JOURNAL OF FOREST SCIENCE, *53*, 2007 (Special Issue): 38–44

Spatio-temporal patterns of the Norway spruce decline in the Beskid Śląski and Żywiecki (Western Carpathians) in southern Poland

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ABSTRACT: A dramatic forest decline due to the bark beetle outbreak, which occurs in the Norway spruce stands in the Western Beskidy (southern Poland) since 2003, was started after severe physiological drought during winter time. An analysis describing some spatio-temporal characteristics of this process, with special regard to the patterns of bark beetle occurrence related to root fungal diseases, is presented. In 2003 the bark beetle occurrence level assessed as high and catastrophic was recorded on 40% of the area, while in 2006 – on 59%. The range of *Armillaria* root disease and bark beetle outbreak increased towards higher altitudes, including the zone above 1,000 m a.s.l. The wind damage in 2004 and 2007, and high temperatures in the summer 2006, further stimulated the increase in bark beetle populations level. Some conclusions on possible development of the outbreak and recommendations concerning related needs in forest protection, are given.

Keywords: *Picea abies* (L.) Karst.; bark beetles; mountain forests; spatial analysis

Mountain Norway spruce *Picea abies* (L.) Karst. stands are exposed to a number of injurious factors with varied duration and intensity of impact. These factors can be of specific nature, related to the specific properties of stands or the site conditions, or of more general one, arising from and/or manifested by a health crisis of stands. Among the most important ones, some abiotic – such as the drought or extreme temperatures, and biotic – mainly tree diseases and insect pests, should be mentioned. It concerns all mountain forests, including the area of the Beskidy Mts. (Beskid Śląski in the northern, Beskid Żywiecki in the southern part of the area described in this paper), located in the western edge of the Carpathians. Damage caused by abiotic factors, especially by wind and snow, is a phenomenon that frequently affects forests in this area; the last serious windthrowns were recorded in 2004 and in January 2007 (Grodzki, Jachym 2007). The *Armillaria* root rot was considered as a serious problem already before World War II (Mańka 2006), but till late 1980s the area of its occurrence was limited to the northern part of the Beskidy Mts. (Capecki 1994). In 1977–1982 a local outbreak of *Zeiraphera griseana* (Hb.) (Lepidoptera, Tortricidae) and resulting damage was recorded in Beskid Żywiecki (Capecki et al. 1989). In 1976–1986 and in late 1990s the outbreaks of sawflies *Cephalcia* spp. (Hymenoptera, Pamphiliidae) caused local defoliations in both parts of the area (Jachym 2002). According to the data from the 1980s (period after the heaviest defoliations), analyzed by Capecki (1994), the health status of stands in northern part of Beskidy Mts. was assessed as poor, and improving southward – the best was in the southern parts of Beskid Żywiecki. In the recent years, the areas of the occurrence of the *Armillaria* disease were found to continuously expand, which results from both favourable site conditions and high share of the Norway spruce in the

stands (Lech, Żółciak 2006). Consequently, the rapid build-up of the populations of bark beetles feeding on Norway spruce, mainly *Ips typographus* (L.), was observed. The resulting increase in the tree mortality was recorded especially in the years after 1996, with the first culmination about 1998 (Grodzki 2004). The process of the forest decline in this region was continuously monitored in order to define the patterns of tree mortality and the spreading of bark beetle outbreak (Grodzki 2004, 2006). The repeated dramatic increase in the intensity of the bark beetle attacks on standing trees started in 2002–2003; in 2006 the situation turned to catastrophic state, with a real risk of a total forest decline on large areas. This paper is aimed to present the spatio-temporal characteristics of this process during last 5 years in a mountain area covering Beskid Śląski and Beskid Żywiecki, in order to better recognize the patterns of the bark beetle occurrence in mountain conditions.

