

## Damage to regeneration in the area after large-scale decline of Norway spruce *Picea abies* (L.) H. Karst. stands in the mountains

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### ABSTRACT

The paper presents harmful factors relevant to the health of regeneration on decline forest areas in the Sudetes and the Carpathian Mountains. It was found, that adverse atmospheric conditions and deer were the main reasons of damages occurring in most stands. Pest insects were only of marginal consequence, although they eliminated the large parts of regeneration. On decline forest areas there were distinguished three zones with different intensity of damages caused by atmospheric factors. These zones are linked to altitudinal gradient. The intensity of damages increase on higher elevations. In distinguished zones, there were specified forest management objectives and general rules for their implementation.

### KEY WORDS

deforested areas, Carpathian Mts., the Sudetes, biotic damaging agents, abiotic damaging agents, regeneration

### INTRODUCTION

In the postwar history of mountain forests, there were created open areas, completely devoid of tree cover, as a result of large-scale decline of Norway spruce *Picea abies* (L.) H. Karst. stands. The oldest open areas are located in the Western Sudetes are now approximately 30 years old. The youngest ones are also created currently, mainly in the Silesian and Żywiec Beskid Mountains (Boratyński et al. 1987; Grodzki 2004; Szabla 2004; Bruchwald and Dmyterko 2010).

Spruce stands degradation caused environmental changes important for initiation and development of regeneration (Gorzela 1995). These were mainly: ones

having adverse impact on forest regeneration, changes in water relations (Kucharska and Woźniak 1994) and in microclimatic conditions (Karaš 1995b; Balcar 2000; Kula et al. 2000; Lomský et al. 2000; Martinková et al. 2000; Šrámek and Šebková 2000) as well as changes in plant cover, with expansion of species competing with the younger forest generation (Fabiszewski and Wojtuń 1994; Gorzelak 1994; Ambroży 2002). Areas affected by disasters were spontaneously colonized by species such as silver birch *Betula pendula* Roth, Norway spruce *P. abies* and European rowan *Sorbus aucuparia* L. Emend. (Ceitel 1994; Gorzelak 1995; Ceitel and Iszkuło 2000). Some tree species were also planted. Of these species, Norway spruce and European larch

*Larix decidua* Mill occupied the largest areas of plantations. Shaped in this way regeneration, occurring in extreme conditions of open space in the mountains, generate a lot of problems with the realization of the main forest management objective for described areas. This objective is silviculture towards stands with much higher stability and resistance to stress, comparing to the collapsed spruce stands, by shaping species compositions adequate to site conditions as well as stand and spatial structure (Matička 2000; Šach et al. 2000; Vacek and Balcar 2000; Szabla 2004; Kantor 2004).

Damage caused by biotic and abiotic factors limit the development of regeneration in the area of large-scale decline as well as hinder the realization of the main forest management objective. For example, in early development phases of one-species birch regeneration, there were recorded defoliation of birch trees and their group dying due to attack of the willow leaf beetle *Lochmaea capreae* (L.) (Kosibowicz 1990, 1994, 1995). It was also found that early phases of regeneration (including birch regeneration) suffer from extreme climatic conditions in deforested areas. This facilitates the attack of pathogenic fungi and pest insects (Balcar 2000; Kula et al. 2000; Lomský et al. 2000; Martinková et al. 2000; Soukup and Pešková 2000; Šrámek and Šebková 2000). The regenerations were also damaged by deer and rodents (Szukiel et al. 1995). The experience gained and methods developed in the initial phase of large-scale decline area management are useful in similar cases arising in the later period. However, the progressive development of regeneration in decline areas creates new challenges for their protection and implementation of the tasks of forest management under these conditions (Grodzki 2008; Kosibowicz 2008).

This research was undertaken to better recognize the factors that could disturb the regeneration process in the open area conditions after large-scale decline of Norway spruce stands in the mountains as well as to determine silviculture and forest protection treatments for regeneration in decline areas, relevant to their current state.

## MATERIAL AND METHODS

The research was conducted in 2007–2009 in the area of a large-scale Norway spruce *P. abies* forest decline in the lower and upper montane forest zones of the Sudetes

and the Carpathian Mts. (Southern Poland). The study focused on both natural and artificial regeneration. Tree species composition and occurring damage were the main criteria, which were applied for the selection of representative plots. Fieldworks included surveys aimed at finding differences of regeneration in terms of species composition and occurring damage, selection of typical objects representing this diversity, location of homogeneous research plots within these objects and works on the research plots according to methodology.

There were identified 21 research plots in the Sudetes (Fig. 1) and the Carpathian Mts (Fig. 2), in the area of a large-scale Norway spruce forest decline.

