Influence of micro-relief and weed competition on natural regeneration of mountain forests in the Šumava Mountains

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ABSTRACT: Natural regeneration and its relationship to micro-relief and weed competition were studied on 6 research plots in mountain spruce forests in the Šumava Mountains. The data on density regeneration, total height and height increment of each seedling were recorded on 50 by 5 m transects. The position of each seedling was adjusted by a satellite system "Field map". The data show that an elevation is a significantly (significance level P = 0.99) preferable micro-relief for seedlings in most cases (7 of the total 9 cases). The regeneration density is low in a high-competition environment, i.e. in grass and ferns, where the number of seedlings is significantly low on all surveyed plots. But dead wood, which is also an elevation in terms of the micro-relief, is the most preferable micro-site. The data show no significant differences in seedling heights due to differently dominant competing plants. Neither was the hypothesis about the beneficial influence of stem or stump in close surroundings on seedlings confirmed by our data.

Keywords: Czech Republic; micro-relief; mountain forests; natural regeneration; weed competition

Natural regeneration is an important part of the mountain forest ecosystem. It is an indicator of forest vitality and stability. The character and progress of natural regeneration in mountain forest conditions are influenced by many factors which are interacting. The influence of micro-relief on regeneration was studied by many authors, for example by Vacek (1981), Hanssen (2002, 2003), Kuuluvainen and Kalmari (2003) or by Diaci et al. (2005). Their results show that natural regeneration is linked with special micro-site, i.e. micro-relief (either in a micro-pan or on an elevation, also slope and flat terrain) and character of soil surface. Of course, the micro-relief is not the only driving variable for natural regeneration. Micro-pans have higher humidity which is important for seedlings (Kozlowski 2002) but at the same time seedlings could suffer from light deficiency and high competition due to excessive and high weeds such as *Calamagrostis* sp. and high ferns, especially *Athyrium distentifolium* (Jonášová, Prach 2004). Micro-pans also have higher seedling mortality due to longer snow cover, where seedlings are attacked by pathogenic fungi, especially *Herpotrichia nigra* (Vacek 1981). Elevations could cause reverse problems, i.e. there is light enough but, on the other hand, there could be rather dry conditions.

The other driving variables for natural regenerations are canopy closure, frost, snow melting and sliding, etc. Plant society is also an important factor in forest regeneration. Ulbrichová et al. (2006) found out that favourite places for natural seedlings in mountain forests are mostly dead wood and, on the other hand, the worse ones are high and dense plant associations like ferns and weeds which represent strong competition for small seedlings above and/or under the ground.

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. 2B06012.

The aim of the present paper is to evaluate the relationship between natural regeneration and microsite conditions, especially micro-relief and character of soil surface, i.e. abundance and dominance of herbal species at a moss and herbal level.

MATERIALS AND METHOD

Research plots are located in Modrava and Plechý areas in Šumava National Park. The altitude ranges from 1,120 to 1,370 m a.s.l., annual precipitation varies between 900 and 1,380 mm and average annual temperature is 3.5–5°C.

There are three research plots in Modrava area (designated Mo1, Mo3, Mo4) and three plots in Plechý area (designate Pl18, Pl19, Pl20) – Table 1 shows their basic description (data from 2007). Two plots in Modrava area (Mo1 and Mo3) with living mature trees are mostly covered by *Vaccinium myrtillus* and plots with dead mature trees (Mo4) by *Calamagrostis villosa*. Plot Pl20 situated at the highest altitude is markedly influenced by specific ecological conditions in a climax spruce mountain forest, therefore this stand has naturally open canopy and the herbal layer is mostly dominated by *Avenella flexuosa*. In lower stony plot Pl19 it is *Vaccinium myrtillus* and in the lowest plot Pl18, which is almost destroyed by the bark beetle, it is *Athyrium distentifolium* and *Vaccinium myrtillus* whereas the share of *Athyrium distentifolium* has increased due to the bark beetle destruction in the last several years. In the moss layer *Polytrichum formosum* dominates; there is also *Sphagnum girgensohnii* on plot Mo3. The first three plots represent three different sites and stand conditions, i.e. growing stand on the slope (Mo1), stand destroyed by the bark beetle in a plain terrain (Mo4) and growing stand in the same terrain (Mo3). The plots in Plechý area represent an altitude gradient (from 1,200 m to 1,350 m) in the mountains at comparable conditions.