MATERIAL AND METHODS

The assessment of the intensity and dynamics of the dying of stands was carried out on the basis of the data collected in the SILP System (the Information System of State Forests) concerning the harvesting of dead, fallen and windthrown trees in 6 Forest Districts in the Beskid Śląski and Beskid Żywiecki (Bielsko, Jeleśnia, Ujsoły, Ustroń, Węgierska Górka and Wisła), as a mountain area under the greatest threat. The yearly data covering the period 2003 to 2006 were used. For this study a simple database was built; it was arranged by forest compartments as the basic area units. The assessment of the bark beetle occurrence was based on the mean volume of infested (standing and lying) trees removed annually from 1 ha of stands. The classification of the stands according to the particular degrees of tree mortality and the occurrence of these insects was based on the scale developed by Capecki (1981) in the version for the stands affected by *Armillaria* spp. (Table 1). In order to visualize the data and to describe the spatial distribution of the process, a digital map covering most of the research area (excluding the northern parts of the Forest District Bielsko and the eastern part of the Forest District Jeleśnia), especially the layer encompassing the forest area units (from forest compartments to forest districts) and major localities, was used.

As a case study for the altitudinal analysis the Forest District Ujsoły was chosen. About 92% of its total forest area is covered by Norway spruce stands – it is the unit with the highest share of this species among the forest districts in Beskid Żywiecki, and almost the highest in the whole Western Beskidy (Capecki 1994). The stands older than 60 years consist about 77% in terms of surface, but about 90% of the wood volume is cumulated there (Strategia … 2007). Taking into account the species composition and age, the susceptibility of these stands to bark beetle attacks should be assessed as extremely high (Netherer, Nopp-Mayr 2005). For the analysis in altitudinal aspect, the detailed digital map of the Forest District Ujsoły was used.

All the thematic layers were generated and analyzed using the ESRI ArcView GIS 3.2 software.

Table 1. The classification of the stands according to the particular degrees of occurrence of bark beetles and related tree mortality

Volume of infested trees (m^3/ha/year)	Bark beetle occurrence level
0–0.4	normal
0.41–1.2	premonitory
1.21–2.4	abundant
2.41–10	high
10.01–20 and more	catastrophic

RESULTS AND DISCUSSION

Dynamics of tree mortality

The last wave of the forest decline in the Beskidy Mountains started after the winter 2002/2003, with the weather conditions unfavourable for Norway spruce (Strategia … 2007). The physiological stress resulting from water shortage (drought) was the direct factor affecting the decrease in tree vitality and their higher susceptibility to the root diseases and bark beetle attacks. A serious wind damage affected the stands in the area of interest in late 2004 – the volume of broken and fallen trees processed in 2005 was over 300 ths m^3 (Fig. 1). This resulted in the size of sanitary cuttings in 2005 (higher than in 2004, but including also lying, infested trees), but also – in the volume of infested standing trees, which was lower than in 2004. The real increase in the tree mortality caused by bark beetle infestations occurred in 2006. Extreme weather conditions during the vegetation season stimulated the bark beetle populations' level build-up, and resulting tree mortality. In conditions of extremely long vegetation period (long and warm autumn), the development of the pre-imaginal stages of bark beetles under the

