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Spontaneous development of early successional vegetation improves Norway spruce forest soil after clear-cutting and renewal failure: a case study at a sandy-soil site

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Abstract: Clear-cutting is the most common silvicultural system. Sometimes, if the new crop is not established successfully, clearcut is left unreforested. This study focused on a site where early successional species such as silver birch (Bi) and rowan (Ro) were accompanied with Norway spruce (Sp) in 13-year-old stand from natural regeneration at 550 m of altitude at an acidic site with eastern aspect and 25% slope. We found five types of stand composition: treeless gaps, Ro-Bi, Ro-Bi-Sp, Bi-Sp and monospecific Sp. Besides these juvenile ones, adjacent 100-year-old spruce (Sp old) stand representing pre-harvesting conditions was studied. In addition to the performance of trees, organic layer (Hum), topsoil (Ah) and upper subsoil (B) horizons were sampled to study an expected shift of chemical properties after clear-cutting and secondary succession at the site of interest. Birch dominated the natural regeneration; rowan and spruce were present mostly in understorey. Old spruce was more acidic and nutrient-poorer compared to the juvenile treatments. The treeless treatment showed also slightly higher pH and comparable nutrients compared to the young mixtures. Young spruce was higher in nitrogen compared to Ro-Bi-Sp mixture.

Keywords: clear-cutting; succession; tree performance; soil properties

The property restitutions have brought many changes to the forests in the Czech Republic after 1989 (Prokopová et al. 2018). Over the years that followed, there were many smaller private forest stands that were not renewed successfully after clear-cutting. Such sites were left to spontaneous development without any additional silvicultural interventions frequently, which resulted in the emergence of naturally regenerated new stands dominated by early successional woody species such as birch, aspen and willow (e.g. Dymov 2017). Where Norway spruce was present within the effective distance needed for its seed dispersal (e.g. Hudjetz et al. 2014), these early successional woody species were likely to be accompanied also with spruce saplings that often developed in understorey.

There is, however, a lack of silvicultural prescriptions for these mixed-species stands because silver birch has been considered a competitive threat to juvenile crop tree species since the dawn of modern forestry. Foresters' negative perception of almost any proportion of birch in forest stands, which is still quite common in Central Europe, dates back to history (e.g. Svoboda 1957). Despite hardly any value attached to them, the genus *Betula* trees were

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not eradicated but became neglected and/or tolerated species in this country. We know, however, a different approach from abroad where birches are even a common part of the managed forests (see Hynynen et al 2010). In the "Black Triangle" European mountains that experienced an increased air pollution load (SO_2), a local rehabilitation of birches for the purpose of their use as a substitute for declining Norway spruce arose in the last decades of the 1900s (Ulbrichová et al. 2005; Podrázský et al. 2005). Nowadays, this issue has been raised again because vast areas of spruce-dominated forests exhibit a die-off due to climate changes and bark beetle outbreaks. Among the expected functions, both nursing and improving effects of birch on late successional juvenile tree species and soil properties, respectively, are more emphasized (Košulič 2006). The natural regeneration of birch frequently develops at the sites exhibiting an intensive Norway spruce decline (Ambroży et al. 2017). The main reasons why birch shows such dominance among the early successional species are fast juvenile growth, ability to perform well in unfavourable conditions, early fertility, and seed dispersal by wind (Úradníček et al. 2009; Dostalova 2009; Fischer, Fischer 2012).

Environmental conditions and type of vegetation present at the site are strongly dependent on each other (Rothe, Binkley 2001). The status and development of soil properties are cardinally influenced by the species composition of forest stand, with particular contribution of ground vegetation (see Laiho, Prescott 1999). Individual woody plants retain substantial amounts of the site nutrients, influence nutrient cycles, water regime of the site and support also particular soil biota communities. Besides that, also silvicultural treatments affect nutrient cycling significantly and clear-cutting is perhaps the most perceptible way of forest stand renewal. There are also some latent consequences. For example, a sudden removal of coniferous forest cover has negative impacts on the mass of fine roots (Lindo, Visser 2003); for example Kohout et al. (2018) estimated the decrease to approximately one-half of the initial amount two years after the disturbance. Harvesting was also proved to affect the site due to both removal and redistribution of nutrients through felling and forwarding (Stutz et al. 2017).

Differences between preceding and successive forest generations greatly impacted on ecological conditions, properties and biodiversity in individual succession stages, carbon storage and also on the economic situation (Chazdon et al. 2016). The early successional birch stands have the lower tree carbon storage as reported for example by Cai et al. (2016) for 62-year-old *Betula platyphylla* with *Larix gmelinii* compared to late successional 300-year-old *Pinus koraiensis* dominating in mixture with other admixed species though the aboveground net primary productivity was not different between the two forest types (Cai et al. 2016). Bose et al. (2014) found the lower birch aboveground biomass than that of pine and comparable with oak and other broadleaves. Early successional species can however improve upper soil properties compared to target species (Martiník et al. 2017). Different tree species life span and tolerance to lower subcanopy light levels are the reasons why the long dominance of late successional species such as spruce can even exclude the shade intolerant birch from a forest stand (Nygaard et al. 2017).

