10 cm (with the accuracy of 0,5 cm), the microsite conditions, the health state and damages.

The spatial structure (horizontal distribution of regenerated trees) was analyzed in relation to the tree species composition and substrate on a soil cover with the use of the Ripley's K - function (original software developed by Zahradník).

$$\text{Ripley's K function: } K(r) = \sum_{0 < |x_i - x_j| \leq r} \frac{1}{\lambda^2 s(|x_i - x_j|)}$$

Where: r is distance, λ stands for the mean number of trees per unit area (stand density),

$$s(r) = \frac{ab - r(2a + 2b - r)}{\pi} \text{ designate the edge correction factor, } a, b \text{ stands for the dimensions of}$$

the rectangle (sample plot) and $|x_i - x_j|$ designate distance between i^{th} and j^{th} tree.

Statistical analyses (the differences in seedlings number among the two types of the plots - the vital forest and the declined forest) were performed by ANOVA (S PLUS version 6 statistical software). Foliar samples were collected to assess nutrient state at the end of October. Needles were collected from adventitious last year shots at the 4th whirl on the sunny side of the crown. The samples were collected from 30 individuals per plot. Chemical analyses by the flame photometry were conducted at the Tomáš laboratory in Opočno.

Results and Discussion

Number of regeneration

The number of regeneration varies strongly between the particular plots, but this difference is dependent on the number of seedlings or the state of the youngest regeneration. The number of regeneration tall up to 30 cm is very high and on some plots (Pl 18, Lu 3) it exceeds 10.000 saplings ha^{-1} . This situation could change rapidly in a few years because the highest mortality is typical for a young trees until the age of 4–5 years in the vital stands (ZATLOUKAL, 2000). It is consistent with the conception of development in the vital natural mountain stands. For such stands is typical extensive source of seeds (in the mature trees), large number of seedlings and a strong influence of selection factors such as light conditions, intraspecific competition and a competition with herbal layer. The lowest number of natural regeneration was observed in the declined stands (Py 1–3) with fertile soil and thus the high competition of grass cover, and in the vital stands (Tr 1–3) probably with the shortage of seeds. The differences between vital and declined plots in number of natural regeneration are significant by Multiple comparison (Scheffe test and 95 % simultaneous confidence interval) just in the height class up to 20 cm.

The number of spruce natural regeneration on the declined, vital and clearcut plots was previously evaluated by ZATLOUKAL (2000). According to this author, there were about 16.700 saplings ha^{-1} (comparable with our results – average 11.795 ha^{-1}). On the plots declined before 1998, there were about 10.700 saplings ha^{-1} (compared to 5.693 ha^{-1} in our case) and on the clearcut plots the number was 1.900 ha^{-1} .

The degree of natural regeneration in the mountain spruce forests was also evaluated by other researchers (SANIGA, SZANYI, 1996; JONÁŠOVÁ, PRACH, 2004). According to JONÁŠOVÁ (2001), the number of regeneration older than 10 years has been only 10–15% of the total regeneration on the declined Šumava plots. The main part have been seedlings originally from the seed years in the 90's. According to ZATLOUKAL (2000), the proportion of spruce seedlings originating from natural regeneration in the height class to 5 cm varies between 42.4% and 76.3 %. In our case, saplings up to 30 cm took up to 17.000 ha^{-1} . According to KORPEL (1993), there should be 270–750 adult trees ha^{-1} and 320–3100 trees ha^{-1} taller than 1.3 m in the declination stage of close to nature mountain spruce forest (close to nature forests in this case means forests which are not significantly affected by people in the spatial, height and species structure). On average 530 ha^{-1} of spruce seedlings were observed on our plots (seedlings taller than 1 m, 415 ha^{-1} on the vital plots and 684 ha^{-1} on the declined plots).