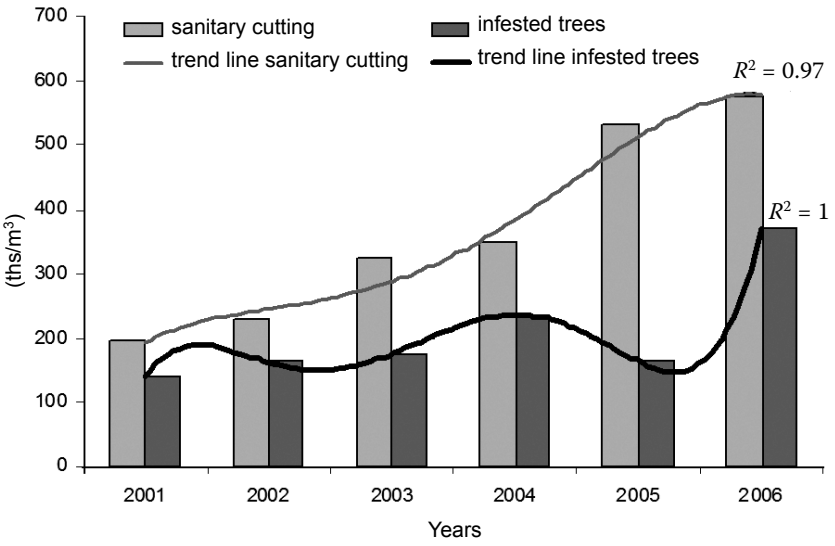

Fig. 1. The size of sanitary cuttings and the volume of processed trees infested by bark beetles in 6 forest districts in the Western Beskidy in 2002–2006

bark was very advanced; mostly adults entered in winter diapause. In consequence, the attack potential of swarming adults in the spring of 2007 was very high.

Spatial aspect

The bark beetle outbreak affected the Norway spruce stands in almost the whole area of the Western Beskidy region. Along with the increase of the size of salvage cuttings (including the removal of infested trees) the area of stands affected by the forest decline increased too (Fig. 2). In 2003 (the first year of the last "wave" of the outbreak) the tree mortality assessed as "normal" (up to 0.4 m³/ha) occurred on more than 30% of the total area of stands, while the serious mortality (over 2.41 m³/ha – "high" and "catastrophic" level) – on about 40% of the area. In 2006 the percentage of the area of stands in these classes were 22 and 59%, respectively. The strongly attacked stands occurred on the whole area, regardless the results of previous assessment of their vitality, health status and resistance to injurious factors (Fig. 3).

Altitudinal aspect

The situation regarding sanitary cuttings and the dynamics of bark beetle populations in the Forest District Ujsoły was the same as in the whole region (Fig. 4, cf. Fig. 1), including the serious wind damage in 2004 and 2007.

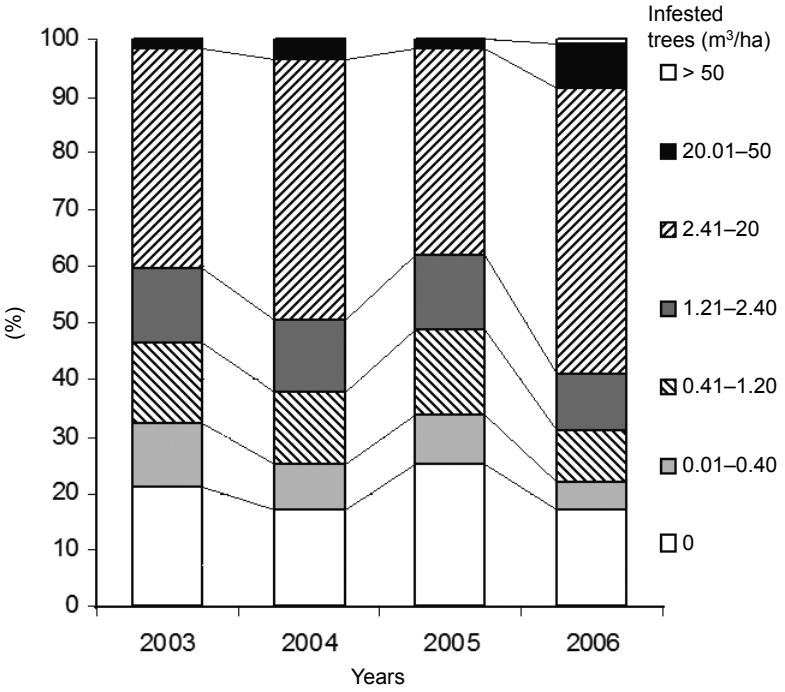

Fig. 2. The distribution of stands in individual classes of the bark beetle caused tree mortality regarding their area in 2003–2006