The study aims at two objectives: 1) to analyse natural regeneration including early successional species and their mixtures on a large clearing 12 years after the mature spruce stand clear-cutting and 2) to analyse the chemistry of both the forest floor and topsoil horizons below different juvenile forest covers and to compare them with adjacent mature spruce stand representing soil conditions prior to the clear-cutting.

MATERIAL AND METHODS

Study site. On the north-east side of the table mountain called Ostaš (50.568 N,16.216 E), the Czech Republic, a renewal of Norway spruce forest (acidic site at 550 m of altitude with eastern aspect and 25% slope) started in 1999 using strip cutting, where stocking was reduced excessively within the standing-tree retention patches left at the site. The mountain belongs to the geomorphological unit Broumov Highlands (Broumovská vrchovina), mean annual precipitation ranges from 700 to 800 mm and mean air temperature is about 7.5 °C. Final cutting of the patches followed in the next year, which led to emergence of a 2.5 ha clearcut surrounded mostly by adjacent meadows and neighbouring with the only stand of 100-year-old spruce (Sp old) on the southwest side. After the renewal failure, no other silvicultural operations were done with the exception of beech planting on a small area. In the new stand, naturally regenerated pioneer species (mostly silver

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Table 1. Basic parameters of stand treatments for soil analyses

Stand treatment	Abb.	N (thousand·ha^{-1})	G (m^2·ha^{-1})	Description
Spruce old	Sp old	Sp 0.5	Sp 51	ca. 100-year-old spruce stand
No trees present	Gap			area without trees – stand gap at present
Rowan-birch	Ro-Bi	Ro 4.3; Bi 1.8	Ro 10.0; Bi 5.0	young stand of rowan with birch
Rowan-birch-spruce	Ro-Bi-Sp	Ro 4; Bi 2.5; Sp 1.6	Ro 3.5; Bi 11.5; Sp 1.5	young stand of rowan with birch and with spruce mostly in understorey
Birch-spruce	Bi-Sp	Bi 4.0; Sp 2.2	Bi 20.0; Sp 2.5	young stand of birch with spruce mostly in understorey
Spruce young	Sp	Sp 7.4	Sp 11.5	ca. 13-year-old spruce from natural regeneration

Abb. – abbreviation; N – number of species; G – stand basal area

birch – Bi and rowan – Ro) dominated with locally prevailing Norway spruce (Sp). Naturally regenerated sycamore maple and planted beech were also present; both were neglected due to their scarcity at the study site. The soils in the area are Cambisols, the parent rock is sandstone.

Stand mensuration. Tree species composition and structure of the stand were investigated on regularly spaced (10 × 20 m) circular plots with 1.79 m radius, i.e. 10 m^2 in area. Trees up to 3 m in height (h) were divided into height classes: < 0.5 m; 0.51 – 1.00 m; 1.01 – 1.50 m; 1.51 – 2.00 m; 2.01 – 2.50 m; 2.51 – 3.00 m. Analysed parameters of all trees with h > 3 m were DBH and height. DBHs were measured to the nearest 0.1 cm. The heights were determined using an electronic laser hypsometer (Vertex® Laser VL5; Haglöf, Sweden) to the nearest 0.1 m, the uniform height curve method was applied for each species. Possible other injuries (growth deformations, damage by game) were also of interest.

Soil sampling. Based on the particular stand conditions, dominant-species treatments (see Table 1) were sampled. The neighbouring mature spruce stand was also sampled to emulate soil conditions in the logged-over stand that was replaced by the new succession.

Soil cores were taken using a vertically halved cylindrical probe with inner diameter of 7 cm. The probe consisted of two metal pieces screwed together. When the two halves were tightened in closed position, the half-cylinder blades were close together and then the probe cylinder was manually driven down into the ground using two handles. After lifting the probe up, the soil core was taken easily from the scissors-open probe pieces. Then the particular layers were separated and samples were labelled. The soil horizons were distinguished according to the presence of diagnostic properties (e.g. Klinka et al. 1997; Němeček et al. 2001; Zanella et al. 2011). Each treatment (see Table 1) was five times replicated within the study site. Each replicate consisted of three sample cores, their appropriate layers were then mixed. Forest floor horizons (L, F, H) were taken together and labelled as Hum. Hum layer and topsoil (Ah) layer were sampled completely and only the top of subsoil (B) layer was taken.

