Cluster reforestation near the timber line

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ABSTRACT: Plantation of spruce in clusters (small collectives with 20–30 individuals with dense spacing) was realized on a small clear-cut and under the forest stand near the timber line in the Krkonoše Mts. in 1993. Gaps among the collectives were planted with dwarf pine and rowan. The height of trees aged 16 years occurring in centres of the small collectives is greater than trees growing on their edges. Lower height growth of underplantings is affected more by the stand shelter than by the position of individuals within collectives. Health status of plantations is comparable on both plots. Tree samples (spruce, dwarf pine) from the underplanting had lower weight and different biomass distribution than samples from clear-cut, samples with different positions in the collectives on clear-cut also differed. Original stand succeeded in keeping its favourable health condition in spite of the occurrence of individually dying trees.

Keywords: dwarf pine; height growth; Krkonoše Mts.; reforestation; spruce; timber line; underplanting

Localities near the forest timber line are severely endangered by external effects due to extreme site conditions (Jeník 1961; Schönenberger 2001). In the Czech Republic, heavy air pollution affected in the past forest communities on these sites and their management. In the Krkonoše Mts, 8,000 ha of mountain forests at high altitudes died off as a result of acid deposition and accompanying phenomena. Exploited or massively opened stands were gradually regenerated; newly emerging even-aged stands established at regular spacing had high mortality. Regeneration of forest stands, damaged by air pollution, claims new approaches to underplantings using (Lokvenc, Vacek 1991; Lokvenc et al. 1992; Vacek et al. 1995). Forest regeneration and forest research in Krkonoše Mts. were supported in by a Dutch foundation "Forests Absorbing Carbon dioxide Emission" 1990s (Hřebačka 1997).

Stands established by planting at regular spacing near the upper forest boundary often suffer from extensive damage by snow, wind and other factors (Fillbrandt 1999; Schönenberger 2001). Plantations at regular spacing are also very costly in these elevations. The risk of damage to stands further increases due to the absence of tending measures controlling the stand density and structure. Reforestation in clusters or small collectives on favourable microsites can reduce the costs of regeneration and follow-up tending while providing for a good growth. Vacant patches between the small collectives enable development of a differentiated stand structure as well as a gradual spreading of the collectives (Schönenberger 2001).

Forest stands form the mosaic structure by natural way in the alpine elevations (Kuoch 1972; Schönenberger 2001). The development of stands in groups near the timber line is known for a long time (Hess 1936; Kuoch 1972). Stands that have developed through natural regeneration are able to keep the structure of small collectives for a long time even when their cover increase later (Ott et al. 1997). Stands at the upper forest limit consist of small collectives at a narrow spacing, separated from the vicinity and with the low-branching crowns of marginal trees. The mutually provided shelter and effect of trees facilitates their more favourable growth and higher stability (Strobel 1997). The group structure of natural stands and newly established plantations at higher eleva-

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tions was studied by many authors (e.g. Hess 1936; Kuoch, Amiet 1970; Strobel 1997). In the 1960s, the terms of "Rotte, Rotten" started to be used in the German literature for closed collectives consisting of 3 to 10 trees growing in close proximity, whose branches reach down to the ground due to open canopy at least in marginal trees (Schönenberger 2001). New findings about the establishment of forest stands by group planting in these mountain elevations mostly originate from recent years. Authors studying artificial stand regeneration of these extreme localities mention a poor health condition of stands planted at regular spacing and a risk of their damage (Schönenberger, Frey 1988; Schönenberger 1986, 2001; Lokvenc et al. 1992; Fillbrandt 1999).

The goal of this paper is to evaluate the growth and prosperity of group plantations of spruce (*Picea abies*) and plantations of dwarf pine (*Pinus mugo*) and rowan (*Sorbus aucuparia*) on the clear-cut and under the stand near the timber line in the Krkonoše Mts.