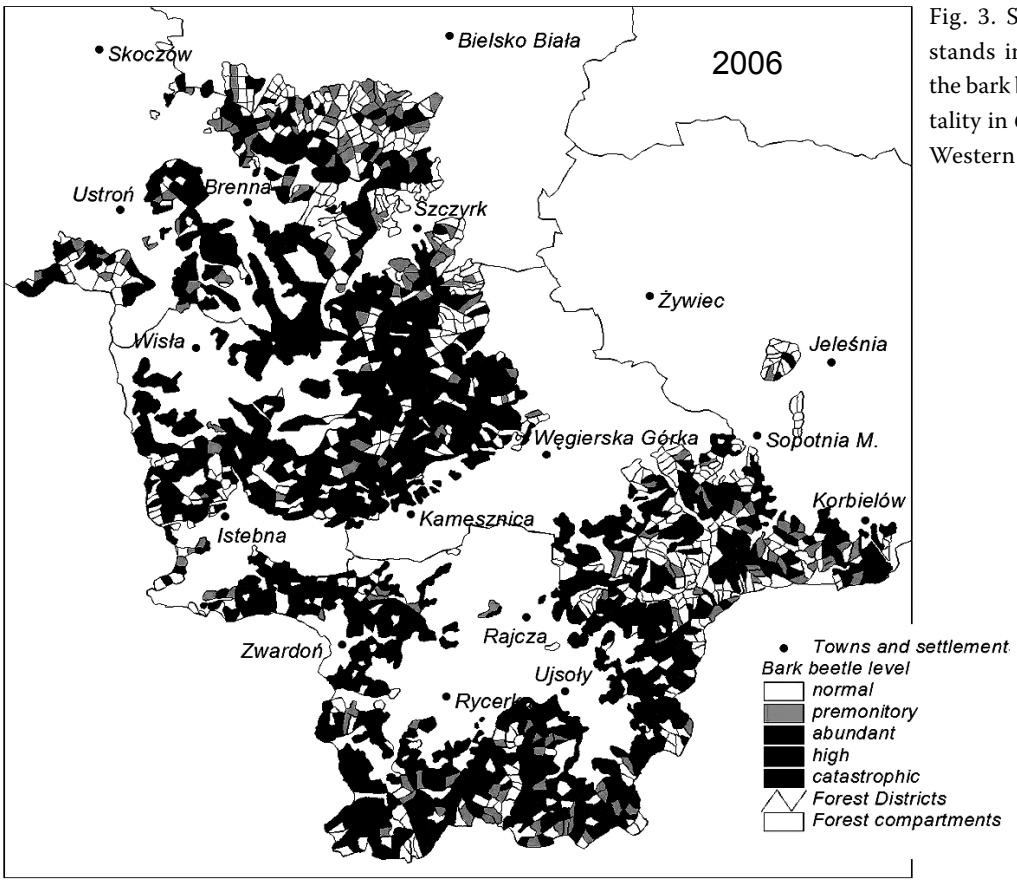

Fig. 3. Spatial distribution of stands in individual classes of the bark beetle caused tree mortality in 6 forest districts of the Western Beskidy in 2006

In 2003 most (60%) of the sanitary cuttings was done in the lower mountain zone – up to 800 m a.s.l., in the stands more attacked by *Armillaria* root disease (Fig. 5). In the next years the tree mortality in the upper zone (over 800 m a.s.l.) increased, up to 50% in 2006; the mortality was relatively stable only in the highest zone – over 1,000 m a.s.l. The same altitudinal pattern occur in the other forest districts of the region, which can be supposed based on the spatial distribution of attacked stands in the whole vertical profile in 2006 (Fig. 3).

In the years of 1980 the occurrence of the root rot caused by *Armillaria* spp. was recorded mainly in the stands of the lower mountain zone; the stands in