The samples were dried and both Hum and Ah layers were weighed. Prior to a chemical assay, the Hum was sieved with a 3-mm mesh soil sieve to separate the coarse fraction such as stones to avoid a weight bias. Oxidizable carbon was analyzed using the Springel-Klee method (e.g. Ciavatta et al. 1989) and nitrogen according to Kjeldahl (Kirk 1950). Other properties analyzed were: pH, soil sorption complex (base cation content − BCC, cation exchange capacity − CEC, base saturation − BS) according to Kappen (1929) and plant-available nutrients using Mehlich III method (Mehlich 1984). Soil acidity was classified according to Ulrich (1981), base saturation and available nutrient contents according to guidelines for the classification of forest soils published by Sáňka and Materna (2004).

Data processing. For the forest stand structure description, basic tree and stand statistics were computed in MS Excel.

The analysis of soil data was carried out in the R environment for statistical computing (R Core Team 2015). Based on methods of exploratory analysis, two outliers were omitted (one in Ro-Bi and one in Sp treatment). The principal component analysis

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(PCA) using FactoMineR package was performed to analyse the whole data set of every soil horizon. The input variables were soil chemical properties (pH H_2O, pH KCl, S, T, V, C_{ox}, N, P, K, Ca, Mg), the treatments were set as factors. The PCA outputs were plotted using the ggbiplot function.

For every soil chemical variable, the treatments were compared using the non-parametrical Kruskal-Wallis test that was followed by pairwise tests using the kruskalmc function of pgirmess package (Siegel, Castellan 1988). The differences were considered significant if $P < 0.05$.

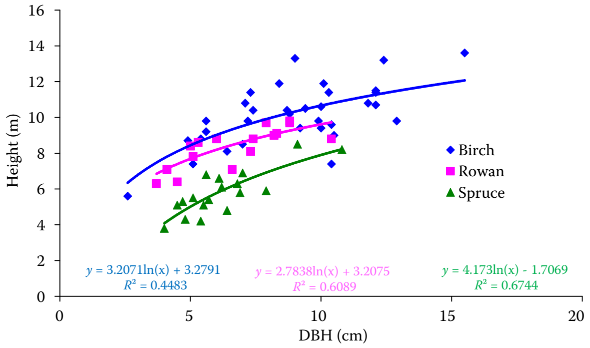

Figure 1. The dominance of birch and young spruce in understorey are obvious; height curves of the most frequently occurring trees with logarithmical trend lines

RESULTS

Tree species performance. The new forest stand originated from natural regeneration was dominated by birch, whereas rowan and spruce were the most frequent species in understorey. Altogether, almost 50% of the area was occupied by the mixture of these three species, and their mixtures accounted in the upper storey for more than 25% (Table 2). According to basal area (BA), birch, rowan and spruce accounted for 55%, 23% and 15% of the stand basal area, respectively. Sycamore was a part of the stand on less than 6% of the area, representation of other species (goat willow, larch) was low. Little more than 3% of the area were treeless gaps. The naturally regenerated stand density of vigorous trees per hectare varied between 1 and 20 thousand for individuals exceeding 3 m in height (average 7.8 thous.)

Table 2. Species mixtures and basal area of the upper storey; scarcely represented species were omitted

Mixture	Share (%)	Basal area (m^2)									
		Bi		Ro		Sp		Sy		Total	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Bi	8.0	25.7	11.9							25.9	12.2
Bi-Ro	17.2	15.2	6.6	2.7	2.6					17.9	6.7
Bi-Ro-Sp	12.6	14.9	8.4	2.6	1.2	1.4	1.0			18.9	8.3
Bi-Ro-Sy	3.4	12.6	4.4	2.4	0.5	1.1	0.4	1.2	0.7	16.9	5.3
Bi-Sp	5.7	19.9	7.7			2.4	1.5			22.3	8.4
Bi-Sp-Ro	8.0	18.4	9.8	1.5	0.9	4.2	2.4			24.1	10.6
Ro	4.6			11.3	8.5					11.3	8.5
Ro-Bi	6.9	3.8	4.0	10.0	2.9					13.9	5.4
Ro-Sp	4.6			7.8	2.5	2.8	1.6			10.6	1.9
Ro-Sp-Bi	4.6	0.3	0.1	7.0	2.4	2.0	0.6			9.3	1.9
Ro-Sy	2.3			2.6	2.1			0.9	0.3	3.5	2.5
Sp	5.7					11.7	7.8			11.7	7.8
Sp-Bi	4.6	3.7	2.3			12.2	3.6			16.2	6.2
Sp-Ro	4.6			2.6	0.7	9.1	4.3			11.8	4.6
Others*	3.4										
Gap	3.4										
Total	100	13.9	10.4	4.4	4.3	4.7	5.2	5.5	9.9	17.1	9.4

SD – standard deviation; Bi – Silver birch; Ro – Rowan; Sp – Norway spruce; Sy – Sycamore; others – different mixtures or small regeneration only; Gap – No trees present; In the mixture abb., species are given in descending order according to their share in the mixture

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and up to 3.5 thousand for smaller than 3 m individuals (average 1.2 thous.). High variability of the DBH to height relation was found for every species (Figure 1). The dominant height of new stand reached 12 m.