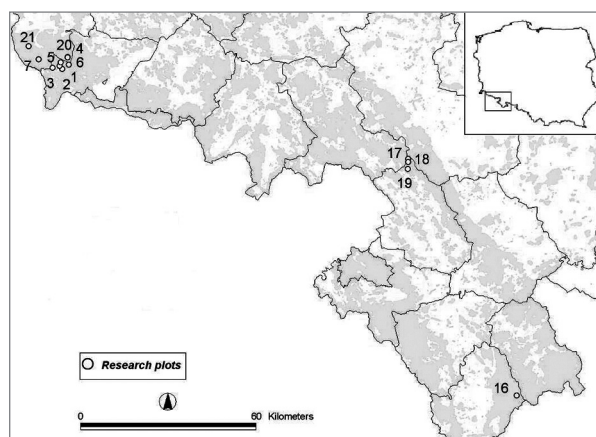


Fig. 1. Location of the research plots in the decline area of Sudetes

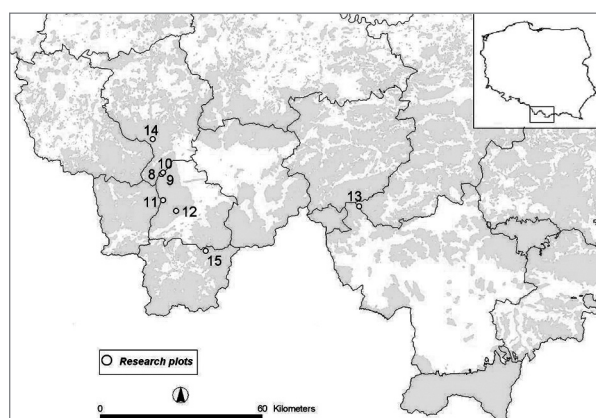


Fig. 2. Location of the research plots in the decline area of Carpathians

The plots numbering was maintained following the order of their establishment. In the Sudetes, research

was carried out mainly in the area of the Jizera Mts. (Świeradów and Szklarska Poręba Forest Districts – plots 1, 2, 3, 4, 5, 6, 7, 20, 21) and also the Śnieżnik Massif (Międzyzlesie Forest District – plot 16) and Owl Mountains (Jugów Forest District – plots 17, 18, 19). In the Carpathians, the plots were established in the area of the Silesian Beskid Mts. (Węgierska Górka and Bielsko Forest Districts – plots 8, 9, 10, 11, 12, 14) and the Żywiec Beskid Mts (Ujsoły and Myślenice Forest Districts – plots 13, 15). Tab. 1 contains characteristics of selected elements of habitat conditions on the research plots established in the decline area.

All research plots were a 20 × 20 m (0.04 ha) squares. For each of these, along randomly selected one of its edges, there was established a subplot (4 × 20 m). For each research plot there was assessed percentage of the area covered by regeneration and regeneration inventory of higher than 50 cm species was prepared. Regeneration up to 50 cm of height was assessed by counting trees in the subplots. For each research plot there were also performed phytosociological records to determine potential plant association.

Due to the very large number of trees on the plots, it was impossible to determine intensity of damage to

**Tab. 1.** Characteristics of selected elements of the habitat conditions on the research plots established in the regeneration in the decline areas

Plot* number	Altitude above sea level (m)	Forest zone**	Slope exposition	Site quality	Potential plant association
1	1070	(I)	NE	low	<i>Calamagrostio villosae-Piceetum</i>
2	1060	(I)	NE	low	<i>Calamagrostio villosae-Piceetum</i>
3	950	(II)	SW	medium/low	<i>Abieti-Piceetum</i>
4	830	(III)	SW	medium	<i>Luzulo luzuloidis-Fagetum</i>
5	870	(III)	N	medium	<i>Luzulo luzuloidis-Fagetum</i>
6	740	(III)	NW	medium	<i>Luzulo luzuloidis-Fagetum</i>
7	930	(II)	SE	medium/low	<i>Abieti-Piceetum</i>
20	830	(III)	SW	medium	<i>Luzulo luzuloidis-Fagetum</i>
21	860	(III)	N	high	<i>Dentario enneaphyllidis-Fagetum</i>
16	1190	(I)	W	low	<i>Calamagrostio villosae-Piceetum</i>
17	990	(II)	SW	medium	<i>Luzulo luzuloidis-Fagetum</i>
18	910	(III)	SW	medium/low	<i>Abieti-Piceetum</i>
19	870	(III)	NW	medium	<i>Luzulo luzuloidis-Fagetum</i>
8	1190	(II)	SE	medium/low	<i>Abieti-Piceetum</i>
9	1200	(I)	NW	low	<i>Plagiothecio-Piceetum</i>
10	1190	(II)	SE	medium/low	<i>Abieti-Piceetum</i>
11	980	(III)	SE	medium	<i>Luzulo luzuloidis-Fagetum</i>
12	800	(III)	SE	high	<i>Dentario glandulosae-Fagetum</i>
14	980	(III)	N	medium	<i>Luzulo luzuloidis-Fagetum</i>
13	1240	(II)	SE	medium/low	<i>Abieti-Piceetum</i>
15	700	(III)	W	high	<i>Dentario glandulosae-Fagetum</i>

\* Sudetes: plots 1, 2, 3, 4, 5, 6, 7, 20, 21 – Jizera Mountains (Świeradów and Szklarska Poręba Forest Districts); plot 16 – Śnieżnik Massif (Międzyzlesie Forest District); plots 17, 18, 19 – Owl Mountains (Jugów Forest District); Carpathians: plots 8, 9, 10, 11, 12, 14 – Silesian Beskid Mountains (Węgierska Górka and Bielsko Forest Districts); plots 13, 15 – Żywiec Beskid Mountains (Ujsoły and Myślenice Forest Districts)

\*\* (I) – upper montane forest zone, (II) – upper part of lower montane forest zone, (III) – middle and lower part of lower montane forest zone

each tree individually. Therefore, for all research plots biotic and abiotic damage to regeneration was evaluated by tree species. There were taken into account only damages which in the opinion of person conducting evaluations could have a substantial effect on further development of the younger generation and cause at least a decrease of growth or significant deformation of the evaluated tree.

