Natural regeneration of Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) in forest stands of Hůrky Training Forest District, Higher Forestry School and Secondary Forestry School in Písek

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ABSTRACT: Possibilities are assessed of the natural regeneration of Douglas fir under conditions of Hůrky Training Forest District, Higher Forestry School and Secondary Forestry School in Písek, in stand 12C7, forest type 3K5. The stand is situated at an altitude of 430 m above sea level in an area with mean annual temperature 7.3–7.5°C and mean annual total precipitation 550–575 mm. Under the stand dominated by Douglas fir (65 years of age), natural regeneration of the mean density of 53,800 seedlings/ha appeared due to lateral light coming from the north. The highest density of Douglas fir natural regeneration was noticed under the stand 10–14 m from the stand margin. The light penetrating through the marginal stand wall was found to be of greater effect on the density of natural regeneration than the upper shading caused by the parent stand. With this method of regeneration, Douglas fir is less light-demanding than spruce. Height and height increment of advance regeneration were greater in places with sufficient light near the stand margin. Thus, natural regeneration of Douglas fir is successful there giving conditions for the origin of a new generation of the stand with a sufficient proportion of Douglas fir.

Keywords: Douglas fir; natural regeneration; parent stand; self-seeding; advance growth; radiation

The paper is aimed at an evaluation of the results of spontaneous natural regeneration of Douglas fir. Natural regeneration of forest trees is known as one of the basic and regular processes in the life cycle of every virgin forest. It is important by reason of preserving genetic resources of partial populations of forest species and as compared with artificial regeneration it brings smaller risks of temporary but also permanent impairment of site conditions during regeneration. The use of natural regeneration enables to grow quality stands because the number of individuals from natural regeneration mostly exceeds the number of planted individuals in artificial regeneration many times, thus giving a greater possibility of selection during silvicultural operations.

Natural regeneration of Douglas fir very often occurs spontaneously in stands of the Training Forest District (TFD) Hůrky with respect to the high proportion of the species. Such regeneration can be considered as an indicator of the suitability of environmental conditions for the species. In Hůrky TFD, Douglas fir is grown on 12.2% of the area (79 ha) in 357 stands. The proportion of Douglas fir in forest stands is different, namely from individual interspersed trees to Douglas fir monocultures. Suitable conditions for research into Douglas fir are also given by the fact that the species is represented there in stands of the 1–12 age class (Fig. 1).

Hůrky TFD is situated at an altitude of 370–476 m above sea level, Forest Natural Region South-Bo-

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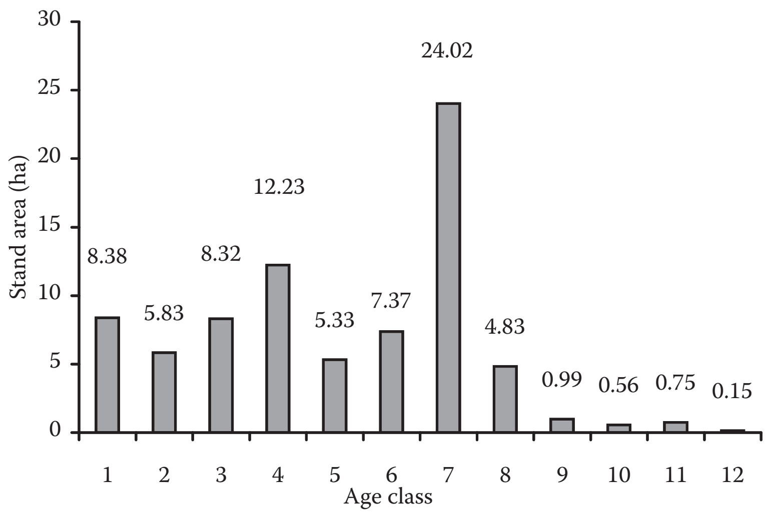

Fig. 1. Proportion of Douglas fir in stands of Hůrky Training Forest District in age classes (according to the working plan as of 1 Jan. 2000)

hemian Basins, mean annual temperature 7.3 to 7.7°C and mean annual total precipitation 550 to 575 mm.

The study was carried out in stand 12C7 with the 90% proportion of Douglas fir. The spontaneous natural regeneration of Douglas fir and other species originated there as a result of felling a neighbouring stand where the access of lateral light under the stand from the north was enabled. Effects of light on the growth of advance regeneration and factors endangering the success of natural regeneration were also studied.

The aim of the study is to characterize favourable conditions for the origin of natural regeneration of Douglas fir and for the subsequent growth of self-seeding and advance regeneration. On the basis of the results we want to determine potential regeneration procedures that could make possible intentional natural regeneration of Douglas fir at required quantity and quality.

AN OVERVIEW AND ANALYSIS OF PROBLEMS OF DOUGLAS FIR NATURAL REGENERATION

In 2004 in forests of the Czech Republic, natural regeneration of all species was recorded on the area of 3,401 ha, i.e. 15% of the total extent of regeneration. Since 2000, the proportion of natural regeneration has been roughly on the same level (Kolektiv 2005). Biological conditions of natural regeneration in Douglas fir are favourable. Úradníček and Chmelař (1995) reported 5- to 7-year intervals between seed years, the beginning of fertility in 20 to 30 years. The fertility is preserved up to high age. Seeds germinate well on the mineral soil, the majority of seeds falling within a distance of 300 m from the stand with bearing Douglas fir trees.

Kinský and Šika (1987) described problems with pollination in individual trees, in small groups and in stands where Douglas fir is only interspersed. There a high proportion of sterile seeds occurs. Female flowers can be damaged by late frosts and seeds are attacked by *Megastigmus spermotrophus* WACHTL.

The natural range of Douglas fir original distribution in North America takes up extensive areas from the coast of the Pacific Ocean to high-elevation locations of the Cascade Mts., from northern Mexico to 56° northern latitude. According to Hofman (1964), this huge range with different natural conditions indicates considerable plasticity of the species. It made it possible to create a large number of provenances with different requirements, growth characteristics and resistance to abiotic and biotic harmful agents. Šika and Vinš (1978) stated that Douglas fir was the most important commercial species in the USA. The species represented nearly ¼ of the growing stock of all coniferous stands. Methods of management in these stands also differ. There are stands that are left to their natural development, and mainly stands where various methods of management of different intensity are used (Kohnle 2001).

