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EFFECT OF STAND EDGE ON THE NATURAL REGENERATION OF SPRUCE, BEECH AND DOUGLAS-FIR

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Abstract

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Our work aimed at studying the strategy of woody plants regeneration during the regeneration of a spruce stand with the admixture of beech and Douglas-fir by border cutting (NW-SE aspect) on acidic sites of higher elevations in the Bohemian-Moravian Upland. Spruce is better adapted to bear shade than Douglas-fir. Nevertheless, in optimal light conditions up to a distance of ca. 35 m (about 16% DIFFSF) from the stand edge, the Douglas-fir can put the spruce into danger as to height growth. By contrast to beech, the density of spruce is significantly higher within the distance of 45 m (about 15% DIFFSF) from the stand edge but further on the situation would change to the benefit of beech. The density of Douglas-fir significantly dominates over beech within a distance of 35 m from the stand edge; from 55 m (less than 15% DIFFSF), the situation changes in favour of beech. Beech can survive in full shade deep in the stand core waiting for its opportunity to come. As compared to spruce and Douglas-fir, the height growth of beech was at all times significantly greater at a distance of 25 m from the stand edge. Converted to practical conditions, spruce and Douglas-fir with individually admixed beech seedlings showed good prosperity approximately up to a distance of one stand height from the edge. A mixture of spruce and beech did well at a greater distance but good prosperity at a distance of 2–3 stand heights was shown only by beech. Thus, border regeneration eliminates disadvantages of the climatic extremes of clear-cutting and specifics of shelterwood felling during which one – usually shade-tolerant tree species dominates in the natural regeneration (e.g. beech).

edge effect, natural regeneration, spruce, beech, Douglas-fir

General mission of sustainable forestry is to achieve mixed stands with the site-corresponding composition of woody species, optimally developed through natural regeneration. However, the purposeful control of the regeneration of existing parent stands is difficult without the knowledge of the regeneration and growth strategy of individual species in the target mixture.

Our work aimed at studying the strategy of woody plants regeneration during the border regeneration of a spruce stand with the admixture of beech and Douglas-fir by border cutting. Key data for our study were those on light requirements and competitive relations among naturally regenerated target species, i.e. spruce, beech and Douglas-fir.

A method of regenerating spruce stands with the admixture of other tree species on natural fir-beech sites increasingly used in the Czech forest practice is border regeneration. The specific variegated mosaic of ecological conditions on the outer (clear-cut or shelterwood strip sized 0.5–1.0 of the height of the exploited stand) and inner (shelter up to 1.0–1.5 of the height of the exploited stand) stand edges is favourable for many woody plants with different light requirements to strike roots (Korpeľ, 1995). On the outer, optimally northern edge, Poleno and Vacek (2009) distinguish 3 zones of light conditions: a) along the stand wall where the shade duration and intensity are considerably long – suitable for shade-bearing woody plants; b) middle zone – root competition and shade diminish – suitable for half-shade bearing woody plants; c) the zone that is most remote from the stand wall, whose ecological conditions partly near a clear-cut area – suitable for sun-tolerant woody plants.

In terms of light requirements, spruce belongs in the category of shade-tolerant tree species, i.e. it is a half-shade bearing woody plant. This characteristic ranks the spruce with the climax species, i.e. species occurring at the end of the forest development stage (Poleno and Vacek, 2007). Beech is a shade-bearing climax woody plant (Mráček, 1989). Douglas-fir is characterized as a light-demanding species, which is tolerant to lateral shade only at young age (Úradníček and Chmelař, 1995).

Beech can survive up to several years at extremely low radiation values 3–5%; however, its growth would be very slow and the growth response to release very instant (e.g. Collet *et al.*, 2001; Wagner *et al.*, 2010). Assessing the competitive relations of beech and spruce regeneration in relation to light and/or other stand characteristics, a majority of works arrive at a similar value of relative radiation (ca. 15%) or basal area (ca. 30–35 m^2) as a certain threshold of the two species. Below this limit, beech would maintain its advantage and above this limit, the height growth of spruce would begin to catch up with the beech. Above 20%, beech would loose the advantage and would be surmounted by spruce as to height growth (e.g. Leder and Wagner, 1996; Unkrig, 1997; Kühne and Bartsch, 2003; Stancioiu and O’Hara, 2006). According to Saniga (1990), the degree of shelter at ≤ 62.5% (in beech stands) creates lower prerequisites for the growth competitiveness of spruce if admixed in clumps. With the basal area reduced to about 60% of the fully stocked stand, the spruce regeneration would start to overtake the beech (Leder *et al.*, 2003).