Tab. 2: Spruce natural regeneration height distribution

Norway Spruce		Mo 1	Mo 4	Pl 18	Pl 19	Pl 20	Tr 1	Tr 2	Tr 3	Lu 1	Lu 2	Lu 3	Py 1	Py 2	Py 3
Avg.	Height	44	33.09	5.9	4.3	29.1	13.02	9.6	20	65.5	35.7	30.5	37.2	99	122
(cm)		9			2										
Amount of regeneration in the particular height classes (pcs/ha)	≤ 10 cm	2400	5400	15680	28400	4120	2280	2200	2240	40	120	1400	120	0	0
		0			0										
	10.1–20	3280	1720	760	1240	3600	1280	880	240	400	840	5000	120	40	0
	20.1–30	1120	1040	560	280	1440	200	240	80	600	1040	4667	240	40	0
	30.1–40	680	1320	280	40	520	80	120	0	840	600	3467	280	400	160
	40.1–50	560	800	200	200	240	0	0	160	560	280	2000	160	80	0
	50.1–60	560	680	120	80	40	40	0	0	520	160	1000	80	120	160
	60.1–70	360	520	80	120	160	0	0	0	320	160	667	120	240	320
	70.1–80	480	200	40	120	40	0	0	0	400	40	0	40	200	160
	80.1–90	480	320	80	80	0	0	0	0	160	0	333	40	80	160
	90.1–100	440	40	0	40	40	0	0	0	280	40	200	0	160	400
	> 100	1120	680	160	160	640	80	40	440	1200	160	67	0	1000	1680
40+	4000	3240	680	800	1160	120	40	600	3440	840	4267	440	1880	2880	
50+	3440	2440	480	600	920	120	40	440	2880	560	2267	280	1800	2880	
150+	360	360	40	80	440	80	40	360	120	0	0	0	400	960	
Total	< 500	11480	12720	17960	30760	10840	3960	3480	3160	5320	3440	18800	1200	2360	3040

This shows naturally higher mortality of the tallest regeneration on the vital plots, due to not sufficient light conditions under the canopy. Variability of spruce natural regeneration under similar conditions, The Krkonoše mountains, was described by ŠERÁ et al. (2000). The quantity strongly varied within the years and particular plots: for the 1993–6 years, the highest number was 226100 seedlings ha⁻¹ to the lowest 700 seedlings ha⁻¹.

There was also a small number of broadleaves species on selected plots (Table 3): *Betula pubescens* Ehrh., *Sorbus aucuparia* L., *Acer pseudoplatanus* L., species that are natural in the spruce forest. Typical sites of these species are as follows: the slopes for maple tree, the tree line for rowan tree and for the pioneer species a declined forest or a disturbed soil cover. There are a few problems connected with these species, such as a very small number of parent trees in the stands, a high competition of *Calamagrostis* herbal cover and also a roe-deer and deer massive browsing.

Tab.3: Broadleaves species (*Betula pubescens* Ehrh., *Sorbus aucuparia* L., *Acer pseudoplatanus* L.) height distribution

Broadleaves species		Mo 4	Pl 18	Pl 19	Pl 20	Lu 1	Lu 2	Lu 3	Lu 3	Py1	Py2	Py3
		Rowan	Rowan	Rowan	Rowan	Rowan	Rowan	Birch	Rowan	Rowan	Maple	Maple
Avg. (cm)	Height	174	54.3	71.5	71.7	109	59.2	86.5	62.5	122.5	161	129.7
Amount of regeneration in the particular height classes (pcs/ha)	≤ 10 cm	120	0	0	40	0	0	0	0	0	0	0
	110.1 - 20	240	40	0	40	0	0	0	67	0	0	0
	20.1 - 30	160	80	80	240	0	40	0	0	0	0	0
	30.1 - 40	40	80	0	40	0	40	0	0	0	0	0
	40.1 - 50	0	40	0	120	0	0	0	0	0	0	0
	50.1 - 60	0	0	0	120	0	0	0	133	0	0	0
	60.1 - 70	0	80	80	0	0	0	0	67	0	0	0
	70.1 - 80	0	40	40	0	0	80	0	0	0	0	80
	80.1 - 90	0	120	0	80	80	40	133	67	0	40	0
	90.1 - 100	0	0	0	0	0	0	0	67	0	0	0
	> 100	0	0	40	320	40	0	0	0	80	200	160
	40+	0	280	160	640	120	120	133	333	80	240	240
	50+	0	240	160	520	120	120	133	333	80	240	240
	150+	0	0	40	80	0	0	0	0	40	160	160
	< 500	560	480	240	1000	120	200	133	400	80	240	240

The quantity of broadleaves natural regeneration is due to the low number of parent trees in the surrounding stands. Exceptions are the stands on Plechý Mount, with relatively well preserved spruce-rowan mountain sites. A relatively better situation is on the vital stands, with lower herbal cover (Fig. 2). On the declined stands, with high cover of *Calamagrostis* or other grass species, there is a low survival probability of the young seedlings. Also the deer browsing is an important factor, which influences the regeneration of broadleaves in taller height classes.

