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Spruce bark beetle (Ips typographus L.) infestation and Norway spruce status: is there a causal relationship?

Ivo Moravec[1], Pavel Cudlín[1,*], Tomáš Polák[2] & František Havlíček[1]

[1]*Department of Forest Ecology, Institute of Landscape Ecology AS CR, Na Sádkách 7, CZ-37005 České Budějovice, Czech Republic*
[2]*Department of Plants Physiology, Faculty of Science, Charles University, Viničná 5, CZ-12844 Prague 2, Czech Republic*
**pavelcu@uek.cas.cz*

Abstract
Outbreaks of the spruce bark beetle (*Ips typographus* L.), normally a secondary pest in Norway spruce forests, can be very rapid under favourable environmental conditions. In the Šumava National Park the spruce bark beetle has always been a significant factor damaging spruce stands that become physiologically weakened by negative effects of wind, glazed frost, snow, air pollution, etc. Forest stand edges infested by spruce bark beetle were investigated in the Modrava forest district in the controlled natural Zone II in years 1999, 2000 and 2001. Selected tree crown transformation features such as total defoliation, primary structure defoliation, percentage of secondary shoots, and crown structure transformation stage were determined. Trees were grouped by bark beetle invasion history, total defoliation and crown structure transformation. Trees with higher crown structure transformation, i.e. trees with more acute need of replacing the defoliated parts of assimilatory organs, were significantly more frequently infested by eight-toothed spruce bark beetles.

Key words: bark beetle infestation, crown transformation, secondary structure, defoliation, *Picea abies*, *Ips typographus*

Introduction

Norway spruce (*Picea abies* [L.] Karst.) is one of the most widespread trees of European forests. Spruce stands cover 54% out of the whole forest area in the Czech Republic, mainly in the mountainous forest belt adjacent to the border with surrounding countries. These Norway spruce forests have been exposed continuously to the human impact during the last centuries. Forests in the Šumava National Park have been affected within three human colonisation waves (Zatloukal 1998). Forest ecosystems with changed tree species (provenance) and age composition have become unstable and highly susceptible to the adverse impact of abiotic and biotic factors. The spruce bark beetle has been one of the most important biotic agents since the period of 1834–1839 (Zahradník & Liška 1998). It considerably influences the structure and the function of the spruce mountain forests and may cause total destruction of the tree layer. In this paper, we concentrated on the problem of selection of Norway spruce (as host plants) by spruce bark beetles.

In the Šumava National Park the spruce bark beetle is a significant detrimental insect species damaging Norway spruce stands that have become physiologically weak as a consequence of various causes. It is known that host plant selection in general is controlled primarily by chemoreception (Jermy 1984). Recent research on food perception among insects has demonstrated that odor and taste are decoded inside the central nervous system as "host" and "nonhost" plant (JOLIVET 1998). Our hypothesis is derived from the presumption that physiologically weakened spruce trees suffering from long-term multiple stress impacts produce and release different mixtures of volatile chemicals into the air than trees in good health. This distinct "smell" acts as an attractant for spruce bark beetles and orients them toward "the right trees". Spruce bark beetle development and also gradation can be conditioned by withering phloem of the stressed Norway spruce trees (ZUMR 1985). The spruce defense mechanism based on filling up spruce bark beetle entrance holes with resin is decreased in weakened spruce trees. This phenomenon is apparently closely related to the decreased water transport in the trunk (JAKUŠ 1998).

Stressed and weakened Norway spruce trees are distinguishable by means of the method of visual crown status assessment using modified approach of LESINSKY & LANDMANN (1985) and GRUBER (1994). Trees are monitored, among other conditions, for defoliation, primary structure defoliation, and percentage of secondary shoots in the production (middle) part of the crown. This approach traces the retrospective stress response of Norway spruce trees during a long-term period of non-mortal acute and chronic stress incidence (CUDLÍN et al. 1999, 2001a).

SITE DESCRIPTION

Study sites are situated in the upper slope region of the mountain range close to the Bavarian – Czech border in the Bohemian Forest (called Šumava in Czech, and Böhmerwald in German), for main site characteristics see Table 1. The bedrock consists of medium-grained to coarse granite. The climate is characterized by high annual precipitation (1661 mm per annum) with a high snow portion (47%) and low annual mean air temperature (2.7°C). The area is largely vegetated by acidophilous spruce forests (*Calamagrostio villosae-Piceetum*) (NEUHÄUSLOVÁ 1997, 1998). The vegetation is dominated by Norway spruce (*Picea abies* [L.] Karst.). All study sites have been placed in the controlled natural Zone II. The forests of the area were not intensively exploited in the Middle Ages. However, they were seriously dam-

Table 1. Main characteristics of study sites in the Šumava NP. BL – Březnický les, PSH I–III – Pod Studenou Horou I–III, 8K – acidic spruce stand, 8S – mesic spruce stand, 8P – gleyic acidic spruce stand.

