

ATTRACTION OF BARK BEETLES (COLEOPTERA: SCOLYTIDAE) TO NORWAY SPRUCE IN TIMBERLINE FOREST IN TATRA MOUNTAINS, WEST CARPATHIANS

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ZACH P., KRŠIAK B., KULFAN J., HOLECOVÁ M.: Attraction of bark beetles (Coleoptera: Scolytidae) to Norway spruce in timberline forest in Tatra Mountains, West Carpathians. Lesn. Čas. – Forestry Journal, **56**(3): 285 – 293, 2010, tab. 2, ref. 21. Original paper. ISSN 0323 – 10468

Attraction of bark beetles (Coleoptera: Scolytidae) to Norway spruce was studied in the timberline forest in Tatra Mountains, West Carpathians, Central Europe, by trapping bark beetles in flight interception traps fixed to the lower parts of the 18 trunks of spruce trees, and by recording colonizations of bark beetles on those trees in 2004. The trees were devoid of needles in the upper crown (1/4 up to 1/3 of the tree top dead) and were growing in three distant sample plots. Each plot was representing three different situations (biotopes) in the timberline spruce forest – forest, forest line and tree line, in altitudes between 1,280–1,560 m. A total of 18 traps yielded a total of 5,015 individuals and 19 bark beetle species associated with spruce, the five of which, *Phorophloeus spinulosus*, *Xyloterus lineatus*, *Pityophthorus pityographus*, *Pityogenes chalcographus*, *Ips typographus*, were also documented to be developing in the the studied trees. Traps in the forest line yielded more individuals of bark beetles (all species considered together) than those in the forest and the tree line, although this was not significant ($P > 0.05$, K-W Anova). The bark beetle assemblages showed very low dissimilarity in their structure between the forest and forest line, however, the assemblages in these two situations, apparently, differed from the assemblage in the tree line. Over the period 2004 – 2008 three (16.7%) of the 18 studied trees died. All documented cases of the tree mortality were associated with colonization by *I. typographus*.

Key words: *Picea abies*, *Scolytidae*, *Ips typographus*, mountain forest

Príspevok sumarizuje výsledky výskumu atraktivity 18 chradnúcich dospelých jedincov smreka (*Picea abies*) pre podkôrníkovité chrobáky (Coleoptera: Scolytidae) v oblasti hornej hranice lesa v Tatrách v roku 2004 a zároveň hodnotí prežívanie týchto smrekov v rokoch 2004–2008. Do chemicky nevnapadených nárazových lapačov umiestnených na kmeňoch predmetných smrekov bolo odchytených spolu 5 015 jedincov a 19 druhov podkôrníkovitých vývinom viazaných na smrek. Najviac

jedincov podkôrníkovitých (všetky druhy hodnotené spolu) bolo získaných z lapačov na smrekoch rastúcich na hranici, resp. v okraji súvislého smrekového lesa, menej z lapačov v smrekovom lese pod touto hranicou a najmenej z lapačov v oblasti jednotlivého výskytu smreka v pásme vysokohorských lúk a kosodreviny. Dva sledované jedince smreka odumreli v roku 2004, jeden jedinec odumrel v roku 2007. Všetky tri prípady odumretia smreka (16,7 %, n = 18) súviseli s úspešnou kolonizáciou smrekov lykožrútom smrekovým.

Kľúčové slová: smrek obyčajný, podkôrníkovité, lykožrút smrekový, horský les

1. Introduction

Bark beetles (Coleoptera: Scolytidae), at least some species among them, e.g. *Ips typographus* (L.), play a crucial role in the dynamics of Norway spruce forests in Europe (CHRISTIANSEN & BAKKE 1988). The role of particular bark beetle species in modifying the structure of natural spruce forests in West Carpathians, Central Europe, has been well recognized (PFEFFER 1955, STOLINA 1969a,b).

Local outbreaks of the bark beetle *Ips typographus* associated with the decline of mountain spruce forests in Tatra Mountains in 2004 (e.g. in Bielowodská, Javorová and Velická dolina (valley)) were the reason to study Norway spruce (*Picea abies* (L.) Karsten) and its bark beetle associates in the remote areas of the timberline forest.