MATERIAL AND METHODS

The experiment with the group plantation of spruce near the timber line in the Krkonoše Mts. was established in the locality of Růžová hora Mt. at an altitude of 1,370 m a.s.l. on a steep NW slope (45°); the upper forest limit in this locality is at 1,380 m a.s.l. The original spruce stand with the individually admixed rowan was severely damaged by air pollution in the 1980s. Aged 105 years (1992), the stand had a mean height and a mean diameter of 6 m and 16 cm, respectively and an average number of live trees per hectare was 350. A considerably high number of dead standing trees reduced light penetration and the occurrence of weeds under the stand. In the autumn of 1992, two research plots were laid out in the locality (clear-cut area and underplanting), each sized 50 × 50 m. In order to reduce the threat of avalanches in lower parts of the slope, high snags were left on the clear-cut area and the plot was ramparted with felled trees to prevent the access of wildlife.

The plots were planted in the spring of 1993 with using the containerized planting material of indigenous spruce (mean height 35 cm). The transplants were placed into holes near the slope in order to reduce their snow lifting. Small collectives of rounded shape with a downhill-situated longer side were established with 20–30 transplants spaced at ca 50 cm; 4–6 near small collectives should form a cluster in the future. Mean distance between the clusters was ca 5 m. The small collectives were established on selected suitable microsites. A similar spatial arrangement was used under the stand too, with the preference being given to open patches. On the clear-cut area, 40 small collectives were established and after elimination of the most shaded patches under the stand, the resulting number of collectives was only 36. The open space between the clusters was planted with dwarf pine and individually admixed rowan at a wide spacing of 1.5 m. Total numbers of transplants at planting corresponded to numbers commonly used in the forestation of such localities (4,000 pcs·ha^{-1}).

Height growth of the plantations was retrospectively measured in 2–5-year intervals, health condition of plantations were evaluated by measurements. Former measurements were realized mainly in the central part of the clear-cut, where the growing conditions were more favourable. Spatial distribution of individuals within the collectives was recorded from 1998 in connection with the gradual canopy closure of plantations on the clear-cut area. In the first years, solitary spruce trees were distinguished in addition to individuals within the small collectives (localized on margins and in centres). With the gradually closing canopy of small collectives and amalgamation of clusters due to the lateral growth of crowns, a greater part of the originally solitary trees became marginal and the category of solitary spruce trees was no longer used. Areas of clusters were measured from air-pictures and drawings in year 2009. Health condition and foliation percentage of original stand on underplanted plot (86 trees) were assessed each year according to the IPC Forests methodology (e.g. Lorenz et al. 2005). In the first years after plantation, snow cover height and quality was measured at 14-day intervals in winter.

Sample trees for the analysis of above-ground biomass were taken in 2007 – four spruce sample trees were taken from under the stand regardless of their localization within the small collectives and 4 and 2 spruce sample trees were taken from margins respectively centres of small collectives growing in the clear-cut. Sample trees of dwarf pine were taken from under the stand (3 pcs) and from the clear-cut area (2 pcs). The sample trees were measured for height increment and the dry weight was determined of trunks, branches, 1-year and older needles. Statistical differences between the collectives were established in the NCSS programme by t-test or by one-factor analysis of variance at a significance level of ($P > 0.05$).

RESULTS

Taking into account the used spacing (0.5 m) and the number of transplants (20–30), the initial size of small collectives was 5–7.5 m^2. Thus, the spruce clusters covered some 10% of the clear-cut area (50 × 50 m) after planting. The area size of small collectives under the stand was equable. At a lower number of clusters (36) and the same number of transplants used on both plots, some clusters had the number of transplants slightly increased. In 2009, the mean area of small collectives on the clear-cut area totalled 30 m^2 (standard deviation 13, median 26 m^2). Some collectives have already merged into larger clusters and some remain separate so far (totally 27 clusters in 2009).

Total mortality of spruce and dwarf pine plantations did not exceed 7% in the first years after planting and was equable on both plots. Individual planting of rowan exhibited high losses due to recurrent injuries by game. In the following years, individual transplants died due to abiotic factors (frost, snow) and game damage. The number of individuals within a small collective fluctuated in 2009 from 15 to 21 and no major differences were observed between the two plots. Sixteen years after planting out, the total mortality of spruce and dwarf pine did not exceed 30%.