Damage to regeneration was determined in the following categories of causal factors:

- damage caused by game,
- damage caused by pathogenic fungi or pest insects,
- damage caused by abiotic factors (wind, snow, ice, settled on the ground iced snow, etc.).

Damage intensity in the above categories was expressed by the percentage share of damaged trees of each species on each research plot. Then there were calculated the average intensity of damage and weighted by the number of trees (individual tree species on each research plot separately).

A preliminary analysis of the damages of individual tree species in regeneration of decline areas indicated increased intensity of some categories of damages in certain zones of elevation in the mountains. This allowed for preliminary selection of three zones and further analysis of data grouped according to location of research plots in the zones.

There were distinguished:

- upper montane forest zone with characteristic plant associations *Calamagrostio villosae-Piceetum* in the Sudetes, and *Plagiothecio-Piceetum* in the Carpathians;
- upper part of lower montane forest zone with appropriate for lower montane forest zone plant associations, but having very similar climatic conditions prevailing in upper montane forest zone, of which the most visible and easily recognizable symptom is the presence of trees with flag form of crowns typically shaped by the wind;
- middle and lower parts of lower montane forest zone with tree crowns not deformed by the wind.

The area covered by trees with flag form of crowns has an uneven width and usually reaches contour line located approximately 100 m (or occasionally more) below the boundary between montane forest zones. It should be noted, that the lower limit of the upper montane forest zone, depending on local conditions in the

research area, was located about 1000 m above sea level in the Sudetes, up to about 1250 m in the Carpathians. Zone I represents plots 1, 2, 9, 16; zone II – plots 3, 7, 8, 10, 13, 17, and zone III – other plots (Tab. 1).

## RESULTS

The total number of trees occurring in regeneration on 21 research plots (main plots and subplots) was 6032. They belonged to 16 species. These were: Norway spruce *P. abies* – 2788 trees, European rowan *S. aucuparia* – 1356 trees, silver birch *B. pendula* – 507 trees, European beech *Fagus sylvatica* L. – 350 trees, silver fir *Abies alba* Mill. – 297 trees, larch *L. decidua* – 217 trees, gray alder *Alnus incana* (L.) Moench – 144 trees, Swiss stone pine *Pinus cembra* L. – 106 trees, Douglas fir *Pseudotsuga menziesi* (Mirb.) Franco – 99 trees, black alder *Alnus glutinosa* (L.) Gaertn. – 80 trees, mountain pine *Pinus mugo* Turra – 43 trees, willows: goat willow *Salix caprea* L. and Silesian willow *Salix silesiaca* Willd. – 37 trees, sycamore maple *Acer pseudoplatanus* L. – 4 trees, common aspen *Populus tremula* L. – 3 trees and Scots pine *Pinus sylvestris* L. – 1 tree.

The characteristics of selected traits of regeneration on research plots established in the decline areas is presented Tab. 2. The largest number of research plots was established in the regeneration of Norway spruce, which dominates in decline areas and in both regeneration of the European beech *F. sylvatica* and the silver fir *A. alba*. Also, there was represented regeneration of the European larch *L. decidua*, artificially introduced onto large areas. An important group are the research plots established in regeneration spontaneously colonizing the decline areas, such as the silver birch and European rowan. The research plots also documented occurrence of species introduced experimentally: black alder *A. glutinosa*, Swiss stone pine *P. cembra*, mountain pine *P. mugo* and Douglas fir *P. menziesi*, and less frequently occurring species: gray alder *A. incana*, willows (goat willow *S. caprea* and Silesian willow *S. silesiaca*), sycamore maple *A. pseudoplatanus*, common aspen *P. tremula*, Scots pine *P. sylvestris*. The mean age of trees growing on the plots ranged from 5-year-old silver birch regeneration to about 25-year-old European rowans with the next generation of other species under their canopy.

