Spatial occurrence and abundance of five phloeophagous beetle species (Coleoptera) in Scots pine trees (*Pinus sylvestris*) growing on sandy soils

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Abstract

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Spatial occurrence and abundance of *Ips sexdentatus, Phaenops cyanea*, *Pissodes piniphilus*, *Tomicus minor* and *Ips acuminatus* (Coleoptera: Curculionidae, Buprestidae) were examined in mature Scots pine trees (*Pinus sylvestris*) growing on poor sandy soils in Záhorská nížina lowland in western Slovakia, Central Europe. In the study area, the five given phloeophagous species are secondary pests of Scots pine spatially separated in pine trunks. Early in March 2006, each of them was recorded in 10 different Scots pine trees, in the lower, middle and upper parts (sections) of the trunks, each section being 4.0 m long. The study was made to clarify in more detail (1) as to whether and to which extent studied species occur in the middle trunks and (2) how their abundance (density) is differing among particular trunk sections of infested trees. All studied species were recorded in the middle trunk sections. However, the four of them, *I. sexdentatus, P. piniphilus*, *T. minor* and *I. acuminatus*, were less frequent here than in the other sections (lower or upper) they were preferring. Abundance of each species per 1,000 cm^2 significantly differed among the trunk sections ($p < 0.001$, Kruskal-Wallis anova). Particular species avoided extreme situations, that is, species inhabiting the lower trunks (*I. sexdentatus* and *P. cyanea*) were not recorded in the upper trunks and those colonizing the upper trunks (*P. piniphilus*, *T. minor*, *I. acuminatus*) were not documented to be developing in the lower trunks. In each species, variability in abundance was greatest in most densely colonized (preferred) parts of the trunks. The results give the evidence that high number of individuals of studied species are developing in dying mature pine trees in a mixed oak-pine forest in Central Europe.

Keywords

Central Europe, phloeophagous beetles, *Pinus sylvestris*, Scots pine, spatial occurrence

Introduction

Scots pine (*Pinus sylvestris* L.) is the most widely distributed conifer species in the world (Nikolov and Helmisaari, 1992), with an extensive natural range stretching from Spain to Norway and from Scotland to Siberia (Mason, 2000). Among numerous other organisms it hosts many insects, often beetles (Coleoptera), many of which occupy subcortical niche in dying or dead trees (Hussler and Müller-Kroehling, 2007).

The main features of distribution of phloeophagpus beetles within a tree are known for a long time in the case of Scots pine, however, they have been studied only extensively (Sauvard in Lieutier et al., 2004). Resource (niche) partitioning in phloeophagous beetle species developing in Scots pine has been documented by qualitative (e.g. Schedl in Freude et al., 1981; Kudela, 1970; Bílý, 1989) and quantitative data mostly available for few pest species, often bark beetles (e.g. Bakke, 1968; Randuška, 1983; Saarenmaa, 1983;

Bouhot et al., 1988; Schroeder and Eidmann, 1993; Amezaga and Rodríguez, 1998), or for assemblages of phloeophagous beetles from different taxonomical groups (Olšovský, 2008; Foit, 2007, 2010).

This study explores spatial occurrence and abundance of *Ips sexdentatus, Ips acuminatus*, *Tomicus minor* (Curculionidae, Scolytinae)*, Pissodes piniphilus* (Curculionidae, Pissodinae) and *Phaenops cyanea* (Buprestidae) in mature Scots pine trees maintaining the stability of poor sandy soils in western Slovakia in Central Europe. The five given phloeophagous species are common, widely distributed pests of Scots pine (Apel et al., 1999; Dajoz, 2000; Sowińska, 2006; Borkowski, 2007; Colombari et al., 2012) which are known to be spatially separated in pine trunks (e.g. Bakke, 1968; Olšovský, 2008). We clarify in more detail (1) as to whether and to which extent the five studied species are also occurring in the middle trunks of Scots pine trees and (2) how abundance of these species differs among the lower, middle and upper parts of the trunks infested. We expected that studied species primarily will occupy, depending on their specific habitat requirements, the subcortical niche in the lower (*I. sexdentatus, P. cyanea*) or upper trunks of infested trees (*P. piniphilus*, *T. minor*, *I. acuminatus*) and, possibly, the niche in the middle trunks too.