The plantations became gradually adapted to site conditions and started to grow up (Figs. 1 and 2). The time of their adaptation to site conditions and height increment differed between the plots. On the clear-cut area, the mean height increment of spruce in the first five years after planting did not exceed 4 cm and the mean height of spruce in 1997 was 54 cm (standard deviation 11). The lateral spread of crowns on the clear-cut area ranged from 6–10 cm per year in the first years after planting. Initial height and lateral increment of spruce plantations on clearcut was comparable with measurements from comparable sites published by Lokvenc et al. (1992). In 2000, the mean diameter of spruce crowns on the clear-cut area reached already 50 cm and the crowns formed a closed canopy within the collectives. With the gradual growing up of the plantations, interaction began to show and better microclimatic conditions within the collectives. From 1998, the height development of spruce was assessed according to the localization within the small collective (Fig. 1). A greater height increment of individuals situated in the centre as compared with individuals growing on the margin was recorded already before a proper canopy closure in the collectives. From 2002, differences between the mean heights of spruce trees were statistically significant in the two groups. The further spreading of crowns led to gradual shading and drying out of lower branches within the collectives. Shrubs of dwarf pine growing in the close proximity of clusters affect the lateral growth and morphology of spruce crowns on cluster margins.

Mean heights of spruce trees planted on the clear-cut area were gradually increasing. In 2009, the mean height of trees in the centre of small collective reached 176 ± 64 cm and the mean height of spruce trees growing on the margin was about 156 ± 57 cm. The increased variability of heights in recent years suggests competition within the groups. The shortening of crowns in spruce trees growing in the centre due to the shading by adjacent individuals has not reflected in their height growth until now.

Foliation of spruce plantations has been stabilized for a long time (80–85%) and corresponds to the site conditions. A higher defoliation of older needles was recorded in recent years on windward parts of crowns. The needles are not rubbed away only by snow and ice, but also by neighbouring spruce and dwarf pine individuals within the small collective. Due to varying defoliation, the variabil-

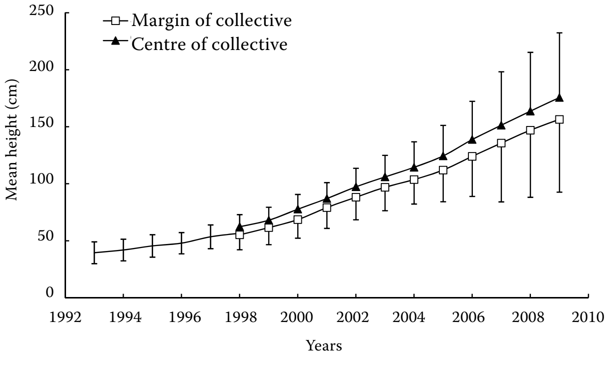

Fig. 1. Height growth of spruce plantations on the clear-cut area in relation to the position within the small collectives

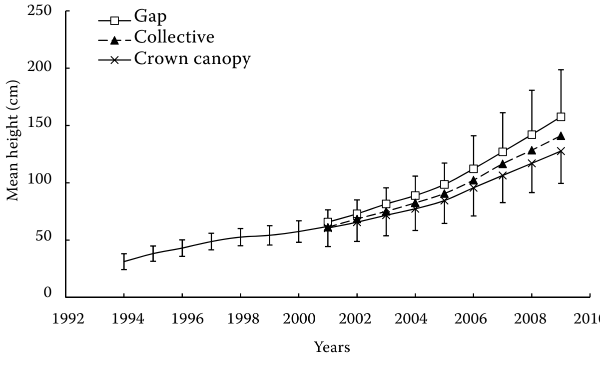

Fig. 2. Height growth of underplanted spruce in relation to its position towards the original stand

ity of spruce foliage on the clear-cut area markedly exceeds the variability of spruce foliage under the stand. The damage to spruce on the clear-cut does not exceed 10%; individually occurring is damage to terminal shoot by snow or game. Damage to branches by snow lifting recorded in the first years after planting gradually decreased. The occurrence of damages due to frost or fungal pathogens did not exceed 5% on the clear-cut.