Abundant plant species under growing stands are: *Vaccinium myrtillus, Calamagrostis villosa, Avenella flexuosa* and *Athyrium distentifolium.* They are followed by *Trientalis europea, Homogyne alpina, Oxalis acetosella, Lycopodium annotinum* and *Maianthemum bifolium.* The plant society under stands destroyed by the bark beetle is dominated by *Chamaerion angustifolium*. Dominant moss species in stands at higher altitude are *Polytrichum formosum, Dicranum scoparium* and *Sphagnum* sp.

The detailed description of research plots is given in Table 1. It should be mentioned that according to our research the age of single trees within the stand varies a lot.

Table 1. Identification and basic description of research plots

Plot label	Stand label	Forest type	Altitude (m)	Exposition and terrain	Average age and stand characteristics	Herbal cover E1	Herbal cover E0	Dominant herbs E1	Foliage 2007	Canopy 2007
Mo1	68B4	8Y1	1,137	E 60°	140 years, vital, occasionally bark beetle sanitation	50	85	*Vaccinium myrtillus* (60%)	48	65
Mo3	69A	8K7	1,123	plain	140 years, declined but still growing	90	70	*Vaccinium myrtillus* (70%)	49	75
Mo4	69A	8K7	1,127	plain	150 years, dead trees	95	20	*Calamagrostis villosa* (85%)	0	0
Pl18	4A6/2/1	7S1	1,245	SE 25°	200 years, total bark beetle destruction	90	80	*Athyrium distentifolium* (45%), *Vaccinium myrtillus* (40%)	50	50
Pl19	5A3/1	8Y1	1,313	SE 40°	160 years, vital, occasionally bark beetle sanitation	90	45	*Vaccinium myrtillus* (80%)	56	80
Pl20	5A3/1	8N1	1,361	NE 3°	160 years, vital, occasionally bark beetle sanitation	95	30	*Avenella flexuosa* (60%)	56	45

The investigation on regeneration was carried out in transects 50 m in length and 5 m in width, oriented down the slope or with the longer side of the stand. The position of each seedling was determined by "Field-map" satellite technology. Total height and species were recorded for each seedling as well as micro-relief and dominant herb species. The micro-relief was set to four basic forms: plain, slope, elevation and depression (micro-pan). The terrain was considered in the circle of 0.5 m around the seedling and the differences among the micro-elevations should be more than 5 cm within the circle to be classified as not plain. The dominant plant cover (herbal and moss level, potentially substrate or litter) was determined by means of ocular estimation of the most dominant species. Dead wood is a part of wood lying on the ground at different stages of disintegration. Height of seedlings could also be positively influenced by preferable microclimate due to a nearby stem or stump. Therefore these circumstances are also taken into account.

Statistical evaluation was done using STATISTICA v 8.0 software. The degree of successful regeneration was based on the following assumptions: if there are n seedlings on the plot, then the probability of living seedling on i plot is P_i. The number of seedlings on the plot is a random variable with binominal distribution with parameters n, P_i. The probability P_i of living seedling on the site should be equal to the area proportion a_i if the micro-relief does not influence the seedling existence. Therefore the null hypothesis about the micro-relief influence on the number of seedlings is formulated as follows (with the abovementioned variables):

$$H_0 : P_i = a_i \quad (1)$$

and its alternative (opposite) hypothesis

$$H_1 : P_i \neq a_i \quad (2)$$

The relative abundance of seedlings was evaluated by the test of fit at a significance level $\alpha = 0.01$. The asterisk (*) denotes the proportion of regeneration at a significance level $\alpha = 0.05$.