Douglas fir is most abundant in the northern part of the Pacific range – in British Columbia, on Vancouver island and in Washington and Oregon. Within the Pacific range, it is possible to define several altitudinal zones differing in the proportion of Douglas fir in stands. According to Hofman (1964), in northern areas of the coastal zone under conditions of humid oceanic climate, Douglas fir manifests itself as a pioneer species with rich fertility, well extensible seed and tolerance to full light. It can quickly occupy extensive bare areas after fires, natural disasters or extensive logging operations. Other species (*Picea sitchensis* CARR., *Tsuga heterophylla* SARG and *Thuja plicata* DON.) occur later under the shelter of Douglas fir. The upper storey of these stands is later created mainly by Sitka spruce and Douglas fir. In uplands and in the submontane zone (in regions of temperate oceanic climate) which is referred to as the climatic and growth optimum of Douglas fir the species reaches about an 80% proportion and forming even pure stands. However, also in these regions, a small regeneration potential of Douglas fir under its stand is noted. Douglas fir is considered to be a climax species only in the driest areas of its natural range where it grows together with various species of pine.

Douglas fir regenerates well in regions out of the range of its natural distribution in countries where it was introduced. Hofman (1964) reported that in the majority of European countries, natural regeneration of Douglas fir occurred under the shelter of a parent stand quite frequently at an age of about 60 years mainly in stands properly tended.

In Bohemia, there is also experience with the natural regeneration of Douglas fir. According to Hofman (1964) lateral regeneration of Douglas fir is more certain and more frequent than regeneration occurring under the Douglas fir stand. It is possible to use various methods of border cutting and strip cutting or perhaps even gap cutting. Douglas fir also regenerates well next to its stand and self-seeding often occurs in young spruce plantations.

Kinský and Šika (1987) dealt with the natural regeneration of Douglas fir in the Květov game preserve. They considered the fact that natural regeneration of Douglas fir took place successfully in countries of Western Europe appearing also in our stands. According to these authors an advantage of this method of regeneration consists in the fact that in parent stands some individuals were preserved which successfully survived climatic extremes in new conditions through selection. Under conditions of the forest type group 3K, Douglas fir naturally regenerated very well, particularly through lateral self-seeding. Continuous regeneration occurred also in places where the nearest Douglas fir trees were within a distance of 25 m.

On the basis of monitoring the stand development in the forest type group 4B Wolf (1998) presented the following findings: natural regeneration of Douglas fir is possible on acid soils with less persistent forest weed. On soils rich in minerals the majority of seedlings dies due to the weed competition, mainly during the second and third year. According to the author's finding self-seeding was nearly missing on water-logged sites.

Šindelář (2003) and Šindelář and Beran (2004) reported that under our conditions it was also suitable and possible to regenerate Douglas fir stands of high quality on favourable sites using natural regeneration. For successful regeneration it was recommended to prepare favourable conditions by the modification of crown closure and suitable scarification or site preparation in the seed year. Sites not infested by weeds or even exposed soils making possible the fast penetration of roots into soil are favourable. Riehl (2000) referred to the experience with drying up Douglas fir seedling in the layer of needle litter during a dry spell.

Malinová (2003) conducted research into Douglas fir natural regeneration in stands of the forest type group 4K of Křtiny TFE which were released by intentional or salvage felling. Mean densities of Douglas fir natural regeneration were high on all trial plots, however, there was a problem with non-uniform distribution on the plot. She found that light conditions provided to self-seeding and advance regeneration were the most important factor affecting natural regeneration. Another important factor is the density of forest weed.

The originated self-seeding and advance regeneration are damaged by game, namely by browsing and fraying. Douglas fir is looked for by game more often if it is rather scarce in the region. In areas with its abundant occurrence damage caused by game is the same as on other tree species. Šika (1988) reported a considerable regeneration potential of Douglas fir after damage.

Based on the evaluation of analyzed information it is possible to conclude that a number of findings on growing Douglas fir makes it possible to work with presented regeneration procedures and care of stands. Particularly natural regeneration of Douglas fir appears to be promising with respect to the higher tolerance to harmful factors, above all physiological drought and game damage. Therefore, it is purposeful to deal with conditions of natural regeneration, regeneration procedures and subsequent care of naturally originating Douglas fir stands, namely under particular stand and ecotope conditions. Thus, with this intention, the present study was also carried out. Moreover, the objective of the study is to implement its results into practical silvicultural recommendations.

MATERIAL AND METHODS

Description of experimental stand

Stand 12C7 is situated at an altitude of 430 m above sea level on a flat ridge with moderate inclination to the north. The stand parent rock is formed of migmatite of orthogneiss appearance, the soil is loamy-sandy poor in nutrients and considerably stony, the soil skeleton often rises up to the soil surface. As for the soil type, it is typical acid Cambisol. Forest floor horizons are as follows: litter L – 1.5 cm, moder F – 0.5 cm, mull H – 2 cm. The thickness of humus horizon Ah is 2–3 cm. The humus form is mor moder to moder. From the aspect of typology, the stand is classified as forest type 3K5 – acid oak/beech community with *Vaccinium myrtillus* on ridges and upper parts of slopes. The herb layer is dependent on light conditions and with respect to soil conditions it is rather poor. At the 12C7 stand margin, particularly *Vaccinium myrtillus* and *Entodon schreberi* occurred, in places with sufficient light also *Calamagrostis arundinacea*. In the shade of stand 12C7, virtually no herbs and mosses occurred.

The stand 12C7 with 90% proportion of Douglas fir (spruce 9%, fir 1%) is of elongated form in E-W direction, stand age being 65 years. From the northern side of the stand, reproduction cutting was carried out in 1984. A narrow strip of the stand was felled using simple border cutting. In 1985, reforestation was carried out using beech, Douglas fir and spruce in the present stand 12C2a. Thus, the access of light was enabled from the northern side to the margin of stand 12C7. Neither site/soil preparation nor intentional reduction of stocking was carried out in the stand. Nevertheless, a considerable amount of spontaneous natural regeneration occurred, particularly of Douglas fir and spruce, which reached deep into the stand 12C7 and also into the young neighbouring stand 12C2a.

Methods of field measurement and evaluation of results

Natural regeneration of Douglas fir in Hůrky TFD was analyzed in stands 12C7 and 12C2a. Two transects were stabilized there 10 m in width in order to cover the occurrence of natural regeneration from the interior of the older Douglas fir stand 12C7 over its margin to stand 12C2a created by a young-growth stand of beech, Douglas fir and spruce. In both transects, two-metre sections were stabilized, i.e. rectangles 2 × 10 m of an area of 20 m^2. The length of the 1^{st} transect was 30 m (15 sections). 10 sections were under a full-grown stand with the predominance of Douglas fir, 1 section under a stand margin and 4 sections in a young stand 12C2a. The length of the 2^{nd} transect was 38 m (19 sections). 13 sections were placed under a full-grown Douglas fir stand, 1 section was under a stand margin and 5 sections were in the neighbouring young stand 12C2a. The longitudinal axis of both transects was oriented perpendicularly to the stand margin in N-S direction.