The mean periodical height increment of underplanted spruce did not exceed 2.5 cm in the first five years and the mean height was 49 cm in 1997 (standard deviation 7). The gradual opening of the upper tree layer due to the dieback of trees with severely reduced foliage after 1998 affected the site conditions and hence the growth of the underplanted spruce. The height and lateral growth of the underplanted spruce was affected by the shelter of the original stand more than by the position within the small collective. The mean diameter of spruce crown was 41 cm in 2000 and the canopy closure of the collectives occurred in the following years. From 2001, the height growth of spruce has been assessed according to the localization of trees within the entire area (gap, small collective, crown canopy). The heights of spruce trees became gradually differentiated (Fig. 2). The achieved height of spruce trees growing in the stand gap in 2009 (158 ± 41 cm) was comparable with the height of spruce trees growing on the adjacent clear-cut area. The mean height of spruce trees in clusters reached 89% of the mean height of spruce trees growing in the gap (141 ± 26 cm). Spruce trees growing under the crowns of the original stand had a height 128 ± 28 cm. Height differentiation according to the position of trees in clusters mostly did not exceed 10 cm in the underplanting. Differences between the mean heights of spruce trees in the gap and under the tree crowns have become statistically significant since 2005 (Fig. 2). The foliation of underplanted spruce is comparable with the foliation on the clear-cut area and no reduction of foliation was observed on the plot due to stand canopy closure. Damage to the underplanted spruce is higher due to a higher accumulation of snow and its falling from the crowns; 29% of spruce trees suffer from malformed shoots or breakages. The snow-bent and malformed trunk base in some individual trees corresponds to the climatic and terrain conditions. Dwarf pine plantations on both plots successfully grow up; the shrubs soon developed elliptical shape with the longer axis situated down the slope. Dwarf pine on the clear-cut area displayed a mean height of 56 ± 14 cm as early as in 1998 and the average area of one shrub was 1 m^2. The height of underplanted dwarf pine was only slightly lower (48 ± 11 cm) but the area of shrubs was only a half (0.46 m^2). The reduced penetration of light and heat through the stand markedly affects the morphology and the lateral spreading of shrubs. On the clear-cut area, the shrubs usually form a compact mass while under the stand the shrubs are formed mainly by individual branches. Thanks to procumbent habit, the plantations of dwarf pine rapidly covered the soil surface on both plots, thus reducing the risk of erosion. In the following years, the mean annual increments of shoots on the clear-cut and under the stand exceeded 12 cm and 19 cm, respectively. In 2009, the mean height of dwarf pine on the clear-cut and underplanted in gaps was 124 cm and 118 cm, respectively. Thanks to the greater spruce height and a good potential for the species' further height growth, the risk of the negative impact of dwarf pine on the growth of spruce in small collectives is low. Dwarf pine is fruiting repeatedly and a singular occurrence of cones was recorded already in 1996.

Snow cover measurement in the first years after establishment revealed a different snow deposition on the two plots (Souček et al. 1996). Although the remaining open stand with the underplanting did not prevent the snow deposition, it rather limited its further transport. The height of snow cover under the stand in the winters 1994/1995 and 1995/1996 repeatedly surmounted 150 cm while the mean height of snow cover on the clear-cut area did not usually reach 70 cm in spite of being considerably differentiated. The stand canopy shade slowed down the snow thawing and the development of thick ice beds under the stand. On the other hand, snow density was increased by snow and water falling from the crowns of the original stand.

Sample trees

The average height of sample trees from the underplanting (115 ± 30 cm) corresponded with the mean height of spruce in the underplanting. Similarly, the heights of sample trees from margins (130 ± 42 cm) and centres (155 ± 42 cm) of small collectives on the clear-cut area did not differ from the mean height measured in the field. The total dry weight of sample trees significantly differed in dependence on the place of sampling (Table 1). The total dry weight of sample trees from the underplanting (707 ± 231 g) was markedly lower than the dry weight of sample trees from the clear-cut area. The dry weight of in-

Table 1. Weight (in grams) of the individual parts of spruce sample trees (average ± SD)

Sample trees from	1-year needles	Older needles	Branches	Stem	Sum
Underplanting	25 ± 4[a]	170 ± 54[a]	382 ± 35[a]	130 ± 139[a]	707
Clearcut–group margins	45 ± 16[a]	441 ± 110[b]	516 ± 49[b]	318 ± 239[b]	1,320
Clearcut-group centres	101 ± 10[b]	722 ± 63[c]	527 ± 88[c]	726 ± 100[c]	2,076