Birch was a key species of the stand production: its height went to 14 m (Figure 1) and where it dominated, total BA increased (Table 2). Monospecific areas with birch in the upper storey and birch with spruce had the highest basal area (up to 26 m^2 per ha). Average BA reached 17 m^2.

Growth deformations (in 4% of individuals) of the trees shorter than 3 m were mostly caused by browsing of terminal shoots of spruce, and also rowan to some extent. The most frequent deformation of the trees taller than 3 m was attributable to snow load; it affected 4.5% of trees, mostly birches. The stand was differentiated markedly. Its substantial parts had a capacity to make a pioneer stand of birch and rowan of sufficient quality and with advanced spruce undergrowth. The present crop restoration would be appropriate in parts where trees of low density or insufficient quality grew; these were found on 5% of the area only.

Forest floor humus and topsoil. The PCA indicated shifts of the soil properties from mature spruce (Sp old) to young stand treatments for all layers. The first two axes of PCA plot explained 72.8% of data variability in **Hum** (Figure 2). The analysis showed lower pH and BS of Hum in Sp old compared to Gap and Bi-Sp particularly, and also higher BCC in Ro-Bi. When we consider the confidence intervals, soil chemical properties of Sp old significantly differed from the other analysed treatments, increased variability was observed in Hum horizons of Bi-Sp. Properties of Ro-Bi differed from Gap and Ro-Bi-Sp.

As for the organic-mineral topsoil (**Ah**), the first two axes of PCA explained 81.5% of data variability. Higher probability of significant differences between treatments was proved. Significantly different chemical properties of Sp old from the early succession treatments were found again,