**Tab. 2.** Characteristics of selected traits of regeneration on research plots established in the decline areas

Plot* number	Species composition** (%)	Mean age (years)	Area covered by regeneration (%)	Number of trees		
				main plot	subplot	total
1	100 <i>Picea abies</i>	15	50	148	–	148
2	61 <i>Larix decidua</i> , 39 <i>Picea abies</i>	15	60	126	–	126
3	64 <i>Alnus glutinosa</i> , 27 <i>Picea abies</i> , 5 <i>Sorbus aucuparia</i> , 4 <i>Betula pendula</i>	15	50	105	4	109
4	34 <i>Fagus sylvatica</i> , 32 <i>Alnus incana</i> , 20 <i>Sorbus aucuparia</i> , 12 <i>Picea abies</i> , 2 <i>Betula pendula</i>	10	20	149	8	157
5	75 <i>Sorbus aucuparia</i> , 21 <i>Picea abies</i> , 3 <i>Fagus sylvatica</i> , 1 <i>Betula pendula</i>	25	80	221	7	228
6	78 <i>Picea abies</i> , 10 <i>Betula pendula</i> , 8 <i>Alnus incana</i> , 3 <i>Sorbus aucuparia</i> , 1 ( <i>Pinus sylvestris</i> , <i>Salix caprea</i> , <i>Larix decidua</i> )	10	70	535	219	754
7	44 <i>Pinus cembra</i> , 30 <i>Picea abies</i> , 16 <i>Salix caprea</i> , 5 <i>Betula pendula</i> , 2 <i>Alnus incana</i> , 2 <i>Sorbus aucuparia</i> , 1 <i>Fagus sylvatica</i>	15	60	161	5	166
20	47 <i>Larix decidua</i> , 17 <i>Picea abies</i> , 16 <i>Sorbus aucuparia</i> , 7 <i>Betula pendula</i> , 7 <i>Alnus incana</i> , 6 <i>Fagus sylvatica</i>	15	70	66	3	69
21	75 <i>Sorbus aucuparia</i> , 13 <i>Abies alba</i> , 11 <i>Betula pendula</i> , 1 ( <i>Picea abies</i> , <i>Salix caprea</i> , <i>Larix decidua</i> )	20	50	988	88	1076
16	40 <i>Picea abies</i> , 25 <i>Pinus mugo</i> , 17 <i>Pinus cembra</i> , 16 <i>Sorbus aucuparia</i> , 1 <i>Betula pendula</i> , 1 <i>Salix silesiaca</i>	15	60	137	3	140
17	90 <i>Picea abies</i> , 7 <i>Fagus sylvatica</i> , 2 <i>Larix decidua</i> , 1 <i>Pinus mugo</i>	15	50	109	1	110
18	91 <i>Picea abies</i> , 6 <i>Betula pendula</i> , 2 <i>Fagus sylvatica</i> , 1 <i>Larix decidua</i>	20	50	68	12	80
19	70 <i>Picea abies</i> , 21 <i>Betula pendula</i> , 8 <i>Fagus sylvatica</i> , 1 <i>Larix decidua</i>	18	70	429	96	525
8	49 <i>Picea abies</i> , 46 <i>Fagus sylvatica</i> , 4 <i>Sorbus aucuparia</i> , 1 ( <i>Salix caprea</i> , <i>Pinus mugo</i> )	15	50	241	6	247
9	69 <i>Picea abies</i> , 28 <i>Larix decidua</i> , 2 <i>Fagus sylvatica</i> , 1 <i>Sorbus aucuparia</i>	20	60	167	2	169
10	43 <i>Fagus sylvatica</i> , 24 <i>Picea abies</i> , 23 <i>Larix decidua</i> , 6 <i>Sorbus aucuparia</i> , 2 <i>Pinus mugo</i> , 1 <i>Betula pendula</i> , 1 <i>Salix caprea</i>	15	40	145	6	151
11	96 <i>Picea abies</i> , 3 <i>Sorbus aucuparia</i> , 1 ( <i>Fagus sylvatica</i> , <i>Salix caprea</i> )	15	60	454	15	469
12	44 <i>Picea abies</i> , 43 <i>Betula pendula</i> , 9 <i>Sorbus aucuparia</i> , 2 <i>Salix caprea</i> , 1 <i>Acer pseudoplatanus</i> , 1 ( <i>Fagus sylvatica</i> , <i>Abies alba</i> , <i>Populus tremula</i> )	5	50	340	62	402
14	54 <i>Picea abies</i> , 44 <i>Sorbus aucuparia</i> , 2 <i>Fagus sylvatica</i> , ( <i>Abies alba</i> )	15	60	404	87	491
13	35 <i>Sorbus aucuparia</i> , 30 <i>Abies alba</i> , 22 <i>Picea abies</i> , 8 <i>Fagus sylvatica</i> , 2 <i>Populus tremula</i> , 2 <i>Acer pseudoplatanus</i> , 1 ( <i>Salix caprea</i> , <i>Betula pendula</i> )	18	70	269	8	277
15	68 <i>Pseudotsuga menziesii</i> , 21 <i>Abies alba</i> , 10 <i>Picea abies</i> , 1 ( <i>Fagus sylvatica</i> , <i>Acer pseudoplatanus</i> )	15	70	136	2	138