Columns marked with the same letter are not significantly different ($P > 0.05$), SD – standard deviation

dividuals from the group margins on the clear-cut was 1,320 ± 237 g while spruce trees from the group centres had a mean dry weight of 2,076 ± 190 g. The underplanted individuals reached only 34% of the weight of individuals from the group centres and the weight of spruce trees situated on the margins of small collectives reached 64% of the weight of individuals growing in the centre (100%).

The largest share in the total dry weight of sample trees from the clear-cut area was that of needles and stems while in the underplanting, the highest weight share was that of branches. The dry weight of 1-year needles was significantly higher in individuals growing in the centre of the small collective on the clear-cut than in other variants. Significant differences between the individual variants were found also in the total weight of needles. The share of the first needle year was comparable in the individual variants (3–5%). The share of needles in the total weight of underplanted individuals was 28% while on the clear-cut, the share of needles in the total weight of individuals was 36–40%. The lower height of trees in the underplanting affected the share of stem in the total weight of individuals (18%). On the clear-cut area, the stems of individuals growing on the margin represented 24% of dry weight and the stems of individuals growing in the centre represented 35% of total weight. Differences in the dry weight of stems were significant. The weight of branches in the underplanting reached 54%. On the clear-cut area, the share of branches in individuals growing on the margins of small collectives (39%) is higher than in individuals growing in the centres (25%), which indicate the early effects of shading and competition. Although the differences in the share of branches in total weight between the compared variants were considerable, differences in the absolute weight values were statistically insignificant (Table 1).

The biomass weight of dwarf pine sample trees exceeded the biomass weight of spruce sample trees and the variability of the values was markedly higher too. The dry weight of underplanted dwarf pine was 4,536 g while on the clear-cut area it amounted to 6,983 g. The weight of dwarf pine needles from the underplanting was lower than that from the clear-cut area. The share of needles in the total biomass reached 37% in both cases.

Development of the original stand

The health condition of trees in the original stand expressed by foliation is impaired by unfavourable site conditions and by the long-term former impact of air pollution. The average initial foliation in 1993

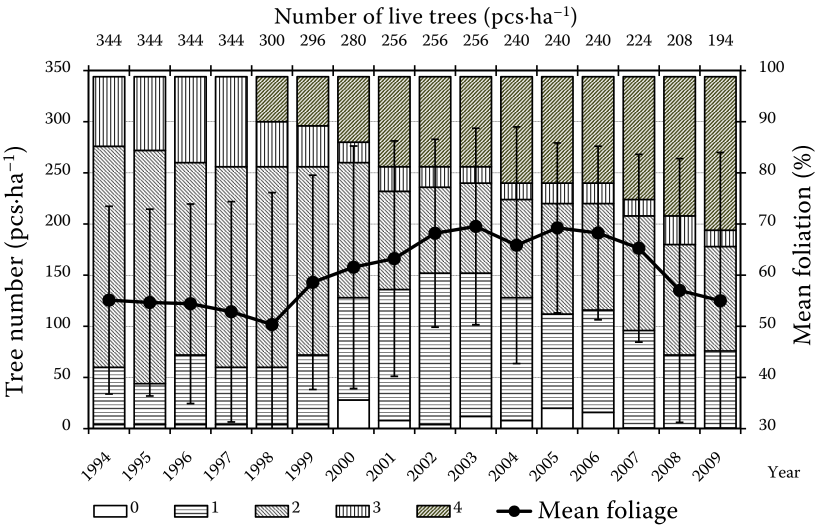

Fig. 3. Development of foliation in the spruce of the original stand
Defoliation classes: 0 – defoliation up to 10%, 1 – defoliation > 10–25%; 2 – defoliation > 25–60%, 3 – defoliation > 60% < 100%, 4 – dead tree

was 55% (standard deviation 18) and trees with a foliation of 40–75% (Foliation class 2) dominated (Fig. 3). The gradual decrease of foliation in the following years was caused by after-effects of the air pollution. After the dieback of the most affected trees, the average foliation of the stand started to improve gradually from 1998. The share of trees with a higher degree of foliation increased too. In 2002–2007, the average foliation reached nearly 70% (standard deviation 16–23). The occurrence of a local focus of eight-toothed spruce bark beetle on a part of the area in 2007 resulted in a steep decrease of foliation. The surveys made in 2009 indicate that 43% of trees from the original stand died of which 13% of trees died in the last few years due to the feeding of spruce bark beetle. Comparable results of stand development under air-pollution and bark beetle pressure near the timber line published Vacek and Matějka (1999).

