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Near-natural methods of forest regeneration

Abstract: The study examines the factors involved in the successful artificial regeneration of Norway spruce *Picea abies* (L.) Karst. by plantation or sowing in wood left behind in mountain forest stands. The issues studied are as follows: regeneration in stumps, trunks and disks (logs); regeneration in wood at various stages of decomposition; regeneration under the stand canopy and on clearings. The work brings a description of technological procedures to ensure success of this regeneration method.

Additional key words: Norway spruce, decomposing wood, regeneration

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Introduction

The success of regenerating mountain forests depends very much on severe climatic conditions which often in synergy combine with air-pollution, rapid disintegration of stands whose tending was neglected, weeds and damage due to game. Although there are several technological procedures of artificial regeneration fitted for the mountain treeline, all of them should respect biological approaches with the limiting factors being light, warmth and plantation within the reach of ecological screen, application of the right species of suitable genetic origin and use of the planting stock of corresponding morphological and physiological quality.

Norway spruce in mountain forests regenerates nearly as a rule on fallen trunks or in the immediate vicinity of stumps. This indicates that the decomposing wood mass offers good conditions for the rooting and growth of woody species of the upper forest boundary.

Former foresters both at home and abroad made use of that fact not only for natural, but also for artificial regeneration (Svatoš 1941; Pěnčík 1958; Berstein 1960; Gensac 1990). In the Czech Republic, there are several places at which artificial regeneration in wood was recently experimentally tested, without much success, though. The goal of the paper is therefore to analyse the biological aspects of this method of regeneration and to define, on the basis of this analysis, the technological procedures that will ensure its successful application in forestry practice.

Material and methods

An analysis was made of Norway spruce *Picea abies* (L.) Karst. artificial regeneration by planting and sowing in two stands operated by the Hanušovice Forest District of the Czech State Forests and situated on a mountain plateau at an altitude of 1240–1270 m.

The material used for regeneration consisted of natural seedlings from the seed crop of 1992. In 1995, the seedlings were lifted and transplanted into plastic bottomless containers 4 × 4 × 5 cm. The plants were lifted and grown in the immediate vicinity of the plots to be regenerated with the containers being installed directly on the soil surface. The substrate in the containers was a mixture of peat and litter.

The regeneration proper was carried out in 1996 and 1997; this means that the planting was made with the containerised 2 + k1 and 2 + k2 plants whose above-ground part reached about 6 cm.

The plants were planted in spruce trunks (which were cut to a length of about 1.2–5.0 m), stumps and disks cut of logs (disk height ranging from about 15 to 40 cm). The plants with rootballs were placed in bored holes of 5 cm in diameter with the upper part of the rootball being placed at a level of the wood mass surface into which the plants were inserted.

The field investigation and measurements proper were made in the first half of October 1999.

Location of trunks, disks and stumps in the stand

With respect to the fact that the limiting factors to a successful regeneration include light and warmth, special attention was paid to the location of trunks, disks and stumps (i.e. planted seedlings) in the stand. The plants were located in:

– shadow, with the trunks, disks and stumps being placed under trees standing in the stand;
– light, with the trunks, disks and stumps being placed on clearings (gaps), and the minimum distance from the wall (drip) of surrounding trees being a quarter of the stand height;
– in between, with the trunks, disks and stumps being placed under the edge or at a distance of about up to a quarter of stand height from the drip.

Trunk diameter

All trunks were classified into two categories in order to find out whether trunk diameter can affect the rate of wood mass decomposition:

– large diameter trunks, with butt end diameter of over 20 cm;
– small diameter trunks, with butt end diameter of under 20 cm.

Stage of wood mass decomposition

As the stage of wood mass decomposition can and will affect regeneration, all trunks, disks and stumps were monitored for the degree of their decomposition. There were two parameters to evaluate: hardness and rot (from the physiological point of view, it is putrefaction rather than rot).

