# Attractiveness of *Picea pungens* to the bark beetle species *Ips amitinus* (Eichh.) and *Pityogenes chalcographus* (L.)

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**ABSTRACT**: Only two cambioxylophagous species (*Ips amitinus* and *Pityogenes chalcographus*) were found on sections of *Picea pungens* and *Picea abies* that belong to economically important pests of Norway spruce. Representatives of the *Isarthron* sp. (Cerambycidae) were developed on the examined sections of both *P. abies* and *P. pungens.* The monitoring of attractiveness of the spruce species *P. pungens* and *P. abies* to cambioxylophages revealed that *P. pungens* was more intensively attacked by *I. amitinus* while *P. chalcographus* was more abundant on *P. abies*. Both bark beetle species preferred shaded parts of tree trunks, although their development was more successful on the sun-exposed side. On *P. pungens*, abundance of *P. chalcographus* decreased and abundance of *I. amitinus* increased with increasing trunk volume. Blue spruce was more attractive to *Isarthron* sp. compared to Norway spruce.

**Keywords**: Krušné hory Mts.; *Picea alba*

Blue spruce (*Picea pungens* Engelm.) is a species native to the Rocky Mountains, USA, (Pavek, Diane 1993) and due to its ability to withstand a high level of sulphur dioxide air pollution load, even in combination with climatic stresses (Materna 1978; Kubelka et al. 1992), it is highly represented in stands of substitute species in montane air-polluted areas of the Czech Republic. In the Krušné hory Mts. it has been planted on an area of 8,860 ha (Slodičák et al. 2008), often in conditions that do not correspond to its ecological requirements (Remeš et al. 2002). The root system of blue spruce ensures sufficient stability even at waterlogged sites, it is not uprooted by snow or wind (Vidakovic 1991; Pavek, Diane 1993; Musil et al. 2003); its tops tend to break off due to ice (Šika 1976; Podrázský 1997) and extremely wet snow (Slodičák et al. 2002; Špulák 2007), hard needles make it less attractive to browsers and its dense branches and low crown prevent the game from bark stripping (Vidakovic 1991; Pavek, Diane 1993; Musil et al. 2003).

Although no outbreaks of phytophagous insects were observed, the crown fauna of butterfly caterpillars (Kulfan et al. 2010) and Symphyta larvae (Hymenoptera) (Kula et al. in print) on blue spruce is relatively rich and corresponds to Norway spruce. As regards fungal pathogens, *Gemmamyces piceae* (Borthw.) destroys blue spruce buds on large areas in the Krušné hory Mts. (Soukup, Pešková 2009).

Partial information on subcortical and wood-destroying blue spruce pests is available from Scandinavia [*Pityogenes chalcographus* (L.), *Dryocoetes autographus* (Ratz.), *Dendroctonus micans* (Kug.), *Isarthron fuscum* (Fabr.), *Rhagium inquisitor* (L.)] (Juutinen 1953; Eidmann 1987) and from central Europe [*P. chalcographus*, *Pityophthorus pityographus* (Ratz.), *D. autographus*, *Hylurgops palliatus* (Gyll.), *Hylastes cunicularius* (Er.) and *Cryphalus abietis* (Ratz.), *D. micans, Ips amitinus* (Eichh.), *Hylecoetes dermestoides* (Ratz.), *Xyloterus lineatus* (Oliv.), *Prionus coriaceus* (L.), *Molorchus minor* (L.), *Pogonochaerus fasciculatus* (Deg.), *Calidium aeneum* (Deg.), *Melanthaxia quadripunctata* (L.), *Urocerus gigas* (L.), *Camponotus herculeanus* (L.), *Pissodes harcyniae* (Herbst.)] (Dominik 1966; Andrš 2001; Kršiak et al. 2010; Kula et al. 2011, 2012).

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 62156489, and by the Netex Ltd., Děčín, Nadace ČEZ Co. in Prague, Lafarge Cement Co. in Čížkovice.