Material and methods

Study area

Acording to the evidence by the National Forest Centre, Scots pine forests maintaining the stability of sandy soils in Záhorská nížina lowland in western Slovakia cover the area of approximately 50,000 ha. Study was carried out within this large forest area, in a mixed oakpine stand (*Pineto-Quercetum*, 30 ha, 227 to 238 m a.s.l., south-east aspect, pine trees approximately 145 years old, 48°36'14" N, 17°19'19" E). Scots pine dominates (90%) the sessile oak (*Quercus petraea*) and other tree species. The herb-layer mostly consists of *Calluna vulgaris, Carex ericetorum, Corynephorus canescens, Thymus serpyllum, Euphorbia cyparissias* and *Festuca ovina.* The biotope is classified as Ls6.1 „Acidophilous pine and oak-pine forest" (Stanová and Valachovič, 2002). The area is characterized by poor dry sandy soils, although moist sites are also present locally (Baňacký and Sabol, 1973). It is climatically warm, with average temperatures in the range from 9 to 10 °C and rainfall between 450 and 700 mm (evidence by the Slovak Hydrometeorological Institute).

Host trees

A total of 10 mature, tall, straight-trunked Scots pine trees with few side branches were examined separately for the occurrence of each of the folowing five beetle species, all phloeophages: *I. sexdentatus, P. cyanea*, *P. piniphilus*, *T. minor* and *I. acuminatus*. The trees were infested by beetles over the growing season 2005 and felled in February 2006. To document occurrence of beetle species in the trunks of infested trees, each trunk was divided into the three distinct, spatially separated sections with the following diameters and distance from the tree base or cut area, respectively: lower section (diameter: 0.30–0.42 m, distance: 0.0 m), middle section (0.22–0.30 m, 8.0 m) and upper section (0.12–0.17 m, 16.0 m), each section being 4.0 m long. Thickness of the bark was measured at the beginning, in the centre and at the end of each section. Average thickness of the bark was calculated for each section as the mean of the three measurements.

To obtain beetles the bark was carefully and completely peeled away from each trunk section early in March 2006. The bark and beetles were sampled, those beetles present in the bark were separated from the breeding substrates in the laboratory. Then, larvae and/or beetle adults (depending on species) were counted and identified. As the scolytid *T. minor* does not overwinter in the breeding substrates, number of individuals of the beetle was detected indirectly, by counting emergence holes on the bark, this being combined with a thorough examination of the beetle galleries under the bark.

Data analysis

Frequency of occurrence of a beetle species in a given trunk section was calculated as the ratio between the observed number of occurrences and the number of all possible occurrences of this species in particular section (n = 10). For comparative purposes, the number of beetles collected from each trunk section was related to the area of 1,000 cm^2. It was compared among the trunk sections by the nonparametric Kruskal-Wallis anova test (Zar, 2010). Significant differences in beetle densities among particular trunk sections were detected by multiply comparisons in K-W anova. Data analysis was performed in the program Statistica (StatSoft Inc., 2005). Presence of studied species related to the trunk diameter and thickness of the bark was shown in the form of scatterplot made in the program R.

Results

The occurrence of *I. sexdentatus, P. cyanea, P. piniphilus*, *T. minor* and *I. acuminatus* in particular trunk sections of Scots pine trees, characterized by particular trunk diameters and bark thickness, is shown in Fig. 1. All species were recorded in the middle section of the trunks examined. Except for *P. cyanea*, they were less frequent in this section compared to the other sections (lower or upper) they were preferring. The bark beetle *I. sexdentatus* was most frequent in the lower, while the jewel beetle *P. cyanea* was found most frequently in the lower and middle section. The weevil *P. piniphilus* and the two scolytid species, *T. minor* and *I. acuminatus*, occurred most frequently in the upper section. No of the five studied species was recorded in each trunk section (Figs 1, 2).

A total of 666 adults of *I. sexdentatus* were obtained from the middle trunk sections (n = 10), against a total of 4,289 adults collected from the lower sections (n = 10). The number of adult beetles varied between 0 and 170 in the middle and between 220 and 660 in the lower section. Number of adults per 1,000 cm^2 significantly differed among the sections ($H_{(2, N = 30)} = 24.1188$, $p < 0.001$, K-W ANOVA) (Fig. 3).

The middle trunk sections (n = 10) yielded a total of 819 larvae of *P. cyanea*, and a total of 3,156 larvae were obtained from the lower sections (n = 10). The number of larvae varied from 29 to 188 in the middle and from 151 to 490 in the lower section. Number of larvae per 1,000 cm^2 was significantly different among the sections ($H_{(2, N = 30)} = 25.8969$, $p < 0.001$, K–W ANOVA) (Fig. 3).