Plot	BL	PSH I	PSH II	PSH III
Latitude	48°58'44"N	48°58'47"N	48°59'02"N	48°58'44"N
Longitude	13°28'42"E	13°28'54"E	13°27'15"E	13°28'42"E
Altitude (m)	1240	1235	1230	1220
Slope (%)	15	10	10	5
Exposition	SE	SE	SE	NW
Age (years)	130	132	175	131
Stand density	8	8	8	9
Mean tree diam. (cm)	28	30	37	35
Mean tree height (m)	33	23	23	25
Forest type	8S	8K	8S	8P
Soil type	Stony podzol on nutrient mesic silicic rocks	Stony podzol on nutrient poor silicic rocks	Stony podzol on nutrient mesic silicic rocks	Peat gleysol

aged by gale disasters followed with spruce bark beetle outbreaks mainly in the 19th century and the second half of the 20th century (Zatloukal 1998).

Methods

Forest edges: bark beetle attack

In the course of the years 1999 and 2000 we monitored four forest edges in the epicentre of spruce bark beetle outbreak (226 trees were monitored in 1999, 251 trees in 2000). In each forest edge about eighty trees, classified as dominant and co-dominant according to Kraft's social status scheme, were followed. Seventy three percent of trees were situated in south-oriented and 17% in east-oriented forest edges in 1999, meanwhile the situation was 50% to 50% in 2000. Investigated trees formed two to three upper-most "rows" (trees overlayed by frontal trees were not selected) in a forest edge.

Trees were evaluated for main crown structure characteristics: social status, crown section partitioning, type of upper crown part, type of the tree top, total defoliation, primary structure defoliation, percentage of the secondary structure, type of crown damage, needle discolouration, and crown structure transformation stage. In accordance with the evaluation of defoliation, degradation, and regeneration processes at the crown level the stress response history of Norway spruce trees, subjected to multiple stress impacts of different duration and intensity, was reconstructed (Cudlín et al. 2001b). In the period of spruce bark beetle activity trees were monitored for spruce bark beetle attack in the interval of ten days. Simultaneously the results of bark beetle counting by the National Park Administration in the pheromone traps situated close to forest edges were excerpted. Two-Sample Tests have been used for statistical analysis of the data: Equal-Variance T-Test for normally distributed data with equal variance and in other cases non-parametric Mann-Whitney U Test.

Forest edges: passive traps

In spring 2001 forty co-dominant Norway spruce trees were selected in the existing south-facing forest edges; twenty trees with low crown transformation (percentage of secondary shoots <50%) and twenty trees with high crown transformation (percentage of secondary shoots ≥50%). Passive bark-beetle landing trap (Swedish type, see Fig. 1) was fixed on each tree at the height of 150 cm. Passive traps were installed in the beginning of May (by the research group of R. Jakus from the Institute of Forest Ecology, Slovakia) and checked in ten-day intervals until the middle of September. Total number of individual species of bark-beetles trapped per tree was recorded. The same above mentioned tests have been used for statistical data processing.

Results and Discussion

Forest edges: bark beetle attack

Total defoliation, primary structure defoliation, and percentage of secondary shoots for infested and non-infested trees, situated on south- and east-oriented forest edges, were tested. In 1999 trees, regardless of orientation, with higher total defoliation, higher primary structure defoliation and higher percentage of secondary shoots were significantly more frequently infested by spruce bark beetle than those with less total defoliation and transformation of crown structure. However, differences in total defoliation were less compared to values of crown structure transformation; they got around the determination error (Fig. 2). There were statisti-