This study focuses on the attraction of bark beetles to mature spruce in the timberline forest in Tatra Mountains. The questions addressed are the following: (1) what bark beetle species are attracted or supposed to be attracted to mature spruce devoid of needles in the upper crown?, (2) do such trees growing in different situations (biotopes) in the timberline forest attract different bark beetle fauna?, (3) what is the magnitude of the spruce mortality associated with the occurrence of bark beetles in the timberline forest?

2. Materials and methods

2.1. Study area, sample plots

The study was carried out in natural spruce forests (nature reserves) in Tatra Mountains, Tatra National Park, West Carpathians, Central Europe, in three separate sample plots in Tomanova (1,280–1,360 m), Velická (1,460–1,520 m) and Bielowodská dolina (valley) (1,360–1,560 m a.s.l.). Each sample plot is characterized by three different situations (biotopes) on altitudinal gradient: 1. Forest (spruce forest, canopy cover 80%), 2. forest line (upper margin of spruce forest, canopy cover 70 – 80%), 3. tree line (the uppermost limit of occurrence of spruce, open biotope with scattered spruce trees). Situation 1 and 2 both are characterized by a Norway spruce-dominated forest where the proportion of spruce is as high as 95%, and where the other tree species like rowan (*Sorbus aucuparia* Linnaeus), Scots pine (*Pinus sylvestris* Linnaeus), dwarf pine (*Pinus mugo* Turra), Arola pine (*Pinus cembra* Linnaeus) and willow species (*Salix* spp.) share the rest 5%. Patches of dwarf pine and mountain (alpine) meadows are typical for situation 3. Forest structure is modified by bedrock, rocky soils, strong winds, avalanches, cool climate, tree competition and bark beetles, of which *Ips typographus* is most important.

2.2. Sampling bark beetles

Bark beetles were sampled by the window flight trapping in 2004. A total of 6 flight interception (window) traps were set for bark beetles in each sample plot. Traps were fixed to mature spruce trees (for

tree description see below) at the heights of 1.3–1.6 m, measured from the ground to the lower margin of trap panes (for tree description see below). In each sample plot they were positioned on two vertical transects which were approximately 200 m distant. Each transect was represented by the three situations (biotopes) characterized above. Traps constituted two transparent acrylic panes (0.60×0.40 m each) crossed at right angles, a circular dark green funnel (diameter 0.4 m) placed below the panes, and a collector containing water, coarse salt (NaCl) and few drops of detergent to reduce surface tension of water solution in collectors. They were emptied over the period 15th May – 30th September 2004, at the end of each month. In the laboratory, bark beetles were separated from the fragments of organic material (e.g. bark, twigs, lichens, other invertebrates, etc.), and then placed in vials containing 70% ethanol.

Bark beetles were identified according to PFEFFER (1989, 1995).

2.3. Monitoring tree mortality

A total of 18 mature spruce trees holding traps in 2004 were monitored with focus on their mortality over the period May 2004 to August 2008. The trees were 0.4 – 0.5 m thick at breast height ($d_{1.3}$) and devoid of needles (reason unknown) in the upper crown (1/4 up to 1/3 of the tree top dead in 2004). In 2004 bark beetles were recorded in the lower trunks and lower branches of all monitored trees (up to the height of 3 m, measured from the ground) by entrance or exit holes produced by adults specimens of bark beetles, or by larval galleries if conditions (e.g. loose bark) allowed this (in the study area mechanical damage to trees by man is strictly prohibited by nature conservation). Later on (2005–2008) the occurrence of bark beetles was only noticed in those monitored trees, which had died.

2.4. Data analysis

Hierarchical classification (cluster analysis, complete linkage, Wishart’s coefficient of dissimilarity) in the program Syntax (PODANI 2001) was used to compare the structure of bark beetle assemblages among the forest, forest line and tree line. Log-transformed data (pooled number of bark beetles caught over the study period) were used for the comparison. Testing for the differences in the yearly catches

