Cent. Eur. For. J. 70 (2024) 275-285 sciendo DOI: 10.2478/forj-2024-0018 CENTRAL EUROPEAN Forestry Journal

ORIGINAL PAPER

Does bark beetle *Ips typographus* (L.) die after flying away from the poisoned trap tree?

Emanuel Kula[1], Petr Hrdlička[2]*, Karel Zvoníček[1]

[1]*Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Forest Protection and Game Management, Zemědělská 810/3, CZ-613 00 Brno, Czech Republic*

[2]*Mendel University in Brno, Faculty of Agri Sciences, Department of Chemistry and Biochemistry, Zemědělská 1665/1, CZ-613 00 Brno, Czech Republic*

Abstract

Ips typographus (L.) is the most significant insect pest in the European spruce forests. Methods of control and monitoring are in the period of *Ips typographus* (L.) outbreaks supplemented with suppressive procedures applying insecticides. The aim of our study was to determine the necessary length of *Ips typographus* (L.) imagoes movement across the treated surface, resulting in their death also in the case of their flying away from the trap tree. Insecticides Forester (active substance cypermethrin) and Dinastia (active substance deltamethrin) were tested in laboratory conditions. Exposure times the beetles moved on the intoxicated bark were 30–300 s. Then the beetles were placed in Petri dishes and their survival rate up to twenty-four hours was established. Experiment duration was 8 weeks from spraying with repeated week control tests. High efficiency of tested pyrethroids ensuring the death of also flying away imagoes within six hours after contamination was established at three weeks. The rate of their survival was increasing from Week 4 independently on the exposure times (deltamethrin). In cypermethrin, the survival rate of imagoes was high and dependent on the exposure times. The efficiency of deltamethrin was higher than that of cypermethrin. During the outbreaks, the pheromone-baited poisoned trap trees causing the death also to flying away imagoes of *Ips typographus* (L.) have to be sprayed with the above-mentioned pyrethroids in a monthly interval at the time of swarming culmination. The efficiency of both insecticides decreased more rapidly on the upper unprotected side of the trap tree.

Key words: eight-toothed spruce bark beetle; *Picea abies* [L.] Karst.; pyrethroids; cypermethrin; deltamethrin; laboratory test

Editor: Bohdan Konôpka

1. Introduction

Bark beetles living on conifers (Coleoptera, Curculionidae, Scolytinae) represent a serious economic threat for forest production. Outbreaks of *Dendroctonus* species are responsible for the whole-area decline of pine (*Pinus* sp.) stands in North America (Víctor & Zúñiga 2016; Hansen et al. 2019). During 2000–2020, *Dendroctonus ponderosae* Hopkins has killed billions of trees across tens of millions of hectares in western North America, when outbreak culminated, 3.5 million ha stands were destroyed in 2009 (Fettig et al. 2022).

In Europe, there are about 8 million ha of Norway spruce stands (*Picea abies* [L.] Karst.) endangered by outbreaks of spruce bark beetle – *Ips typographus* (L.) (Grégoire & Evans 2004; Stadelmann et al. 2013; Seidl et al. 2014; Jeger et al. 2017; Senf et al. 2018). In the Czech Republic, 61 million m^3 of standing and lying wood infested during *I. typographus* (L.) outbreak was logged in 2015–2022 (Knížek et al. 2023).

In addition to primary attractants, *I. typographus* (L.) uses aggregation pheromones during the attack, thus coordinating the success in infesting the spruce stands (Wood 1982; Bakke 1989; Schiebe et al. 2011).

Methods of controlling and eliminating the harmfulness of *I. typographus* (L.) consist in compliance with forest hygiene (timely removal of disposable timber – windthrows, breakages, logging residues) in active search of trees infested by spruce bark beetle and their timely removal from the stand (Stadelmann et al. 2013; Økland et al. 2016). The monitoring of the occurrence of imagoes is allowed by lying trap trees (Skuhravý 2002;

*Corresponding author. Petr Hrdlička, e-mail: hrdlicka@mendelu.cz

Holuša et al. 2021) or by pheromone traps (Raty et al. 1995; Wichmann & Ravn 2001; Jakuš & Blaženec 2002; Blaženec et al. 2021). Although the pheromone slots traps were applied in Europe at mass trapping (Hübertz et al. 1991; Weslien 1992; Jakuš 1998; Schlyter et al. 2001; Fettig & Hilszczański 2015), their effectiveness does not have to be always high (Weslien 1992; Zahradník et al. 1993). Mechanized debarking can be used during the whole development of *I. typographus* (L.) (Hnatek et al. 2021). The use of anti-attractants against *I. typographus* (L.) in forest protection is mentioned by Jakuš et al. (2003), and Jirošová et al. (2022).