In particular transects, the following parameters were assessed:

– Density of natural regeneration of Douglas fir and other species. The regeneration density was determined by counting up all individuals of the particular species in transect sections.
– Mortality of Douglas fir and other species was determined at the repeated inventory of the number of trees.
– The age of trees was determined by the calculation of annual increments.
– Health status, damage and marked growth deformities of individuals in natural regeneration were recorded according to the type or origin of damage: low-grade growth, browsing, fraying, dry leading shoot and drying Douglas fir trees.
– The root collar diameter of individual seedlings was measured in E-W direction using a metal slide gauge to the nearest 1 mm.
– The height of individuals of natural regeneration. Douglas fir and other naturally regenerated species were included in height classes at the primary enumeration (Table 1).
– Height increments. Distinct whorls and last year increments were measured and also retrospectively from previous years. Height and height increments were measured to the nearest 1 cm. To measure the root collar diameter, height and height increment in particular years height classes were selected given in Table 2. In each of the height classes, 15 Douglas fir trees were measured.

Table 1. Height classes of Douglas fir and other species in natural regeneration

Height class (cm)														
< 10	10–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–110	111–120	121–200	201–300	> 300

Table 2. Height classes used to assess the root collar diameter, height and height increment

Height class (cm)									
< 10	10–20	21–30	31–40	41–50	51–60	61–70	71–80	81–120	> 120

The first measurement was carried out in 2001, the second one after two years in 2003.

On the basis of acquired data the relationship was analyzed between the density of natural regeneration of Douglas fir and shading by the parent stand and effects of lateral light from the stand margin. Attention was also paid to different demands on light for the successful natural regeneration of Douglas fir and spruce.

In parts of transects situated under the parent stand shelter the dependence of natural regeneration density on shading by the parent stand and the effect of light on the later growth of advance regeneration were determined. For these purposes positions of full-grown trees reaching by their crowns above transects were determined using a rectangular coordinate system (x, y). The measurement was carried out to the nearest 5 cm. In addition, crown projections were measured with a tape in four directions (N, S, E, W) to the nearest 10 cm. Based on data on the position of trees on the plot and parameters of crowns, crown projections were mapped for each of the transects. Areas covered by crown projections (regardless of crown overlapping) were determined with a digital planimeter to the nearest 0.01 m^2. Thus, the shading area was determined in particular sections of the transect the proportion of which (in % of the total area of sections) represents the percentage of shading.

All data were stored and later processed using computer techniques, particularly MS Excel program. The density of regeneration of Douglas fir and other species was assessed separately and numbers of individuals determined in particular sections were converted to m^2 or ha. Determined values were classified to samples and their statistical analysis was carried out. Results were processed in tables and diagrams.

Based on the results of measurements a model distribution of the natural regeneration density of Douglas fir was carried out in relation to a distance from the stand margin. Subsequently, homogeneity of the experimental selection distribution of frequencies was tested by a theoretical model on the level of significance $p = 0.05$. χ^2 test was used. The premise that experimental frequencies differ only randomly and not systematically was set as a zero hypothesis.

RESULTS OF EXAMINATION – ANALYSIS OF NATURAL REGENERATION

Density of natural regeneration

Transect 1 (2001)

The number of individuals of Douglas fir in particular sections (20 m^2) of Transect 1 is given in Table 3. The mean number of individuals of Douglas fir in the whole transect was 60,900 seedlings/ha. The first continuous occurrence of Douglas fir seedlings (25,000 plants/ha) was found in section No. 1 under a closed Douglas fir stand 20 m from its margin. Most individuals of Douglas fir occurred in section No. 4, where 205,000 seedlings/ha of Douglas fir from natural regeneration were found. The parent stand shelter reached 100% there, however, the effects of lateral light from the northern stand margin within a distance of 12–14 m became already evident. Sections 12 to 15 shaded by the young stand 12C2a were almost free of natural regeneration.

As for other species the proportion of spruce in natural regeneration was significant (on average 11,300 plants/ha). Other species occurring on the transect area were as follows: beech (1,100 plants/ha), oak (1,000 plants/ha), fir (100 plants/ha) and sporadically pine, larch, sycamore maple, maple.

Transect 2 (2001)

The number of Douglas fir individuals from natural regeneration in Transect 2 sections is given in Table 3. As compared with Transect 1, stand 12C7 with full-grown Douglas fir trees was less closed. The mean number of individuals in the whole transect was 46,700 seedlings/ha. A higher number of Douglas fir seedlings (32,000 plants/ha) was found under the Douglas fir stand 26 m from its margin. The densest natural regeneration was in section No. 9, where 173,000 seedlings/ha were found. It occurred 8–10 m from the northern stand margin. In sections 15–19 in the young stand 12C2a, the occurrence of Douglas fir natural regeneration was small.

Moreover, the proportion of spruce in natural regeneration was significant amounting to 25,300 seedlings/ha. The following species were interspersed: fir (3,100 seedlings/ha), oak (1,600 seedlings/ha), pine (100 seedlings/ha), beech (100 seedlings/ha) and sporadically maple and larch.

Transect 2 (2003)

In repeated measurements in 2003, a smaller number of Douglas fir individuals occurred in Transect 2 (Table 4). The mean density of Douglas fir natural regeneration was 38,500 seedlings/ha. The highest density (157,000 seedlings/ha) was in section No. 8 some 10–12 m from the stand margin. As for other species, spruce in a number of 11,500 seedlings/ha occurred in natural regeneration, however, a considerable amount of spruce died (some 10,700 dry individuals per ha were recorded). The proportion of other species in the transect was not changed.