DISCUSSION

Group plantations were not generally used on these localities in the Czech Republic in the past, notes about this method of reforestation in older literature presented mainly foreign information (Lokvenc et. al 1992). Plantations under stands or in small gaps were recommended for reforestation of stands near the timber line damaged by air pollution (Vacek, Lokvenc 1992; Vacek et. al 1995). First results from stands underplatings on these localities confirmed variation of microsite conditions under stands, importance of stands ecological shelter and different height growth of species under shelter and in gaps. Quality container plants and protection against hoofed deer secure forest reforestation on these sites (Vacek, Lokvenc 1992).

Results from our experiment with cluster reforestation in the Krkonoše Mts. cannot be strictly compared with the above-cited works of foreign authors, which are mostly concerned with much more numerous plantations of equal height structure. Schönenberger (2001) presents results from the research of group plantations of diverse species 13 years after planting pointing out that the period of growth was short and the character of his comments preliminary. Small collectives consisting of 20–30 transplants at a spacing of 70 cm were growing up successfully. Mean heights of spruce and Swiss stone pine reached 1 m while the faster growing larch and dwarf pine reached a mean height of 1.7 m. The height of individuals growing on the margins of the collectives was greater than that of individuals growing in the centres only in dwarf pine; individuals of other species growing on the margins exhibited a lower height. Spruce showed statistically significant height differences according to the position within the collective. Group plantations of spruce favourably affected snow thawing. Trees on the margins were damaged by game more than trees situated in the centre of the collectives. A higher share of individuals deformed by snow in the centre than on the margin was recorded only in larch. The size of collectives and the spacing were too tight for the fast growing larch and dwarf pine. On the other hand, the slowly growing Swiss stone pine would require an even closer spacing (Schönenberger 2001). Fillbrandt (1997, 1999) assessed 8 different group plantations of spruce; most stands were older with considerably higher numbers of individuals in the groups. He claims that after the canopy closure, the crown length as well as the height increment gradually decreases in the centre of group plantations. The suppressed height increment and the gradual shortening of crowns show in the impaired stability of individuals growing in the centre of the group. When the centre of the group is impacted by snow, a gradual destruction often occurs of the whole group (Fillbrandt 1999). Spacing and number of individuals in small collectives for the forestation of extreme mountain elevations are recommended according to site conditions and species potential so that the canopy of the plantations becomes closed within 5–10 years after planting.

Our findings about the growth of group plantations in the locality of Růžová hora Mt. correspond to published findings only partly. The measurement of height growth on the plots demonstrated a positive influence of group plantations on the growth of plants even before canopy closure in the small collectives. The positive effect of small collectives persisted even after their canopy closure. Individuals situated in the centre of the small collective exhibited a significantly higher height increment than individuals growing on the margins. Initially individually growing spruce trees had lowest height increment (Souček 2004, 2007), amalgamation of the small collectives into the clusters gradually affected height growth of individual trees in their surroundings. The height increment of spruces within the groups is equable so far; a gradually suppressed growth and vitality of individuals growing in the centres of small collectives can be expected with the increasing competition. Longer crown and lower competition should gradually provide for the higher growth of marginal individuals. The height increment of individuals growing in the centres can be expected to decrease with the further growing up of spruce trees in the collectives.

Plantations on the surveyed plots did not show any major injuries. Schönenberger (1978) mentions an increased risk to the plantations by snow. Danger of frost injuries to plantations in localities with the lack of snow describes e.g. Turner (1988) or Schönenberger (1978). The limited extent of damages found on the two plots can be explained by favourable snow conditions and by the lower age of the plantations. The damage to plantations by creeping snow may increase with the increasing stem diameter and rigidity.