\* – location of the plots as in table 1

\*\* – in the brackets are the species with the share of less than 1 per cent

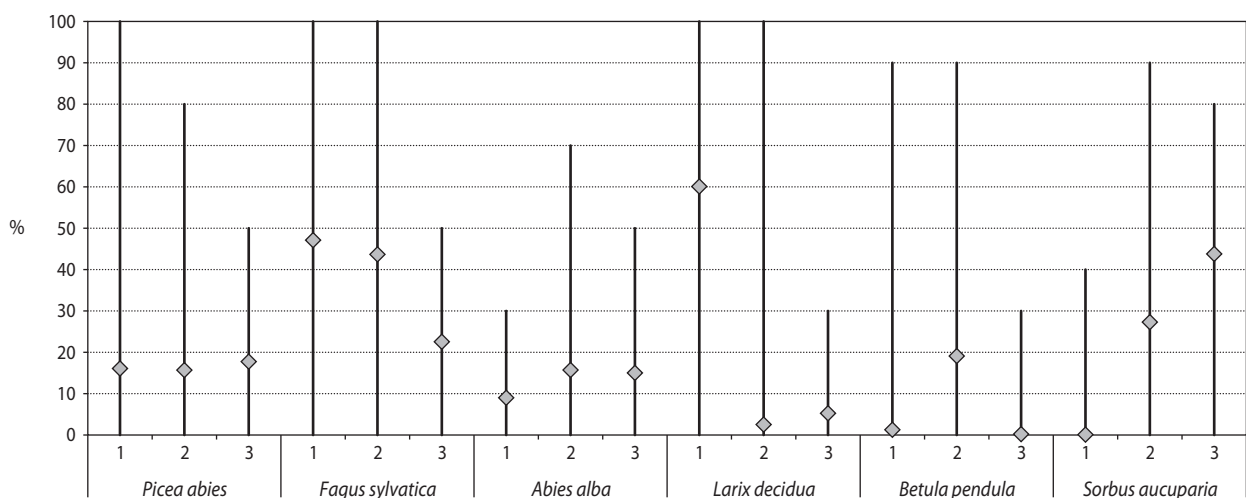
The areas covered by regeneration on the plots were very diverse. The lowest coverage (20%) was recorded for the plantation of the European beech (with admixture of gray alder planted at the same time) which was affected by deer damage. In turn, the oldest European rowan regeneration had coverage up to 80%. The average 50–60% area coverage by the regeneration evidenced of mosaic spatial distribution, with free spaces between groups and clusters of trees.

A significant variable was also the total number of trees in the research plots. There was the highest (1076 trees), where the mass appeared the European rowan seedlings and saplings, and lower for seedlings and saplings of spruce and silver birch. The lowest total number of trees was observed in the research plots with artificial regeneration, located in extremely harsh environmental conditions, like the upper montane forest zone or high elevation and exposed slopes of the lower montane forest zone. In such locations, natural regeneration was insignificant.

The character and average intensity of damage to the main tree species occurring within the research plots is shown in Fig. 3. The average intensity of abiotic and biotic damage does not exceed several per cent for regeneration of spruce. Abiotic damage affecting regeneration of this species is concentrated in the upper montane forest zone and the upper part of lower montane forest zone. There are extremely adverse climatic conditions for tree growth. The damage is caused both, by the

wind and snow. The wind causes shaping crowns into similar to flags forms.. Wet snow and iced snow settled on the ground cause breakage of young trees trunks and branches. This is essential for development of plantations and thickets in extreme conditions of the open area after the collapse of the Norway spruce stands. Intensity of such damage is minor in lower elevations. Locally important for the development of spruce trees are damages caused by biotic factors. Among them, the highest intensity of damage is caused by game, mainly by deer, but also by the European mouflon *Ovis aries musimon* Pallas in the regions of its occurrence. Observed damages were caused mainly by browsing. In comparison to damages described above, damages caused by pathogenic fungi or pest insects, despite similar intensity, are now of marginal importance for regeneration of spruce in the decline areas in the mountains. This is due both the spatial dispersion of damages, and to the fact that they are caused mainly by the brown felt blight *Herpotrichia juniperi* (Duby) Petr. or folivore insects, and these usually result only in growth decrease. On the other hand, it was observed dying of the oldest spruce regeneration (single trees or groups of trees), caused by the European spruce bark beetle *Pityogenes chalcographus* L.

The average intensity of abiotic damage to regeneration of the European beech is almost 50%. They beech suffers from iced snow settled on the ground, which breaks the trunks and branches of young trees. What's



**Fig. 3.** The range, average intensity and character of damage to the main species in the regeneration on research plots: 1 – damage caused by abiotic factors, 2 – damage caused by game, 3 – damage caused by pathogenic fungi or insects

more, snow load causes deformation of young beech trees, which take the form of bushes with almost trailing branches. This occurs mainly in the lower montane forest zone near the border with the upper montane forest zone. Important for regeneration of beech is biting top shoots by deer. Average intensity of this kind of damages on the research plots was almost equal to intensity of abiotic damages. Locally, all the beeches growing in the plantation were damaged by biting. Observed damages caused by insects (slightly higher than 20%), mainly from genus *Phyllobius*, were of small significance.