Table 3. Number of Douglas fir seedlings according to height classes in particular sections (20 m^2)

Section No.	< 10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–110	111–120	121–200	201–300	> 300	Total
Transect 1 (2001)																
1	24	26														50
2	41	119	12													172
3	35	198	40	1												274
4	13	221	145	27	4											410
5	3	130	129	14	6	1		1			1	1				286
6	1	47	45	18	6	5	2	4			2	1	4	3	1	139
7	2	22	55	38	23	12	2	1	2			3	2		2	164
8	2	22	44	56	35	9	6	6		1			1	2	1	185
9	1	12	25	39	17	10	7		1		1		2	1	4	120
10		5	4	1	1										5	16
11		2	4	1		1				1			1		1	11
12																
13															1	1
14																
15																
Total	122	804	503	195	92	38	17	12	3	2	4	5	10	6	15	1,828
Plants/ha	4,067	26,800	16,767	6,500	3,067	1,267	567	400	100	67	133	167	333	200	500	60,933
Transect 2 (2001)																
1	40	24														64
2	35	21														56
3	43	25	1													69
4	41	32														73
5	51	37	2													90
6	36	45	28	19	1											129
7	33	83	50	23	5											194
8	15	54	83	85	59	35	1					1				333
9	37	39	63	70	70	52	10	4				1				346
10	21	19	25	42	32	33	38	10	7	2	1			1		231
11	3	5	7	8	25	14	17	13	11	6	1		2		2	114
12		2	4	3	2	2	1		3	3	2			4	2	28
13		1	1			1	1	1					1			6
14															1	1
15	4	1														5
16	3															3
17																0
18							1			1					1	3
19	6	4	5	4	3	3	1			1		2				29
Total	368	392	269	254	197	140	70	28	21	13	4	4	3	5	6	1,774
Plants/ha	9,684	10,316	7,079	6,684	5,184	3,684	1,842	737	553	342	105	105	79	132	158	46,684

Table 4. Number of Douglas fir seedlings according to height classes in particular sections (20 m^2)

Section No.	< 10 cm	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–110	111–120	121–200	201–300	> 300	Total
Transect 2 (year 2003)																
1	15	21	4													40
2	22	16														38
3	20	26	1													47
4	38	26	2													66
5	36	28	5													69
6	25	53	24	20	2											124
7	25	63	42	20	7											157
8	3	22	69	105	69	42	2	1					1			314
9	12	20	59	62	64	44	13	6	2	1			1			284
10	6	7	16	31	25	28	31	21	10	8	3	1	1	1		189
11			1	3	5	20	9	15	11	10	5	1	2		2	84
12				2	1	2		3			3	3	2	1	5	22
13			1				2			1			1			5
14															1	1
15		1														1
16																0
17																0
18								1				1		1		3
19		4	4	2	2	2	3				1		2			20
Total	202	287	228	245	175	138	60	47	23	20	12	6	10	3	8	1,464
Plants/ha	5,316	7,553	6,000	6,447	4,605	3,632	1,579	1,237	605	526	316	158	263	79	211	38,526

Mortality of natural regeneration

The density of Douglas fir natural regeneration in Transect No. 2, where repeated measurements were carried out, decreased from average 46,700 to 38,500 plants/ha in the course of two years. In the majority of sections, a decrease in the number of individuals occurred, in three sections the number was not changed. The number of Douglas fir individuals in natural regeneration decreased by 17% during two years. The most numerous occurrence of Douglas fir natural regeneration occurred in sections 8 and 9.

A greater decrease was noted in spruce. Due to dry summer 2003 some 48% spruce regeneration dried up. Losses occurred particularly in height classes from 21 to 80 cm. In the height class of 41–50 cm, even 68% individuals dried up. Marked damage to spruce contrasted with small damage to Douglas fir. Its decrease was also noticeable, however, it occurred above all in lower height classes up to 30 cm and only several taller Douglas fir trees got dry. It is evident that under these conditions Douglas fir regeneration is more resistant to dry spells than spruce.

Dependence of regeneration density on the amount of light

The dependence of natural regeneration density on the influence of lateral light from north (expressed by a distance from the stand margin) and on the percentage of shading by a parent stand determined by the measurement of the shading area of crowns in particular sections of transects was determined separately. Based on the distribution of the number of Douglas fir trees in particular sections it is evident that just the amount of light is one of the main conditions of successful natural regeneration.

Transect 1 (2001)

The values determined in sections 1–11 under the parent stand are given in Fig. 2. The number of individuals in particular sections varied considerably regardless of the shading percentage. The maximum density of natural regeneration occurred in sections under a totally closed parent stand. In sections under the open stand, the density of Douglas fir regeneration was lower. Higher dependence was found in relation to a distance from the northern stand margin (the amount of lateral light). The number of Douglas fir trees gradually decreased from its maximum in section No. 4 (12–14 m from the stand margin) towards the stand interior. It is of interest that with the increasing input of light towards the stand margin (sections 5–10) the regeneration density also decreased to the mean value of 8,000 seedlings/ha in section 10 under the stand margin. In section 11 on a transition to the neighbouring young stand, the density of regeneration was even lower. There, the effects of shading caused by the neighbouring young stand were already noticeable.

Transect 2 (2003)

Values determined in sections 1–14 under the parent stand are given in Fig. 3. The number of individuals from the natural regeneration of Douglas fir did not show a dependence on the percentage of shading in this transect either. The number of Douglas fir in particular sections considerably fluctuated regardless of the % of shading by the parent stand. The high density of regeneration (over 140,000 seedlings/ha) was found in sections 8 and 9 with 88% and 92% shading, respectively. However, in section No. 3 with the same shading (92%), the density of regeneration was markedly lower (24,000 seedlings/ha). Similarly like in Transect 1, there is a dependence on light from the open stand margin. The highest density was found in section No. 8 (157,000 seedlings/ha) 10–12 m from the stand margin. Towards the stand interior, the number of Douglas fir seedlings in particular sections decreased to a value of 20,000 seedlings/ha in section No. 1 some 24–26 m from the stand margin. Towards the stand margin (sections 9–13), the number of individuals decreased to a mean value of 3,000 seedlings/ha in section No. 13 under the stand margin. Even there in section No. 14 on a transition to the younger neighbouring stand, the density of regeneration was low (1,000 seedlings/ha).

Comparing both transects we can conclude that the mean % shading of the stand was similar in both transects, namely in Transect 1 some 88% and in Transect 2 some 83%. Lower % shading in Transect 2 (mainly in remoter sections from the stand margin) favourably affected the origin of Douglas fir self-seeding at a greater distance from the stand margin – up to a distance of 26 m. Lateral light from the north promoted the origin of the high amount of self-seeding to the stand interior to about 14 m. Farther, the number and size of seedlings decreased. From the aspect of silviculture a finding that under given site conditions the effect of lateral light on natural regeneration was more important than the actual shading of the stand was of crucial importance.