Bušina (2006) claims that a decisive condition for Douglas-fir germinate and further grow is light accessing the stand from above or from below-side. Insufficient or excessive light is considered an unfavourable condition. Regeneration of Douglas-fir on stand edges is therefore more certain and more abundant than regeneration under the stand; this is why various methods of border and strip felling and/or group felling are recommended. According to Kinský and Šika (1987), Douglas-fir regenerates only with difficulties under closed canopy; self-seeded plants soon die due to shade and root competition. Similarly, Malinová (2003) points out a conclusive influence of light in the development of natural regeneration. If the shelter stand density is high, the Douglas-fir either would not strike roots at all or would disappear within a short time. According to Blaščák (2003), the Douglas-fir is more light- intensive at regeneration than the spruce. By contrast, Bušina (2006) observed that the self-seeded spruce has higher light requirements in the first years than the Douglas-fir and can do better against weed competition, too.

METHODOLOGY

The research object consists of three spruce stands on acidic sites of higher elevations (type of site – Czech management unit 531) that have been worked by border felling from the northeast (Tab. I). The experimental stands are situated in the Bohemian-Moravian Upland near the town Pelhřimov at identical altitudes of 630 ma.s.l., in flat lands where the mean annual precipitation amount is about 700 mm and the mean annual temperature is ca. 6 °C. The Křemešník locality (RP I) shows the regeneration of beech and Douglas-fir as admixture in addition to spruce (Tab. I) while the second and third (RP IIa and IIb) stands contain only the regenerating spruce. All localities were subjected to border felling (made ca. 8 years ago) – strip wide up to one stand height, at all times in NW-SE aspect as the most commonly used regeneration procedure of spruce stands in the given conditions. The similar natural and stand conditions make it possible to compare the course of natural regeneration.

A representative research plot was established in each stand (three in total) sized 50 × 50 m, oriented at all times from the stand edge (except of RP I) into the stand interior. Regarding the regeneration of shade-tolerant beech on RP I deep in the stand, the research plot boundary had to be moved in this case to a distance of about 20 m from the stand edge. At all times, the research surveys took place in the centres (1 m^2 around the centre) of partial research plots 5 × 5 m (300 in total) distributed in regular grid within each 50 × 50 m plot. Stand parameters ascertained on the partial plots were as follows: basal area (G) by using prism wedge (m^2), distance to stand edge (B) in metres, diffuse site factor (DIFFSF%) and direct site factor (DIRSF%) by fish-eye method (Nicon Coolpix 4500 + fisheye convertor FC-E8 assessed by means of WinsCanopy 2008a). We mesured these parameters of regeneration: tree density per 1 ha,

I: *Research plots data*

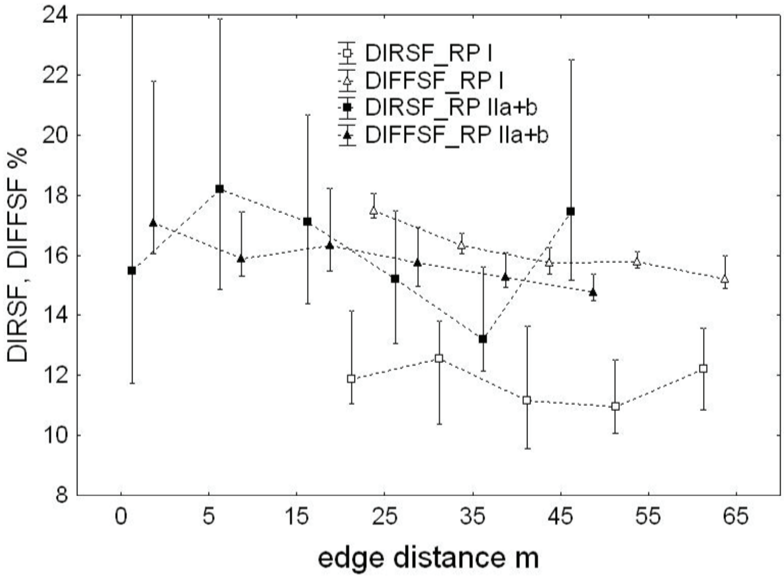
RP	Stand	Area ha	Age years	Stock density	Volume $m^3.ha^{-1}$	Admixture	N	E
I	33a10	5.57	102	0.9	563	5 % beech and Douglas-fir	49°24’47”	15°19’16”
IIa	305 B 12a/2s/1r	9.68	118	1	723		49°19’49”	15°1’9”
IIb	305 A 12a/2p	5.98	113	1	719		49°19’49”	15°1’9”