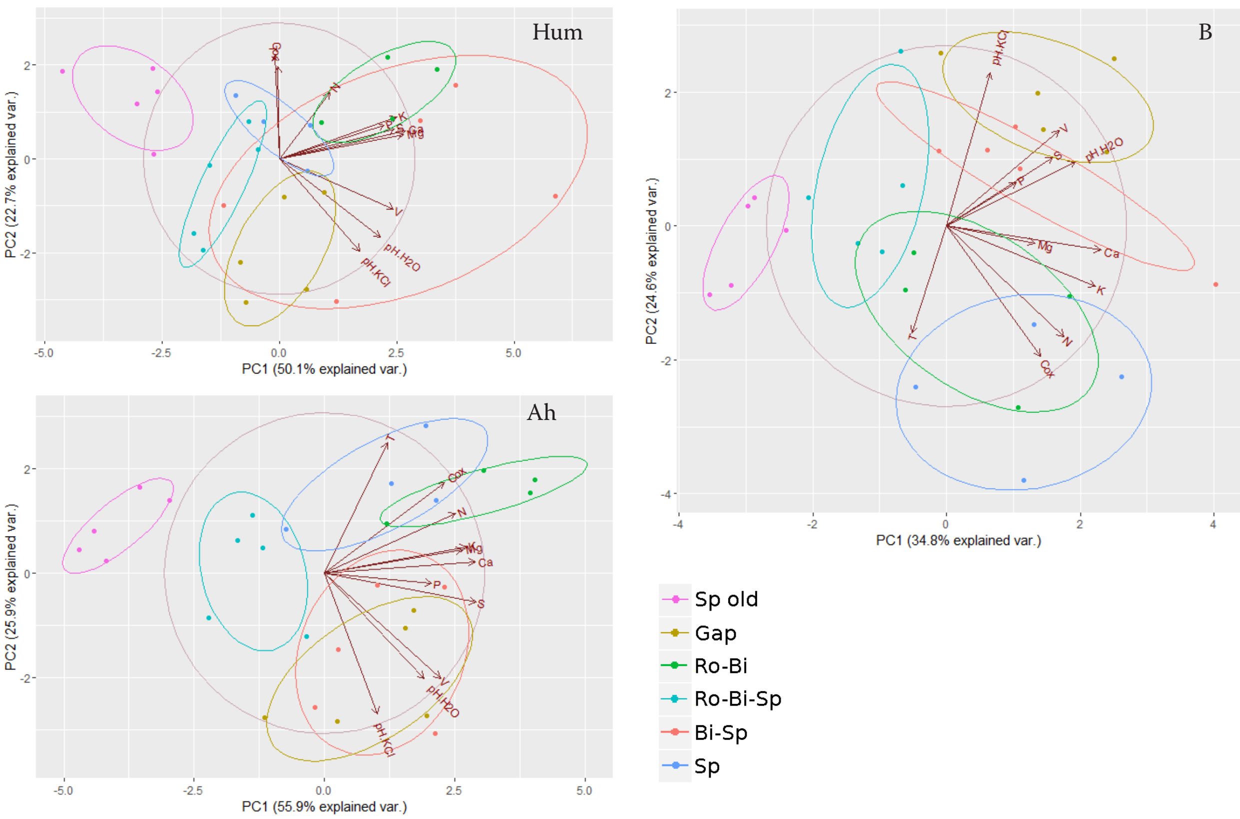

Figure 2. The new stands differ from the mature spruce monospecific stand as it is shown in an ordination diagram from PCA of floor Hum (left above), topsoil Ah (left bellow) and underlying B horizon (right); the percentage depicts variability explained by the first and second principal axes; the colours denote particular treatments. The brown circle indicates the theoretical maximum extent of the arrows, the ellipses are 68% data ellipses for each of the treatments in the data

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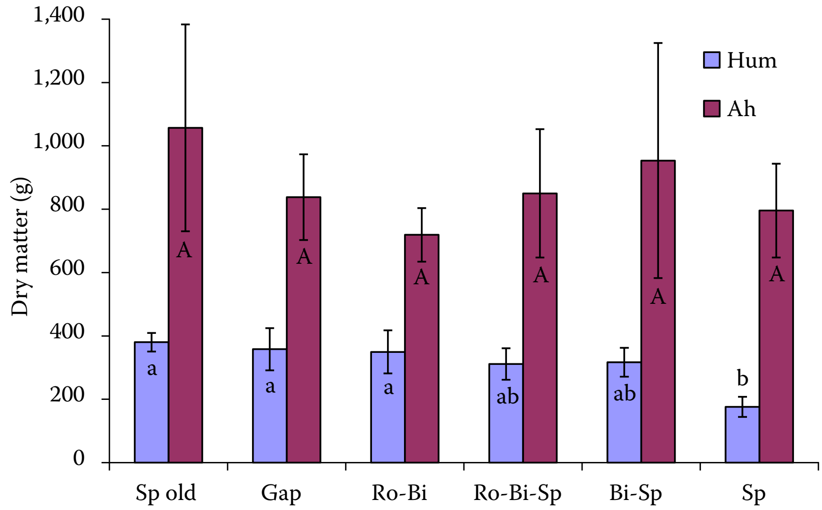

Figure 3. Mean dry matter of forest floor (Hum) and topsoil Ah horizon (g·m^{-2}); error bars denote standard deviation; the same letters indicate a statistically homogeneous group within the horizon; Kruskal-Wallis: P = 0.010 for Hum, P = 0.717 for Ah; Sp old – Spruce old; Gap – No trees present; Ro – Rowan; Bi – Silver birch; Sp – Norway spruce

Sp old inclined to lower BCC and higher soil acidity. Among the early succession treatments, both Bi-Sp and Gap showed higher pH compared to Sp and Ro-Bi-Sp.

The PCA explained 59.4% of the variability in **B horizon** only. In this deeper soil, Sp old showed also lower BCC, probability of the other differences among the treatments was lower than in upper horizons indicating the effect of vegetation on soil.

Average **dry matter** of Hum ranged from 170 to 450 g·m^{-2}. It was significantly lower in Sp compared to Sp old, Gap and Ro-Bi treatments (Figure 3). Dry matter of Ah was between 719 and 1,056 g·m^{-2}, the differences among treatments were not significant.

All soils of the treatments studied at the site were very to extremely strongly acidic (according to Ulrich 1981). In Sp old, pH values were the lowest, the differences were significant compared to Gap and Bi-Sp (Table 3). Active soil acidity (pH H_2O) of Bi-Sp was significantly lower compared to Ro-Bi-Sp in Hum, Ah and also B horizons.

The lowest contents of **basic nutrients** in Hum, Ah and also in B were found in Sp old. The differences were significant particularly in comparison with Ro-Bi and Sp (Table 4). Both Hum and Ah horizons were the highest in N, P, K, Ca and Mg in Ro-Bi.

The BCC content of Hum and Ah was the lowest in Sp old, significantly from Ro-Bi, in Ah also from Gap (Table 5). The BS of Ah and B horizons was classified as lower to very low. The soil in Gap was the highest in BS: the differences were significant from Sp old in the whole analysed profile, in B also from Ro-Bi.