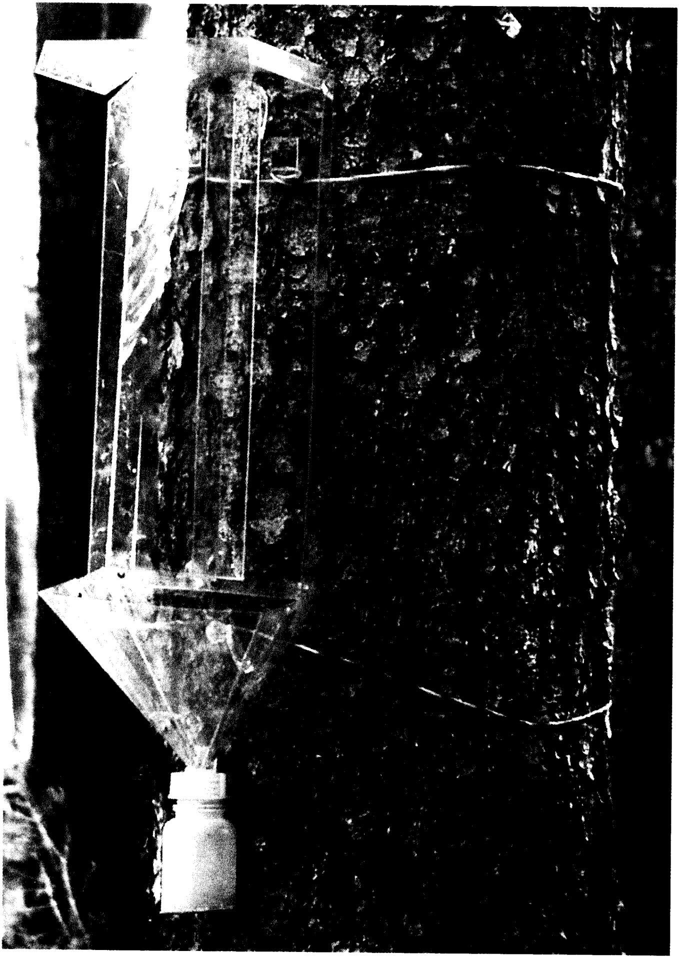

Fig. 1. Passive bark-beetle landing trap.

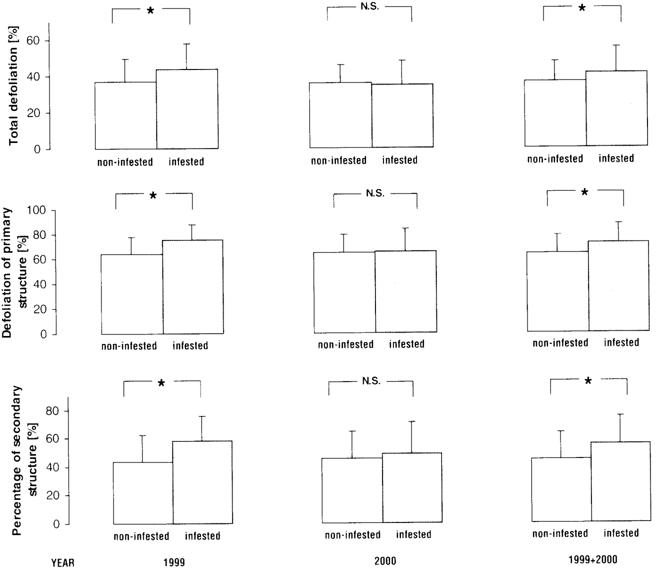

Fig. 2. Means of main parameters of Norway spruce crown status for infested and non-infested trees (vertical lines standard deviations; * – significant difference between infested and non-infested trees in the given year at $\alpha = 0.05$; N.S. – not significant; total n = 477, number of non-infested trees in 1999 = 93, number of infested trees in 1999 = 133, number of non-infested trees in 2000 = 193, number of infested trees in 2000 = 58).

cally significant differences between infested and non-infested trees for all parameters observed for the south-oriented parts of forest edges; for the east-oriented forest edges only the percentage of secondary shoots was not significantly different (Fig. 3). There was no statistically significant difference between early, just after first swarming, and lately infested trees. Explanation could be the fact that spruce trees, considered as late infested, were subjected to the second swarming after one month of bark beetle very low activity.