The criterion for judging hardness was whether the studied object made it possible to drive in a screwdriver with one hand. Hardness was at all times evaluated at a distance of about 10 cm from the drilled holes and at the bottom of these holes. The classification scale was as follows:

– hard trunk: a screwdriver could not be driven in, or penetrated to a maximum depth of 1 cm;
– soft trunk: a screwdriver penetrated to a depth greater than 10 cm (usually the whole tool's length);
– between: a screwdriver penetrated to a maximum depth of 4 cm when a considerable force was used.

The degree of wood mass decomposition was also assessed by rot colour change. A notch was made with an axe in all measured trunks at a minimum depth of 3 cm; the notches were led to lateral sides (mantle), and at the same time the rot was monitored also on the stem bases (cutting areas). In disks and stumps in which the notches could not have been made due to a risk of their disintegration, the rot was monitored by cleaving the wood mass out by means of a screwdriver at a distance of about 5 cm from the drilled hole. The classification scale was as follows:

– white rot: wood mass colour was white or light yellow;
– brown rot: wood mass colour was brown;
– between: this stage included all colour shades between the white and brown rots.

Vitality of plants

All plants planted in the trunks, disks and stumps were analysed for vitality; the classification scale was as follows:

– live plants: plants with the assimilatory apparatus of green (even light green) colour, at least a minimum increment on the terminal shoot or branches in 1999 and defoliation not exceeding 50%;
– starving plants: plants with the assimilatory apparatus of yellow colour, even with no increment on the terminal shoot in 1999 and defoliation not exceeding 50%; this category included also light green plants with no increment in 1999 and light green plants with a minimum increment in 1999 and defoliation exceeding 50%;
– dead plants: dead plants and plants which did not meet the criteria of "starving" plants.

Results

The research results are summarised in Table 1. It can be seen that the total success of regeneration is very modest – only 14% of "live" plants. With respect to the limited extent of the paper and the fact that the success of regeneration after planting in trunks, disks or stumps is in principle equal, the author will hereinafter document only the planting in trunks; the planting in stumps and disks will be limited to verbal comments.

Table 2 demonstrates that the position of trunks in the stand had hardly any influence on the success of regeneration. The key factor that affected the plants' vitality was the stage of trunk rot.

Table 3 indicates that there is a direct dependence between the degree of trunk hardness and the stage of trunk rot. 75% of the "hard" trunks exhibited the "white" rot while the remaining part showed the "between" rot. 73% of the "soft" trunks exhibited the "brown" rot while the remaining portion showed mainly the "between" rot. At the time of estimation, the two stands had 66% of the "hard" trunks, 20% of the "soft" trunks and 14% of the trunks with the "between" hardness.

It further follows from Table 3 that the least success of regeneration was achieved in the trunks with the "white" rot ("dead" 68%, "live" 1%) while the greatest success was recorded in the trunks with the "brown" rot ("dead" 7%, "live" 80%). Among all trunks investigated in the stand, the trunks with the "between" rot showed a considerable percentage of "dead" plants (41%) and the highest proportion (50%) of "starving" plants.

Table 1. Planting in wood – summarised results

Item	Condition of plants (pcs)				Condition of plants (%)			
	dead	live	starving	total	dead	live	starving	total
Analysed trunks (379 pcs)	928	227	612	1767	53	13	34	100
Analysed stumps (74 pcs)	73	31	32	136	54	23	23	100
Analysed disks (37 pcs)	40	23	41	104	39	22	39	100
Total	1041	281	685	2007	52	14	34	100

Table 2. Planting in wood – trunks (evaluation of regeneration success as dependent on trunk rot stage and trunk location in the stand)

Trunk rot	Trunk location															
	light				shade				between				total			
	trunks (pcs)	condition of plants (pcs)			trunks (pcs)	condition of plants (pcs)			trunks (pcs)	condition of plants (pcs)			trunks (pcs)	condition of plants (pcs)		
		dead	live	star-ving		dead	live	star-ving		dead	live	starv-ing		dead	live	star-ving
White	88	319	3	131	56	203	10	94	55	175	4	92	199	697	17	317
Brown	25	6	62	12	20	5	60	11	15	3	42	3	60	14	164	26
Between	39	83	13	104	53	96	21	107	28	38	12	58	120	217	46	269
Total	152	408	78	247	129	304	91	212	98	216	58	153	379	928	227	612
		condition of plants (%)				condition of plants (%)				condition of plants (%)				condition of plants (%)		
White		70	1	29		66	3	31		65	1	34		68	2	30
Brown		8	77	15		7	79	14		6	88	6		7	80	13
Between		42	6	52		43	9	48		35	11	54		41	9	50
Total		56	11	33		50	15	35		50	14	36		52	13	35