***Pityogenes chalcographus* (six-toothed spruce bark beetle)**. Ecology and bionomics of *P. chalcographus* were described by Ratzeburg (1839), Stark (1930), Karpinski (1933), Galoux (1948), Klausert (1954), Pfeffer (1955), Schwerdtfeger (1957), Postner (1974), Novák (1976), Zumr and Soldán (1981), Wood and Bright (1987, 1992) and Brigit and Skidmore (1997, 2002). *P. chalcographus* appears in all areas with the presence of *Picea abies* (L.) Karsten and other spruce species. It is reported as a forest pest (Escherich 1923; Byers et al. 1988), inhabiting windbreaks, felling debris or branches and occasionally invading young spruce stands. It is able to detect weakened trees (i.e. due to a drought spell). *I. typographus* and *P. chalcographus* do not affect each other by their pheromones in the selection of trees to attack (Hedgren 2004). *P. chalcographus* is attracted to host species by a mix of monoterpenes (Chararas 1962; Kangas 1968; Vite, Pitmann 1969; Byers et al. 1988), transformed in the bowels into an aggregation pheromone with synergic effect (Francke 1977; Byers et al. 1988, 1990), often allowing a massive attack on a tree. With increasing stem diameter, the occurrence of six-toothed spruce bark beetle decreases. Byers (1993) concluded that interspecies competition between *I. typographus* and *P. chalcographus* is regulated by pheromones affecting their dispersion on the trunk.

***Ips amitinus* (small spruce bark beetle)**. The bark beetle *Ips amitinus* belongs to a group of secondary insect pests of *Picea abies* (Pfeffer, Skuhravý 1995; Grodzki 1997, 2004; Mazur et al. 2006). It is widespread throughout Europe (Pavlovskij 1955; Pfeffer 1955; Jurc, Bojović 2004; Voolma et al. 2004) and it has been reported from *P. abies*, *Abies alba* (Mill.), *Larix decidua* (Mill.), *Pinus sylvestris* (L.), *Pinus cembra* (L.) (Hellrigl 1985; Stauffer, Zuber 1998), *Pinus mugo* (Turra) (EPPO/CABI 1997; Knížek, Trýzna 2002; Dominik 2003) and *Picea pungens* (Engel.) in Central Europe (Kula et al. 2009, 2011).

*I. amitinus* prefers the middle part of the crown with relatively small trunk dimensions for its reproduction (Zumr 1984; Grodzki 1997; Jakuš 1998; Kula, Ząbecki 2001; Plašil, Cudlín 2005). Galleries of *I. amitinus* are often found on younger trees (Grodzki 2009) and in the upper part of weakened trees (Jurc, Bojović 2004).

Competition exists between *P. chalcographus, I. amitinus* and *I. duplicatus* as they all prefer thin and smooth-barked parts of trunks. *I. amitinus* frequently appeared together with *I. typographus* in all areas and both species reproduce at the same time (Jurc, Bojović 2004; Økland, Skarpaas 2008).

The objective of the contribution was to determine the level of *P. pungens* attractiveness to the bark beetles *I. amitinus* and *P. chalcographus* that are both known to occur on *P. abies* and were reported from standing trees as well as felling debris of *P. pungens* (Kula et al. 2009, 2011, 2012).

The following questions were formulated: (*i*) Is there a difference in tree species (*P. abies, P. pungens*) selection between the bark beetles *I. amitinus* and *P. chalcographus*? (*ii*) Do site conditions affect the place of attack and the level of development success? (*iii*) Is the attractiveness affected by the size (volume) of the trunk section?

## MATERIAL AND METHODS

The experiment was set up at three localities: Sněžník (Děčín Forest District, Tisá locality, Děčínská vrchovina Upland, 2 sites, 50°46'51,24''N, 13°03'57,91''E, 622 m a.s.l., flat terrain); Boleboř (Jirkov municipal forests, eastern Krušné hory Mts., 1 site, 50°32'58,32''N, 13°23'02,13''E, 790 m a.s.l., S–E exposure) and Dlouhá louka (Litvínov Forest District, eastern Krušné hory Mts., 1 site, 50°38'55.85''N, 3°37'46.66''E, 870 m a.s.l., flat terrain).

