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THE EFFICACY OF A NEW PHEROMONE TRAP SETUP DESIGN, AIMED FOR TRAPPING *IPS TYPOGRAPHUS* (COLEOPTERA, CURCULIONIDAE, SCOLYTINAE)

UČINKOVITOST NOVOG NAČINA POSTAVLJANJA FEROMONSKIH KLOPKI NAMIJENJENIH ULOVU *IPS TYPOGRAPHUS* (COLEOPTERA, CURCULIONIDAE, SCOLYTINAE)

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Summary

The primary aim of this paper is to compare the efficacy of traditional set-up of pheromone traps (along a stand wall at a distance of 20 m between each other) and a new arrangement where the pheromone baited trap is placed in the middle of a stocking area with no space between single traps. A secondary aim is to find the best use of pheromone baits in trapping systems where: i) every trap is baited, ii) every second trap is baited, iii) only traps at the edges and middle of arrangements are baited.

The results showed that the new organisation of pheromone baited traps is more effective than the traditional one and can provide a better tool for active forest protection in managing outbreaks of spruce bark beetles.

KEY WORDS: spruce bark beetle, pheromone baited traps, spatial trap design, control.

INTRODUCTION
UVOD

Pheromone traps for protection against the spruce bark beetle were introduced in the late 1970s to replace the trap trees which had been in use for the previous 200 years. The first mention of the spacing between pheromone traps, the safety distance, and also the first mention of the association of pheromone traps with minimum spacing appeared shortly after their first use (Bakke and Strand 1981; Regnander and Solbreck 1981; Eidmann 1983). With only minor variations, these same guidelines are still being used today, but without adequate support from empirical research. Research into the relative merits of different approaches to trap placement has been conducted in Scandinavia (primarily Norway and subsequently in Sweden) primarily using pipe pheromone traps (Bakke 1985; Bakke and Strand 1981; Weslien at al. 1989), but Central Europe soon switched to the barrier pheromone trap, either the window-trap (catching beetles from two directions) or cross-vane (catching beetles from four directions) (e.g. Brutovský 1984, Novák 1984; Vaupel 1991). Other approaches to pheromone trap set-up began to appear in the beginning of the 1980s and usually involved three to five individual traps over a smaller area with a maximum spacing of 1 m (Niemeyer 1987). Bakke et al. (1983) tested the efficacy of placing traps over these shorter dis-

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tances in set-up of a large number of pheromone traps in large clear cuts, but it was not widely used.

An alternative set-up approach, known as a "barrier system" was first tested in the Slovak High Tatra National Park and later in the Czech Republic's Šumava National Park by Jakuš (1998); Jakuš and Blaženec (2003); Jakuš and Šimko (2000). This system was based on the installation of long lines (occasionally many kilometres) of pheromone traps with shorter distances between them and sometimes superimposed into more lines in relation to the distance from the stand wall.

The aim of our work is to establish if there is a more effective system for the set-up of pheromone traps than the current standard set-up along stand walls, to be measured both by the total number of captured beetles and the time required to install/check the traps and any resulting economic savings.

MATERIALS AND METHODS
MATERIJALI I METODE

Study area – *Područje istraživanja*

The study was carried out in 2009 and 2010 in the Boletice military area of the Arnoštov forest district in the Šumava Mountains, the Czech Republic. According to the Climate Atlas of Czechoslovakia (1958) experimental areas are situated in climatic zones: B – moderately warm. The July average temperature above 15 ° C., the average annual temperature is 5.6 ° C, in the growing season 10.4 ° C. The average annual rainfall 700–800 mm, in the growing season 500 mm. The average length of growing period 100–125 days. Soils oligotrophic to mesotrophic (Cambisol with transitions to Ranker soil type, sometimes with gleying). Sandy with different ratio of skeletal fraction. In the forest stands around clearings spruce representation 85–95%, age 115–135 years, altitude 920–1020 m a. s. l. It is an area with a naturally high occurrence of spruce bark beetles, with the number of beetles having risen even further since hurricane Kyrill in 2007. Trappings increased to hundreds of thousands in this forest district.