Height distribution of regeneration

According to the results of other authors (ZATLOUKAL 2000; KORPEL 1993) there are tendencies for: the great number of natural regeneration (especially of the seedlings) on the plots with vital adult trees and smaller number of regeneration on the clearcuts (or declined stands). At the same time, higher increments were observed on the plots with better light conditions (in the declined stands). The average height of spruce trees is about 20 cm on the vital plots, and about 65 cm in the declined stands (Fig. 1, 2). The difference is not only due to the higher increments in the better light conditions, but mainly because of a very high quantity of small seedlings in the vital stands.

Fig. 1: Norway spruce regeneration height distribution, comparison of vital and declined stands

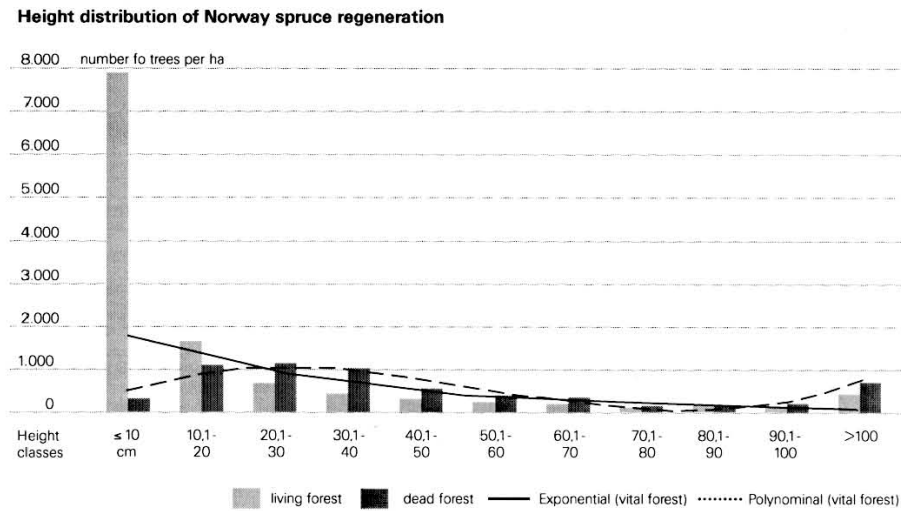
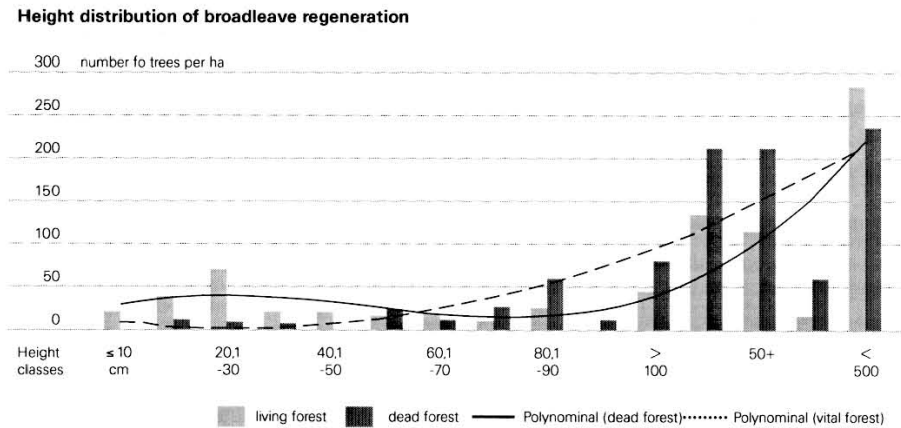


Fig. 2: Broadleaves species regeneration height distribution, comparison of vital and declined stands