height in metres and height increment as an average of the last two years.

We analyzed the relation between the categorized distance (values representing centres of the intervals of 10 m) from the stand edge and light conditions, and regeneration characteristics. The Kruskal-Wallis test and t-test were further used to test the dissimilarity of the parameters of regeneration.

RESULTS

The predominantly spruce stands are in the initial stage of regeneration, which is corresponded to by the relatively low values of direct and diffuse radiation (ca. 15%) on both research localities (Tab. II). Radiation values on the two plots rather decrease with the increasing distance from the stand edge (Fig. 1). On RP I, the values of not-decreasing direct radiation are at all times markedly lower than the values of mildly decreasing diffuse radiation. On RP IIa and IIb, the mean values of diffuse and direct radiation are relatively equable with the ration of direct and diffuse radiation changing approximately at a distance of 15 m from the stand edge (Fig. 1). The unexpected increase of direct radiation at a greater distance from the stand edge on both research plots was apparently due to local gaps in the crown canopy.



1: *The mean values of direct and diffuse site factor according to category of edge distance*

II: *Regeneration and light attributes*

	median/avg	25%	75%	min	max
DIRSF RP I [%]	11.8	10.4	13.5	5.7	16.4
DIRSF RP IIa+b [%]	15.7	13.1	19.5	7.2	44.9
DIFFSF RP I [%]	16.2	15.6	16.8	13.8	18.9
DIFFSF RP IIa+b [%]	15.8	14.9	17.0	9.7	31.4
Density_spruce RP I [1000.ha^{-1}]	20.0/37.7	0.0	75.0	0.0	160.0
Density_spruce RP IIa+b [1000.ha^{-1}]	50.0/85.45	0.0	150.0	0.0	460.0
Density_beech RP I [1000.ha^{-1}]	0.0/10.8	0.0	20.0	0.0	70.0
Density_Douglas-fir RP I [1000.ha^{-1}]	0.0/5.9	0.0	10.0	0.0	100.0
Height_spruce RP I [cm]	32.0	25.0	44.0	20.0	65.0
Height_spruce RP IIa+b [cm]	32.0	18.0	59.0	10.0	103.0
Height_beech RP I [cm]	55.0	40.0	70.0	20.0	200.0
Height_Douglas-fir RP I [cm]	80.0	50.0	110.0	20.0	150.0
Height increment_spruce_RP I [cm]	4.0	2.5	5.8	1.0	9.5
Height increment_spruce RP IIa+b [cm]	6.5	3.6	8.9	1.0	15.1
Height increment_beech RP I [cm]	11.3	8.3	15.0	6.5	67.0
Height increment_Douglas-fir RP I [cm]	12.0	8.5	15.0	4.0	20.5

Under the given stand and light conditions, the highest mean value of regeneration density was found in spruce on both research plots (Tab. II), followed by beech and Douglas-fir on RP I. Another situation was detected in height growth where the greatest mean height was found in Douglas-fir followed by beech. Mean values of height increment in beech and Douglas-fir are similar and greater than in spruce. Dynamics of spruce density and height growth in relation to the stand edge were similar in the two localities (RP I, II) (Figs. 2–4). However, the dynamics of density and height growth were significantly affected by the distance from the stand edge (Tab. III, Figs. 2–4).