The test of fit was used for evaluation of total seedling height and its normal distribution. Leven's test proved that the seedling height variance for different micro-reliefs and weed competition is identical. The influence of these two factors on seedling height could then be evaluated by one-factor analysis of variance. Tukey's test was used to determine which sets of data are different if the null hypothesis could be rejected. The sets which have no differences (at a significance level $\alpha = 0.05$) in height differ in symbols ("A" or "B").

RESULTS AND DISCUSSION

An overview of the species composition of regeneration on research plots is given in Table 2.

On plots Mo1, Mo3, Pl19 and Pl20 the share of spruce regeneration on dead wood was markedly higher than on the other micro-site types. This fact is caused by the special wood-decay fungus called *Fomitopsis*, when the dead wood (stems) is decomposed still with bark and that means better conditions for natural spruce regeneration (cf. Jankovský 1999). On the other hand, on plot Mo4 the regeneration on dead wood is very poor although the share of dead wood on this plot is very high. This can be explained by another wood-decay fungus *Gleophyllum*, which decomposes stems without bark after the great bark beetle destruction.

Modrava plots (Mo1, 3, 4) are nearly purely regenerated by Norway spruce (more than 97% of the total seedling number) while Plechý plots (Pl18, 19, 20) show an increasing number of rowan *(Sorbus aucuparia* [L.]) between 10 to nearly 40% although

Table 2. Species composition of natural regeneration on plots

Plot	Number of seedlings/Relative proportion in regeneration (%)													
	total		spruce			rowan			birch			beech		
	psc	psc·ha^{-1}	psc	psc·ha^{-1}	(%)	psc	psc·ha^{-1}	(%)	psc	psc·ha^{-1}	(%)	psc	psc·ha^{-1}	(%)
Mo1	255	10,200	248	9,920	97.3	5	200	2.0	1	40	0.4	1	40	0.4
Mo3	127	5,080	123	4,920	96.9	3	120	2.4	X	X	X	1	40	0.8
Mo4	223	8,920	218	8,720	97.8	5	200	2.2	X	X	X	X	X	X
Pl18	64	2,560	39	1,560	60.9	25	1,000	39.1	X	X	X	X	X	X
Pl19	49	1,960	44	1,760	89.8	5	200	10.2	X	X	X	X	X	X
Pl20	93	3,720	60	2,400	64.5	31	1,240	33.3	1	40	1.1	1	40	1.1

Table 3. Evaluation of the micro-relief influence on regeneration density (%)

Plot	Tree species	Depression		Swelling		Plain		Slope	
		plot cover	number of seedlings	plot cover	number of seedlings	plot cover	number of seedlings	plot cover	number of seedlings
Mo1	spruce	25	**9.7**	6	**27.8**	19	**12.5**	50	52.8
Mo3	spruce	7	6.5	9	**43.1**	48	**33.3**	36	**20.3**
Mo4	spruce	24	13.8	19	20.6	33	28.0	24	39.9
Pl18	spruce	4	2.6	3	**28.2**	21	**2.6**	72	66.7
	rowan		0		**20.0**		4.0*		76.0
Pl19	spruce	36	0	12	**70.5**	13	0*	39	29.5
	rowan		0		0		40.0		60.0
Pl20	spruce	27	**1.7**	14	**78.3**	39	**13.3**	20	**6.7**
	rowan		9,7*		**32.3**		29.0		29.0

* Significance level α = 0.05

Norway spruce is still the main species in regeneration.

The influence of micro-relief on natural regeneration was evaluated by the test of fit. The evaluation was carried out not only for Norway spruce seedlings but also for rowan seedlings on the second series of research plots. The results are given in Table 3. In the cases where the micro-relief has a highly significant influence on the number of seedlings, the data are in bold (significance level $P = 0.99$) and where it is still significant (significance level $P = 0.95$), the data are designated by asterisk (*).

