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Efficacy of synthetic lures for pine bark beetle monitoring

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Abstract: The Scots pine (*Pinus sylvestris*) plantations in central Europe are currently damaged by a large-scale infestation by bark beetles (Scolytinae). *Ips acuminatus* and *Ips sexdentatus* are among the most aggressive species causing infestations of pine trees that are currently simultaneously attacked by *Ips typographus*. In pine plantations prone to damage, it is therefore necessary to carry out the bark beetle monitoring. One of the used methods is the pheromone bark beetle trapping using synthetic lures. The efficacy of synthetic lures differs. We tested the efficacy of commercially available lures used in the protection of pine trees. In total, we deployed 10 trap series, each consisting of traps with eight different lures and two unbaited traps (controls). *Ips acuminatus* and *I. sexdentatus* were most abundantly captured in Pheagr-IAC- and Sexowit-baited traps. Interestingly, the spruce species *I. typographus* was also captured and most often found in traps with Pheagr-IAC and Erosowit Tube lures. The number of captured beetles was consistent with the gradation phase of bark beetles. Our results suggest the suitability of pheromone traps for bark beetle monitoring. The use of Sexowit can be recommended especially in southwestern Moravia, where *I. sexdentatus* occurs in high numbers in the long run. In other parts of the Czech Republic, Pheagr-IAC alone can be used with sufficient efficacy. The use of the Erosowit Tube lure is also suitable for *I. typographus* and *I. sexdentatus* monitoring.

Keywords: *Ips acuminatus*; *Ips sexdentatus*; pheromone; trap; Czechia

The Scots pine (*Pinus sylvestris*) plantations in central Europe are currently affected by a large-scale bark beetle infestation. Its primary drivers can be climate change and socioeconomic conditions which influence the implementation of preventive and curative forest protection management (Skrzecz, Perlińska 2018; Kunca et al. 2019; Liška et al. 2021). The significance of this situation mainly lies in the fact that the Scots pine has a wide economic use and its current proportion in the forests of the Czech Republic is more than 16% (Ruotsalainen, Persson 2013; MZe 2021). The sudden tree death and subsequent deforestation over large areas are environmentally harmful, due to the crucial role of forests in the landscape (Borrelli et al. 2017; Blumroeder et al. 2019). Therefore, it is essential to pay immediate attention to protection of these forests and conduct pest monitoring and careful follow-up protection interventions (e.g., sanitation felling of infested trees, pheromone traps, trap trees, chemical insecticides, biological agent) (Zahradník 2014).

The most harmful cambiophagous insects in the Scots pine in the Czech Republic include several species of bark beetle (Coleoptera: Curculionidae, Scolytinae) like *Ips acuminatus* (Gyllenhal, 1827) and *Ips sexdentatus* (Boerner, 1766), and to a much lesser extent, *Tomicus minor* (Hartig, 1834) and *Tomicus piniperda* (Linnaeus, 1758) (Liška et al. 2021).

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The occurrence of *I. sexdentatus* has long been known only from southwestern Moravia (Pfeffer 1955), but in recent years it has expanded its range to other regions (Knížek 2020). Under favourable conditions, *I. sexdentatus* can be one of the most destructive pine beetles with extremely high densities and considerable dispersal potential (Jactel, Gaillard 1991). At high population densities, *I. acuminatus* can attack even vigorous trees otherwise not prone to infestation (Colombari et al. 2013) and its harmfulness increases with higher spring temperatures (Chinellato et al. 2014). In Central Europe, *I. acuminatus* is now one of the first colonizers of weakened trees, sometimes attacking even healthy ones (Foit, Čermák 2014). The intensity of tree infestations by *I. acuminatus* has recently been increasing, making this species one of the most aggressive bark beetles within Europe (Faccoli et al. 2012; Colombari et al. 2013; Plewa, Mokrzycki 2017; Liška et al. 2021). *Ips typographus* (Linnaeus, 1758) is primarily associated with Norway spruce, it can also kill pines at higher densities (Komonen et al. 2011).