In spring ($8^{th}$–$9^{th}$ April 2011), 1.5 m long sections of blue spruce (PP; volume 0.34–30.16 $dm^3$) and Norway spruce (PA; volume 1.21–26 $dm^3$) trunks were obtained from felled and delimbed trees aged 25 to 30 years; 80 sections of each species were set up at each site. The sections were placed on logs to prevent contact with soil and vegetation, and were leaned against a wooden support from two sides (forming a roof). Sections of both species alternated and the opposite sections were of similar volume. Sections were numbered, marked by signal colour according to species, their middle diameter was measured and the volume of each section was calculated ($dm^3$).

Attractiveness of each tree species (intensity of bark beetle invasion) was determined from the numbers of entrance and exit holes. Three control spots of 0.5 $dm^2$ were chosen on both the sun-exposed and the shaded side of each section, at 30 cm from top, in the middle and at 30 cm from the bottom of the section (i.e. 6 spots per section). Entrance holes were checked in June 2011 and exit holes in November 2011. Once the number of exit holes was counted, the section was debarked, phloem quality was described and the galleries were examined to determine the intensity of attack and stage of bark beetle (*P. chalcographus* and *I. amitinus*) development. The total number of analysed sections was 621 (309 PP, 312 PA).

The intensity of subcortical pest attack was assessed according to the method by Kula and Ząbecki (1996): scattered attack (sporadic occurrence of feeding marks on the examined section); increased attack (feeding marks take up 1/3–2/3 of the section surface); heavy attack (feeding marks occur on more than 2/3 of the section surface). We took records of the following stages of development: entrance holes, nuptial chambers, mother galleries, larvae, dead larvae, pupae, imagoes and exit holes. Mortality of the larvae was derived from the degree of development of their galleries.

Occurrence of the significantly represented bark beetles (*P. chalcographus, I. amitinus*) on sections was tested according to tree species and position of the section in the experiment ($\alpha$ = 0.05) (Meloun et al. 2005). Data showed normal distribution, therefore, non-parametric statistics ANOVA (Kruskal-Wallis test) was used (StatSoft 2010).

## RESULTS

Only two cambioxylophagous species (*P. chalcographus* and *I. amitinus*) and representatives of the *Isarthron* sp. (Cerambycidae) were found on the examined sections of both *P. abies* and *P. pungens.*

The occurrence of *P. chalcographus* was high on both Norway spruce (99.4%) and blue spruce (94.0%) sections. There was a difference in the intensity of the attack as only a small share of the Norway spruce sections suffered scattered and increased attack (10.4 and 19.8%, respectively) and heavy attack was found on 69.1% of the sections, while in blue spruce, the attack was mainly of scattered intensity (46.1–27.3–20.55%).

*I. amitinus* showed the twice higher frequency of occurrence on blue spruce sections (88.0%) compared to Norway spruce ones (39.3%). In Norway spruce sections, the scattered attack intensity prevailed (34.3–3.7–1.3%), in blue spruce the increased and heavy intensity of attack was observed (45.8–21.0–21.2%). A difference in the attractiveness of blue spruce and Norway spruce was also found out in longhorn beetles in the frequency of occurrence (21.2 × 5.6%) as well as in the intensity of the attack (18.3–2.6–0.3% × 5.3–0.3–0%).

The decision to mark out three positions of the control spots for the monitoring of entrance and exit holes contributed to the objectivity of the occurrence assessment as the statistical analysis (ANOVA) confirmed that on sections of both tree species, *P. chalcographus* preferred the upper part of the section and towards the bottom of the section its abundance decreased [$F$ (5, 3720) = 69.095; $P$ = 0.0000]. On blue spruce, a statistically significant difference in the number of entrance and exit holes was found only between the upper and the bottom position of the control spots while on Norway spruce, the same trend was observed and a significant difference was found between the upper and the middle position as well as between the upper and the bottom position. At the same time it was proved that *P. chalcographus* development was successful on Norway spruce along the whole length of the section (Fig. 1).

Numbers of entrance holes indicated that *P. chalcographus* preferred to attack the shaded parts of the sections [$F$ (3, 3722) = 138.37; $P$ = 0.0000] (Fig. 2a); however, by the exit holes, development was more successful on the sun-exposed sections [$F$ (3, 3722) = 108.04; $P$ = 0.0000] (Fig. 2b).