Data suggests that an elevation is the most preferable micro-relief for seedlings as in most cases (7 out of the total 9 cases) there is a significantly higher proportion of seedlings. On two plots in Plechý area even the majority of the seedlings (more than 70%) are growing on elevations while the slope and depression (micro-pan) are the micro-reliefs which are not preferable sites for seedling germination and growth. In the conditions of the high altitude gradient on Plechý Mt. a major part of regeneration grows on elevations because of the temperature which is the main limiting factor, on elevations snow also melts sooner (by about two weeks) and seedlings are not seriously damaged by pathogenic fungi (mainly in early spring). This trend is partly reduced by introskeletal erosion, which is very marked on plot 19 (cf. Vacek, Krejčí 2008). The regeneration on slopes and in depressions is attacked by *Herpotrichia nigra.* Elevations also have lower abundance and dominance of the herbal and

Table 4. Evaluation of the influence of dominant plants or close environment on regeneration density (%)

Plot	Tree species	Bare ground		Dead wood		Blueberries, mosses		Grass, ferns	
		plot cover	number of seedlings	plot cover	number of seedlings	plot cover	number of seedlings	plot cover	number of seedlings
Mo1	spruce	29	**8.1**	2	**28.2**	65	**56.9**	1	0
Mo3	spruce	28	15.3	7	**40.3**	55	**35.5**	2	**0**
Mo4	spruce	12	5.0	21	8.3	33	48.6	33	0
Pl18	spruce	37	15.4	2	**0**	31	**46.2***	30	5.1
	rowan		52.0		**8.0***		28.0		12.1*
Pl19	spruce	11	**0***	1	**56.8**	82	36.4	0	0
	rowan		40*		0		60.0		0
Pl20	spruce	8	**1.7**	9	**38.3**	22	**6.7**	58	**13.3**
	rowan		6.5		**0**		38.7*		45.2

* Significance level α = 0.05

Table 5. Seedling height differences according to different micro-site conditions

Plot No.	Dominant species, substrate			
	significance level	microhabitat type	average height (cm)	homogenic groups
1	0.07200	stump	15.0000	A
		food of tree	35.6400	A
		dead wood	44.6300	A
		bluberries	46.3900	A
		grass, ferns	60.0000	A
		bare soil	80.6700	A
3	0.00000	dead wood	29.0200	A
		bluberries	62.8600	B
		food of tree	77.5000	B
		bare soil	87.5800	B
4	0.66000	dead wood	116.2200	A
		bluberries	117.5600	A
		grass, ferns	124.8300	A
		food of tree	127.6200	A
		bare soil	145.2700	A
18	0.45600	bare soil	37.6600	A
		food of tree	56.3300	A
		bluberries	36.2800	A
		grass, ferns	60.0000	A
19	0.00000	food of tree	12.0000	AB
		dead wood	16.1600	A
		stump	30.5000	AB
		bluberries	72.7500	B
20	0.54200	bare soil	15.0000	A
		dead wood	12.8700	A
		stump	18.7300	A
		food of tree	7.5000	A
		bluberries	24.2500	A
		grass, ferns	14.0000	A

moss level, thus the competition of species is lower such as air humidity, so in this micro-site the pathogenic fungi are not so dangerous. Further, seedlings in depressions are covered by *Calamagrostis villosa* during winter, which nearly always causes the mortality of seedlings in connection with the attack by pathogenic fungi (cf. Vacek, Krejčí 2008). The results are the same for seedlings of Norway spruce and rowan, even for the latter species our data is rather poor. These results are in accordance with findings of Kuuluvainen and Kalmari (2003) and Diaci et al. (2005). Similar evaluation was done for the influence of dominant plants and/or close environment, i.e. bare ground and dead wood, on the density of regeneration. Data and statistical evaluation are given in Table 4 based on the same hypothesis (1, 2) as the previous table.