Trapping systems – *Lovni sustavi feromonskih klopki*

Nine "Theysohn" (producer THEYSOHN Kunststoff GmbH, Germany) type pheromone traps with FeSex Typo (2-methyl-3-buten-2-ol 95,5-96,8 %; [S]-*cis*-verbenol 3,2-4,5 %; ipsdienol 0,3–0,4 %; producer Ubik Karel) pheromone dispensers were used in each research plot. There were 8 research plots within 1 km of each other at a height of 950 m a. s. l. Four different pheromone trap set-up systems were compared, each in 2 repetitions. The first (A1) followed the traditional system according to Czech technical standard ON 48 2711 (Zahradník et al. 1988) with pheromone baited-traps set approximately 15 m from forest edge that were placed approximately 20 m apart. The second system (A2) was comprised of pheromone-baited traps set in the middle of the clear cut area with no separation between them. Each trap was baited (a total of 9 dispensers in 9 traps). The third system (A3) was the same as A2, but the pheromone dispensers were only placed at every second trap starting with the 1st (a total of 5 dispensers in 9 traps). The fourth system (A4) was the same as A2 and A3, but the dispensers were only placed in the middle and 2 outside traps (a total of 3 dispensers in 9 traps). Every system was repeated twice (Figure 1).

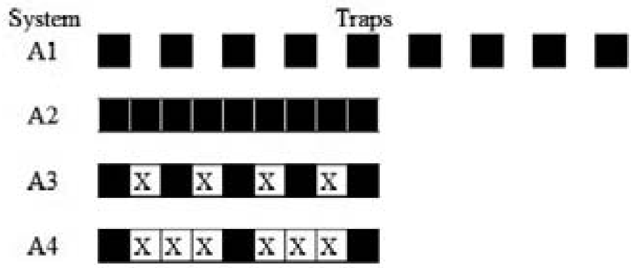

Figure 1 Trap set-up designs. Black squares represent traps baited with a pheromone dispenser; the X squares are empty traps. White gaps at A1 present 20 m distance.

Slika 1. Testirani rasporedi i montaža feromonskih klopki. Crni kvadrati predstavljaju klopke opremljene feromonom, kvadrati označeni slovom "X" predstavljaju klopke bez feromona, a bijeli međuprostori u varijanti "A1" predstavljaju razmake od 20m metara između pojedinih klopki.

The pheromone-baited traps were emptied weekly. Beetles were counted individually when fewer were captured and a graduated measuring-glass was used to calculate the number of higher quantities of beetles, with 1 ml considered to be 35 beetles (Zahradník 2006). Before measuring larger quantities of beetles, contaminations such as other beetle species and organic matter like needle debris were removed.

During all of the tests, insect invasion of forest edge was visually checked and no infestation was found.

Statistical analysis – *Statistička analiza*

ANOVA tests were conducted using QC.Expert statistical software with location as the first factor and the system of trap set-up as the second factor. A second ANOVA tested the statistical significance of pheromone baited and unbaited traps. All tests were carried out at a 95% confidence level.

The efficacy (%) of a particular trapping system was tested. The traditional system (A1) of trapping *I. typographus* was chosen as the standard (efficacy 100 %).

RESULTS
REZULTATI

The location factor was found to be statistically insignificant so the localities were considered to be identical in the following assessment. The significance of factor A (system of pheromone traps set-up) using an analysis of variance was examined fist. The count Fisher-Snedecor test criteria F_e = 30, 185 is higher than the critical value of fractile $F_{1-0,05}$(4–1, 18–4) = 2,74, confirming the alternative hypothesis on the significance of the set-up system effect. The system of set-up is statistically significant with a probability of 3,408E–021.

A more detailed focus is provided by the pair test which compares each system against another (Table 1). There was no statistical significance in the differences between the traditional system (A1) and system with every baited trap (A2) and also statistically insignificant is the difference between the system with every second trap baited (A3) and the middle and margin traps baited (A4). All of the other comparisons were statistically significant.