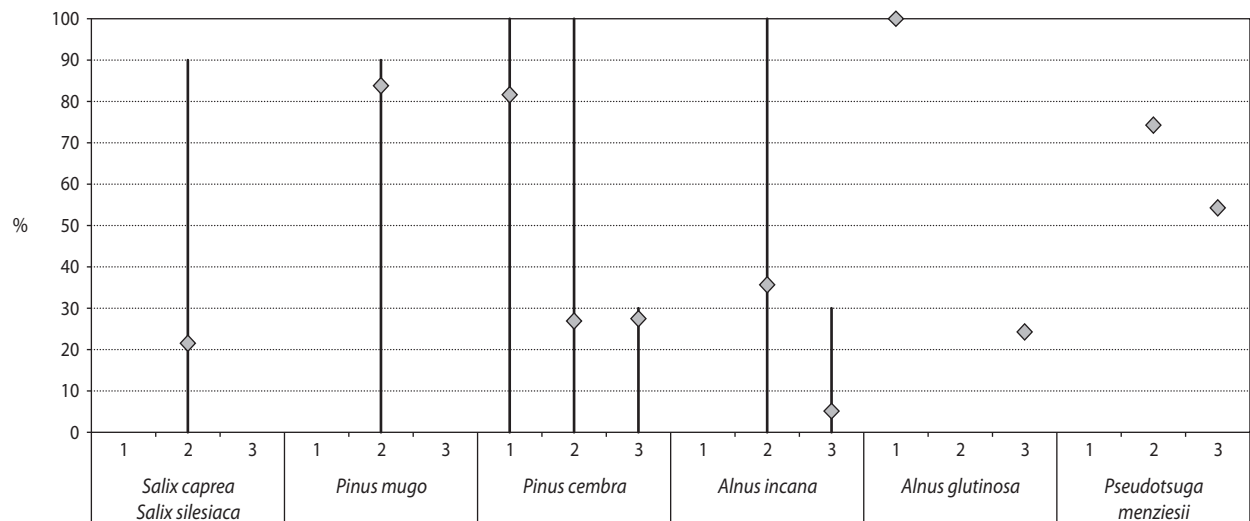
For regeneration of the silver fir, average intensity of abiotic damages did not exceed 10%. Occurring of this kind of damage caused mainly by snow is limited to the highest elevations of the lower montane forest zone. Intensity of damage caused by deer (mainly by browsing) did not exceed 20%, and generally it was not high only for the reason that a few plantations of the silver fir are protected. Scattered, isolated natural regenerations of fir are completely destroyed. Insects and pathogenic fungi do not play a significant role in relation to this species. Damages were caused mainly by aphids.

Similarly to the Norway spruce, abiotic damages are essential for growth of European larch regeneration in the extreme conditions of open space after the collapse of stands. Damage intensity reached 60%. The area of damage (upper montane forest zone and upper

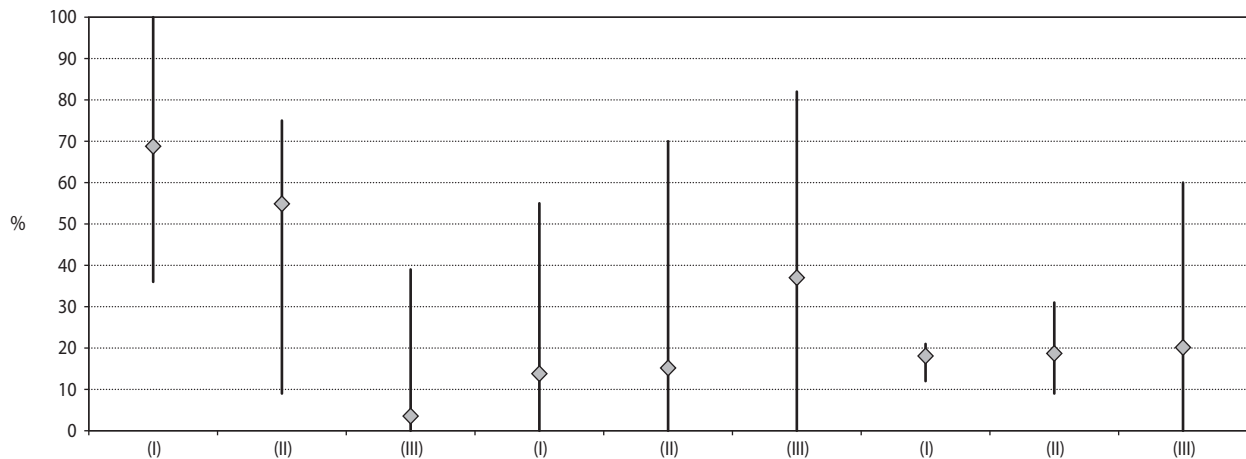
part of lower montane forest zone), driving forces (wind, snow), as tree characteristics (flag form of crowns, many top shoots) were analogous. Damages caused by biotic agents generally had much less importance. Their intensity on the research plots did not exceed a few per cent. Locally, there were reported damages caused by game. The main injury symptom registered was striping. Threat to existence of the oldest larch regeneration can be the large larch bark beetle *Ips cembrae* (Heer) which in recent years has contributed to dying of weakened larch trees in the upper montane forest zone of Jizera Mountains. Although pest presence was not found on living larch trees on the research plots, but feeding galleries of this species were observed in the stumps and trees felled left behind after tending cuttings.

Damage intensity to silver birch regeneration was generally not high. Damage caused by snow, do not skip this species in the upper zone of its occurrence, identified in the decline areas. However, birch regenerations on these elevations were not numerous. Locally, they were grazed by deer, but mainly in the places where the birch was rare admixture in extensive regeneration of other tree species such as the spruce or larch. Damages caused by other biotic agents, including the willow leaf beetle *L. capreae* were less important.