A total of 482 larvae of *P. piniphilus* were recorded in the middle trunk sections (n = 10), and a total of 1,194 individuals were documented in the upper sections (n = 10). Number of larvae varied from 0 to 113 in the middle and from 38 to 214 in the upper section. Number of larvae per 1,000 cm^2 significantly differed among the sections ($H_{(2, N = 30)} = 23.7771$, $p < 0.001$, K–W ANOVA) (Fig. 3).

Based on the counts of emergence holes, the middle trunk sections (n = 10) produced a total of 3,711 adults of *T. minor* at least, while the upper sections (n = 10) supported at least 12,737 adults. The number of emergence holes varied from 0 to 1,130 in the middle and between 603 and 2,135 in the upper section. There was a significant difference in the number of emergence holes per 1,000 cm^2 among the sections ($H_{(2, N = 30)} = 23.9517$, $p < 0.001$, K–W ANOVA) (Fig. 3).

In the case of *I. acuminatus*, the middle trunk sections (n = 10) yielded a total of 2,882 adults, and as many as 16,148 adults were obtained from the upper sections (n = 10). The number of adults varied from 0 to 785 in the middle and from 980 to 2,669 in the upper section. Number of adults per 1,000 cm^2 significantly differed among the sections ($H_{(2, N = 30)} = 24.0209$, $p < 0.001$, K–W ANOVA) (Fig. 3).

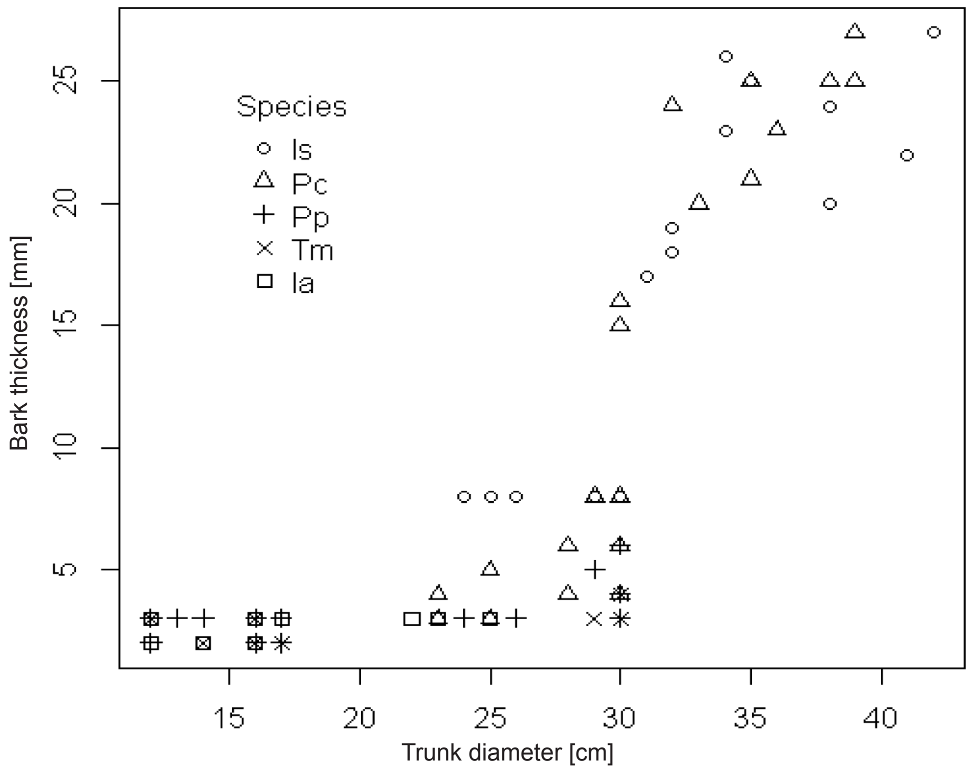

Fig. 1. The occurrence of *Ips sexdentatus* (Is), *Phaenops cyanea* (Pc), *Pissodes piniphilus* (Pp), *Tomicus minor* (Tm) and *Ips acuminatus* (Ia) in mature Scots pine trees related to trunk diameter and bark thickness. Three distinct groups (from left to right) represent the upper, middle and lower section of the 10 tree trunks examined separately for the presence of each species. Species data is overlapping, especially in the middle and upper trunk sections. Záhorská nížina lowland, western Slovakia, March 2006.