Overall, *I. acuminatus*, *I. sexdentatus* and *I. typographus* share many ecological characteristics and *I. acuminatus* and *I. sexdentatus* often occur together (Wermelinger 2004; Liška et al. 2021). All three species are associated with pathogenic fungi and produce aggregation pheromones for a mass attack (Krokene, Solheim 1996; Kirisits 2007; Lieutier 2007). Mass attacks play a crucial role in overcoming the resistance of even healthy host trees (Mulock, Christiansen 1986; Toffin et al. 2018). Aggregation behaviour requires efficient communication, ensured by physiological and anatomical adaptations providing the production and reception of chemical signals (Dickens, Payne 1977; Blomquist et al. 2010). This behaviour is exploited to capture bark beetles in traps baited with synthetic pheromones and/or kairomones. Pheromone traps are used to monitor the presence and abundance of bark beetles in many countries (Galko et al. 2016). The efficacy of synthetic pheromones may be reduced by the fact that the natural production of pheromones, as well as the response to them, varies among individual beetles and depends on environmental parameters such as physiological state of the host trees, weather conditions, distance of trap from the trees (Birgersson et al. 1984, 1988; Duelli et al. 1997; Erbilgin et al. 2007; Lieutier 2007).

We tested the efficacy of eight commercial lures intended for the protection of pine trees against the bark beetle attack and infestation. We also focused on the bark beetle monitoring in different regions of the Czech Republic. Specifically, we tested whether the number of captured individuals of *I. acuminatus* and *I. sexdentatus* depends on the geographic location and type of pheromone bait used. Considering high densities of *I. typographus* in the landscapes and high risk of forest damage by this serious pest of Norway spruce, we also included it in our investigations.

MATERIAL AND METHODS

Data collection. Our study was carried out in five localities (Figure 1) with large Scots pine plantations. The sites differed in the intensity of bark beetle infestation and climatic conditions, and they were situated in different biogeographical regions of the Czech Republic (ČHMÚ 2021, Table 1). In 2019 and 2020, we deployed two series at each locality consisting of 10 standardized pheromone traps. The series were located approximately 500 m apart. Eight traps were baited with different types of lures: Erosowit Tube – designed for *Orthotomicus erosus* (Wollaston, 1857); Gallopro Pinowit – *Monochamus galloprovincialis* (Germar, 1818), *I. sexdentatus*, *Hylurgus ligniperda* (Fabricius, 1787); Chalcoprax – *Pityogenes chalcographus* (Linnaeus, 1760); Lineatin Kombi – *Trypodendron* spp.; Ligniwit Tube – *Hylurgus ligniperda*; Pheagr-IAC – *I. acuminatus*; Sexowit – *I. sexdentatus*; Tomowit – *T. piniperda, T. minor*; and two control traps without any pheromone bait. The traps were located in young pine stands adjacent to the affected mature stands, set in rows, at a distance of 15 m at least. The traps were installed at the beginning

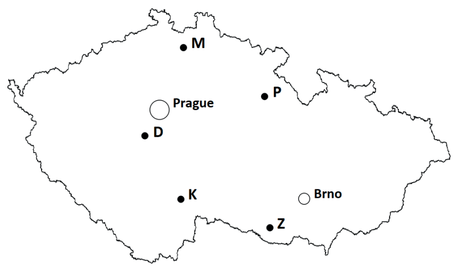

Figure 1. Location of the five study sites

D – Dobříš; K – Kardašova Řečice; M – Mimoň; P – Polánky nad Dědinou; Z – Znojmo

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Table 1. Characteristics of the study localities; climatic characteristics are based on the period 1981 – 2010 (ČHMÚ 2021)

Locality	Altitude (m a.s.l.)	Bark beetle gradation phase	Scots pine stand age (years)	Average temperature (°C)	Average precipitation (mm)
Mimoň	330	endemic	60–80	7	750
Dobříš	400	culmination	60	8	500
Kardašova Řečice	450	epidemic	60–80	7	600
Znojmo	320	culmination	40	9	450
Polánky nad Dědinou	250	endemic	60–80	8	550

of the expected swarming period of the first generation of beetles (beginning of April) and uninstalled at the end of October. They were regularly checked at two-week intervals. The captured bark beetles were identified in the laboratory using keys (Pfeffer 1955, 1995).

Data analysis. Using a generalized linear model (GLM) with pairwise contrasts (Denis 2019) in IBM SPSS Statistics (Version 28.0, 2021), we tested whether the number of captured individuals varied among traps with different lures and among localities.

RESULTS

Ips acuminatus. A total of 95 884 individuals were captured. *Ips acuminatus* was most abundantly captured in Pheagr-IAC-baited traps (88 525 ex.) and less abundantly in Sexowit-baited traps (6 800 ex.; Figure 2). The test (χ^2 = 19.7, P = 0.01) showed no significant differences between these lures (P = 0.7). However, these captures were significantly different from those in traps with all the other lures ($P \leq 0.05$). A comparison of localities (χ^2 = 11.1, P = 0.03) showed that most individuals of *I. acuminatus* were captured at Dobříš (85 783 ex.; Table 2), followed by much fewer individuals of this species captured at Polánky nad Dědinou and Kardašova Řečice. Captures at Dobříš were significantly different from the other sites ($P \leq 0.05$). Apart from Dobříš, the numbers at K. Řečice were not different from those at other sites ($P > 0.05$), and the numbers of captured individuals did not differ between Mimoň and Znojmo (P = 0.46) and Polánky nad Dědinou and Znojmo (P = 0.13).