DISCUSSION

Tree species performance. At the analyzed site, birch grew taller than rowan and spruce. It corresponds with the rapid development of juvenile birch as reported for example by Fischer, Fischer (2012). Bose et al. (2014) mentioned the ability of birch to perform well in terms of dominant height over 80 years. The reason why spruce is mostly in undergrowth was rapid development of birch overgrowth which reduced suitable conditions for spruce. For example, birch is capable of impeding the spruce growth indirectly through reducing subcanopy light levels to 10%, thus affecting the spruce survival negatively as reported by Comeau et al. (2003) for paper birch and white spruce. Also Kranabetter, Coates (2004) found availability of light as responsible for tree growth. However, the birches are not able to compete with late successional species for a long time due to their shorter life span as they show a sudden increase in the population size followed by a rapid loss of individuals a decade later (see Fischer, Fischer 2012). Therefore we consider the juvenile silver birch to be a temporarily dominant species at the site of interest, where it is expected to be outcompeted and replaced by Norway spruce (see e.g. Ivanov, Shadrikov 2010) which can show both early and late successional growth

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Table 3. Soil acidity in Hum, Ah and B horizons from the treatments of interest: (A) average and standard deviation, (B) multiple comparisons (Kruskal-Wallis, (*P*))

(A)	Treatment	Hum		Ah		B	
		Average	SD	Average	SD	Average	SD
$pH(H_2O)$	Sp old	3.56	0.093	3.29	0.058	3.50	0.064
	Gap	4.29	0.147	3.88	0.084	4.07	0.097
	Ro-Bi	3.99	0.015	3.58	0.030	3.79	0.029
	Ro-Bi-Sp	3.86	0.098	3.47	0.055	3.61	0.161
	Bi-Sp	4.50	0.210	3.90	0.094	4.12	0.075
	Sp	3.92	0.058	3.64	0.082	3.88	0.058
pH(KCl)	Sp old	2.78	0.069	2.64	0.060	2.93	0.064
	Gap	3.41	0.160	3.06	0.070	3.23	0.060
	Ro-Bi	3.12	0.046	2.78	0.025	2.93	0.041
	Ro-Bi-Sp	3.24	0.099	2.91	0.094	3.15	0.107
	Bi-Sp	3.48	0.240	3.03	0.127	3.18	0.074
	Sp	2.93	0.075	2.72	0.065	2.95	0.068

(B) Treatment comparison	$pH(H_2O)$			pH(KCl)		
	Hum	Ah	B	Hum	Ah	B
	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Bi-Sp × Gap						
Bi-Sp × Ro-Bi						
Bi-Sp × Ro-Bi-Sp	*	*	*			
Bi-Sp × Sp						
Bi-Sp × Sp old	*	*	*	*	*	
Gap × Ro-Bi						
Gap × Ro-Bi-Sp		*				
Gap × Sp						
Gap × Sp old	*	*	*	*	*	*
Ro-Bi × Ro-Bi-Sp						
Ro-Bi × Sp						
Ro-Bi × Sp old						
Ro-Bi-Sp × Sp						
Ro-Bi-Sp × Sp old						
Sp × Sp old						

SD – standard deviation; Sp old – Spruce old; Gap – No trees present; Ro – Rowan; Bi – Silver birch; Sp – Norway spruce

strategies. Spruce can overcompete birch in various site conditions and stand species proportions: when the development of a spruce-birch mixture of different proportions was compared, the greatest increase in the proportion of spruce was found in stands initially dominated by birch (Shanin et al. 2014). Although birch is capable of survival for relatively longer periods in the successive stands (Dostalova 2009), the loss in birches is mostly greater than in spruces over the 20-year stand development. Spruce performance can however be reduced by recent climate change and bark beetle attack (e.g. Balazy et al. 2019). Rowan can also show a rapid rate of increasing stand species density and moderate loss of individuals, which ranks its population dynamics as intermediate between birch and spruce (Fischer, Fischer 2012). Anemochorous birch and spruce seed dispersal was attrib-

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Table 4. Mean concentrations of oxidizable carbon and nutrients in Hum, Ah and B horizons from the treatments studied: (A) average and standard deviation