Norway spruce sections placed on the shaded side of the roof were more frequently attacked by *P. chalcographus* according to the entrance holes [$F$ (3, 3722) = 113.81; $P$ = 0.0000] (Fig. 3a), but with lower effectiveness of development completion. Developmental success was higher on the sections placed on the sun-exposed side of the roof [$F$ (3, 3722) = 91.174, $P$ = 0.0000] (Fig. 3b). On blue spruce with lower attractiveness, such relations were not proved in *P. chalcographus.*

Monitoring of the bark beetle galleries on the part of sections (156) was important to determine the success of development of the generation from the number of entrance holes through stages of die-off to exit holes. *P. chalcographus* showed a high rate of larval-stage mortality on 77.5% of the blue spruce sections, successful development was

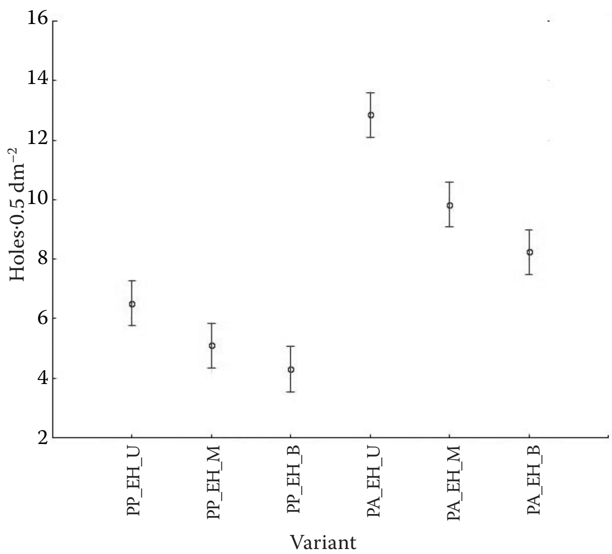


Fig. 1. Differences in the occupation of the section profile (U – upper, M – middle, B – bottom) between *Picea pungens* (PP) and *Picea abies* (PA) by *Pityogenes chalcographus* (2011) according to exit holes (EH)

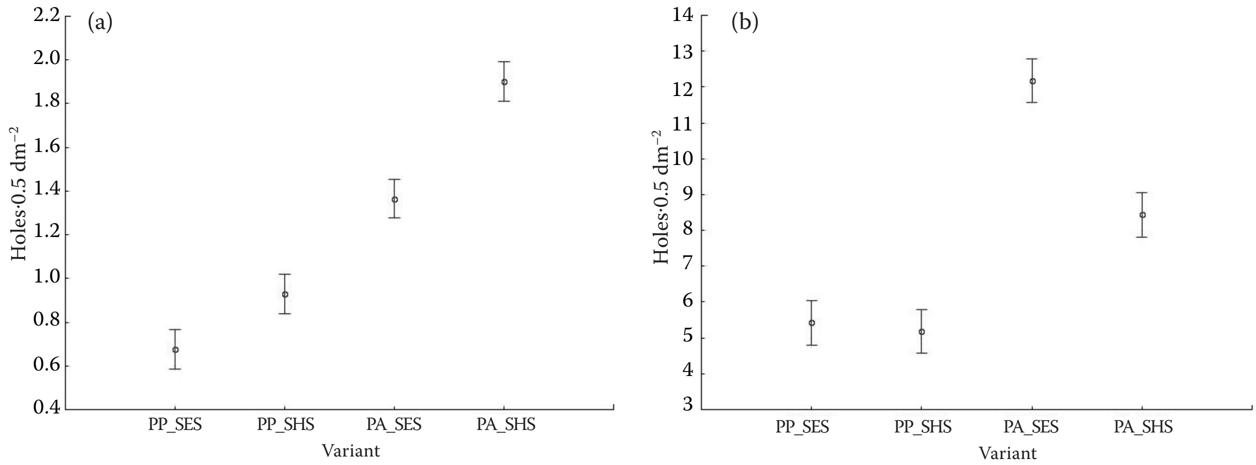


Fig. 2. Effect of the exposition of sections to the sun (SES – sun-exposed side, SHS – shaded side) in *Picea pungens* (PP) and *Picea abies* (PA) on the attack of *P. chalcographus* (2011) according to (a) entrance holes and (b) exit holes

observed only on 15.0% of the sections. On Norway spruce, the situation was similar (77.4 and 23.9%).