Analyzing the data shown in Fig. 3 it can be concluded, that the European rowan appears to be highly



**Fig. 4.** The range, average intensity and character of damage to the admixture and introduced experimental species in the regeneration on research plots: 1 – damage caused by abiotic factors, 2 – damage caused by game, 3 – damage caused by pathogenic fungi or insects



**Fig. 5.** The range and average intensity of damage to regeneration in research plots located in the different zones of elevation in the decline areas: (I) – upper montane forest zone, (II) – upper part of lower montane forest zone, (III) – middle and lower part of lower montane forest zone

resistant to damages caused by weather conditions. However, this species was readily eaten by game (mainly shoots biting and bark peeling were observed). Average game damage intensity in the research plots was almost 30%. However, average intensity of damage due to folivore insects from the genus *Phyllobius* was relatively high (over 40%), and locally even complete defoliation was recorded.

Damage character and its average intensity in admixture and introduced experimentally species occurring on the research plots established in the mountains' decline areas are shown in Fig. 4. The analyzed cases show, that spontaneous spread of goat willow *S. caprea* and Silesian willow *S. silesiaca* regeneration in the decline areas was limited due to grazing by deer. Also, the mountain pine *P. mugo* artificially introduced to the decline areas was eliminated in the research plots due to deer damage. Stripping was the main injury symptom registered. Intensity of this damage was very high and reached 80%.

Very high intensity of abiotic damage to artificially introduced regeneration of the Swiss stone pine *P. cembra* was mainly caused by inappropriate choice of places for growing this species. These were the places with settled on the ground iced snow, where young trees extremely suffered from breaking under snow weight. Swiss stone pine ability to compete the Norway spruce is limited because of its greater vulnerability to damages caused by deer. Among other biotic harmful

factors diseases caused by pathogenic fungi were most important. Here, the major role was played by brown felt blight *H. juniperi*. Their intensity even locally does not threaten the existence of Swiss stone pine plantings.

Locally, gray alder regeneration was subjected to very strong pressure from game, especially when planted within extensive reforestation with the spruce or larch. Game damage intensity was approximately 30%. Damages were caused mainly by browsing. Other harmful factors' effects were not observed in the gray alder.

Because of the presence of the black alder *A. glutinosa* and the Douglas fir *P. menziesi* only on individual plots, the results should be treated with caution. However, very high intensity of damage caused by some factors may be important indication talked about merits and possible conditions of introducing these species in the decline areas.

The main factor behind progressive elimination of black alder regeneration was disastrous, amounting to 100%, intensity of damage caused by snow. Damages caused by insects, mainly by the alder leaf beetle *Agelastica alni* L., are much less important. The Douglas fir were mainly damaged by deer (stripping). Intensity of Insect pests (aphids) attacked half of the trees in the plot, but these trees were not infested to the extent directly threatening their endurance. There was no occurrence of damage caused by abiotic factors.

The analysis of average damage intensity of regeneration in the research plots located in the distinguished



zones showed that damages caused by abiotic factors were very high in the upper montane zone, and reached almost 70%. In the upper part of the lower montane forest zone this kind of damages was still high – 55%, but in the middle and lower parts of the lower montane forest zone, they reached only a few per cent (Fig. 5). This part belonged to the area of the highest intensity (nearly 40%) of damage caused by game. Game damage was there more than twice damage to regeneration growing in the plots located in the two other zones. Damage caused by pest insects and pathogenic fungi showed no differences in intensity with regard to zone altitude. Damage intensity in the observed areas ranged from 18 to 20%.

## DISCUSSION

Several investigators observed climatic changes taking place in open spaces of the decline areas and the impact of these on the young phases of regeneration in such areas (Konca 1994; Karaš 1995 b; Balcar 2000; Kula et al. 2000; Lomský et al. 2000; Martinková et al. 2000; Šrámek and Šebková 2000). This study showed that the problem was still present also in older regenerations with varying degrees of abiotic damage.

Damages caused by deer are still important factors limiting the development of regeneration on the decline areas, There was not observed damage caused by rodents.

When compared to damage caused by atmospheric factors and game during this investigations, there was found a low level of damage caused by pest insects (especially by folivore insects) and fungal diseases. However, such damages were significantly higher in the first phase of development of the decline areas (Kosibowicz 1990, 1994, 1995; Kula et al. 2000; Lomský et al. 2000; Martinková et al. 2000; Soukup and Peškova 2000; Vacek et al. 2000).

Occurrence of secondary pests associated with the spruce and larch on the decline areas was noted by many authors (Kula and Zabecki 2003; Kula et al. 2007; Grodzki 2008, 2009; Grodzki and Kosibowicz 2009). The most dangerous are insect pests such as the European spruce bark beetle *P. chalcographus* or the large larch bark beetle *I. cembrae*, that are capable of infesting trees of even small dimensions. During the research

period on the assumed plots there was no increased activity of these insect species. But with the development of regeneration, of which the oldest is already about 30 years old, an increase of importance of secondary pests is expected. Thus, it is necessary to take account of these risks during the implementation of the objectives of forest management for the decline areas.

The implementation of the main objective of forest management in the described areas, which is to achieve future forest stands of much greater stability and resistance to stress, than the collapsed spruce stands (Matička 2000; Šach et al. 2000; Vacek and Balcar 2000; Szabla 2004; Kantor 2004) needs to consider the impact of damage zones to the regeneration. The consequence of this is to define specific objectives for each zone.