At the same time, there are suppressive procedures applying insecticides to reduce the occurrence of *I. typographus* (L.) which include poisoned trap trees of various lengths (Adlung et al. 1986a, 1986b; Drumont et al. 1992; Lubojacký & Holuša 2011; Kula et al. 2022) whose efficiency is higher than that of pheromone slots traps and lying trap trees. The advantage of poisoned trap trees is their unlimited capacity; they do not require regular control, need not be replaced during the growing season or cleaned up by debarking (Kula et al. 2022). The trap trees have to be baited with pheromone lure (attracting bark beetles to come) and then treated with insecticide in the defined interval. The negative is the threat to non-target invertebrates after a contact with the toxic surface of the trap tree (Zahradník & Kapitola 1993; Lubojacký & Holuša 2013; Lubojacký & Holuša 2014; Skrzecz et al. 2015; Zhu et al. 2020).

Poisoned trap trees in the form of tripods assembled usually from three to six logs of 1.5–2 m in length were tested in the control of *I. typographus* (L.), *Ips duplicatus* (Sahlberg), *Ips cembrae* (Heer) (Hurling & Stetter 2012; Lubojacký & Holuša 2013; Špoula & Kula 2023). The prohibition of alfacypermethrin as active substance throughout the European Union ended the possible application of commonly used insecticide Vaztak® Active, (BASF Ltd.) as well as of the insecticidal net Storanet® (BASF Ltd.). The net was used to clean up infested wood. In the Trinet® P system (BASF Ltd.), it was an alternative to the poisoned trap trees in the form of tripods (Skrzecz et al. 2015; Zahradníková & Zahradník 2015; Kula et al. 2022). Experimentally tested were also standing poisoned trap trees (Raty et al. 1995; Juha & Turčány 2008) which did not find application in practice. In North America *Ponderosa* stems infested by *Dendroctonus* were sprayed up to a height of 10–15 m (Hall et al. 1982; Hastings et al. 2001; Fettig et al. 2018).

Killing the bark beetles with insecticides remains one of the most efficient methods to stop their spreading in the forest and halt forest decline. Pyrethroids represent a group of synthetic biodegradable insecticides with a range of applications against many insect pests (Ray & Burr 2014; Rivera-Dávila et al. 2022). They are considerably toxic to insects, aquatic animals while being little toxic to mammals (Zhu et al. 2020). It is exactly their toxicity to insects that predetermines them as suitable insecticides. They are not persistent and in general easily metabolizable (Aznar-Alemany & Eljarrat 2020). The toxicity of pyrethroids is low (Ray & Burr 2014) with the degradation time (DT50) up to 60 days (Aznar-Alemany & Eljarrat 2020; Rivera-Dávila et al. 2022). Due to their very low water solubility and considerable hydrophobicity, they are readily adsorbed in soils and sediments (Laskowski 2002). Even so, their application is limited in protected areas and near water sources and watercourses.

However, as their application in the natural environment is generally risky, their application is a subject to strict EU regulations (European European Comission 2023).

The aim of this paper is to determine in laboratory conditions the effect of insecticide with active substance cypermethrin or deltamethrin on the mortality of *I. typographus* (L.) imagoes in dependence:

(i) on the necessary length of the movement of imagoes across the treated surface,

(ii) on time gap from the treatment with insecticide.

At the same time, we would like to assess the validity of two hypotheses:

(i) is the mortality of imagoes decreasing in dependence on time elapsed since the insecticide application?

(ii) will perish the imagoes flying away from the poisoned surface of trap tree due to contamination?