Abundance of *P. chalcographus* entrance holes was higher on the shaded side of Norway spruce sections (2.39–4.43 holes $dm^{-2}$) compared to the sun-exposed side (1.52–3.36 holes $dm^{-2}$). Abundance of its exit holes (16–24 holes $dm^{-2}$) on Norway spruce sections according to their volume (0.47–29.4 $dm^3$) revealed that the statistically most suitable for *P. chalcographus* development are stems of the 3rd and 4th volume class (5–10 $dm^3$) [$F$ (13, 3712) = 22.928; $P$ = 0.0000] (Fig. 6); in blue spruce sections with the volume of 0.2–39.4 $dm^3$, the abundance of exit holes was lower (6.5 to 13 holes·$dm^{-2}$) and without any statistical relation (Fig. 4).

However, the density of exit holes in the monitored localities always varied with the dominant position of *P. chalcographus* on the sun-exposed side of Norway spruce.

Norway spruce sections showed lower attractiveness to *I. amitinus* compared to blue spruce [Kruskal-Wallis test: H (1, $n$ = 3726) = 750.1475, $P$ = 0.000)] and no relation was proved in the occupation of the section. According to its entrance holes, *I. amitinus* preferred the sun-exposed sides of the sections in blue spruce (Kruskal-Wallis test: H (1, $n$= 1854) = 17.95401 $P$ = 0.0000) and unshaded rows of sections in the roofs; however, this relation was not statistically significant (Kruskal-Wallis test: PP $P$ = 0.07, PA $P$ = 0.06). The analysis of *I. amitinus* exit holes confirmed a positive statistical relation to the sun-exposed sides of the sections [$F$ (3, 3722) = 210.35; $P$ = 0.0000] as well as to the rows of sections within the roofs [$F$ (3, 3722) = 195.23; $P$ = 0.0000] (Figs 5 and 6).

*I. amitinus* developed on blue spruce and on Norway spruce in a different way. Although the mortality of imagoes at the stage of emerging nuptial chamber was equal on both tree species

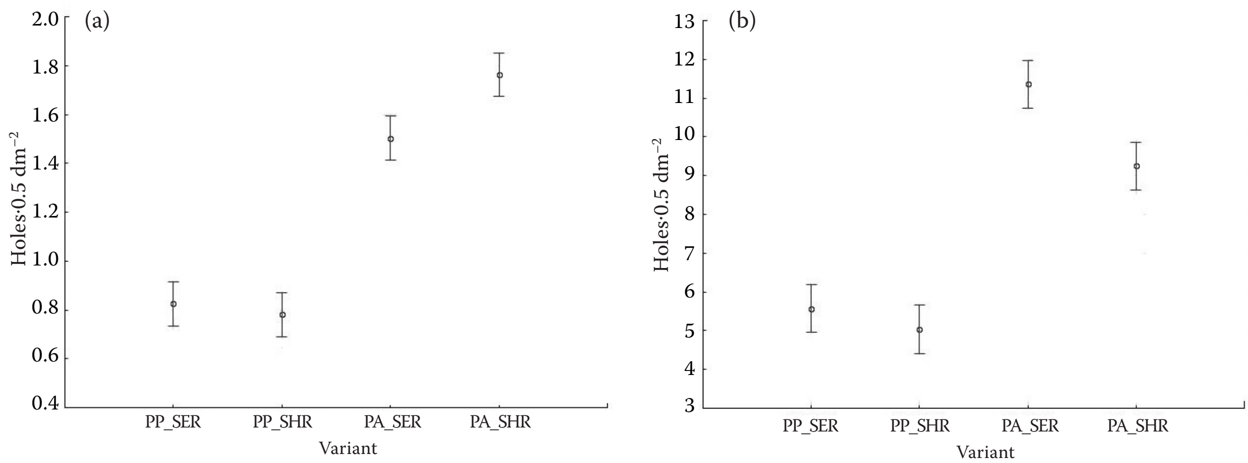


Fig. 3. Influence of the position of section rows (SER – sun-exposed, SHR – shaded) in *Picea pungens* (PP) and *Picea abies* (PA) on the occupation by *P. chalcographus* (2011) according to (a) entrance holes and (b) exit holes