(A)	Treatment	Hum		Ah		B	
		Average	SD	Average	SD	Average	SD
Cox (%)	Sp old	25.4	3.5	5.5	0.8	1.3	0.2
	Gap	15.3	2.1	7	1.7	1.8	0.3
	Ro-Bi	21.5	3.4	11.4	1.6	2.4	0.3
	Ro-Bi-Sp	15.8	2.2	5.9	0.7	1.6	0.3
	Bi-Sp	23.3	4	8	1.6	1.8	0.4
	Sp	22	3.1	12.7	2.3	4.1	0.4
N (%)	Sp old	1.17	0.102	0.29	0.071	0.07	0.015
	Gap	1.28	0.279	0.43	0.082	0.11	0.024
	Ro-Bi	1.42	0.036	0.58	0.038	0.14	0.033
	Ro-Bi-Sp	0.99	0.187	0.31	0.025	0.08	0.009
	Bi-Sp	1.18	0.243	0.44	0.074	0.13	0.041
	Sp	1.39	0.027	0.6	0.044	0.18	0.026
P (mg·kg^{-1})	Sp old	25.2	3.49	7.6	3.14	2.6	3.2
	Gap	40.4	8.71	18.8	3.19	12.4	5.39
	Ro-Bi	78	7.48	32.3	1.92	14.3	9.01
	Ro-Bi-Sp	35.6	1.5	19.2	4.83	11.6	6.62
	Bi-Sp	60	20.28	18.2	9.5	9.8	8.7
	Sp	75	23.17	14.5	2.69	6.3	1.48
K (mg·kg^{-1})	Sp old	406.4	72.02	88.8	10.17	39.2	3.82
	Gap	521.2	86.58	166.2	31.36	67.4	9.95
	Ro-Bi	691.5	87.27	238.5	47.1	79.5	9.76
	Ro-Bi-Sp	465.2	91.18	138.2	30.64	61.2	11.97
	Bi-Sp	687.6	189.49	199.4	41	93.2	17.97
	Sp	599	55.52	190	28.04	90	11.25
Ca (mg·kg^{-1})	Sp old	1355.2	173.84	313.8	50.64	237.4	13.78
	Gap	1768.4	145.63	628.6	96.05	347.4	35.49
	Ro-Bi	2656.5	325.28	854.3	76.36	341.5	38.77
	Ro-Bi-Sp	1539.6	158.46	446.4	58.97	254.8	21.89
	Bi-Sp	2262.4	451.49	594	81.16	318.8	60.68
	Sp	1853	211.73	658.3	153.24	350	71.6
Mg (mg·kg^{-1})	Sp old	163.2	19.12	50	5.76	38.2	2.14
	Gap	213.6	21.89	70	12.84	41.6	3.83
	Ro-Bi	383.5	44.46	95.3	13.33	48.8	4.66
	Ro-Bi-Sp	237.2	45.19	68.6	3.38	41	2.37
	Bi-Sp	370	113.07	78.2	6.11	43.8	4.35
	Sp	226	40.42	74	11.36	37.5	6.8

SD – standard deviation; Sp old – Spruce old; Gap – No trees present; Ro – Rowan; Bi – Silver birch; Sp – Norway spruce

utable to their better colonization capability compared to zoochorous rowan (see Dostalova 2009). Rowan was also found to recruit in advance of gap formation (Żywiec, Ledwoń 2008).

Forest floor humus and topsoil. Mean amounts of Hum (L, F, H) layers ranged between 170 and 450 g·m^{-2}. The 13-year-old spruce showed significantly lower values compared to other treatments.

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Table 4. To be continued – Mean concentrations of oxidizable carbon (Cox) and nutrients in Hum, Ah and B horizons from the treatments studied: (B) multiple comparisons (Kruskal-Wallis (*P*))

(B) Treatment comparison	Cox (%)			N (%)			P (mg·kg^{-1})			K (mg·kg^{-1})			Ca (mg·kg^{-1})			Mg (mg·kg^{-1})		
	Hum	Ah	B	Hum	Ah	B	Hum	Ah	B	Hum	Ah	B	Hum	Ah	B	Hum	Ah	B
	0.004	0.003	0.001	0.045	<0.001	0.002	0.001	0.004	0.073	0.019	0.004	0.001	0.002	<0.001	0.004	0.004	0.003	0.070
Bi-Sp × Gap																		
Bi-Sp × Ro-Bi																		
Bi-Sp × Ro-Bi-Sp																		
Bi-Sp × Sp																		
Bi-Sp × Sp old											*	*	*			*		
Gap × Ro-Bi																		
Gap × Ro-Bi-Sp																		
Gap × Sp																		
Gap × Sp old	*														*			
Ro-Bi × Ro-Bi-Sp					*									*				
Ro-Bi × Sp																		
Ro-Bi × Sp old		*	*		*		*	*			*		*	*		*	*	
Ro-Bi-Sp × Sp					*	*												
Ro-Bi-Sp × Sp old	*																	
Sp × Sp old		*	*		*	*	*				*	*						

Sp old – Spruce old; Gap – No trees present; Ro – Rowan; Bi – Silver birch; Sp – Norway spruce

This is likely attributable to the stand age and also to the time when spruces shed their foliage as the litterfall begins in the oldest needle age classes. For example Kayama et al. (2002) reported the Norway spruce needle half-life longer than 5 years; another half of needles was shed by year 7 (Kayama et al. 2007). Therefore one can estimate the total amount of needle litterfall accounts for no more than two needle classes in Sp treatment. Besides that, the young spruce canopy closure reduced light levels penetrating to the surface, which is also likely to diminish ground vegetation contributing to an amount of litter.

Interestingly, Sp acidity did not differ significantly from the treatments with early successional species though Carnol, Bazgir (2013) found both rowan and birch as increasing the forest floor pH and particularly rowan contributed to higher levels of forest floor base cations compared to spruce. Martiník et al. (2017) revealed a significant positive impact of aspen on both forest floor and topsoil as it increased pH significantly compared to spruce, beech and birch below the 20-year-old stand that replaced the declining mature spruce stand at the end of the 1990s at lime-rich sites with potential oak-hornbeam vegetation. On neutral to moderately alkaline soils were reported effects of glades increasing significantly soil pH compared to dominantly deciduous-broadleaf forest (Rhoades et al. 2005). Schua et al. (2015) reported that spruce litter of different ages could be found in the Of horizon, while birch litter consisted mainly of the leaves from the preceding autumn, which reflects more intensive decomposition rates typical of many broadleaves. In our study, the young spruce has not impacted on the Hum (L, F, H) properties probably due to almost negligible litterfall.