Space distribution of regeneration

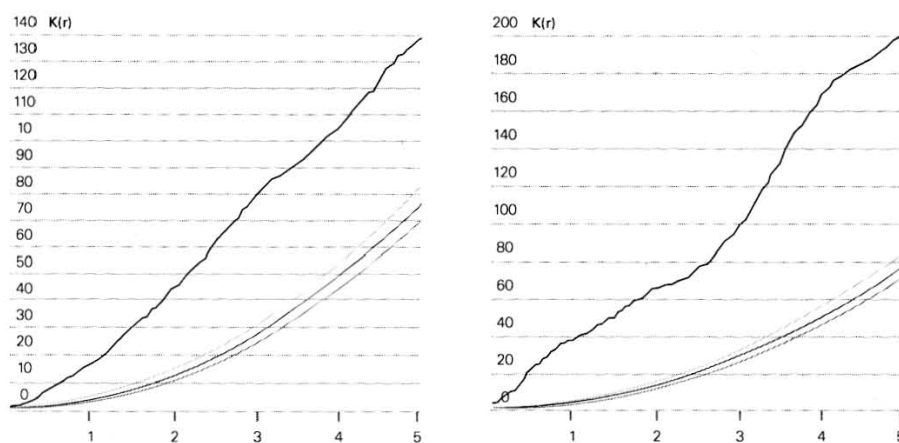


Fig.3: Spatial structure of the spruce natural regeneration by Ripley's K -function. Plot Lu 2 (*left*) – declined forest, Plot Tr 2 (*right*) – vital forest. Note: r stands for tree distance in metres and $K(r)$ describes tendency of trees to aggregation within the specific distance

High sociability (Fig. 3) of regeneration indicates the concentration of individuals on micro-sites with favorable conditions. This trend is typical for natural regeneration in mountain forest (VAČEK, LOKVENC, SOUČEK, 1996). No differences were observed between vital and declined stands. Spatial pattern of regeneration was performed by Ripley's K -function on the all plots. The two of them were chosen as a typical sample (Fig. 3). Thin irregular line shows K -function for real trees on the stand. The central of the three curves designates K -function of random spatial pattern and both lateral curves demonstrate 95 % confidence interval for a random spatial pattern. In our case K -function for the real situation runs over this interval, which indicates strong aggregation of natural regeneration, in the whole spatial scale (given by the size of the transects).

Tab. 4: Nutrient state of spruce natural regeneration on the vital and declined plots (deficiency limit by BERGMANN, 1988) Note: nutrient proportion assessed in the dry foliar samples matter

Nutrient	N%	Std. dev	P%	Std. dev	K%	Std. dev	Ca%	Std. dev	Mg%	Std. dev	S%	Std. dev
Vital stands	1.42	0.10 8	0.15	0.01 9	0.63	0.07 6	0.13	0.02 3	0.07	0.00 9	0.15	0.03 2
Declined stands	1.56	0.06 5	0.19	0.02 6	0.54	0.08 1	0.23	0.07 5	0.07	0.01 1	0.14	0.02 4
Deficiency limit	1.2	0.15		0.35		0.15		0.07		0.12 2		

The nutrient status of the spruce seedlings originating from natural regeneration is in accordance with relatively poor nutrient soil status on granite rock. The small differences in the nutrient content in the samples were observed between the vital and the declined stands. The amount of nitrogen, phosphorus and calcium was higher in the declined stands, due to the decaying wood. The temporary immission load is probably relatively low, as reflects the sulphur content in the last year foliar samples. The health of the spruces was good in the vital stands, no color change (yellowing) was observed. In the declined stands the situation was similar with slight (up to 10% of trees) tendencies of yellowing. Health status of broadleaves seedlings (originated from natural regeneration) was good, there were no color changes, but there was abundant deer and roe deer browsing damage, about 70% of the rowan tree and relatively lower of birch. The grouse damage was also reported mainly in the declined stands.

Conclusion

- Basic difference between the stand with vital and declined mature tree layer is in the quantity of seedlings and natural regeneration in the first age class.
- Accordingly, there are differences in the natural regeneration age and the height structure between the vital and declined stands. The highest number of regeneration is observed in the first age class in the vital stands. The natural regeneration structure is much more Gaussian in the declined stands, contrary to the distribution in the close to nature forests.
- Space structure of natural regeneration is similar in the vital and declined stands, trees growth in clusters, which comport with altitude and character of mountain spruce forests.
- Although quantity of natural regeneration is relatively sufficient on the majority of plots, its structure in the declined stands is not natural in Central Europe forest conditions and is closer to boreal forests.

Temporary state of natural regeneration of the declined stands could in the future lead to an even-aged forest with a risk of similar damage like the bark beetle calamity in 1995.

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