2. Materials and methods

2.1. Site and conditions

Spruce logs 1.5–2 m long with fine bark cut from freshly felled trees were placed on an open sunlit area on the premises of Mendel University in Brno, Czech Republic. After the spraying, the position of logs was fixed in order to differentiate upper and lower side throughout the experiment and to prevent their movement.

Climatic conditions for treated wood in open area during the experimental period (18 July–11 September 2023) are characterized by data from the climatic station situated in the Botanical Garden and Arboretum of Mendel University in Brno, at a distance of ca. 500 m from the treated logs: mean air temperature 20.8 °C, total precipitation amount 152 mm, mean global radiation 16.5 $MJ \cdot m^{-2}$.

The experiment was carried out in the laboratory with controlled air temperature ranging between 23.2–26.3 °C (Data Logger HOBO MX 1101 Temp), which supported the movement activity of imagoes situated onto a treated bark inserted in the plastic box.

2.2. Establishment of the laboratory experiment

Peeling off bark with phloem
Samples of bark with phloem (ca. 1.5 dm2) were peeled from the upper side of both control and treated logs. The first sampling was made two hours after the applied insecticide dried up, and the other sampling procedures followed in regular weekly intervals in the period from 18 July to 11 September 2023 (altogether 9 controls). After four and eight weeks since the spraying, bark samples with phloem were collected also from the lower "shaded" parts of the logs.

Each sample of bark with phloem collected from the treated logs and from the control log was trimmed and inserted tightly onto the bottom of plastic box (13 × 5.5 × 5 cm).

Bark beetles (*Ips typographus* (L.))
Imagoes of *I. typographus* (L.) used in the experiment were collected from the pheromone slot traps (Theysohn) 6–24 hours before being introduced into the experiment. Selected slot traps were cleaned 1–2 days before the collection. The imagoes were transported from the field in a plastic container (volume of 10 litres) with non-contaminated spruce bark as a potential food offer, which was covered with airy fabric.

2.3. Laboratory work procedure

Imagoes of *I. typographus* (L.) with high movement activity (always 30 pcs) were in contact for five exposure times (ET) 30, 60, 90, 180, 300 s with the surface of bark treated with the tested insecticide or of untreated control. These "contaminated" individuals were placed in ten pieces (3 repetitions) in Petri dishes with the filter paper on the bottom and with the description of samples (insecticide and ET, e.g., Dinastia D1–3, ET 30–300 s) (Fig. 1B).

In each term of the experiment, the basic number of active *I. typographus* (L.) imagoes was used 450 pcs and +300 pcs more, if the lower sides of the logs were tested.

The following reaction of imagoes was evaluated in the interval of 0.5, 1, 2, 3, 4, 5, 6, 12 and 24 hours. In the mentioned time sequences, the condition of imagoes was classified in three categories:

- imagoes alive, active, capable of movement,
- imagoes dying, showing the movement of extremities and antennae but incapable of movement,
- imagoes dead.

The recorded number of live imagoes in the controlled times was an input for classifying the efficiency of the both insecticides and duration of the necessary contact with the treated bark surface. Similarly, as in toxicology, a key rate is considered to be more than 50% of dead individuals within 24 hours.

Fig. 1. Placement of logs treated with insecticides and control logs to collect bark samples with phloem for the laboratory assessment of impact on *Ips typographus* (L.) (Brno, 2023) (A); partial preview of the arrangement of laboratory experiment with contaminated imagoes in Petri dishes (B).

2.4. Insecticides applied

Permitted insecticides used in the experiment were commercial product Dinastia and Forester.

Dinastia (eAGRI 2023) contains deltamethrin (Burr 2014b). It is available over the counter with no restrictions concerning competence of users. It is delivered as emulsion (oil in water) with the deltamethrin content of 50 g l^{-1}. After dilution with water to 0.25% of active substance, it is applied as spray. Manufacturer does not recommend application at temperatures over 24 °C (Zahradník et al. 2023).

Forester (Agriphar 2009; eAGRI 2022) contains cypermethrin (Burr 2014a). It is available over the counter with no restrictions concerning competence of users. It is delivered as emulsion (oil in water) with the cypermethrin content of 100 g l^{-1}. After dilution with water (10 ml l^{-1}) it is applied as spray (Zahradník et al. 2023).