In 2000 no statistically significant difference in all investigated parameters between infested and non-infested trees, regardless of orientation, were found (Fig. 2). Infested and non-infested trees for both the south-oriented and east-oriented parts of forest edges differed only in total defoliation. Regarding the fact that infested trees in the east-oriented forest proved to be exceptionally less defoliated than non-infested trees, the difference in this parameter for all trees was not significant (Fig. 3). The effect of forest edge orientation on the results is still more obvious after association of data from both years. All studied parameters are significantly different for trees situated on south-oriented edges and no parameters for east-oriented ones (Fig. 3). Similar situation was worth for the whole set of data from both years, regardless of orientation: all observed characters were statistically different between infested and non-infest-

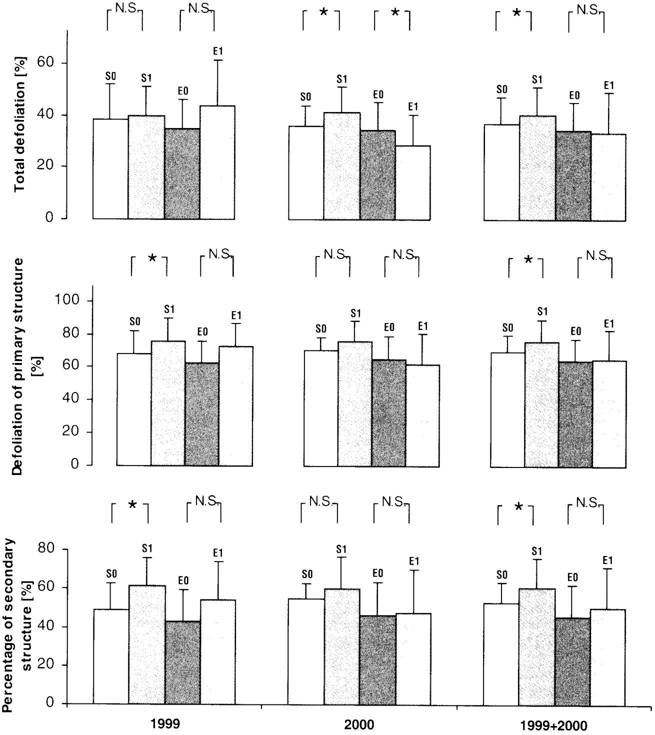

Fig. 3. Means of main parameters of Norway spruce crown status for trees situated in south (S) and east (E) oriented forest edges (0 – non-infested trees, 1 – infested trees; vertical lines standard deviations; * – significant difference between infested and non-infested trees in the given year at $\alpha = 0.05$; N.S. – not significant; total n = 477, $S0_{1999} = 49$, $S1_{1999} = 116$, $E0_{1999} = 44$, $E1_{1999} = 17$, $S0_{2000} = 101$, $S1_{2000} = 28$, $E0_{2000} = 92$, $E1_{2000} = 30$).

ed trees (Fig. 2). Trees infested early, just after first swarming, and late infested trees did not statistically differ.

There are more possible ways to explain the difference between individual years of observation. One explanation could be different sets of observed trees, concerning crown structure transformation. In general, the set of trees selected in 1999 proved to have much higher value variability of defoliation of primary structure and percentage of secondary shoots compared

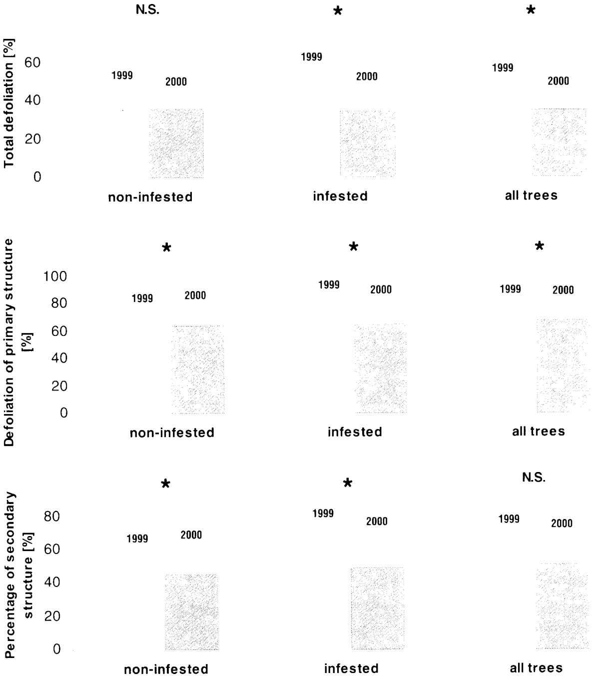

Fig. 4. Means of main parameters of Norway spruce crown status for infested, non-infested, and all trees (vertical lines standard deviations; * – significant difference between infested and non-infested trees in the given year at $\alpha = 0.05$; N.S. – not significant; total n = 477, number of non-infested trees in 1999 = 93, number of infested trees in 1999 = 133, number of non-infested trees in 2000 = 193, number of infested trees in 2000 = 58).

to the tree set selected in 2000. The latter set is similar to the set of non-infested trees from 1999 (Fig. 4).