Table 1 Pair comparison – Scheffé's method
Tablica 1 Scheffe test parova

Compared pairs (**Parovi**)	Significance (**Signifikantnost**)	Probability (**Vjerojatnost**)
A1 – A2	insignificant (nije značajno)	0,1231976237
A1 – A3	significant (značajno)	0,0001045618833
A1 – A4	significant (značajno)	1,01668487E-005
A2 – A3	significant (značajno)	9,016489182E-009
A2 – A4	significant (značajno)	6,632173719E-010
A3 – A4	insignificant (nije značajno)	0,9365963554

The traditional A1 system was chosen as the standard for efficacy evaluations as percentages, i.e. 100 % (Figure 2, Table 2). In 2009 no other system showed greater efficacy (A2 91 %, A3 61 %, A4 51 %,). Although A2 showed an efficacy of 140 % in 2010, it was only 79 % for A3 and 64 % for A4.

Table 2 Total trappings in 2009 and 2010 (number of beetles)
Tablica 2 Ukupni ulovi u 2009. i 2010. (broj ulovljenih potkornjaka)

	A1	A2	A3	A4
2009	384317	350898	233274	194509
2010	247988	348020	196082	158082

DISCUSSION
RASPRAVA

As early as the first use of pheromone traps in Norway and Sweden at the end of the 1970s, traps have been placed along a stand wall after storms and subsequent bark beetle outbreaks. In Norwayinstalled drainpipe traps – types Borregaard 1979 and Borregaard 1980 (with funnels connected to collecting containers on the bottom part of the trap) in groups of 3–8 traps spaced 5 metres apart at a distance of 30 metres from the stand wall (Bakke and Strand 1981). In Sweden, drainpipe traps were placed in groups of 12–15 spaced 2–10 metres apart (Regnander and Solbreck 1981). In Sweden initially, single traps were generally used but the placement of traps in groups proved more effective (Eidmann 1983). Pheromone traps were used in an extensive gradation; average catches in pheromone traps during the flight activity each season ranged from 7 to 20 thousand and even more in some areas. There were already attempts at that time to determine the optimum placement of pheromone traps. Bakke at al. (1983) tested the efficacy of six hexagonally arranged drainpipe traps with spaces of 0,5 m, 1,5 m, 3 m, 6 m and 12 m between the traps in each group. No significant differences between catches were found. They also tested the placement of 91 pheromone traps arranged hexagonally and spaced 20 m apart in a large, clear-cut area. Catches in individual traps rarely exceeded 1000 beetles and were less than 500 beetles per season in approximately half of the traps. Later, Bakke (1985) also tested groups of 3 drainpipe traps arranged in a triangle and spaced 5 m apart. Similarly, Niemeyer and Watzek (1982) used groups of 3 pheromone traps (various types) spaced 5 m apart from each other and at a distance of 60 m between the groups of traps. The number of catches in the pheromone traps was not considered to be the key criteria, rather their evaluation was based on the comparison of the initial number of infested trees and the number of installed pheromone traps in the given area, and then the subsequent number of newly damaged trees in the following year.

These results are likely to have contributed to the more common use of varying spacing for the placement of pheromone traps along stand walls. The actual distance between traps depends on the population density of beetles: in la-