To determine the model distribution of natural regeneration density in relation to a distance from

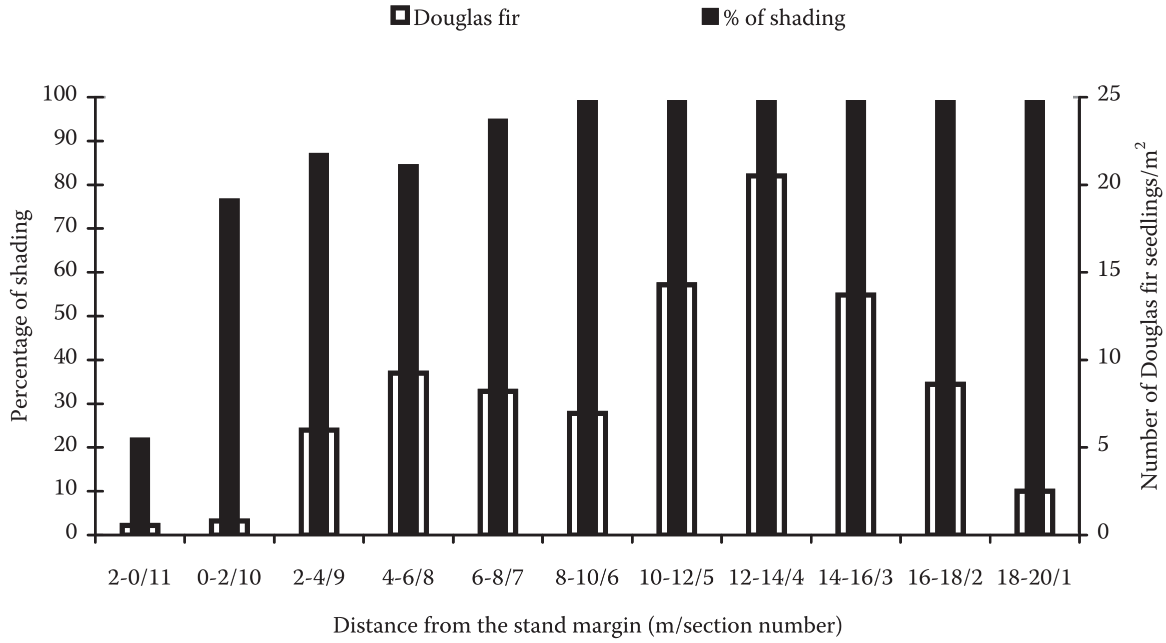

Fig. 2. The number of Douglas fir seedlings in individual sections and the percentage of shading by a parent stand (arranged according to the distance of sections from the stand margin) in Transect 1

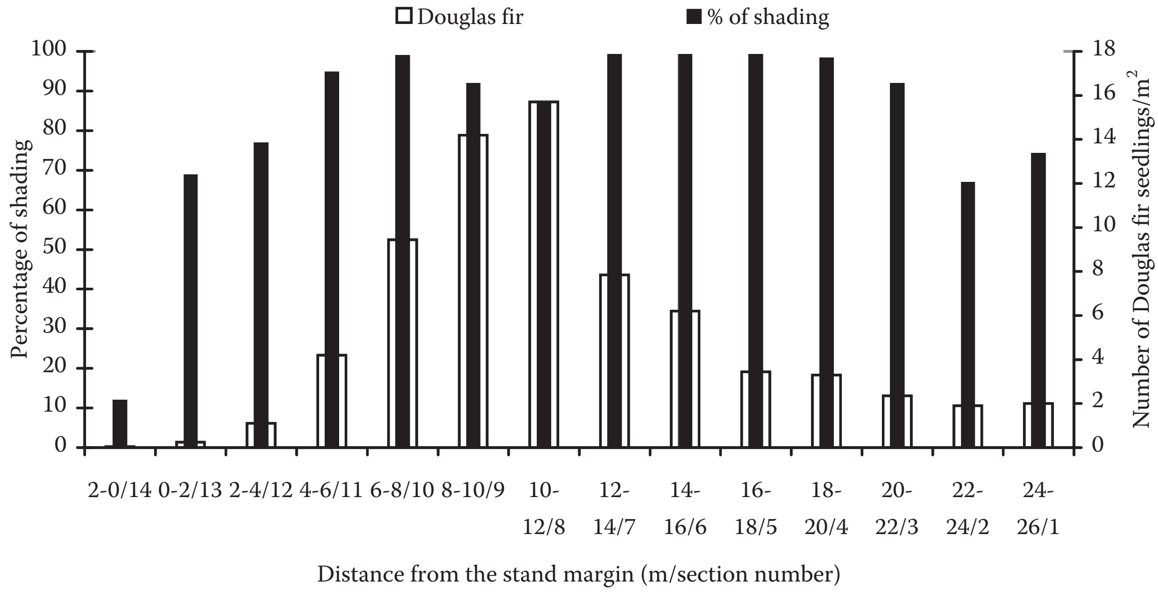

Fig. 3. The number of Douglas fir sedlings in particular sections and the percentage of shading by a parent stand (arranged according to the distance of sections from the stand margin) in Transect 2

the stand margin the values from both transects were used (Fig. 4).

To test the homogeneity of experimental sample distribution of frequencies with a theoretical model χ^2 test was used.

Test criterion:

$$\chi^2 = \sum_{j=1}^{k} \frac{(n_{e,j} - n_{o,j})^2}{n_{o,j}}$$

where: $n_{e,j}$ – experimental frequencies,
$n_{o,j}$ – model frequencies,
k – the number of groups where the sampling was classed at the primary statistical analysis of data

$\chi^2 = 4.45$
$\chi^2_{0.05} = 5.23$
$\chi^2 = 4.45 < \chi^2_{0.05} = 5.23$

The homogeneity of the experimental and model distribution was confirmed at 97% reliability. The difference on the level of significance $p = 0.05$ is not statistically significant.

A comparison of natural regeneration of Douglas fir with that of spruce (Fig. 5) is interesting.