The data show a similar picture like previous Table 3. The regeneration density is low in a high-competition environment, i.e. the number of seedlings is

Table 6. Seedling height differences according to different micro-relief

Plot No.	Micro-relief			
	significance level	microhabitat type	average height (cm)	homogenic groups
1	0.29400	elevation	38.94	A
		depression	44.22	A
		slope	51.30	A
		flat	55.03	A
3	0.00015	elevation	35.06	A
		flat	60.19	B
		slope	71.24	B
		depression	98.75	B
4	0.00070	depression	103.60	A
		slope	112.55	A
		elevation	120.16	AB
		flat	147.97	B
18	0.08150	depression	44.00	A
		elevation	21.72	A
		flat	34.00	A
		slope	46.69	A
19	0.00039	elevation	22.29	A
		slope	73.08	B
20	0.48470	depression	5.00	A
		elevation	15.64	A
		flat	13.38	A
		slope	25.00	A

significantly low in grass and ferns on all plots (except for rowan seedlings on plot Pl20). A surprisingly low number of seedlings is also on the bare ground where no competition exists. This fact could be explained by severe microclimatic conditions which are probably too harsh for the germination and survival of seedlings. But dead wood, which is also an elevation in terms of the micro-relief, is the most preferable micro-site. The stage of wood decomposition seems to be an important precondition for successful regeneration on dead wood. There is a lot of lying but not yet decaying logs on plot Mo4 and the density of regeneration is low on their surface (Ulbrichová et al. 2006; Štícha et al. 2008).

The seedling heights (influenced by different weed competition and micro-site conditions) are analyzed in Table 5.

The data show no significant differences in seedling height due to different dominant plants except for plot Mo3 and partly for plot Pl19. The former plot Mo3 has statistically significantly lower heights of seedlings growing on dead wood compared to other types of micro-sites, i.e. berries, bare ground and stem foot. The latter plot has even less clear interpretation of gathered data. The differences on plot Mo3 are not statistically proved on all other plots. The hypothesis about the beneficial influence of stem or stump in close surroundings on seedlings was not confirmed by our data.

The analysis of micro-relief influence on seedlings height is given in Table 6.

Only two plots (Mo3, Pl19) have significantly lower seedling heights on elevations. No other differences could be found due to micro-relief. Our data suggests that the micro-relief has no significant influence on seedling growth as shown in Table 6.

CONCLUSIONS

Our results suggest that an elevation is the most preferable micro-relief for seedlings as in most cases (7 out of the total 9 cases) a significantly higher proportion of seedlings was found there. On two plots on Plechý Mt. even the majority of the seedlings (more than 70%) are growing on elevations while slope and depression (micro-pan) are the micro-relief which does not represent preferable sites for seedling germination and growth. These facts are in accordance with Holeksa et al. (2007).

The regeneration density is low in a high-competition environment, i.e. in grass and ferns where the number of seedlings is significantly low on all surveyed plots. But dead wood, which can also be considered as an elevation in terms of the micro-relief, is the most preferable micro-site.

The data show no significant differences in seedling heights due to different dominant plants. The hypothesis about the beneficial influence of stem or stump in close surroundings on seedlings was not confirmed. Special microhabitat conditions are of higher importance (Kuuluvainen, Kalmari 2003). Natural regeneration is also influenced by the bark beetle disturbance, not only due to the decay of mature trees but also due to different stage of dead wood decomposition. An important factor is also the decay rate which influences the ground vegetation development and soil processes (especially in skeletal soils on plot Pl19 and Mo1) such as litter mineralization.

It can be concluded that micro-reliefs (namely elevations) have a positive influence on the density of regeneration but not on their height growth. Dominant herbs as main competitors diminish the seedling growth but, on the other hand, herbs can protect the germinating seedlings since regeneration density is significantly lower under conditions of bare ground.

Acknowledgements

The authors thank Ing. Lukáš Bílek, Mgr. et Mgr. Bc. Filip Dostál and Jan Štícha for their help during research works.

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Received for publication: February 25, 2009
Accepted after corrections: April 26, 2010

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