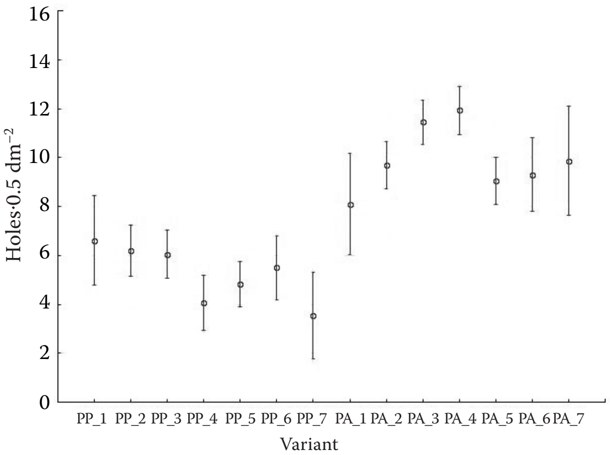


Fig. 4. Attractiveness and developmental success of *P. chalcographus* on sections of *Picea pungens* (PP) and *Picea abies* (PA) of different volume (1: < 2.49; 2: 2.5–4.99; 3: 5–7.49; 4: 7.5–9.99; 5: 10–14.99; 6: 15–19.99; > 20 dm$^3$) according to exit holes (2011)

(6.5 × 7.9%), the share of the sections with dead larvae was different (63.6 × 29.5%); a similar situation was in the sections where *I. amitinus* completed its development (17.5 × 1.9%).

The frequency of *I. amitinus* occurrence was found to depend on the volume of sections only in blue spruce. Entrance holes were observed on all sections, but with higher abundance in the 5$^{th}$–7$^{th}$ volume class (> 10 dm$^3$) [$F$ (6, 1847) = 7.5720; $P$ = 0.0000] (Fig. 7a). The number of exit holes gradually increased and culminated at the section volume of 10–15 dm$^3$ (5.1 holes·dm$^{-2}$) [$F$ (6, 1847) = 9.9428; $P$ = 0.0000] (Fig. 7b). The density of exit holes was higher on the sun-exposed side (1.70–6.06 holes·dm$^{-2}$) compared to the shaded side (1.56–4.24 holes.dm$^{-2}$).

Blue spruce was more attractive to *Isarthron* sp. compared to Norway spruce (21.20 × 5.60%).

# DISCUSSION

Only two cambioxylophagous species (*I. amitinus* and *P. chalcographus*) were found on sections of *P. pungens* and *P. abies* that belong to economically important pests of Norway spruce. Of the 39 species of Norway spruce bark beetle fauna (Pfeffer 1955), 14 were observed on blue spruce (Juutinen 1953; Eidmann 1987; Kršiak et al. 2009; Kula et al. 2009, 2010, 2011, 2012; Pop et al. 2010). Phloem quality in the sections from spring felling limited the attacks of a wider spectrum of cambioxylophagous species, thus eliminating a stronger effect of interspecies competition. The composition of bark beetle synusia on Norway spruce as well as on blue spruce is affected by the time of the year when felling debris appears on the site (Kula, Kajfosz 2006, 2007; Kula et al. 2011). After Roundup application for the purpose of chemical thinning, the quality of blue spruce phloem changed significantly (partially fermented), attracting a wider spectrum of cambioxylophages (10 species) with dominant *H. palliatus* and significant occurrence of *I. amitinus* and *P. chalcographus* (Pop et al. 2010).

The frequency of *P. chalcographus* occurrence on both spruce species confirmed that this beetle prefers stems with thin outer bark, where *I. typographus* cannot develop (Ratzeburg 1839; Schwerdtfeger 1957; Postner 1974; Zumr, Soldán 1981; Benz, Zuber 1993); however, *I. amitinus* can be considered as a competing species. Blue spruce was less attractive to *P. chalcographus,* probably due to its high content of resin in the phloem and its slow wilting. Interestingly, it prefers to attack the shaded parts of the sections, despite the fact that lower