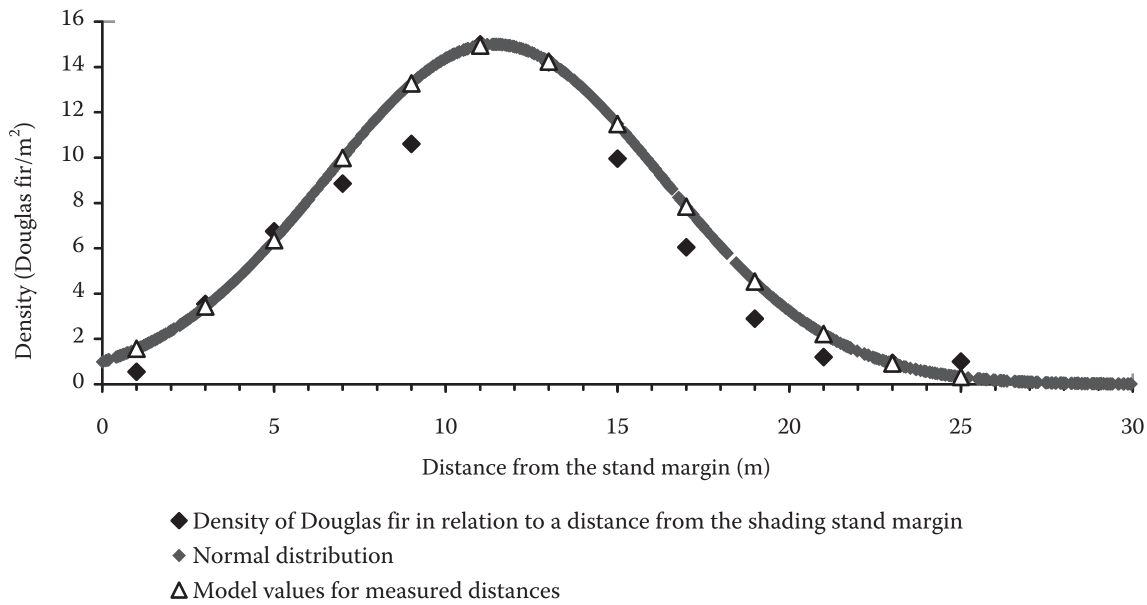

Fig. 4. A theoretical model of the distribution of frequencies of natural regeneration in Stand 12C7 in relation to a distance from the stand margin

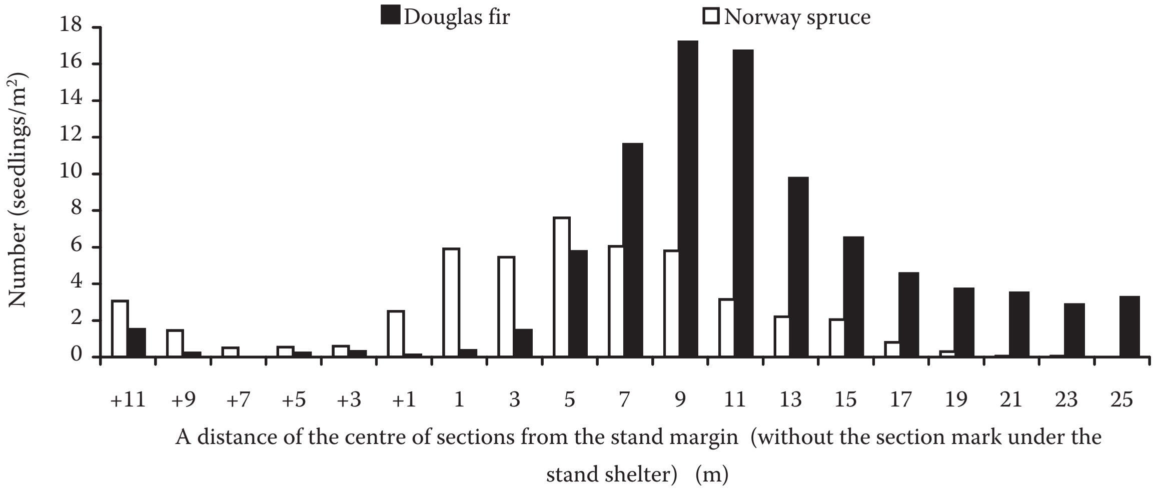

Fig. 5. Comparison of the number of individuals of Douglas fir and spruce in particular sections of Transect 2

Spruce also regenerated sufficiently abundantly in both transects, mainly through self-seeding from neighbouring stands. As compared with Douglas fir, spruce occurred nearer the stand margin, which indicates its higher requirements for light during the first stages of natural regeneration.

Age of Douglas fir in natural regeneration

The age of Douglas fir in natural regeneration was determined in Transect 1 in 2001. The youngest Douglas fir plants were 2 years old, the oldest 15 years old. The majority of Douglas fir seedlings in the transect were four and five years old, namely 27,200 and 22,000 seedlings/ha, respectively. Douglas fir plants aged 10 and 15 years (Table 5) occurred in lowest amounts. With respect to the long-term effect of lateral light (since 1984 when the neighbouring stand was felled) the age structure of natural regeneration was considerably heterogeneous. It means that Douglas fir produced quire regularly seed in the stand.

Health condition and damage to Douglas fir in natural regeneration

In assessing the health condition in Transect 1, it was found that damage or low-grade growth occurred in 540 individuals of Douglas fir (30% of the total number). Damage is given in Table 6. Most Douglas fir trees were damaged by game browsing resulting in low-grade growth in the majority of the cases. Damage caused by fraying was also rather frequent.

In assessing the health condition in Transect 2, damage or low-grade growth were found in 321 Douglas fir individuals (18% of the total number). Damage was caused by similar factors like in Transect 1 (Table 7). After two years, damage or low-grade growth were found in 19% Douglas fir trees (Table 8). Thus, the worsening of the condition of self-seeding and advance growth did not occur. Particularly in older Douglas fir trees, an increased attack by Swiss needle cast (caused by *Phaeocryptopus gaeumannii*) was noted as compared with 2001.

However, with respect to the considerable number of individuals, the existence and subsequent development of natural regeneration are not endangered.

Root collar diameter, height and height increments of individuals from natural regeneration

Transect 1 (2001)

Mean values of the root collar diameter, height and height increments in individual height classes are given in Table 9.

With respect to the considerable age range of individuals in natural regeneration great differences occurred also in measured parameters. The amount of light under the stand showed considerable effects on the rate of growth. The height of seedlings in shaded sections was low and annual increments were small. With the increasing amount of light towards the stand margin the height of Douglas fir trees also increased and at the stand margin where the input of light was highest Douglas fir was also generally tallest.

The minimum diameter of root collar was 1 mm, maximum 44 mm. The smallest seedlings were 7 cm tall, the tallest Douglas firs measured 288 cm. Douglas fir showed the highest proportion in a height class of 11–20 cm, the smallest number of seedlings occurred in a height class of 91–100 cm.

Table 5. Total numbers of Douglas fir seedlings according to age in height classes (Transect 1, 2001)

Age (years)	(cm) < 10	10–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–110	111–120	121–200	201–300	> 300	Total (plants/transect)
2	3	7														10
3	49	64	37	3												153
4	69	596	81	50	17	2										815
5		135	366	99	41	17	2	1								661
6	1	2	17	45	32	18	7	7	2		1	2	1			135
7					2	1	5	2	1	1		1	3			16
8							3	2		1	2	2	3	1		14
9											1		2	2		5
10													1	1		2
11														2	4	6
12															9	9
15															2	2

Table 6. Damage to Douglas fir seedlings in Transect 1 (2001)

Type of damage	Number of Douglas fir seedlings/transect	% number
Low-grade growth	309	16.9
Browsing	152	8.3
Fraying	7	0.4
Dry leading shoot	24	1.3
Drying up	48	2.6
Total	540	29.5

Table 7. Damage to Douglas fir seedlings in Transect 2 (2001)