The abnormal way of spruce bark beetle first swarming, compared to year 1999, seems to be another explanation. In 2000 *Ips typographus* flew out much earlier and individually than usually (Fig. 5). Therefore, the very beginning of the swarming could not be recorded. An additional factor that differed in both years, was decreasing bark beetle outbreak in 2000; only 22% of trees on selected forest edges were invaded compared to the year 1999 (60% of trees). Direction of prevailing wind differed probably in individual growing period, too. Statistical data processing did not reveal any interrelationship between the attack of different transformed

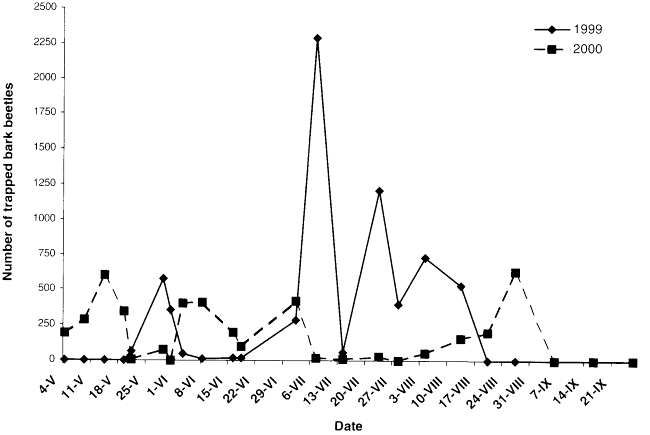

Fig. 5. Mean number of trapped eight-toothed spruce bark beetles per pheromone trap, located close to forest edges, in the period from May to September in years 1999 and 2000.

trees and the course of bark beetle swarming. However, it could be caused by too rough time interval between single bark beetle observations (10 days).

Forest edges: passive traps

Differences between selected low and high transformed trees in total defoliation, primary structure defoliation, percentage of secondary shoots and number of trapped spruce bark beetles per tree for these two tree groups were tested based on data from 2000. Trees with higher structure transformation were proved to be more attractive for spruce bark beetle than those with lower transformation of crown structure. Both groups significantly differed in parameters of crown structure transformation, however, they were almost identical in total defoliation (Fig. 6). It leads to the reason that the crown structure transformation plays the crucial role in the tree attractive force for *Ips typographus*. In passive traps we also found specimens of double-eyed spruce bark beetle (*Polygraphus polygraphus*), conifer ambrosia beetle (*Xyloterus lineatus*), and bark beetle predator – ant beetle (*Thanasimus formicarius*). Regarding to the low quantity of trapped individuals, statistical analysis was done only for *Ips typographus*.

Conclusions

Our early field experiments in the Bohemian Forest which started in 1997 and continued 1998 outlined some connection between health status and spruce bark beetle infestation (Cudlín, unpubl.). The statistical processing of data for years 1999 and 2000 together and for passive traps showed that there is a relationship between tree crown status and spruce bark beetle infestation. Norway spruce trees with more progressive crown structure transformation seem to

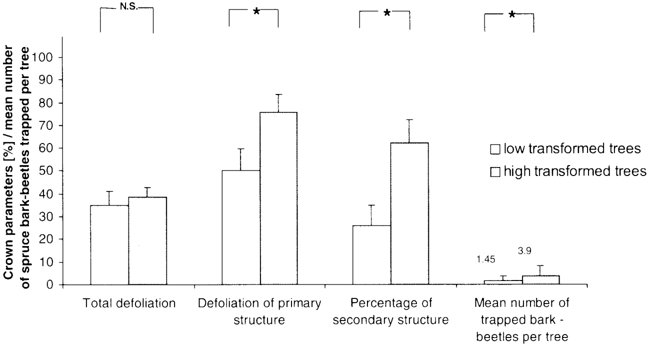

Fig. 6. Means of main parameters of crown status for low and high transformed Norway spruce trees and mean number of trapped eight-toothed spruce bark beetles per tree in the period from May to September in 2001 (vertical lines standard deviations; * – significant difference between low and high transformed trees in the given year at $\alpha = 0.05$; NS – not significant; total n = 40).

be more predisposed to bark beetle attack than those with slightly to medium crown transformation. Our hypothesis, that bark beetles prefer the trees with progressive stage of crown structure transformation, was also proved in forest edges on the permanent research plots in the High Tatra NP (Cudlín et al. 2001c). There is still an unanswered question whether the results of the year 2000 are consequences of the abnormal way of spruce bark beetle first spring swarming (compared with years 1997, 1998, when preliminary observations were done, and 1999) and/or of the difference in tree sets, selected for observation in 1999 and 2000, or some additional factors. From higher statistically significant differences of crown transformation data and from passive traps compared to data of tree infestation we can hypothesize that "smell attraction" of spruce bark beetles by tree would be more operational mode of tree selection than "resin defense" of Norway spruce trees (that could not manifest oneself). It is obvious from these data that crown structure transformation plays more important role than recent total defoliation because selected tree sets differed only in crown structure transformation features.