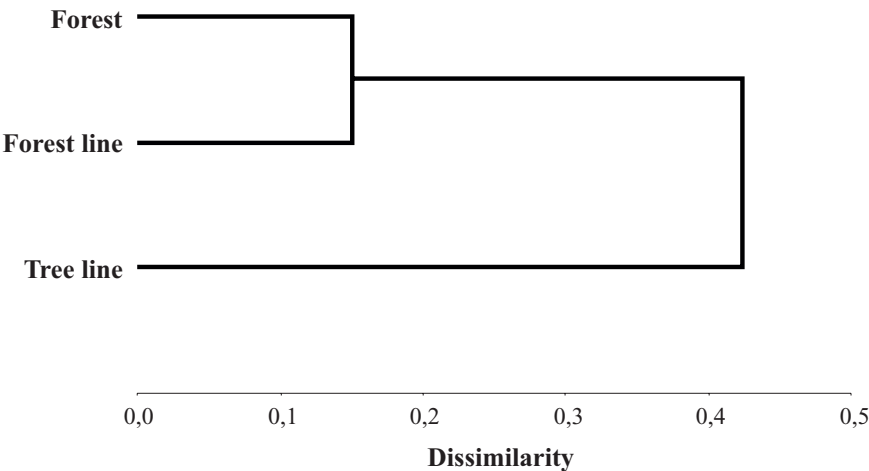


Fig. 1. Comparison among the bark beetle assemblage structure in traps fixed to mature spruce trees in the forest, forest line and tree line. Hierarchical classification, cluster analysis, complete linkage, Wishart’s coefficient of dissimilarity. Data from a total of 18 traps, six traps set in each situation. Tatra Mountains, 2004.

Table 1. Numbers of bark beetles caught in flight interception traps fixed to mature spruce trees in three different situations (forest, forest line, and tree line) in the timberline forest in Tatra Mountains in 2004. In each situation numbers of bark beetles caught in a total of 6 traps are given

Situation / habitat	Forest						Forest line						Tree line					
	V1++	V2+	T1	T2	B1	B2	V1	V2	T1	T2+	B1	B2	V1	V2	T1	T2	B1	B2
Species / site and transect																		
<i>Xylechinus pilosus</i> (Ratzeburg)		2	2	2	1	1			5	13			4					
<i>Phthorophloeus spinulosus</i> Rey			1		*					1	*	1	3*	1	3	1		1
<i>Hylurgops glabratus</i> (Zetterstedt)		3								10	1							
<i>Hylurgops palliatus</i> (Gyllenhal)		10								9								
<i>Hylastes cunicularius</i> Erichson	3	668	29	63	107	40	12	1	151	1624	18	99	8	3	95	242	26	113
<i>Hylastes brunneus</i> Erichson		5			1				41	91		1						
<i>Hylastes opacus</i> Erichson												1						
<i>Polygraphus grandiclavus</i> Thompson															1			
<i>Polygraphus polygraphus</i> (Linnaeus)		2							2	15	6							
<i>Crypturgus cinereus</i> Herbst				1					7									
<i>Xyloterus lineatus</i> (Olivier)	11	171*	18	22	7	2	1	1	56*	282*	1	11			18	6		3
<i>Dryocoetes autographus</i> (Ratzeburg)		74	1		1	3			2	217	2	7			6	3		9
<i>Dryocoetes hectographus</i> Reitter	1	15	5	1	4	3			10	72	3	4				16	1	4
<i>Pityophthorus pityographus</i> (Ratzeburg)		1			1*					1	2*	1*			2	1*	3	
<i>Ptyogenes chalcographus</i> (Linnaeus)		*				5	*		5	10*	12*	1			6*			2
<i>Ips typographus</i> (Linnaeus)		50*			1				1	13*	2	2			2	1		3
<i>Ips amitinus</i> (Eichhoff)		11													1			1
<i>Cryphalus saltuarius</i> Weise													1					
<i>Cryphalus abietis</i> (Ratzeburg)						2						1				1	2	12
Number of individuals (N)	15	1012	56	89	123	56	13	2	280	2358	47	129	16	4	134	271	32	378
Number of species (S)	3	12	6	5	8	7	2	2	10	13	9	11	4	2	9	9	4	11

An asterisk (*) indicates cases of colonization of bark beetle species on lower parts of trunks or lower branches of mature spruce trees in 2004. Tree marked “+” died in 2004; tree marked “++” died in 2007.

V – Velická dolina, T – Tomanovská dolina, B – Bielevodská dolina (valley). 1 – transect 1, 2 – transect 2.

of bark beetles among particular situations was performed by Kruskal-Wallis Anova (SOKAL & ROHLF 2000). This non-parametric test was made separately for all bark beetle individuals recorded, and the two predominant scolytid species *Hylastes cunicularius* Erichson and *Xyloterus lineatus* (Olivier). Computations were made in the programme Statistica (STATSOFT INC. 2005).