Ips sexdentatus. *Ips sexdentatus* was captured most abundantly in Sexowit-baited traps (1 570 ex.) and Pheagr-IAC (964 ex.). It was abundant only at Znojmo (4 647 ex.) and occurred only infre-

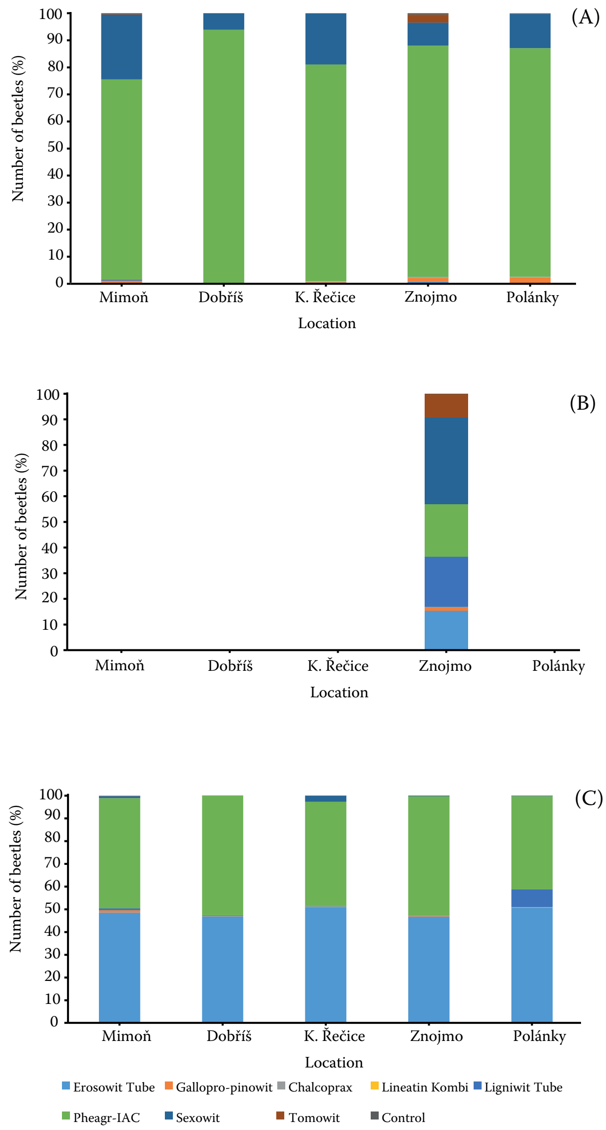

Figure 2. Numbers of beetles (in percentage) captured in different pheromone traps at the five study sites

(A) – *I. acuminatus*; (B) – *I. sexdentatus*; (C) – *I. typographus*; *I. sexdentatus* is shown only in Znojmo due to the small number of individuals captured in other localities

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Table 2. Number of bark beetles captured in five study localities

Bark beetle	Mimoň	Dobříš	Kardašova Řečice	Znojmo	Polánky nad Dědinou
Ips acuminatus	887	85 783	3 152	583	5 439
Ips sexdentatus	5	1	1	4 647	1
Ips typographus	16 554	18 601	51 221	31 153	15 058

quently at other localities, where it was found only in the second study year. Its abundance was influenced by the site ($\chi^2 = 143.2$, $P = 0.01$) and the lure used ($\chi^2 = 34$, $P = 0.01$).

Ips typographus. *Ips typographus* was most abundant at K. Řečice (51 221 ex.) and Znojmo (31 153 ex.). The factor location did not affect its abundance ($\chi^2 = 5.5$, $P = 0.29$). Most individuals of this species were captured by Erosowit Tube (65 058 ex.) and Pheagr-IAC (63 946 ex.) traps. The captures of beetles in these traps differed from those in traps baited with other lures ($P \leq 0.05$) but they were not different from each other ($P > 0.05$).