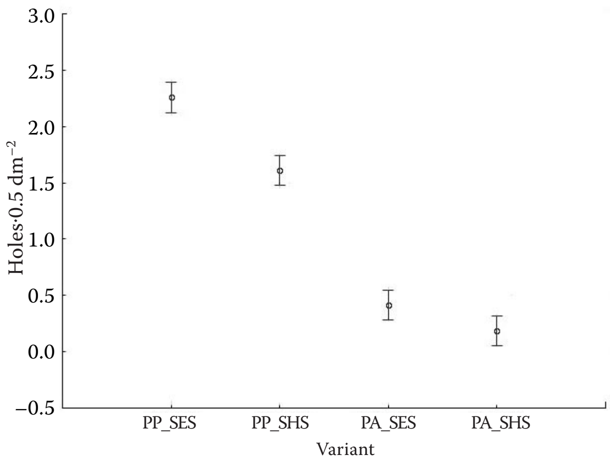


Fig. 5. Effect of the exposition of sections to the sun (SES – sun-exposed side, SHS – shaded side) in *Picea pungens* (PP) and *Picea abies* (PA) on the development of *I. amitinus* according to exit holes (2011)

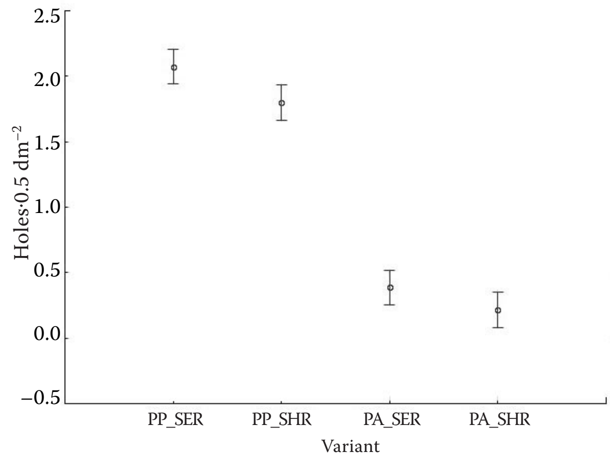


Fig. 6. Influence of the position of section rows (SER – sun-exposed, SHR – shaded) in *Picea pungens* (PP) and *Picea abies* (PA) on the occupation by *I. amitinus* according to exit holes (2011)

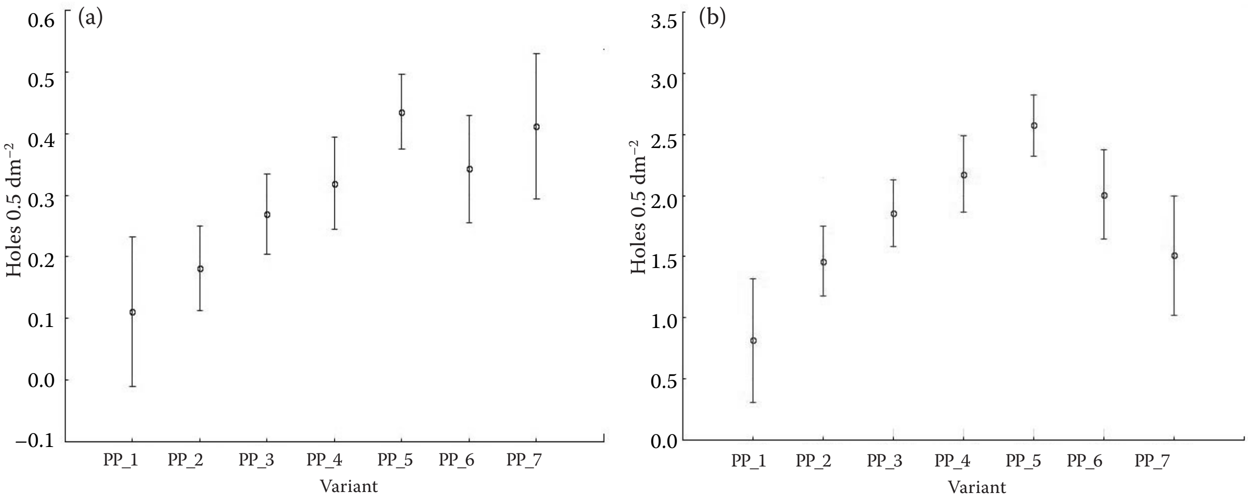


Fig. 7. Attractiveness of *P. pungens* (PP) sections of differentiated volume (1: < 2.49; 2: 2.5–4.99; 3: 5–7.49; 4: 7.5–9.99; 5: 10–14.99; 6: 15–19.99; > 20 dm$^3$) to *I. amitinus* (2011) according to (a) entrance holes and (b) exit holes