The principal objective for the upper montane forest zone should be to develop tree stands with protective functions. The leading species in these stands is the Norway spruce, being best adapted to prevailing conditions.

For the upper part of lower montane forest zone, where regeneration is damaged and deformed as a result of weather conditions, the specific objective will be to develop tree stands with protective as well as productive functions, and with species composition adequate to the site, using a temporary cover of other tree species. In this zone, there are mainly the European larch and the Norway spruce, but sometimes there also occur the silver birch and the European rowan. Ultimately, this species should be gradually replaced by other tree species, or should be reduced to the role of admixtures.

The same objective (stands adequate to the site) should be implemented in regeneration growing in the middle and lower parts of the lower montane forest zone, where damaged trees are in the minority. However, in this case some larch trees can and should remain in the stand to the end of the rotation period, as the producer of large volume of high-quality wood.

Given the existing conditions, the realization of the forest management objectives in each of the listed above three categories of regenerations will be done differently. In the upper montane forest zone, the general principle should be to abstain from tending cuttings. This was evident both for mosaic spatial distribution of regeneration, with free spaces between groups and clusters of trees, and the areas with high degree of damage to trees. Increasing density in tree groups and clus-

ters causes establishing of biogroups, where trees are mutually reinforcing (Karaś 1995 a). Due to damages and extreme environmental conditions almost all of the trees are at the edge of existence. Cutting down even one tree, especially from the middle of biogroup can determine its fate. The process of the inevitable self-thinning of thickets should be kept in check by sanitary cuttings with removal of cut trees. Planting of young trees should be carried out with the maximum use of existing cover capabilities of the youngest generation, by already growing trees.

High degree of damage to trees in the upper part of the lower montane forest zone indicates prevailing severe climatic conditions (multiplied by large-scale deforestation). These conditions, probably temporary, are more similar to the climatic environment of the upper montane forest zone than that of the lower montane forest zone. The climatic effects of large-scale deforestation should be gradually relaxed in a natural way with the progressive development of stands. This will allow introduction of target species, compatible with the site. Planting of these species should therefore take place with the use of cover even most damaged trees, as long as possible. First, regeneration should be sited within existing gaps and places with low tree density, and observing their development in this specific conditions. Only when the introduced species have a positive silviculture assessment, there should be considered next steps to achieve the stated silviculture objectives. This will be introduction of target species under the canopy of other species.

In the case of European larch young stands there exists a risk mass occurrence of the large larch bark beetle (Grodzki 2008; Grodzki and Kosibowicz 2009). Therefore, tending cuttings must be exercised only where absolutely necessary and where it is possible to remove cut material. The cuttings also have a task to prepare most dense thickets and young stands for introduction of target species. Further silviculture processing is dependent on development of under-canopy planted species.

The principal thesis of silviculture recommendations made for regenerations permanently damaged by atmospheric factors and located in the upper part of lower montane forest zone also finds its justification in relation to the rest of regenerations in the lower montane forest zone, where damaged trees are in the minority. The main differences arise from the possibility of de-

lay of introduction of target species due to the reduced risk of damage. This is particularly important for the introduction of these species under the canopy of the European larch. Indeed, it is reasonable to leave in the stand to the end of the rotation period a quantity of larch as a significant producer of high quality wood. The attention should be more paid to positive selection in the course of tending cuttings in European larch stands. In addition to the threat of the large larch bark beetle, for possible late beginning of tending cuttings speaks also rapid volume increment, which takes place when larch young stands have already begun production of timber (Szymkiewicz 2001). Greater wood volume obtained from cuttings will improve the economic efficiency of treatment.

In conclusion it can be stated as follows:

- In specific conditions created in the open space after large-scale decline of Norway spruce stands in the mountains, the location of existing regenerations have a decisive impact on their overall condition, mainly dependent on intensity of damage caused by atmospheric factors.
- Due to intensity of damage caused by atmospheric factors three basic categories of regeneration can be distinguished in the decline areas: regeneration in the upper montane forest zone permanently damaged by atmospheric factors, regeneration located in the upper part of the lower montane forest zone high damaged by atmospheric factors where damaged trees are more than 50% of the total, and regeneration in the middle and lower parts of the lower montane forest zone, where damaged trees are the minority. Featured categories of regeneration are characterized by different forest management objectives and methods of their implementation.
- Apart from damage caused by abiotic factors there is important damage caused by game, with highest intensity in the middle and lower parts of the lower montane forest zone. These now play a much greater role for the health of regeneration than pest insects and fungal diseases.
- Although currently low intensity of damage caused by pest insects and pathogenic fungi, it should be monitored in artificially as well as naturally generated regenerations. This will allow for early preparation for action and development of a method for control of pest insect populations and fungal diseases.

- Particular attention should be paid to growing in large areas one-species regeneration of the Norway spruce or the European larch. In the course of tending cuttings the cut trees should be removed, because of the danger of excessive proliferation of pest insects on cut wood left behind in forest and repopulation of the Norway spruce by the European spruce bark beetle and the European larch by the large larch bark beetle while trees are in young age classes.

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