On 17 July, the logs were treated with the 0.5% solution of Dinastia insecticide (2 pcs) in the recommended dose of 5–8 l m^{-3}, 1% solution of Forester insecticide (2 pcs) in the recommended dose of 5 l m^{-3} with the other logs remaining as controls (Fig. 1a). The insecticides were applied using the industrial sprayer Marolex Industry Acid Line with the composite rod, nozzle Malorex MR 1.5 mm (volume 7 litres).

2.5. Statistical evaluation

The efficiency of tested insecticides was determined from the number of live imagoes recorded in the respective exposure times and in the sequence of experiments from Week 0 to Week 8 since the treatment.

Statistical data were processed in the programme STATISTICA (TIBCO Software Inc. 2018) using the modules of Basic Statistic/Descriptive statistics and Nonparametrics/Kruskal-Wallis ANOVA & Median test (K-W test). The data were subjected to the control of normality and it turned out that the conditions of normality are not fulfilled. This is why the data processing with non-parametric methods was selected.

3. Results

Two insecticides: Forester (active substance cypermethrin) and Dinastia (active substance deltamethrin) were evaluated for their efficiency limiting the survival of *I. typographus* (L.) imagoes at the differentiated duration of their movement across the contaminated surface. Bark from the control untreated section was used in order to determination of the influence natural mortality.

3.1. Effect of the length of contact with the treated surface on the survival of *Ips typographus* (L.) imagoes

Control

The high activity and the rate of live *I. typographus* (L.) imagoes in the control remained on the initial level throughout the experiment (9 controls), which confirmed the quality selection of individuals as well as the suitability of the laboratory environment (N = 150, mean ±SD, after 6 h/98.9 ±0.9%, 12 h/96.4 ±2.1%, 24 h/94.2 ±2.1%).

Insecticides

Dinastia

The movement (30–120 s) across the freshly treated bark was survived by 12% of *I. typographus* (L.) imagoes (0.5 h). One week from the spraying, less than 50% of live imagoes were recorded two hours since their contact with the treated bark surface. After five hours, the presence of live individuals was sporadic (1%) (Fig. 2).

Two weeks after the spraying, the amount of live individuals was differentiated below 50% between ET 90, 180, 300 s and ET 30 and 60 s. After six hours, only 11% of individuals survived the contact with the treated surface, and after twelve hours no occurrence of live imagoes was recorded (Fig. 2).

In Week 3, the representation of live imagoes after 5–6 hours fell below 50% except for ET 30 s (67% of live individuals), with only 2% of live individuals remaining after 12 hours.

After one month after the treatment, the share of live imagoes decreased below 50% in all ET variants up to 12 hours (to 15%) and to 3% after 24 hours (Fig. 2).

In Week 5, the number of live individuals was gradually decreasing during six hours since intoxication (70–93%) and 13/6% of live imagoes were recorded after 12/24 hours.

Six weeks from the insecticide application, the reaction of imagoes during six hours differed between ET 30 and 60 s, and ET 90, 180 and 300 s. After 12/24 hours, the situation in ET unifies and the share of live individuals falls below 50% to 43% and 12% (Fig. 2).

Week 7 is characterized by the high share of live individuals (92%) still within a gap of six hours from the contact with the treated surface (ET 30. 60 and 90 s). After 12/24 h, the presence of live imagoes decreased to 37/12% (Fig. 2).

Final investigation (Week 8) confirmed the diversion in the representation of live imagoes after six hours, when the log surface was intoxicated (60–93%), after twelve hours, the difference in the surviving individuals between ET 30 and 60 s was 53%, and at higher ET 120–300 s, it was 19%. The difference (23/3%) remained after 24 hours (Fig. 2).