Discussion

Scots pine tolerates a wide range of growing conditions, occupying sites unfavourable to other tree species, often characterised by poorer sandy soils (Mason, 2000). Despite this, mature pine trees die frequently on dry sandy soils in the study area (Olšovský, 2008) where the five studied beetle species affect the health of Scots

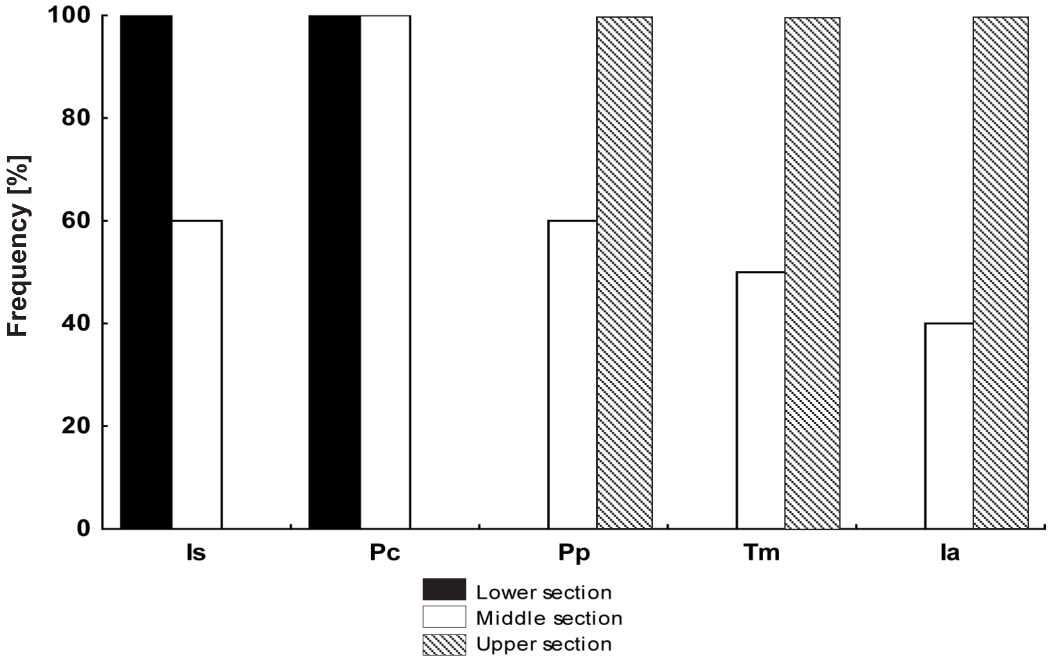

Fig. 2. Frequency of occurrence of *Ips sexdentatus* (Is), *Phaenops cyanea* (Pc), *Pissodes piniphilus* (Pp), *Tomicus minor* (Tm) and *Ips acuminatus* (Ia) in three trunk sections of the 10 mature Scots pine trees examined separately for the presence of each species. Záhorská nížina lowland, western Slovakia, March 2006.