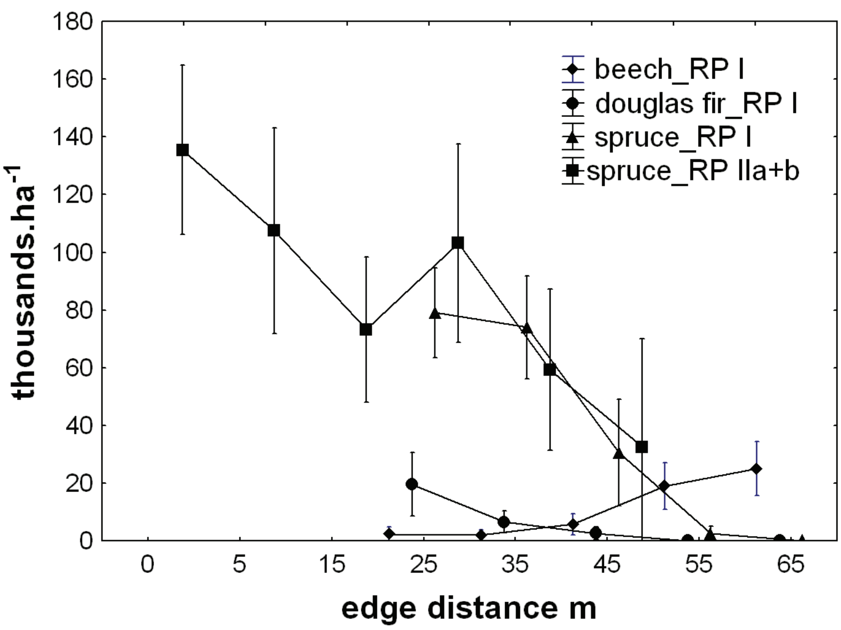
III: *Spearman correlation coefficient – relation between the distance from the stand edge, light conditions and regeneration*

	Edge distance
DIRSF RP I	–0.075
DIRSF RP IIa+b	–0.225
DIFFSF RP I	–0.733
DIFFSF RP IIa+b	–0.362
Density_spruce RP I	–0.810
Density_spruce RP IIa+b	–0.389
Density_beech RP I	0.593
Density_Douglas-fir RP I	–0.631
Height_spruce RP I	–0.785
Height_spruce RP IIa+b	–0.335
Height_beech RP I	–0.575
Height_Douglas-fir RP I	–0.758
Height increment_spruce_RP I	–0.709
Height increment_spruce RP IIa+b	–0.409
Height increment_beech RP I	–0.550
Height increment_Douglas-fir RP I	–0.571

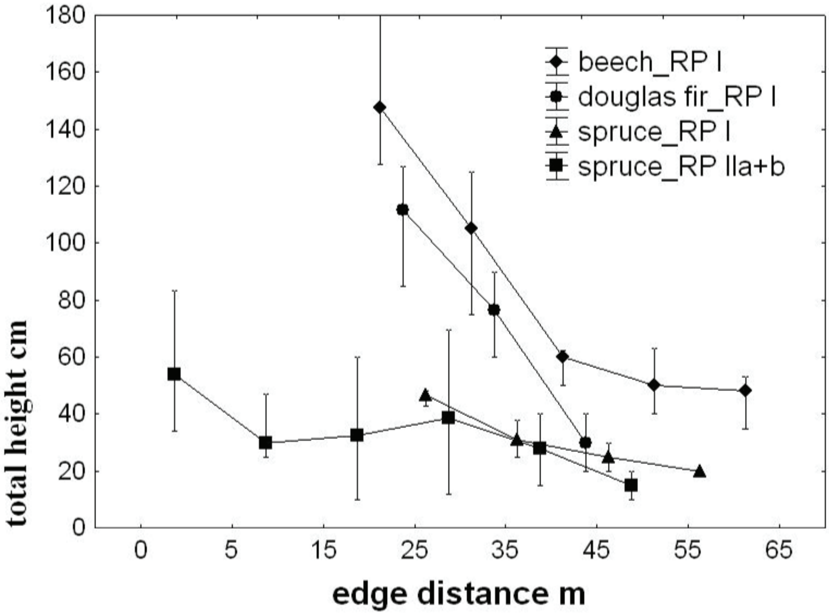
A majority of measured regeneration parameters showed negative correlations with the distance from the stand edge, apart from the regeneration density of shade-tolerant beech – positive correlation (Tab. III).