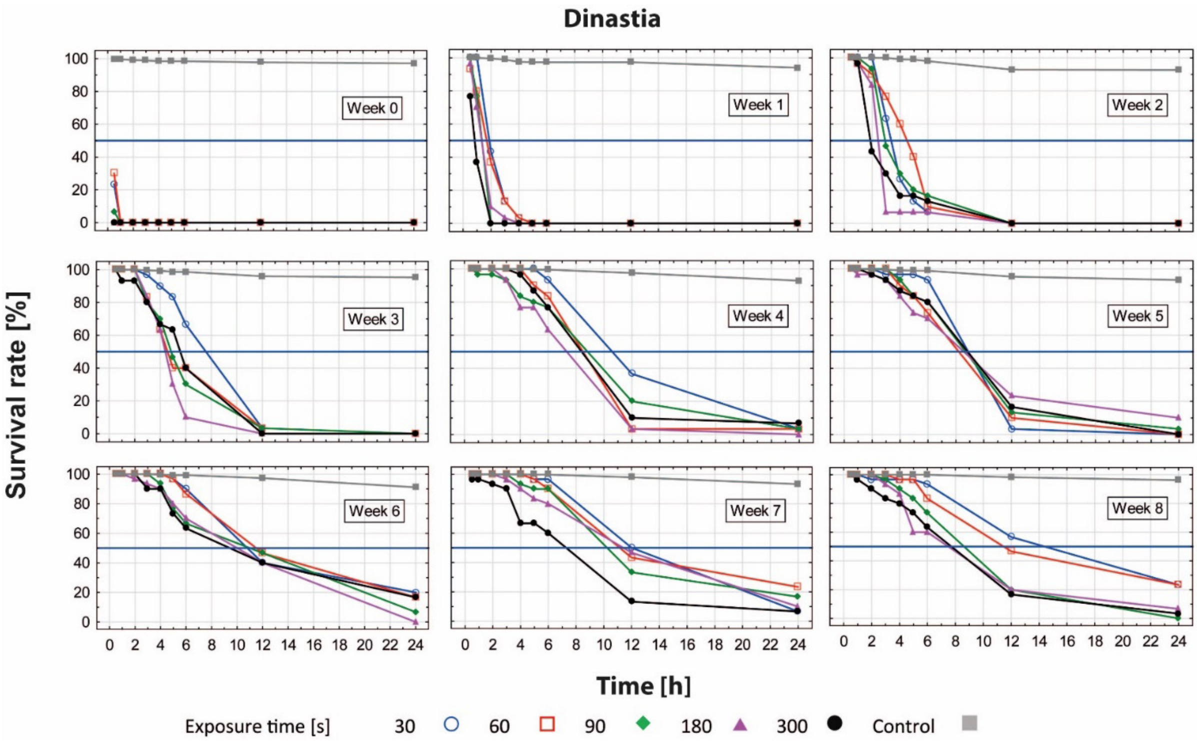

Fig. 2. Shares of live Ips typographus imagoes after contamination on bark treated with the Dinastia insecticide at differentiated exposure times during 8 weeks (18 July–11 September 2023) (laboratory conditions, horizontal solid blue line corresponds to 50% survival rate).

Forester

The movement of imagoes across the bark with the dried up fresh spray resulted in the reduced occurrence of live *I. typographus* (L.) imagoes to 88% within 0.5 h (ET 30 s) up to 40% (ET 300 s) and only 12% of individuals then survived within one hour.

In Week 1 after spraying, active imagoes were recorded in all ETs below 50% two hours from contact with the treated bark surface (Fig. 3).

The reduced number of live individuals in all ETs after 4–6 hours below the level of 50% (in total 28%) was caused by the bark surface treated two weeks ago.

Three weeks apart from the spraying, the share of live imagoes dropped below 50% only 6–12 h after intoxication (10%) (Fig. 3).

One month from the spraying, the representation of live imagoes reached more than 80% six hours after contamination (ET 30, 60, 90 s) and a decline below the level of 50% of live imagoes was established as well as after twelve hours (22%) and twenty-four hours (8%) from contamination (Fig. 3).

The reaction of imagoes to the treatment within a gap of five weeks (Week 5) was close to that of controls for 6 hours from their exposure to the treated surface (93%) except for ET 300 s (70%). Shorter ETs did not endanger the imagoes to such an extent that their share would decrease below 50% after 24 hours, except for ET 300 s (10%) (Fig. 3).

In Week 6 from the spraying, the share of live imagoes after six hours differentiates between ET 180 and 300 s (64%), and ET 30, 60 and 90 s (89%). The occurrence of live individuals below the level of 50% was recorded only after twenty-four hours (in total 34%) except for ET 30 s (Fig. 3).