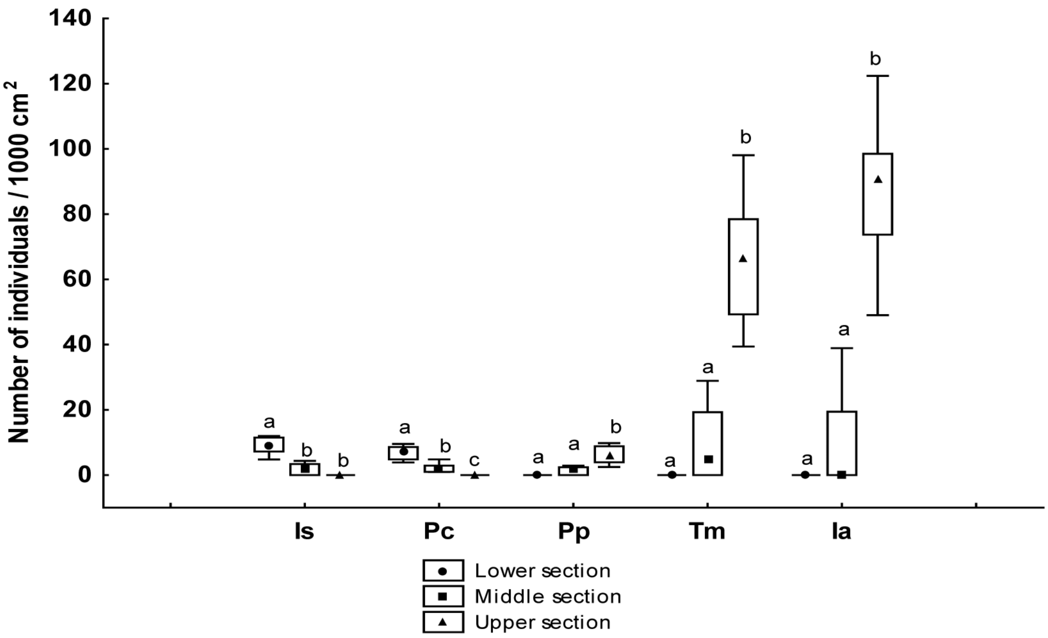

Fig. 3. Variation in abundance (ind./1000 cm^2) of *Ips sexdentatus* (Is), *Phaenops cyanea* (Pc), *Pissodes piniphilus* (Pp), *Tomicus minor* (Tm) and *Ips acuminatus* (Ia) in three distinct trunk sections of the 10 mature Scots pine trees examined separately for the presence of each species. Different letters indicate significant differences at α = 0.05 (multiply comparisons in K–W anova). Box and whisker plots – box: median, 1st and 3rd quantile, whiskers: non-outlier range (minimum and maximum). Záhorská nížina lowland, western Slovakia, March 2006.

pine secondarily, together with other phloeophagous (e.g. *Tomicus piniperda*, *Pityogenes quadridens*, *Pityogenes chalcographus*) and phyllophagopus beetles (Holecová and Kulfan, 2010), moths (Kulfan and Holecová, 2010), sawflies (Kulfan et al., 2011) and other insects. They all are frequently (Fig. 2) and abundantly (Fig. 3) developing in the trunks of infested trees, increasing in number after warm and dry weather and/or after wind and snow disturbances, forest fires and anthropogenic impacts (e.g. tree felling) modifying the canopy cover. In the study area they greatly increase their abundance locally, as documented, for example, in the case of *I. sexdentatus* in France (Dajoz, 2000), *P. cyanea* in Germany (Apel et al., 1999), *Tomicus* spp. in Poland (Borkowski, 2007) and *I. acuminatus* in Switzerland (Colombari et al., 2012).

Knowledge of spatial occurrence of the given five beetle species in the trunks of mature Scots pine trees presented here is in agreement with that in the literature (e.g. Bakke, 1968; Randuška, 1983; Foit, 2007). All studied species were documented to occupy the subcortical niche in the middle trunks of infested trees. However, *I. sexdentatus, P. piniphilus*, *T. minor*, *I. acuminatus*, were less frequent here compared to their preferred locations in the lower or upper trunks (Fig. 2). All species were always (in each tree) less abundant in the middle part of the trunk than in their preferred (lower or upper) location (Fig. 3). Thus, the middle trunks, if 20–30 cm thick, may be considered as being less favourable but not unimportant for the development of studied beetle species. As expected, they all avoided extreme situations. That is, the species *I. sexdentatus* and *P. cyanea*, developing in the lower and middle trunks, were not found in the upper trunks and the species *P. piniphilus*, *I. acuminatus* and *T. minor*, inhabiting the upper and middle trunks, were not recorded in the lower trunks (Figs 1–3). This gives a sound evidence of partitioning of the food and habitat resource (e.g. Bakke, 1968; Amezaga and Rodríguez, 1998) and, possibly, of the competitive interactions among co-occurring species. According to Sowińska (2006) and our knowledge, too, the bark beetle *I. sexdentatus* and the jewel beetle *P. cyanea* may co-occur in the lower and middle trunks. Two scolytid species, *T. minor* and *I. acuminatus*, often, consume much of the phloem in the upper trunks, the weevil *P. piniphilus* being their frequent but much less abundant associate here (Figs. 2, 3).

Number of individuals of studied species developing within a particular trunk section was varying to some extent. In each species, great variation in abundance primarily was associated with the most densely colonized trunk sections (Fig. 3). Greatest variation in abundance was documented in the case of *T. minor* and *I. acuminatus* (Fig. 3). Numerous emergence holes produced by the adults of *T. minor* document successful development of the beetle in standing trees over the growing season 2005. Compared to other species in the study, the scolytid *T. minor* has a more complex biology (Kudela, 1970). According to Långström (1983) it overwinters in the litter. This explains its absence in the breeding substrates examined. In the study area, *T. minor* is among the most important insect pests of Scots pine, together with *I. acuminatus*. Although a large part of the adults of *I. acuminatus*, irrespective of generation, may leave the breeding substrates before hibernation (Colombari at al., 2012), many adults of the beetle still may be found overwintering in the trunks as shown in the results.