Type of damage	Number of Douglas fir seedlings/transect	% number
Low-grade growth	236	13.3
Browsing	18	1.0
Fraying	2	0.1
Dry leading shoot	3	0.2
Drying up	62	3.5
Total	321	18.1

Table 8. Damage to Douglas fir seedlings in Transect 2 (2003)

Type of damage	Number of Douglas fir seedlings/transect	% number
Low-grade growth	104	7.1
Browsing	33	2.3
Fraying	2	0.1
Dry leading shoot	2	0.1
Drying up	137	9.4
Total	278	19.0

In 1998–2001, height increment increased virtually in all height classes, marked increment being noted in 2001. In 2001, the largest mean height increment reached 43 cm in Douglas fir in a height class > 120 cm, the smallest increment was 3 cm in Douglas fir in a height class < 10 cm. Height increments in 1996 and 1997 which could be measured only in higher height classes, however, show that in 1998, a decrease in height increment occurred in measured Douglas fir. Douglas fir trees in a height class > 120 cm reached larger height increments in 1996 and 1997 than in the following three years 1998–2000.

Transect 2 (2003)

Mean values of the root collar diameter, height and height increments in particular height classes are given in Table 10.

Site and light conditions in Transect 2 were similar like in Transect 1. The minimum diameter of root

Table 9. Mean values of the root collar diameter, height and height increments of Douglas fir seedlings in particular height classes (Transect 1, 2001)

Height class	Root collar diameter (mm)	Height (cm)	Increment (cm)					
			1996	1997	1998	1999	2000	2001
Less than 10 cm	1.9	8.7				1.6	1.8	2.8
11–20 cm	3.4	17.3			1.9	1.8	2.1	5.3
21–30 cm	4.8	26.8			2.9	3.3	3.1	8.6
31–40 cm	5.7	37.5			3.1	5.9	6.3	13.2
41–50 cm	6.4	47.5			4.1	7.2	8.2	17.8
51–60 cm	7.5	56.7			6.1	8.7	10.2	19.3
61–70 cm	9.3	66.7		7.0	7.4	10.8	11.0	18.9
71–80 cm	10.3	76.1		8.3	7.2	9.9	11.9	23.8
81–120 cm	15.8	104.9		11.3	11.3	12.8	14.6	29.8
More than 120 cm	27.5	204.9	26.0	26.4	18.8	19.8	23.9	42.7

collar was 1 mm, maximum 74 mm. The range of heights was also greater, namely from 5 to 512 cm. Most Douglas fir seedlings were noted in a height class 11–20 cm, the lowest number in a height class 121–200 cm.

The values mentioned above show that till 2001 mean annual height increments increased similarly like in Transect 1. After the great height increment in 2001 (maximum 47 cm in Douglas fir of a height class > 120 cm) a decrease followed in the majority of height classes in 2002. In height classes 81–120 cm and > 120 cm, a decrease in the Douglas fir height increment continued also in 2003.

The causes of the great height increment in both transects in 2001 were not explained demonstrably although the effects of climatic factors are possible. The year 2001 was more humid and cooler as compared with previous two years. The following decrease in 2002 was not obviously affected by climatic factors (2002 was more humid and warmer than 2001) but probably by increasing requirements of the growing up natural regeneration for light.

As for height increment, Douglas fir mostly exceeds spruce in the stage of self-seeding and advance growth although the highest number of Douglas fir seedlings occurred in a height class 11–20 cm (44%) and the highest number of spruce seedlings occurred in a height class 21–30 cm (38%). In the general assessment of natural regeneration Douglas fir takes the position of the main species on a major part of the area. It is necessary to note that spruce does not show its climatic optimum under conditions of TFD Hůrky and its natural regeneration is markedly limited by the amount of precipitation.

DISCUSSION AND CONCLUSION

The results of research carried out in the forest type group 3K in Hůrky Training Forest District show one of the possibilities of natural regeneration of Douglas fir under its parent stand when comparing these results with older literature. However, Hofman (1964), who reported possibilities of natu-

Table 10. Mean values of the root collar diameter, height and height increments of Douglas fir seedlings in particular height classes (Transect 2, 2003)

Height class	Root collar diameter (mm)	Height (cm)	Increment (cm)					
			1998	1999	2000	2001	2002	2003
Less than 10 cm	1.1	7.9					1.9	2.8
11–20 cm	3.0	17.7			3.0	3.5	3.3	3.7
21–30 cm	4.3	26.5			4.4	5.2	3.7	5.1
31–40 cm	5.3	35.5		4.6	5.3	6.7	4.7	6.2
41–50 cm	6.1	46.7	3.7	4.8	6.7	8.5	6.9	8.5
51–60 cm	7.5	55.8	5.4	6.0	7.9	9.8	7.9	9.1
61–70 cm	8.3	65.1	5.8	6.6	11.3	10.9	11.4	11.5
71–80 cm	8.1	75.9	7.5	9.6	11.1	12.2	11.0	11.3
81–120 cm	10.6	94.8	7.5	10.9	12.7	21.5	15.7	13.8
More than 120 cm	35.6	248.2	21.8	27.6	28.8	47.3	31.6	19.8

ral regeneration under conditions of the Czech Republic, stated that "we can find self-seeding under the actual stand of Douglas fir only scarcely". The author ascribed this situation to the high density of stands and recommended regeneration next to the actual Douglas fir stand as a more simple method of natural regeneration.

Under similar conditions of the forest type group 3K, Kinský and Šika (1987) found successful natural regeneration of Douglas fir at the mean density of 400–5,000 trees/ha, i.e. considerably smaller density than that found in Stand 12C7, Hůrky Training Forest District. According to findings of these authors, Douglas fir regenerates with difficulty under a closed stand and the self-seeding soon dies due to shading and root competition of the parent stand. They found the successful regeneration of Douglas fir under heliophilous species (larch and pine) in a mixed stand with Douglas fir. The height increment of Douglas fir natural regeneration reached 20–70 cm at an age of about 10 years. Under conditions of Hůrky Training Forest District, height increments were smaller. The smaller height increments can be caused by various climatic conditions in particular years and the height increment is also affected by the amount of light which can penetrate into the Douglas fir regeneration under the parent stand.

Malinová (2003) found the high density of natural regeneration in Douglas fir (19,500 plants/ha and 66,700 plants/ha) in the forest type group 4K. Similarly like in Hůrky Training Forest District, natural regeneration was affected there by the amount of light and small competition of forest weeds.

Šindelář and Beran (2004) reported the cases of Douglas fir natural regeneration in stands where the intentional conditions for natural regeneration were not prepared. According to these authors, natural regeneration of Douglas fir as well as of other species can be supported by the adjustment of crown cover and suitable site/soil preparation.