mortality during development was found on the sun-exposed sides of sections, mainly in the case of Norway spruce. Kula and Kajfosz (2006) reported that *P. chalcographus* was attracted to Norway spruce sections cut in spring and the intensity of the attack was linked to the extent of section shading. At the same time, material from summer tending felling was found to be unattractive (Kula, Kajfosz 2007). Felling debris produced in the autumn months enables the development of one generation during the following vegetation season, however, with marked differentiation of the attack intensity and the rate of development in relation to insolation (Kula, Kajfosz 2007).

*P. chalcographus* attacks are not so aggressive as this species is associated with blue-stain fungi or with *Ceratocystiopsis minuta* (Kiritis et al. 2000), which do not cause the tree to die like *Ceratocystis polonica* (Siemaszko) C. Moreau found in association with *I. typographus* (Horntvedt et al. 1983; Krokene, Solheim 1996). According to Hedgren (2004), only *P. chalcographus* is able to break through the protective potential of healthy spruces by its mass attack; however, conditions in the studied area of the Krušné hory Mts. are not suitable for such attack due to the long-lasting low share of Norway spruce. Branches and stems of blue spruce attract *P. chalcographus* as an accompanying species after the tree is attacked by *D. micans* (Kula et al. 2012), which is reported to be a predisposition factor for the attack of *I. typographus* and overcoming of spruce resistance (Coulson, Witter 1984).

Zumr (1984) reported that *I. amitinus* is the most abundant bark beetle in mountain spruce forests. According to Holuša et al. (2012) it is common from the lowest locations to the highest ones in the Carpathians in Central Europe. *I. amitinus* accepts a variety of food supply such as dying or weakened standing trees and felled trees (Knížek 2001; Mihalciuc et al. 2001; Kuś, Kuś 2004; Grodzki et al. 2006; Kula et al. 2007; Økland, Skarpaas 2008; Witrylak 2008; Grodzki 2009). Only sporadic information is available regarding the basic ecological characteristics of *I. amitinus* (Zumr 1982; Zuber 1992; Coeln et al. 1996). The sun-exposed sections of both tree species were more favourable for development of this species; in addition, larvae developing on blue spruce showed higher vitality and number of galleries indicating that the completed development was higher.

The analysis of attacked sections revealed that the phloem found in stems of 25–30 years old blue spruces is sufficiently thick and attractive to *I. amitinus* development, while Norway spruces of the same age had the thinner phloem and thus lower attractiveness. Due to the fact that *I. amitinus* develops also in the upper parts of tree stems with thin outer bark and on thick branches (Kula, Ząbecki 2010), the phloem thickness was not a limiting factor. The intensity of the attack was simultaneously affected by the volume of sections: the scale of the attack as well as developmental success increased up to the section volume of 10–15 dm$^3$. In sections of larger volume, the coarse flaky outer bark restrained the attack.

With regard to light conditions on the studied localities, *P. chalcographus* and *I. amitinus* exhibited similar requirements for their development like on felling debris (Kula et al. 2011). On the sun-exposed side, both bark beetle species developed with lower mortality; nevertheless, a higher share of entrance holes was found on the shaded sides of the sections.

## CONCLUSIONS

*P. pungens* is more attractive to *I. amitinus* than *P. abies*, while in *P. chalcographus*, higher abundance was found on *P. abies*. Both *P. chalcographus* and *I. amitinus* preferred to attack the shaded side of the stem sections, although their development was more successful on the sun-exposed side. On *P. pungens*, *P. chalcographus* abundance decreased and abundance of *I. amitinus* increased with the volume of the sections. Larvae of *Isarthron* sp. appeared on *P. pungens* together with the monitored bark beetle species.

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Received for publication October 9, 2013
Accepted after corrections November 13, 2013

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