Thickness of the bark correlates with the trunk diameter and is varying greatly for certain trunk diameters in the case of Scots pine, especially in the lower and middle trunks (Fig. 1). Species data in Fig. 1 shows some overlap due to similar sizes of trunk sections and/or precision of measurement of bark thickness. Data from spatially separated trunk sections (Fig. 1) does not cover the whole gradient of the bark thickness with the presence of a certain beetle species. Therefore it is difficult to realistically judge here how abundance of any studied species depends on thickness of the bark. Nevertheless, thickness of the bark is known to be a good segregating variable explaining differences in within-tree distribution of phloeophagous beetle species in Scots pine (Saarenmaa, 1983; Amezaga and Rodríguez, 1998; Foit, 2010). In addition, microclimate, too, especially surface temperature of the bark during the colonization of a tree by phloeophagous beetles, may be influencing spatial occurrence of studied species in host trees. For example, the jewel beetle *P. cyanea* prefers sunny situations and/or sunny habitats (Apel et al., 1999); the trees colonized by it have higher surface temperature than those not inhabited (Sowińska, 2006). Frequent occurrence and high abundance of this buprestid in the colonized parts of the trunks (Figs 2, 3) indicate the influence of infrared (solar) radiation in a fragmented forest, the canopy of which was strongly modified (reduced) by tree felling. The scolytid *T. minor* occupies the lower surfaces in the top of pine trees and does not settle on the upper surfaces favoured by *I. acuminatus*; such distribution pattern, similarly, is explained by thermal preferences in these two co-occurring species (Bakke, 1968; Dajoz, 2000).

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Priestorový výskyt a početnosť piatich druhov floeofágnych chrobákov (Coleoptera) na borovici lesnej (*Pinus sylvestris*) rastúcej na piesočnatých pôdach

Súhrn

Práca hodnotí výskyt a početnosť piatich druhov floeofágnych chrobákov, *Ips sexdentatus, Phaenops cyanea*, *Pissodes piniphilus*, *Tomicus minor* a *Ips acuminatus* (Coleoptera: Curculionidae, Buprestidae), na borovici lesnej (*Pinus sylvestris*) rastúcej na piesočnatých pôdach Záhorskej nížiny na západnom Slovensku. Študované druhy sa tu uplatňujú ako sekundárne škodce borovice urýchľujúce odumieranie dospelých stromov a ich porastov. Kvantitatívne údaje boli získavané pre každý druh chrobáka osobitne na súbore 10 kmeňov dospelých borovíc spílených vo februári a analyzovaných začiatkom marca 2006. Priestorový výskyt jednotlivých druhov bol hodnotený v spodnej, strednej a hornej časti kmeňa, v sekciách charakterizovaných hrúbkou kmeňa a dĺžkou 4 m. Cieľom výskumu bolo objasniť, či a do akej miery sa uvedené druhy vyskytujú, vzhľadom na ich priestorovú separáciu, aj v strednej časti kmeňov borovíc a ako sa odlišuje ich početnosť medzi jednotlivými časťami (sekciami) kmeňa. Všetky študované druhy boli zaznamenané v strednej časti kmeňa s hrúbkou od 20 do 30 cm. S výnimkou krasoňa *P. cyanea* tu však boli menej časté ako v druhovo špecificky uprednostňovanej dolnej alebo hornej časti kmeňa. Detekované boli štatisticky signifikantné rozdiely v hustote kolonizácie porovnávaných sekcií borovicových kmeňov študovanými druhmi ($p < 0{,}001$, Kruskal-Wallis ANOVA). Druhy uprednostňujúce spodnú časť kmeňa (*I. sexdentatus, P. cyanea*) neboli zistené v hornej časti kmeňa a druhy uprednostňujúce hornú časť kmeňa (*P. piniphilus*, *T. minor*, *I. acuminatus*) neboli zaznamenané v spodnej časti kmeňa. Vysoká variabilita početnosti študovaných druhov bola dokumentovaná predovšetkým v častiach kmeňa s vysokou hustotou kolonizácie. Najväčšia variabilita početnosti bola zistená u druhov *I. acuminatus* a *T. minor* v hornej časti borovicových kmeňov. Podľa prezentovaných výsledkov v odumierajúcich dospelých boroviciach prebieha vývin mnohých jedincov študovaných druhov chrobákov. S výnimkou druhu *T. minor* tieto zimujú v mieste vývinu v hostiteľských stromoch.

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