3. Results

The 18 traps set in three different situations (biotopes) in the timberline forest in Tatra Mountains in 2004 yielded a total of 5,015 individuals and 19 species of bark beetles associated with spruce (Tab. 1). Most individuals (all 19 species considered together) were caught in the forest line (56.4%), followed by the forest (26.9%) and the tree line (16.7%). Number of species recorded was equal in the forest and forest line (16 species and 80% of all species recorded) and slightly lower in the tree line (13 species and 70% of all species recorded). Predominant species (dominance of abundance over 10%) were represented by *Hylastes cunicularius* (all situations), *Xyloterus lineatus* (forest and forest line) and *Pityophthorus pityographus* (Ratzburg) (tree line). In addition to bark beetle species listed in Table 1, two specimens of *Pityogenes conjunctus* (Reitter), the species not associated with spruce, were also recorded.

The bark beetle assemblages showed very low dissimilarity in their structure between the forest and forest line, however, the assemblages in these two situations differed from the assemblage in the tree line (Fig. 1).

The number of bark beetles caught (all species together) showed a great deal of variability within the forest, forest line and tree line (Tab. 1). It did not differ significantly among these situations ($H(2, N = 18) = 0.035, P = 0.983$, K-W Anova), and the same was true for the two predominating scolytid species, *Hylastes cunicularius* ($H(2, N = 18) = 0.073, P = 0.964$, K-W Anova) and *Xyloterus lineatus* ($H(2, N = 18) = 4.263, P = 0.119$, K-W Anova).

Some of the 18 studied spruce trees were found to be colonized by *Phorophloeus spinulosus* Rey (branches), *Xyloterus lineatus* (trunks), *Pityophthorus pityographus* (branches), *Pityogenes chalcographus* (branches) and *Ips typographus* (trunks) (Tab. 1).

Three of the 18 studied trees (16.7%) died over the period 2004 – 2008. Two trees died in the forest, one tree died in the forest line. All documented cases of the tree mortality were associated with colonizations by *Ips typographus*.

4. Discussion

Norway spruce in Central Europe has a species-rich bark beetle fauna (PFEFFER 1955, 1989, 1995 ZUMR 1984, KULA & ZABECKI 2000, 2002). The species list in Table 1 includes approximately two-thirds of the known bark beetle associates of spruce in West Carpathians (PFEFFER 1955, 1989). Most species recorded in this study are common associates of spruce. The record of a single specimen of *Polygraphus grandiclava* Thompson (Tomanovská dolina (valley), tree line, Tab. 1) is worth noticing. In the mountain spruce forests in Tatra Mountains, this wide polyphage – host plants include the representatives of Pinaceae and Rosaceae (PFEFFER 1955, 1995, AVTZIS *et al.* 2008), is developing in Arola pine, spruce and, possibly, in dwarf pine too. It is collected only rarely. The occurrence of *P. grandiclava* in the tree line is documenting a broad

ecological plasticity in the beetle spread from the lowlands to the uppermost limit of its distribution in West Carpathians. The scolytid *Pityogenes conjunctus* (not listed in Tab. 1) should also be mentioned here in more detail. The beetle is typical for the timberline forest where it is developing in dwarf pine and Arola pine (PFEFFER 1955). Two specimens of *P. conjunctus* (Tomanovská and Bielovodská dolina (valley), tree line), highly likely, were caught by accident. In Tatra Mountains, *T. conjunctus* seems to be more frequent and abundant than *P. gradiclava*.

In spruce forests, and especially in forest margins, more bark beetles are expected than at sites where a few trees occur. The timberline forest with a high or relatively high density of trees (e.g. forest and forest line) provides more resources for bark beetles than environments characterized by a few scattered trees (e.g. tree line in this study). Such trees in the tree line, moreover, are more exposed than those in dense forest structures, much less sheltered and thus less protected against strong wind currents which may affect the occurrence of bark beetles. Despite this, a large number of bark beetle individuals and species may be attracted to certain individuals of singly growing trees in the tree line (Tab. 1).

In Table 1 bark beetle species are listed by particular situation in the timberline forest, as they were caught in 2004. Numbers of bark beetles sampled reflect, first, the attraction (affinity) of bark beetle species to each of the 18 spruce trees and, second, the abundance and/or activity of bark beetle species in the given situation. Great deal of variability in the number of bark beetles (all species) sampled in the forest (5 – 1,012), forest line (2 – 2,358) and tree line (4 – 379 individuals, Tab. 1) might indicate that the attraction (affinity) of bark beetles to particular trees differs a lot within each of those three situations, meaning that particular trees in particular situations, highly likely, have remarkably different attractivity for bark beetles.