Table 3. Planting in wood – trunks (evaluation of regeneration success as dependent on trunk hardness and trunk rot stage)

Trunk hardness	Trunk rot															
	white				brown				between				total			
	trunks (pcs)	condition of plants (pcs)			trunks (pcs)	condition of plants (pcs)			trunks (pcs)	condition of plants (pcs)			trunks (pcs)	condition of plants (pcs)		
		dead	live	star-ving		dead	live	star-ving		dead	live	star-ving		dead	live	star-ving
Hard	187	667	13	293	1	1	0	1	63	114	24	143	251	782	37	437
Soft	7	11	3	17	55	13	155	22	13	17	8	32	75	41	166	71
Between	5	19	1	7	4	0	9	3	44	86	14	94	53	105	24	104
Total	199	697	17	317	60	14	164	26	120	217	46	269	379	928	227	612
		condition of plants (%)				condition of plants (%)				condition of plants (%)				condition of plants (%)		
Hard		69	1	30		50	0	50		41	8	51		62	3	35
Soft		35	10	55		7	82	11		30	14	56		15	60	25
Between		70	4	26		0	75	25		44	7	49		45	10	45
Total		68	1	31		7	80	13		41	9	50		52	13	35

Table 4 supports an unambiguous deduction that the stage of trunk decomposition is not affected by trunk diameter.

When plants are planted in the "hard" trunks, and often even in the trunks with the "between" hardness, they are placed in an environment which is impermeable to water and roots. The compact wood mass does not allow roots to grow in; the roots twist and tangle within the hole's space and the plants can take up nutrients only from the reserves in the rootball substrate, the result being growth stagnation, gradual loss of vitality and root deformations. When the plants are placed in the "soft" trunks, and in the trunks with the "brown" rot in particular, the roots can grow into the surrounding wood mass from which they can draw nutrients; root system deformations do not occur and the biomass of both the root system and the above-ground part gradually increases. Unlike the "live" plants, the "dead" and "starving" ones can be easily pulled out from the hole.

The plants placed into impermeable holes are further exposed to unfavourable hydrological conditions. "Hard" wood is a very bad heat conductor and its permeability to water is low. In dry periods the plants often suffer from water deficit, soil moisture being minimal due to the poor heat conductivity, and the trunks are frequently not in any contact with soil, either; regarding the fact that the rootball substrate is in a greater part formed of peat, it loses water at a much higher rate than soil. However, on the studied sites the plants placed in impermeable holes had to face even a more serious problem – excessive water. Water can dwell in the holes for a very long time. When a trial was made in which the holes were emptied of both plants and substrate and filled with water, the water level in the holes did not show any drop after 48 hours.

The clearly best results were achieved with the plants placed in the "soft" wood with the "brown" rot. This is due not only to the permeability of this wood mass to roots and water, but also to the fact that wood decomposition is accompanied by the release of phytotoxic substances, especially at stages when the rot colour is white and light. Even the natural seeding appearing on undecomposed wood gradually rapidly disappears.

In about 10% of trunks the decomposition did not proceed from the mantle to the inside of the trunk but from the trunk centre towards its mantle (in a majority of cases these trunks were infested with wood-decaying fungi as early as the time of regeneration). It is often the case with these trunks that the whole plant will sink after planting in a cavity in the trunk centre. Should there be at least a small bit of the sunken plant protruding out from the drilled hole above the trunk mantle, the plant would continue its normal development. If it is the entire plant that sinks into the trunk hollow, the result is impaired vitality or even death of the plant.