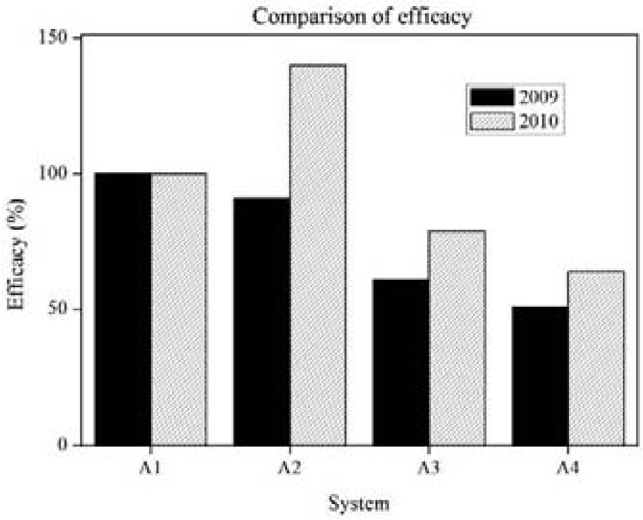

Figure 2 Comparison of total efficacy of each system in 2009 and 2010 based on A1 trap design scaled as 100%.
Slika 2. Usporedba ukupne učinkovitosti svakog od načina postavljanja feromonskih klopki u 2009. i 2010. godini s referentnom vrijednosti od 100% za uobičajeni način montaže A1

tency distances less than 200 m were not recommended, and in gradation they were generally arranged in groups spaced 50–100 m apart (up to 160 m apart in exceptional cases), but the spaces between pheromone traps within each group were not specified (Novák 1985). In Poland, the typical spacing between traps is approximately 15 m (Grodzki et al. 2008), while in Switzerland the recommended spacing between traps was 50 m (Maksymov and Kuhn 1984).

Other arrangements of traps have been tested but without ever being put into practice. For instance, Dubbel et al. (1985) spaced individual traps 2 m apart when evaluating the influence of trap colours. Weslien and Lindelöw (1989, 1990) used pipe traps in groups of 10–20 traps arranged in triangles with minimal spacing between them for the recapture of beetles. Vaupel and Dubbel (1985) used a single arrangement of 21 Theysohn slit traps placed closely together in a cross-like shape and with a single pheromone dispenser in the centre of the formation. The highest catch was registered in the centre, with a gradual decrease towards the outside of the formation. The central trap captured 15.1% of the beetles, those around the centre 8.43–14.39%, and those situated 3 m from the centre only captured 0.99–1.62%.

In all of these cases, the arrangements were made along the stand wall, either in groups or as individual pheromone traps. As stated previously, in most cases the results were not evaluated in relation to the types of trap arrangement.

Another type of arrangement is the setting of slit traps (Theysohn) in a star-like formation – three traps with one dispenser (Dimitri et al. 1986; Vaupel et al. 1986; Niemeyer 1987; Brutovský 1990; Zahradník 1997). All of these researchers saw increases in catches of 200% when compared to an individual Theysohn pheromone trap when using this arrangement with a single pheromone dispenser. Vaupel et al. (1986) also made an economic evaluation of this system, and the price ratio between the individual arrangement and the star-like arrangement of slit traps with one pheromone dispenser was 98:131.

At the turn of the millennium in areas with the gradation of *I. typographus*, testing began on the efficacy of pheromone traps installed in barriers along longer stand walls several hundred metres apart (Jakuš 1998; Jakuš and Šimko 2000; Jakuš and Blaženec 2003). The spacings between pheromone traps within the barriers were at a distance of 10–20 m (Jakuš 1998). Jakuš (2008) later installed triangular barriers (isosceles triangles with 12 m sides) of pheromone traps which made two lines of traps along each stand wall. Instead of comparing the efficacy of these arrangements against other types of set-up, these studies evaluated the resulting effect on the potential damage to other trees (number of infested trees). The safe distance from the stand wall was settled on as being at least 15 m (Dubbel et al. 1985; Novák 1984, 1985). Longer distances between the pheromone traps and the stand wall were rarely used, for example Jakuš (1998) placed traps 20–25 m from the stand wall.

The experimental approach in this research is based on the principles set out by the original Scandinavian researchers who placed the pheromone traps at the centre of a clear-cut area without making any comparison to the standard arrangement along the stand wall (references or parts of the above text). We did make this additional comparison and, at the same time, removed pheromone dispensers from some of the traps located in the centre of the clear-cut areas, similar to the way Vaupel et al. (1986) did in their star-like arrangement of Theysohn slit traps. However, unlike their study we did not evaluate the economic impact of such an arrangement.