By contrast, snow on the clear-cut area is drifted away by action of the A-O system of the Úpa River (Jeník 1961), which results in the mechanical injury to needles and shoots. Snow deflation repeatedly observed in the first years after planting increased the risk of frost injury to soils and plantations. The risk of snow deflation and soil freezing decreased with the growing up of the plantations. The clear-cut area also showed a recurrent development of ice beds due to solar radiation, which injured the spruce plantations by pulling out branches. High stumps left on the plot efficiently block the snow movement while accelerating snow thawing in the spring.

CONCLUSIONS

– Regeneration by planting in small collectives (clusters) assures better growth conditions for plantations on extreme sites. In the research plot of Růžová hora Mt. in ridge parts of the Krkonoše Mts., small collectives of 20–30 spruce trees at a close spacing successfully grow up on a clear-cut area as well as under the original stand.
– After 16 years of growth, spruce trees inside the small collectives on the clear-cut area exhibit a greater height (176 ± 64 cm) than individuals on their margins (156 ± 57 cm). Mean height differences between the two groups have been statistically significant since 2002. The more favourable growing environment inside the small collectives affected the height growth of spruce trees in the centres of groups already before their canopy closure. The higher competition of spruce trees inside the small collectives has not reflected in their height growth so far.
– The growing up of group plantations under the stand shelter has a similar character as on the clear-cut area. The position of spruce trees in small collectives is of limited importance, decisive is their position with respect to the original stand. Sixteen years after planting, the height growth of trees in the most open patches is comparable with that on the clear-cut area. The height of spruce in the underplanting is 128 ± 28 cm and the mean height of spruce in the centre of small collectives is 141 ± 26 cm.
– Dwarf pine planted in gaps between the small collectives of spruce has covered the ground and successfully grows up. The shelter of the original stand curtails the spread of dwarf pine bushes. The height growth of dwarf pine on the clear-cut area and in the underplanting is comparable.
– Improved microclimatic conditions on the site and increased fertility of neighbouring stands supported the occurrence of spruce natural regeneration in recent years. The natural regeneration of spruce and broadleaved pioneer species occures particularly on originally denudated mineral soil.
– The health condition of the original stand expressed by foliation gradually improved with the reduced air pollution load. In recent years, the number of live trees was reduced by the feeding of eight-toothed spruce bark beetle on a part of the area.
– The biomass analysis of spruce and dwarf pine sample trees in the underplanting and on the clear-cut area revealed that biomass growth and distribution within a tree differ on the two plots. The above-ground biomass of an average spruce tree from the underplanting reaches only 34% of the biomass of sample trees from the centre of small collectives on the clear-cut area. Biomass distribution differed both according to the plots and according to position within the clusters on the clear-cut area. Sample trees from underplanting had the highest biomass volume accumulated in branches.
– The gradual canopy closure and the subsequent merging of small collectives should give rise to a stand differentiated in both spatial arrangement and growth. The growing up spruce will gradually suppress the growth of dwarf pine whose individual shrubs are expected to remain only at places with a sufficient light. However, the stand structure will not remain favourable for ever and the stand will call for tending and management measures.

References

Borůvka L., Podrázský V., Mládková L., Kuneš I., Drábek O. (2005): Some approaches to the research of forest soils affected by acidification in the Czech Republic. Conference paper Soil Science and Plant Nutrition, *5*: 745–749

Fillbrandt T. (1999): Strukturentwicklung gepflanzter Fichtenkollektive (Rotten) in der hochmontanen und subalpinen Stufe. Schweizerischen Zeitschrift für das Forstwesen, ***87***: 145.

Frey W. (1985): Schäden durch Schneelast in Fichtenaufforstungen: Folgerungen, Behandlungsvorschläge. Schweizerischen Zeitschrift für das Forstwesen, ***4***: 311–319.

Hess E. (1936): Neue Wege im Aufforstungswesen. Beihefte zur Schweizerischen Zeitschrift für das Forstwesen, ***15***: 5–45.