When planting in stumps, it was found that with the procedure used the location of stumps in the stand had no influence on the success of regeneration. The mortality and vitality of plants were primarily affected by the stage of rot and hence by stump hardness. 100% of the "hard" stumps exhibited the "white" rot, 81% of the "soft" stumps showed the "brown" rot, and the rest was the "between" rot. At the time of assessment, the two stands had 52% of the "hard" stumps, 28% of the "soft" stumps, and 20% of stumps with the "between" hardness. The least success of regeneration was recorded in the stumps with the "white" rot ("dead" 85%, "live" 0%), and the greatest success – in the stumps with the "brown" rot ("dead" 0%, "live" 97%). The stumps with the "between" stage of rot exhibited a relatively low percentage of "dead" plants (19%) but a high proportion of "starving" plants (70%).

Similarly, when planting in disks, a decisive factor in the success of regeneration was the stage of wood decay. 100% of the "hard" disks showed the "white" rot, 67% of the "soft" disks exhibited the "brown" rot, and the rest was the "between" rot. At the time of assessment, the two stands had 54% of the "hard" disks, 16% of the "soft" disks, and 30% of the disks with the "between" hardness. The least success of regeneration was recorded in the disks with the "white"

Table 4. Planting in wood – trunks (evaluation of trunk decomposition rate as dependent on trunk diameter, hardness and rot)

Trunk dia-meter	Trunk hardness											
	hard (pcs)			soft (pcs)			between (pcs)			total (pcs)		
	white	brown	between	white	brown	between	white	brown	between	white	brown	between
Large	139	1	43	7	38	11	4	3	34	150	42	88
Small	48	0	20	0	17	2	1	1	10	49	18	32
Total	187	1	63	7	55	13	5	4	44	199	60	120
	hard (%)			soft (%)			between (%)			total (%)		
Large	76	1	23	12	68	20	10	7	83	54	15	31
Small	71	0	29	0	89	11	8	8	84	50	18	32
Total	74	1	25	10	73	17	9	8	83	52	16	32

rot ("dead" 57%, "live" 5%), and the greatest success – in the disks with the "brown" rot ("dead" 0%, "live" 75%). The disks with the "between" stage of rot exhibited 25% of the "dead" plants and, once again, a high percentage (50%) of the "starving" plants.

With the disks, too, we can claim that the factors affecting the success of regeneration are the same as those in the trunks. Although the number of the planted disks was relatively low (37), it appears that the rate of decomposition is greater in small-height disks. In the stumps, rot proceeds from the stump mantle towards the centre; there were several exceptions, though, with the rot proceeding from the drilled holes in all directions. In spite of the fact that this progress of rot is in principle retained also in the disks, it appears considerably more intensive (rapid), particularly in the small-height disks. However, the disintegrating disks deform growth and denude the root system or bury the plants because their root systems did not reach the ground and the plants were not stabilised mechanically.

Conclusions

Factors to be considered when regenerating forests in wood are as follows:

1. Regeneration must be made in decomposed wood ("brown" rot) since the wood hardness is minimal at this stage of decomposition and one can make use of common tools for manual work (no necessity of drilling holes).
2. As wood decomposition takes even several decades (depending on climatic conditions and the condition of wood mass at tree felling), regeneration is of long-term (on some sites even continual) character. This is why the regeneration success (established crop) cannot be judged by common procedures.
3. Light and warmth belong to limiting factors in regenerating forests in mountain regions. This is why the stands must be gradually worked on over a longer period of time with this method of regeneration.
4. Trunks and disks should be placed in such a way that they are in direct contact with soil along their entire length or cutting area (if possible, they should be partly sunk into the soil). The presently used storage of wood in heaps, piles and mounds can be considered as an element of forest cleanliness rather than a good groundwork for the regeneration in wood.
5. The rate of wood decomposition should be stimulated by splitting large-diameter trunks or by applying biological preparations to support wood decomposition.
6. It is not always necessary to use only pre-grown natural seedlings for regeneration; it is also possible to use a common planting stock (from acclimation nurseries) or direct sowing; also sowing under plastic covers can by advantageous.
7. Regeneration in stumps calls for very low stumps; it is even advisable to make a pronounced depression in the centre of the stump (or to cut out the entire centre). Similarly, the height of disks should be small – up to about 20 cm.

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