This method may be particularly appropriate in locations after salvage felling or in clear-cut areas with a surface area of 1–2 ha or more (depending on the shape of the clear-cut area and likely to be more suitable for long rectangle-like or elongated clear cuts). Manipulation (setup) of pheromone traps in single locations, rather than long lines of traps as with the standard arrangement, can make the process quicker and therefore cheaper. The decreased number of dispensers can bring economic benefits, but is likely to result with decrease in the number of trapped beetles.

CONCLUSIONS
ZAKLJUČCI

The statistical significancy of pheromone trap setup design was confirmed and with 95% statistical confidence it can be concluded that the set-up of pheromone traps affects bark beetle trapping. This is shown in the results from a calculated Fisher-Snedecor‘s criterion Fe = 30.185 which becomes higher than the critical value of the quantile of F1-0, 05 (4–1, 18–4) = 2.74.

There is no difference in the efficacy of traps when pheromone dispensers are installed in every other trap or in the middle/margin traps. Traditional set-up is considered to be equally efficient to traps installed closely without spaces between them and with a pheromone dispenser at each trap. This is confirmed by Scheffe‘s multiple comparison method which shows that the pairs of values A1 – A2 and A3 – A4 can be considered to be identical.

The greatest efficacy was provided by traditional set-up (A1) along a stand edge and in the middle of a clear-cut area with all traps baited (A2). With regard to difficulty of setup and its trappings the A2 setup seems to be optimal.

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Sažetak

U radu se uspoređuje lovna učinkovitost različitog načina postavljanja feromonskih klopki u smislu opremanja feromonskim dispenzerima i prostornog rasporeda. Uobičajeni, tradicionalni način postavljanja označen kao „A1“, sastoji se od niza feromonskih klopki postavljenih uzduž šumskog ruba i međusobno udaljenih 20 metara. Testirani novi načini montaže (Slika 1) sastojali su se od niza klopki poredanih jedna uz drugu bez razmaka, gdje je svaka klopka bila opremljena feromonom („A2“), svaka druga opremljena feromonom („A3“) i gdje su samo dvije rubne i srednja klopka imala obješeni feromonski dispenzer („A4“).

Za uobičajeni način postavljanja klopki (“A1“) lovna učinkovitost definirana je kao referentna vrijednost od 100% (Slika 2). Prema rezultatima ulova u 2009. godini nije bilo statistički značajnih razlika u smislu boljih ulova bilo kojim od testiranih lovnih sustava (“A2” – 91 %, “A3” – 61 % i “A4” – 51 %). Iako je raspored “A2” u 2010. godini pokazao veću očinkovitost od 140%, preostala dva rasporeda imala su učinkovitost od 79 % (“A3”) i 64 % (“A4”). Ukupni ulovi tijekom 2009. godine iznosili su: “A1” – 384 317 potkornjaka, “A2” – 350 898 potkornjaka, “A3” – 233 274 potkornjaka i “A4” – 194 509. Ukupni ulovi tijekom 2010. godine iznosili su: “A1” – 247 988 potkornjaka, “A2” – 348 020 potkornjaka, “A3” – 196 082 potkornjaka i “A4” – 158 082.

Prema rezultatima provedenog istraživanja, najveća lovna učinkovitost sustava feromonskih klopki za lov smrekinog pisara potvrđena je uobičajenim postavljanjem feromonskih klopki s razmakom i uzduž šumskog ruba („A1“ sustav), dok je u središtu progala posječenih čistom sječom po učinkovitosti dominirao raspored bez razmaka („A2“ sustav). U kontekstu sanacije žarišta napada ovog potkornjaka, provedeno istraživanje ukazalo je na mogućnost optimizacije postavljanja feromonskih klopki na način da se umjesto uobičajeno razmaknutih klopki one mogu postavljati neposredno jedna uz drugu, čime se olakšava i pojednostavljuje montaža klopki. Time je osigurana i bolja učinkovitost u susatvu aktivne kontrole i ograničavanje gradacija smrekinih potkornjaka.

KLJUČNE RIJEČI: smrekini potkornjaci, feromonske klopke, prostorni raspored klopki, suzbijanje potkornjaka