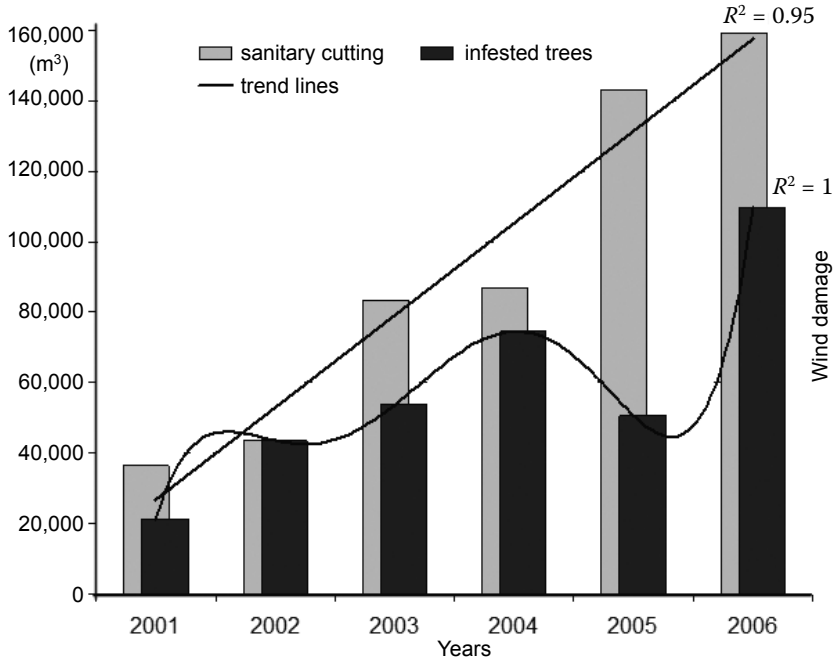

Fig. 4. The size of sanitary cuttings and the volume of processed trees infested by bark beetles in the Forest District Ujsoły in 2001–2006

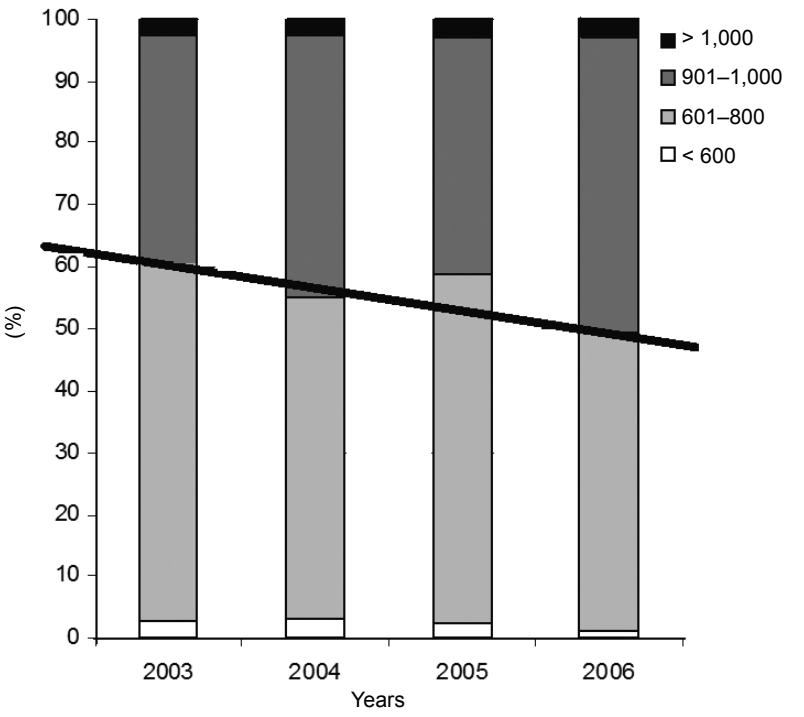

Fig. 5. The distribution of the volume of processed trees infested by bark beetles in 4 zones of altitude (m a.s.l.) in the Forest District Ujsoły in 2003–2006