It is possible to conclude that recent experience shows the potential of Douglas fir for natural regeneration particularly on acid sites. These findings can be a contribution to a broader discussion on the suitability or unsuitability of using introduced species in forest stands. However, there arises a new question about the risk of replacing indigenous species by Douglas fir within natural regeneration at some sites. In this respect, research into and proposals of optimum stand mixtures with Douglas fir are always topical in order to utilize the high production potential of Douglas fir and not to disturb the ecological stability of forest ecosystem.

Natural regeneration of each species demonstrates its viability and the potential of self-reproduction under conditions of its occurrence. In Douglas fir, an introduced species, this phenomenon can be considered to be one of the indicators of a possibility of using the species under conditions of Hůrky TFD and generally under conditions of acid sites of uplands of the Czech Republic. In the stand where the study was carried out, natural regeneration of Douglas fir occurred spontaneously without any intentional interventions to ensure the regeneration. Thanks to this fact it is also possible to observe the competitiveness of Douglas fir as compared with other "domestic" species. This comparison could be carried out considering the high number of individuals in natural regeneration particularly with spruce, however, spruce cannot be considered to be a "domestic" species in climatic conditions of the 3rd forest vegetation zone. Species that are autochthonous on these sites, i.e. mainly sessile oak and Scots pine, occurred only sporadically in natural regeneration.

In stand 12C7, it was natural regeneration originating due to cutting down a neighbouring stand using clear felling – a simple border cutting. Thus, lateral light from the north penetrated into the stand predominated by Douglas fir. At the stand margin, abundant natural regeneration particularly of Douglas fir and spruce appeared. This regeneration procedure is quite simple and safe because natural regeneration occurred along the whole length of the stand margin (ca 100 m) reaching 20–25 m to the stand interior. Douglas fir predominated over the other species due to its vitality and growth. In the stand margin, the proportion of spruce was also quite high being, however, a little lower than that of Douglas fir. Moreover, after dry summer in 2003, a considerable number of spruce individuals (48%) in natural regeneration died. The highest density of Douglas fir natural regeneration was found 10–14 m from the stand margin. Towards the stand interior, the regeneration density decreased with respect to the lack of light. The regeneration density decreased also towards the parent stand margin with the higher amount of light where the greater competition of forest weeds and spruce can be the cause. In some places, however, self-reduction in the number of growing Douglas fir plants plays its role. From the aspect of light requirements for the germination of seeds and the growth of seedlings in the first years Douglas fir appears to be a modest species tolerating even rather considerable shading, namely higher than spruce. In deep shading 20 and more metres from the stand margin, Douglas fir seedlings occurred, however, they died already during the first growing season.

For the further growth of self-seeding and advance regeneration Douglas fir requires more light as evident from the height and height increments of the species near the stand margin or right under the margin. Deeper under the stand, not only the density of natural regeneration but also its height decreased. At a depth of 12–25 m from the stand margin, Douglas fir seedlings survived but their height increments were low. Effects of shading by the parent stand on the density and height of regeneration showed less markedly in the stand than the effect of lateral light. However, in a stand with more open canopy natural regeneration was detected even at a greater distance from the stand margin (even 26 m).

On the basis of our findings it is possible to state and recommend:

– Natural regeneration of Douglas fir under the northern stand margin is simple and sure in acid sites poor in nutrients and with the small competition of forest weeds.
– It is possible to recommend regeneration by border felling with the procedure of regeneration from the north. Traditional border cutting with an outer margin up to 20 m in width and shaded inner margin within a depth of 30 m is optimal. The outer margin of border felling can be reforested by soil-improving and reinforcing species (e.g. beech). At the same time, it is possible to expect natural regeneration of Douglas fir through lateral self-seeding. Of course, it is supposed that there is a sufficient proportion of Douglas fir of suitable provenance and a site without a risk of heavy weed infestation.
– To ensure the timely release of natural regeneration in the inner margin of border cutting it should be carried out at the height of advance regeneration about 1 m. Later release means losses through the retardation of height increment and higher risk of damage to the young stand by logging operations.
– To preserve admixed spruce as a subordinate species for its nurse function during decreasing the density of advance regeneration, however, at the high stand density its precocious death occurs due to Douglas fir competition or in consequence of drought.
– Beech is a valuable admixed species in a Douglas fir stand for its soil-improving and nurse function. It is necessary to support sporadic beech trees in a stand.
– Fraying done by roe deer is the most important biotic factor causing damage to future Douglas fir crop trees.
– As for abiotic factors, the lack of light and in dry years also the lack of moisture under the stand reduce the number of seedlings.

On the basis of the above-mentioned findings it is evident that Douglas fir shows a very good potential of natural regeneration under the parent stand on this site. The northern margin of the stand ensures favourable microclimatic conditions, mainly sufficient moisture for the germination of Douglas fir seed and the subsequent growth of seedlings even in upland regions rather poor in precipitation. The number of individuals in natural regeneration highly exceeded other species and their vitality was good. The density of regeneration was high and evenly distributed throughout the stand area. At timely releasing successful regeneration can be ensured.

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Přirozená obnova douglasky tisolisté (*Pseudotsuga menziesii* [Mirb.] Franco) v porostech Školního polesí Hůrky VOŠL a SLŠ v Písku

ABSTRAKT: Ve studii jsou posuzovány možnosti přirozené obnovy douglasky tisolisté v podmínkách Školního polesí Hůrky VOŠL a SLŠ v Písku v porostu 12C7 na lesním typu 3K5. Porost se nachází v nadmořské výšce 430 m, v oblasti s průměrnou roční teplotou 7,3–7,5 °C a s průměrným ročním úhrnem srážek 550–575 mm. Pod porostem s převahou douglasky (věk 65 let) se vlivem bočního světla pronikajícího ze severní strany objevilo přirozené zmlazení o průměrné hustotě 53 800 ks/ha. Největší hustota přirozeného zmlazení douglasky byla zaznamenána pod porostem ve vzdálenosti 10–14 m od okraje. Bylo zjištěno, že větší vliv na hustotu přirozeného zmlazení douglasky zde má světlo pronikající otevřenou okrajovou porostní stěnou než horní zaclonění mateřským porostem. Douglaska je při tomto způsobu obnovy méně náročná na světlo než smrk. Výška a výškový přírůst nárostu byly větší v místech s dostatkem světla blíže porostnímu okraji. Přirozená obnova douglasky je zde úspěšná a dává předpoklad vzniku nové generace porostu s dostatečným zastoupením douglasky.

Klíčová slova: douglaska; přirozená obnova; mateřský porost; nálet; nárost; podzáření

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