DISCUSSION

The numbers of captured beetles roughly correspond to those from other pine forests (Martín et al. 2013; Sukovata et al. 2021). The results support the previous experience concerning the importance of the lure component in attracting bark beetles (Symonds, Gitau-Clarke 2016; Sukovata et al. 2021). Pheagr-IAC and Sexowit proved to be the most suitable lures. Pheagr-IAC, primarily intended for luring *I. acuminatus*, proved to be suitable also for *I. sexdentatus* and *I. typographus*as. The high efficacy of Pheagr-IAC lure for *I. acuminatus* can be explained by its composition, as it contains ipsenol, ipsdienol, and cis-verbenol, which are substances secreted by *I. acuminatus* males. Pine terpenes are also attractive chemicals (Bakke 1978), which are represented by 2-methyl-3-buten-2-ol in the case of Pheagr-IAC. The results are in agreement with Sukovata et al. (2021), who found high efficacy of an experimental lure (coded as ACW2), whose composition is similar to that of Pheagr-IAC (Sci-Tech 2004; Sukovata et al. 2021).

Ips sexdentatus also produces the pheromone components ipsenol and ipsdienol (Vité et al. 1972; Francke et al. 1986; Kohnle et al. 1992; Etxebeste et al. 2012). This explains why *I. acuminatus* responded almost equally to the lures for *I. sexdentatus* and why this species was captured in high numbers in traps baited with Pheagr-IAC and Sexowit. The general similarity in pheromone composition in the representatives of the genus *Ips* (Byers 1989) could be the reason why *I. typographus* was also captured in traps baited with Pheagr-IAC developed for luring the bark beetle associates of pine trees. The efficacy of traps baited with Erosowit Tube can be explained similarly. A similar relationship is manifested in *Orthotomicus erosus*, which was captured in traps set for *I. typographus*, containing 2-methyl-3-buten-2-ol and ipsdienol (Giesen et al. 1984; Klimetzek, Vité 1986; Mendel 1988).

The number of captured beetles is consistent with the gradation phase of bark beetles. The results of *I. acuminatus* trapping confirm our knowledge of the gradation phase at Dobříš (Table 1, Figure 1). High *I. acuminatus* captures were also recorded at Polánky, confirming the westward spread of *I. acuminatus* gradation from Moravia (Lubojacký, Knížek 2021). The high abundance of *I. sexdentatus* limited to the Znojmo locality is due to the long-term (historical and present) occurrence of this species in southwestern Moravia, while its occurrence in Bohemia was only sporadic until recently, without economic importance (Pfeffer 1955; Knížek 2020; Liška et al. 2021). The approximately equal abundance of *I. typographus* at all localities indicates the general high population density of this species in the landscapes and its considerable tendency to migrate (Lubojacký, Knížek 2021; Hlásny et al. 2021). This serious pest can be observed even at a distance of several kilometres from the nearest spruce trees (Furuta et al. 1996). Primary attraction together with upwind flight are the prerequisites for the reproductive success of *I. typographus* (Gries et al. 1989).

Results confirm the suitability of pheromone lures for the bark beetle trapping. In particular, the Pheagr-IAC and Sexowit lures are highly effective. This was confirmed by successful trapping of *I. sexdentatus* in locations in the western part of the Czech Republic, where abundance of this species is low and where its occurrence was previously unknown. These two lures effectively attract target bark beetle species as taxonomically

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related species. The lure Sexowit can be recommended especially in southwestern Moravia, where *I. sexdentatus* occurs abundantly in the long run. For other parts of the Czech Republic where the abundance of this species is low, Pheagr-IAC alone can be used with sufficient efficacy. This lure has proved to be suitable for the monitoring of *I. typographus*. The use of the Erosowit Tube lure can also be considered suitable for *I. typographus* and *I. sexdentatus*, however, using the previous two types of lures shows better results in the case of *I. sexdentatus* monitoring.

However, pheromone traps give only a general indication of population density. The dispersal of bark beetles in the forest landscape is not random. It depends on the presence of suitable host trees close to the beetle development sites. On the other hand, even without the aid of wind, bark beetles can actively fly several kilometres away (Jactel, Gaillard 1991; Colombari et al. 2013). Thus, the location of traps could bias the data about local population density. For monitoring purposes, however, this may not be a problem. While high captures of bark beetles in traps may not correlate with high infestations, low captures usually indicate the low infestation risk (Weslien 1992a; Lindelöw, Schroeder 2001). Pheromone traps also have the disadvantage that some of the attracted beetles colonise the surrounding trees – they can increase population densities due to the absence of competitors, and pheromone trapping may also affect non-target species (Weber 1987; Etxebeste et al. 2012; Panzavolta et al. 2014). Therefore, pheromone traps can be recommended only for monitoring, not for reducing bark beetle populations, specifically during the bark beetle outbreak, because the efficacy of pheromone trapping is very low (3–5%) (Weslien 1992b; Lobinger, Skatulla 1996; Wichmann, Ravn 2001; Galko et al. 2016).

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