At this point it is necessary to stress that interaction of spruce bark beetle vs. Norway spruce is the very complex problem. Results obtained only in three years of field experiment cannot be expected to be generally valid. They show just essential picture and enable us closer look into the topic which has been hot since the foundation of the Šumava NP and whose after-effects will be necessary to solve in the very near future.

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References

Cudlín P., Novotný R. & Chmelíková E., 1999: Recognition of stages of montane Norway spruce response to multiple stress impact using crown and branch structure transformation analysis. *Phyton*, 39: 149–153.

Cudlín P., Novotný R., Moravec I. & Chmelíkova E., 2001a: Retrospective evaluation of the response of montane forest ecosystems to multiple stress. *Ecology (Bratislava)*, 20: 108–124.

Cudlín P., Moravec I. & Chmelíková E., 2001b: Retrospektivní sledování stavu smrkových ekosystémů v Národním parku Šumava [Retrospective evaluation of Norway spruce montane forests status in the Šumava National Park]. *Silva Gabreta*, 6: 249–258 (in Czech).

Cudlín P., Moravec I., Chmelíková E., Havlíček F. & Gronský R., 2001c: *Risk assessment of forest ecosystems under multiple stress impact*. Periodic Technical report 3 (2001) for EU project TATRY – Integrated risk assessment and new pest management technology in ecosystems affected by forest decline and bark beetle outbreaks, Contract NR IC15-CT98-0151.

Gruber F., 1994: Morphology of coniferous trees: possible effects of soil acidification on the morphology of Norway spruce and silver fir. In: *Effects of acid rain on forest processes*, Godbold D.L. & Huttermann A. (eds) Wiley-Liss, New York, pp. 265–324.

Jakuš R., 1998: A method for the protection of spruce stands against *Ips typographus* by the use of barriers of pheromone traps in north-eastern Slovakia. *Anzeiger für Schädlingskunde Pflanzenschutz Umweltschutz*, 71: 152–158.

Jermy T., 1984: Evolution of insect / host plant relationships. *American Naturalist*, 124: 609–630.

Jolivet P., 1998: *Interrelationship between insects and plants*. CRC Press, Boca Raton, 309 pp.

Lesinsky J.A. & Landmann G., 1985: Crown and branch malformation in conifers related to forest decline. In: *Scientific Basis of Forest Decline Symptomatology*, Cape J.N. & Mathy P. (eds) Commission of the European Communities, Brussels, *Air Pollution Research Report*, 15: 92–105.

Neuhäuslová Z. (ed), 1997: *Mapa potenciální přirozené vegetace České republiky 1 : 500 000 [Map of potential natural vegetation of the Czech Republic]*. Botanický ústav AV ČR Průhonice (in Czech).

Neuhäuslova Z. (ed), 1998: *Mapa potenciální přirozené vegetace České republiky – textová část [Map of potential natural vegetation of the Czech Republic – text part]*. Academia Praha, 341 pp. (in Czech, English abstr.).

Zahradník P. & Liška J., 1998: Problematika smrčin a kůrovců rodu *Ips*. [Problems of spruce stands and spruce bark beetles of genus *Ips*]. In: *Geoecological problems of the Giant Mts.*, Sarosiek J., Štursa N., Matysiak J. & Palucki A. (eds) Karkonoski Park Narodowy, Przesiece, Part II: 133–137.

Zatloukal V., 1998: Historické a současné příčiny kůrovcové kalamity v Národním parku Šumava [Historical and current factors of the bark beetle calamity in the Šumava National Park]. *Silva Gabreta*, 2: 327–357 (in Czech, English abstr.).

Zumr V., 1985: *Biologie a ekologie lýkožrouta smrkového (Ips typographus) a ochrana proti němu. [Biology and ecology of eight-toothed spruce bark beetle (Ips typographus L.), and forest protection measures]*. Academia Praha, 124 pp., (in Czech).