The density of beech surmounts that of Douglas-fir and spruce at a distance of ca. 40 m and 50 m from the stand edge, respectively (Fig. 2). The significance of compared density values for the pairs of tree species in the individual categories of distance from the stand edge is shown in Tab. IV. By contrast to beech, the density of spruce is significantly higher within the distance of 45 m from the stand edge but further on the situation would change to the benefit of beech. Douglas-fir significantly dominates over beech within a distance of 35 m from the stand edge; from 55 m, the situation changes in favour of beech.

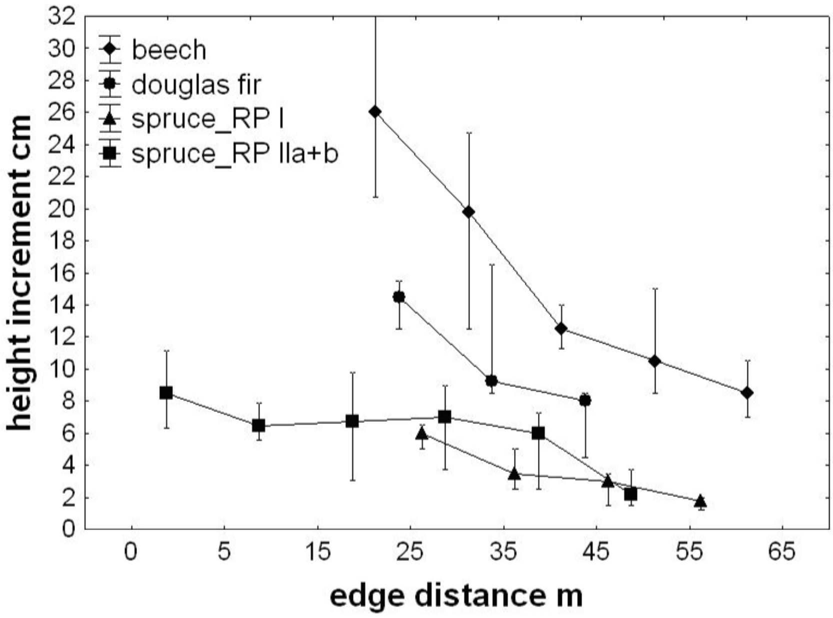
Although the height growth decreased with the increasing distance from the stand edge, the rate of decrease differed in all tree species (Figs. 3 and 4). While spruce and Douglas-fir showed a similar trend of distinct height growth decrease, the decrease of height growth in beech was only mild. As compared to spruce and Douglas-fir, the height growth of beech was at all times significantly greater at a distance of 25 m from the stand edge (Tab. IV). As compared to spruce, the height growth of Douglas-fir was significantly greater up to the measured distance of 45 m. From a distance of 55 m from the stand edge where the values of height increment are already negligible in spruce and Douglas-fir does not occur any more, beech still shows very good prosperity.



2: *The mean values of density of regeneration according to category of edge distance*



3: *The mean values of height increment of regeneration according to category of edge distance*



4: *The mean values of total height of regeneration according to category of edge distance*

IV: *Statistical tests of the dissimilarity of the regeneration according to category of edge distance*

Edge distance	spruce vs. beech		spruce vs. Douglas-fir		beech vs. Douglas-fir	
	Density	Height incr.	Density	Height incr.	Density	Height incr.
25		●	●	●	●	●
35	●	●	●	●	●	●
45		●	●	●		●
55	●	●	●		●	
65	●	●			●	

DISCUSSION AND CONCLUSIONS

For planning the spatial and temporal parameters of natural forest regeneration, the forest manager needs data about the representation of individual tree species for the regeneration and silvicultural goal. In our work, we studied the space pattern and growth characteristics of the natural regeneration of spruce, Douglas-fir and beech on the inner stand edge (NW-SE aspect) during the border forest regeneration (acidic sites of higher elevations). Our results corroborate the findings of many other authors (e.g. Leder and Wagner, 1996; Unkrig, 1997; Kühne and Bartsch, 2003; Stancioiu and O'Hara, 2006b; Bušina, 2006 and others) about the shade tolerance of the given tree species – by the order expressed as Douglas-fir-spruce-beech. Whereas the spruce and the Douglas-fir regenerated at the stand edge, beech did very well in the stand core.