Hřebačka J. (1997): Face Nadation. In: Ročenka 1996. Vrchlabí, Správa KRNAP: 83–85. (in Czech)

Jeník J. (1961): Alpine vegetation of Krkonoše Mts., Kralický Sněžník Mt. and Hrubý Jeseník Mts. Praha, ČSAV: 412. (in Czech)

Kuhn W. (1965): Waldbau im Gebirge. In: Gebirgshilfe als forstliche Aufgabe. Beihefte zur Schweizerischen Zeitschrift für das Forstwesen, ***37***: 45–53.

Kuoch R. (1972): Zur Struktur und Behandlung von subalpinen Fichtenwäldern. Schweizerische Zeitschrift für das Forstwesen, ***2***: 77–89.

Kuoch R., Amiet R. (1970): Die Verjüngung im Bereich der oberen Waldgrenze der Alpen mit Berücksichtigung von Vegetation und Ablegerbildung. Mitteilungen der Schweizerischen Anstalt für das forstliche Versuchswesen, ***4***: 159–328.

Lokvenc T., Dušek V. Jurásek A., Martincová J., Podrázský, V., Vacek S. (1992): Refforestation of the Krkonoše Mts. Opočno, VÚLHM: 111. (in Czech)

Lokvenc T., Vacek S. (1991): VDevelopment of tree species planted on the clearcuttings and under the stands decaying due to air pollution impact. Lesnictví, ***37:*** 435–456. (in Czech)

Lorenz M., Becher G, Mues V., Fischer R., Becker R., Calatayud V., et al. (2005): Forest Condition in Europe. [Technical Report.] Geneva, Federal Research Centre for Forestry and Forest Products.

Ott E., Frehner M., Frey H.U., Lüscher P. (1997): Gebirgsnadelwälder. Ein praxisorientierter Leitfaden für eine standortsgerechte Waldbehandlung. Bern, Stuttgart, Wien, Verlag Paul Haupt: 287.

Schönenberger W. (1978): Ökologie der natürlichen Verjüngung von Fichte und Bergföhre in Lawinenzügen der nördlichen Voralpen. Eidgenössische Anstalt für das forstliche Versuchswesen, ***3***: 215–361.

Schönenberger W. (1986): Rottenaufforstung im Gebirge. Schweizerischen Zeitschrift für das Forstwesen, ***6***: 501–509.

Schönenberger W. (2001): Cluster afforestation for creating diverse mountain forest structures – a review. Forest Ecology and Management, ***145***: 121–128.

Schönenberger W., Frey W. (1988): Untersuchungen zur Ökologie und Technik der Hochlagenaufforstung-Forschungsergebnisse aus dem Lawinenanrissgebiet Stillberg. Schweizerische Zeitschrift für Forstwesen, ***9***: 735–820.

Souček J. (2004): Forest regeneration bellow the upper tree line. Lesnická práce, ***9***: 458–459. (in Czech)

Souček J. (2007): Group refforestation below the upper tree line. Zprávy lesnického výzkumu, ***1***: 1–4. (in Czech)

Souček J., Vacek, S. Podrázský V. (1996): Snow conditions and their influence on plantation development on steep slopes in Krkonoše Mts. In: Vacek. S. (ed.): Monitoring, Výzkum a Management Ekosystémů na Území KRNAP: Opočno 15.–17. April 1996: 108–113.

Strobel G. (1997): Rottenstruktur und Konkurrenz im subalpinen Fichtenwald. Beiheft zur Schweizerischen Zeitschrift für Forstwesen, ***81***: 203.

Turner H. (1988): Mikroklimate in der Versuchsfläche Stillberg. Schweizerische Zeitschrift für das Forstwesen, ***9***: 751–762.

Vacek S., Lokvenc T. (1992): Forest regeneration of protective forests bei underplantations in Krkonoše Mts. Lesnická práce, ***5***:141–144. (in Czech)

Vacek S., Lokvenc T., Souček J. (1995): Underplantation of Forest Stands. Praha, MZE: 32. (in Czech)

Vacek S., Matějka K. (1999): The state of forest stands on permanent research plots in the Krkonoše Mts. in years 1976–1997. Journal of Forest Science, ***7***: 291–315.

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