The Sp old differed significantly from the other treatments. After clear-cutting, many processes related to fine roots and mycorrhizal fungi cease and/or decrease and saprotrophic species relative abundance increases (see Kohout et al. 2018). The better chemical properties under Gap and early successional young stands can, therefore, be a result of breakdown of the preceding forest ecosystem organs and fungal communities typical of mature spruce forest. These processes can also be affected by warming up of surface humus and upper soil layers as reported by Dymov, Startsev (2016) in taiga spruce forest after clear-cutting. Increased concentration of plant-available calcium in gaps formed in old-growth spruce-pine-birch forest with bilberry

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Table 5. Soil sorption complex (Kappen) in Hum, Ah and B horizons according to the treatments: (A) average and standard deviation, (B) multiple comparisons (Kruskal-Wallis (*P*))

(A)	Treatment	Hum		Ah		B	
		Average	SD	Average	SD	Average	SD
BCC (mmol·kg^{-1})	Sp old	12.5	3	1.6	0.5	0.4	0.1
	Gap	15.7	4	5.5	1.1	1.6	0.6
	Ro-Bi	23.1	2.8	5.9	1.2	0.3	0.2
	Ro-Bi-Sp	18.1	2.7	3.7	0.8	1.1	0.3
	Bi-Sp	23.7	7	5.2	0.8	1	0.6
	Sp	15.9	2.1	4.7	0.7	0.8	0.6
CEC (mmol·kg^{-1})	Sp old	67.8	7.2	24.4	3.3	13.1	1.2
	Gap	43.9	9.3	22	3.4	10.8	1.3
	Ro-Bi	66.8	4.6	33	3.7	11.5	1.7
	Ro-Bi-Sp	67.6	9.9	28.5	4.7	15.1	2.6
	Bi-Sp	58.1	11.1	23.1	3	11	1.7
	Sp	52.8	12	31.2	3.8	14.6	1.3
BS (%)	Sp old	18.6	4.8	6.6	1.1	3.2	0.9
	Gap	35.4	1.7	25.1	3.6	14.4	4
	Ro-Bi	34.4	2.3	17.7	2.5	2.6	1.9
	Ro-Bi-Sp	27	2.8	13.3	3.6	7.2	1
	Bi-Sp	40.4	7.8	22.7	4.1	8.7	3.9
	Sp	31.9	9.2	15	2	5.6	4.3

(B) Treatment comparison	BCC			CEC			BS		
	Hum	Ah	B	Hum	Ah	B	Hum	Ah	B
	0.013	0.003	0.010	0.033	0.008	0.023	0.001	< 0.001	0.005
Bi-Sp × Gap									
Bi-Sp × RoBi									
Bi-Sp × RoBiSp									
Bi-Sp × Sp									
Bi-Sp × Sp old		*					*	*	
Gap × Ro-Bi			*		*				*
Gap × Ro-Bi-Sp									
Gap × Sp									
Gap × Sp old		*					*	*	*
Ro-Bi × Ro-Bi-Sp									
Ro-Bi × Sp									
Ro-Bi × Sp old	*	*							
Ro-Bi-Sp × Sp									
Ro-Bi-Sp × Sp old									
Sp × Sp old									

Sp old – Spruce old; Gap – No trees present; Ro – Rowan; Bi – Silver birch; Sp – Norway spruce BCC – base cation content; CEC – cation exchange capacity; BS – base saturation

undergrowth was found by Nygaard et al. (2017). Also logging residues left at the site after clear-cutting can contribute to additional inputs of nutrients (Siebers, Kruse 2019). Lower pH under older treat-

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ment is comparable to Shresta, Chen (2010) findings; they reported decreasing pH with the stand age in boreal conditions. From this point of view, if spruce dominates the stand again, the forest floor and soil properties are likely to shift towards more acidic conditions described in the Sp old treatment.

CONCLUSION

The study of stand variability and soil properties under different types of naturally regenerated young stand developed on large clearcut, in forest gap and under adjacent mature spruce stand proved the following essential findings:

Birch prevailed in the early successional juvenile mixed stands so far and spruce was the dominant species in understorey. Birch dominated both in number and height. Old spruce forest floor was both more acidic and nutrient poorer compared to all juvenile forest floors including the gap. Young spruce stand accumulated less topsoil humus than the other treatments, the differences in soil chemical properties below juvenile spruce from the mixed treatments with early successional broadleaves were scarce.

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