Assessing the shade-tolerant character only according to the density of attending woody plants could be misleading with regard to the different number of fructifying trees (in our case dominant spruce). It advised to use direct evaluation of height growth instead. In any case, spruce is better adapted to bear shade than Douglas-fir. Nevertheless, in optimal light conditions up to a distance of ca. 35 m from the stand edge, the Douglas-fir can put the spruce into danger as to height growth. In given conditions, the competition line between spruce and Douglas-fir is about 40 m from the edge. When the height growth dynamics was assessed alone, the beech demonstrably showed a similar trend as the Douglas-fir from a distance of 25 m from the stand edge and thus surmounted the spruce. In agreement with many other authors, we confirmed the broad ecological valence of beech and the species' high adaptability to changing conditions of the environment. Beech can survive in full shade deep in the stand core waiting for its opportunity to come, as corroborated also by Collet *et al.* (2001).

Converted to operational conditions, spruce and Douglas-fir with individually admixed beech seedlings showed good prosperity approximately up to a distance of one stand height from the stand edge. A mixture of spruce and beech did well at a greater distance but good prosperity at a distance of 2–3 stand heights was shown only by beech. Species occurring on the outer stand edge, which was not subject of our research, were only spruce and Douglas-fir. With using the given regeneration procedure on the given sites we can therefore expect coming into existence of a variegated valuable mixture of tree species with a high production potential.

It was demonstrated that the existence of stand edge has far-reaching importance in forest development. Stand edge is an element that significantly affects light conditions, the structure of natural regeneration and hence the structure of the following forest generation, which is generally confirmed by all books on silviculture (Korpeľ, 1995; Poleno and Vacek, 2009).

The combination of the open area environment (outer stand edge) and the stand canopy (inner stand edge) provides diverse ecological conditions creating prerequisites for the development of a variegated composition of tree species according to specific requirement of individual species. The outcome is a stand mixed of sun-tolerant, semi-shade bearing and shade-tolerant species. Thus, border regeneration eliminates disadvantages of the climatic extremes of clear-cutting and specifics of shelterwood felling during which one – usually shade-tolerant tree species dominates in the natural regeneration (e.g. beech).

SUMMARY

Our work aimed at studying the strategy of woody plants regeneration during the regeneration of a spruce stand (Tab. I) with the admixture of beech and Douglas-fir by border cutting on acidic sites of higher elevations in the Bohemian-Moravian Upland. Stand edge is an element that significantly affects light conditions, the structure of natural regeneration and hence the structure of the following forest generation. In our work, we studied the space pattern and growth characteristics of the natural regeneration of spruce, Douglas-fir and beech on the inner stand edge (NW-SE aspect) during the border forest regeneration (acidic sites of higher elevations). Our results corroborate the findings of many other authors about the shade tolerance of the given tree species - by the order expressed as Douglas-fir-spruce-beech. Whereas the spruce and the Douglas-fir regenerated at the edge, beech did very well in the stand core (Tab. II, Fig. 2, 3 and 4). In agreement with many other authors, we confirmed the broad ecological valence of beech and the species' high adaptability to changing conditions of the environment. Beech can survive in full shade deep in the stand core waiting for its opportunity to come. Converted to practical conditions, spruce and Douglas-fir with individually admixed beech seedlings showed good prosperity approximately up to a distance of one stand height from the edge. A mixture of spruce and beech did well at a greater distance but good prosperity at a distance of 2–3 stand heights was shown only by beech. With using the given regeneration procedure on the given sites we can therefore expect coming into existence of a variegated valuable mixture of tree species with a high production potential. Thus, border regeneration eliminates disadvantages of the climatic extremes of clear-cutting and specifics of shelterwood felling during which one – usually shade-tolerant tree species dominates in the natural regeneration (e.g. beech).

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