Hierarchical classification (Fig. 1), in addition to differences in species composition, reflects the lower number of bark beetles sampled in the tree line compared to that gathered in the forest line and forest, although this is not significant based on the sample evidence (low median numbers of bark beetles caught in all situations). The study design employed here is not a robust one. It does not allow to separate between the effect of „attraction“ and that of „accidental trapping“ on the occurrence of bark beetles in traps. High catches of certain bark beetle species in traps, undoubtedly, have much to do with „attraction to trees and/or tree attractivity“ but there is some uncertainty about this as some bark beetle species not attracted to the trees may also be caught in traps, especially in areas or situations where their populations are high.

Surprisingly, the bark beetle *Hylastes cunicularius* highly predominated in samples from all situations, however, its development in the studied trees was not recorded (Tab. 1). In natural spruce forests in the study area, the beetle is widespread and abundant everywhere where the wind-felling and avalanches regularly modify the forest structure, providing the beetle with a supply of breeding material in the form of spruce roots, stumps and, less frequently, spruce logs well-touching (penetrating) the soil surface. The beetle is known to aggregate near suitable resources and at the beetles of its own species which have located such resources (EIDMANN & KULA & LINDELÖW 1991). Ex-

periments showed a positive response of the beetle to mechanical damage (cuts) on pine logs (EIDMANN & KULA & LINDELÖW 1991). In the study area, avallanches, tree, ice and rock fall are responsible for the frequent occurrence of wounds on the base of the trunks of the studied (monitored) trees which might attract individuals of the beetle showing a positive response to ethanol (SCHROEDER & LINDELÖW 1989), a product of microbial processes. In this study, low positioned traps could caught individuals flying to the trees low above the ground. Similarly, *H. cunicularius* was shown to be a highly predominant scolytid in the wind-felled forest in the Alps (WERMELINGER & DUELLI & OBRIST 2002).

Two scolytid species, *Hylurgops palliatus* (Gyllenhal) and *Hylurgops glabratus* (Zetterstedt), were caught in the forest and forest line but not in the tree line. Attack densities of *H. palliatus* on spruce bolts increase markedly from the forest clearcut-edge towards the forest interior (PELTONEN & HELIÖVAARA 1999); in *H. glabratus* similar pattern of habitat preference may be expected. Also, *Dryocoetes autographus* (Ratzeburg) and *Dryocoetes hectographus* Reitter, based on their catches in traps, tended to be more in the forest and forest line than in the tree line. None of them was found to be developing in the studied trees in 2004.

The bark beetle *Ips amitinus* (Eichhof.) is frequent and abundant in mountain spruce forests in Tatra Mountains. Preference of the beetle for the upper parts of the spruce trunks (ZUMR 1984) may explain its infrequent and low occurrence in traps (Tab. 1). The beetle was not recorded in the forest line by the flight window trapping (Fig. 1), although it was present there (P. Zach, personal observation). This calls for a more robust study design based on more replicates (traps) in the lower, but also in the middle and upper parts of the spruce trunks.

Five (26.3%) of the 19 bark beetle associates of spruce in this study were documented to be developing in the lower parts of the trunks and/or in the lower branches of the studied trees in 2004. The cases of development of certain bark beetle species in particular trees are marked with an asterisk attached to the number of bark beetle individuals caught (Tab. 1). Two scolytid species, *P. spinulosus* and *P. chalcographus*, were not always caught in the traps fixed to the trees in which they were developing. Such cases are marked with an asterisk only.

Tree death is an ecological process (FRANKLIN & SHUGART & HARMON 1987). As evident, in the timberline forest in Tatra Mountains a good number of individuals and species of bark beetles are attracted or supposed to be attracted to mature spruce devoid of needles in the upper crown. Such trees, often classified as dying and not healthy, are typical for the timberline forests in Central Europe. Based on our knowledge, they can live over a long period of time if not wind-felled, damaged by avallanches or successfully attacked by *I. typographus* and pathogenic fungi. In 2004 bark beetles were sampled in areas where *I. typographus* outbreaked (Bielovodská and Velická dolina (valley)), or where its population was retaining low (Tomanovská dolina (valley)). *I. typographus* was found to attack and kill the two trees holding the traps yielding its highest catch (forest, tree V2 – 50 individuals; forest line, tree T2 – and 13 individuals of *I. typographus*, Tab. 1). Its local outbreak in Velická dolina (valley) led to