the southern (higher located) part of Beskid Śląski and Żywiecki were considered as relatively free from the disease (Capecki 1994). In consequence of the changes in the vitality of stands caused mainly by abiotic factors, the present occurrence of this pathogen reached the altitude of about 1,100 m a.s.l. (Lech, Żółciak 2006). The enlargement of the zone affected by this disease (in both spatial and altitudinal aspects) can be understood as the main cause of bark beetle related spruce decline, but also as an indicator of dramatic collapse in tree health and vitality. The fast increase in the bark beetle population level, started and supported by favourable breeding and weather conditions (warm summers, wind damage, stressed trees), fits perfectly in the patterns of their population dynamics as described by theoretical model (Christiansen et al. 1987). According to this model, the close relation exists between the bark beetle population density and the stand resistance: the higher is the number of beetles attacking the trees, the stronger (more resistant) trees are successfully colonized and killed. In the present state we are facing the most acute phase of the bark beetle outbreak, which is demonstrated by very high potential of bark beetle attack, resulting in very high tree mortality, even between relatively "healthy" (= resistant) trees.

The rapid increase in the bark beetle caused tree mortality in 2006 was stimulated by the extreme weather conditions, supported by the effects of large wind damage from late 2004. According to the rules found in several areas, the impact of windthrowns on the bark beetle populations usually occurs in the second vegetation season after the damage (Göthlin et al. 2000; Grodzki et al. 2006a,b). As the repeated wind damage occurred on large areas in early 2007, a further increase in the risk, resulting from already high level of bark beetle populations, can be expected also in 2008.

The *I. typographus* outbreaks usually develop in very dramatic way, reflected by a rapid increase of the insect populations and its spread (especially in progradation phase) from already attacked parts of stands to new tree spots. The outbreak is also favoured by climatic conditions, such as high temperatures, which is favourable for insect development (Sauvard 2004). This increases the threat to stands, resulting in a substantial tree mortality rate. In these circumstances, the relevant control measures can be taken to reduce the damage (direct control) and to mitigate its possible further effects in the form of stand weakening and their increased vulnerability to bark beetle attacks. It concerns mainly the timely removal of infested trees, as well as the use of the trap logs and artificial pheromone traps, according the rules adopted for the mountain forests (Grodzki et al. 2003).

The effect of *I. typographus* outbreaks is a deep change in the ecological conditions, caused by the stand decline and also by the control measures taken against this species. Therefore, in the post-outbreak stands, it is necessary to flexibly respond to qualitatively new threats related to an increase in the frequency of insects which, as they accompany

I. typographus, are usually considered species of secondary significance (Grodzki 2003). This could be a challenge for the forest protection services. On the other hand, it is necessary to take pro-active silvicultural measures, particularly in the scope of spruce stand conversion, ensuring their greater species diversification, according to the site conditions.

Acknowledgements

The author thanks the State Forest Administration of the Forest Districts Bielsko, Jeleśnia, Ujsoły, Ustroń, Węgierska Górka and Wisła for kindly providing the data and map used for the analyses presented in this paper, and Dr. Marcin Jachym for the basic digital map used for data visualization.

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Časoprostorové zákonitosti rozpadu smrkových lesů v pohořích Beskid Śląski a Żywiecki (západní Karpaty) v jižním Polsku

ABSTRAKT: Dramatický rozpad lesa způsobený gradací lýkožroutů, který nastal na smrkových stanovištích v západních Beskydech (jižní Polsko) v roce 2003, byl nastartován silným fyziologickým suchem v průběhu zimního období. Analýza popisuje časoprostorové charakteristiky tohoto procesu se zvláštním ohledem na zákonitosti výskytu lýkožroutů v závislosti na kořenových hnilobách. V roce 2003 byla úroveň výskytu lýkožroutů hodnocena jako vysoká a katastrofická a kůrovec byl zaznamenán na 40 % území, zatímco v roce 2006 již na 59 % území. Území výskytu václavky a gradace kůrovce směřuje k vyšším nadmořským výškám (zahrnuje i zónu nad 1 000 m n. m.). Škody větrem v letech 2004 a 2007 a vysoké teploty v létě 2006 dále napomáhají zvyšování početnosti populace lýkožroutů. Jsou prezentovány závěry o možném rozvoji gradace a doporučení k potřebné ochraně lesa.

Klíčová slova: *Picea abies* (L.) Karst.; kůrovci; horské lesy; prostorová analýza

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