numerous cases of spruce death over the summer 2004 and later on (2005 – 2008). In Velická dolina (valley) another tree (tree V1, Tab. 1) died in 2007 due to the attack by the beetle. In this study, only those of the studied trees died which were colonized by *I. typographus*. This agrees with the observations by HEDGREN (2004) who found experimentally that the mortality of spruce is strongly related to the presence of *I. typographus* and less to the presence of *P. chalcographus*.

A highly excessive wind disturbance in Tatra Mountains, dated 19th November 2004 (KOREŇ 2005, ZACH *et al.* 2007), has resulted in the outbreak of *Ips typographus* also in Tichá dolina (valley), the area adjacent to Tomanovská dolina (valley). The present outbreak of *I. typographus* in the mountain area is expected to accelerate the mortality of mature spruce trees in the timberline forest.

Acknowledgements

This publication is the result of the project implementation (project Centre of Excellence of Biological Methods of Forest Protection, coded ITMS 26220120008), supported by the Research & Development Operational Programme funded by the ERDF.

The State Forests of Tatra Mts. National Park and the Administration of Tatra Mts. National Park provided administrative support to field studies. P. Tuček (Institute of Forest Ecology, Slovak Academy of Sciences) assisted with beetle collections and separation.

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Resumé

V oblasti hornej hranice smrekového lesa v Tatrách (Tomanovská, Velická a Bielovodská dolina) bola od polovice mája do konca septembra 2004 študovaná atraktivita 18 dospelých smrekov pre podkôrníkovité chrobáky (Coleoptera: Scolytidae). Smreký mali odumretú jednu štvrtinu až jednu tretinu koruny (odumretá vrcholová časť) a ich prežívanie bolo monitorované do konca augusta 2008 v troch rôznych biotopoch: smrekový les, hranica súvislého smrekového lesa, hranica výskytu jedincov smreka. Na kmene smrekov vo výške 1,3–1,6 m nad úrovňou terénu boli upevnené chemicky nevňadené a pre chrobáky farebne neatraktívne lapače. Tieto odchytili spolu 5 015 jedincov a 19 druhov podkôrníkovitých vývinom viazaných na smrek (tab. 1) a dva jedince lykožrúta *Pityogenes conjunctus* žijúceho na borovici horskej (kosodrevine) a borovici limbovej (limbe). V odchytoch vysoko prevládal lykokaz sadenicový (*Hylastes cunicularius*); odchyty lykožrúta smrekového (*Ips typographus*) boli nízke. Najviac jedincov podkôrníkovitých (všetky druhy spolu) bolo odchytených na smrekoch rastúcich na hranici (v okrají) súvislého smrekového lesa, menej v smrekovom lese pod touto hranicou a najmenej v oblasti jednotlivého výskytu smreka v zóne vysokohorských lúk a kosodreviny (tab. 1), no rozdiely neboli štatisticky významné ($P > 0.05$, K-W Anova). Abundančná štruktúra fauny podkôrníkovitých v porovnávaných biotopoch bola iba málo, resp. relatívne málo nepodobná (obr. 1). Odchyty odrážajú atraktivitu spodnej časti kmeňa smrekov pre podkôrníkovité a tiež početnosť a pohybovú aktivitu podkôrníkovitých. V spodnej časti kmeňa študovaných smrekov bol dokumentovaný vývin *Phorophloeus spinulosus* (konáre), *Xyloterus lineatus* (kmeň), *Pityophthorus pityographus* (konáre), *Pityogenes chalcographus* (konáre) and *Ips typographus* (kmeň). Dva zo sledovaných smrekov odumreli v roku 2004, ďalší v roku 2007. Všetky tri prípady odumretia smreka (16.7%, $n = 18$) súviseli s úspešným osídlením lykožrútom smrekovým. Zo sledovaných jednotlivito rastúcich smrekov v pásme borovice horskej a vysokohorských lúk neodumrel počas výskumu žiadny. Očakávame, že súčasné premnoženie lykožrúta smrekového v Tatrách urýchli odumieranie dospelých smrekov a ich porastov v oblasti hornej hranice lesa.