In Week 7, the reaction of imagoes on the exposure to the poisoned surface was generally mild for six hours (90–97% of live imagoes). After twelve hours, differences in the representation of live individuals increase due to the action of insecticide in dependence on the increasing ET 30, 60/90, 180/300 s (83/50/13%) (Fig. 3).

After two months, a high occurrence of live individuals was recorded throughout the monitoring time in ET 30 s (after twenty-four hours 70%). In the other ET, the share of live individuals was differentiated and decreased below 50% after twelve hours from intoxication (Fig. 3).

3.2. Effect of insecticide stability after application

Efficiency of insecticides in the two-month monitoring was evaluated by the non-parametric test (K-W test: $H(2, N = 3645) = 781.53$ $p = 0.000$). The control untreated section clearly differentiated from the two sections treated with the insecticide. The Dinastia insecticide appears to be slightly more efficient that the Forester insecticide (Fig. 4).

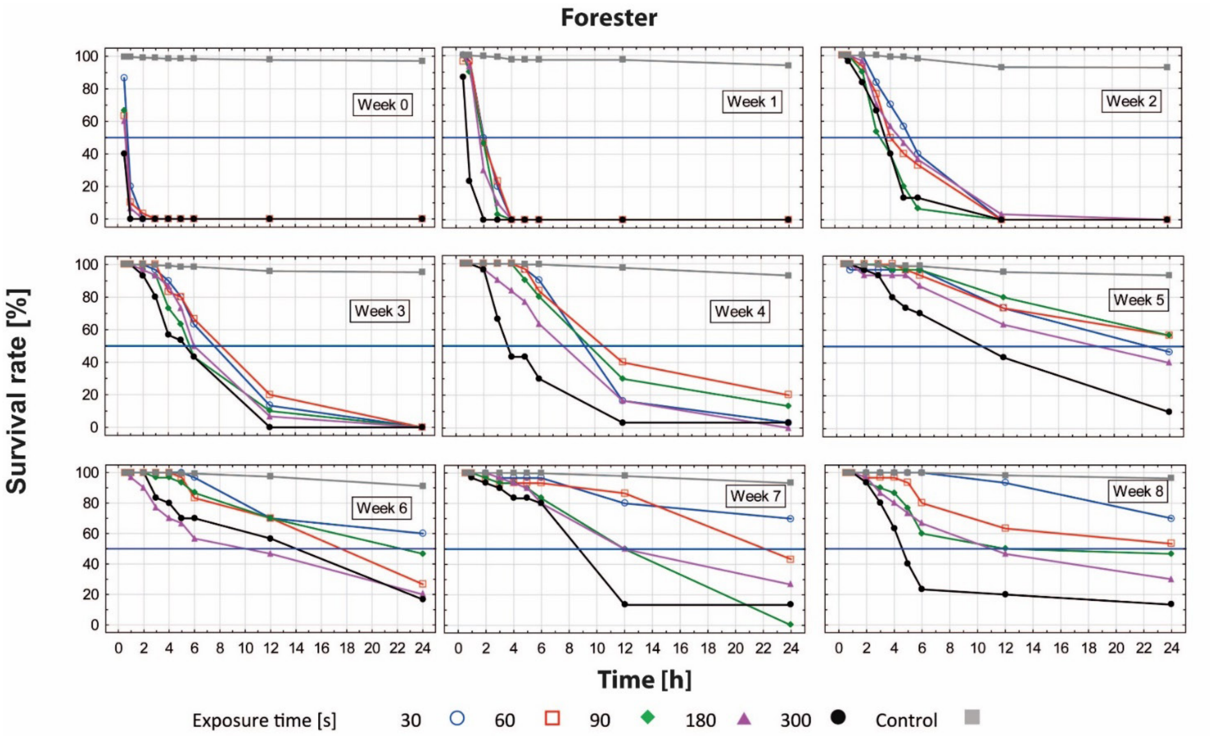

Fig. 3. Shares of live *Ips typographus* (L.) imagoes after contamination on bark treated with the Forester insecticide at differentiated exposure times during 8 weeks (18 July–11 September 2023) (laboratory conditions, horizontal solid blue line corresponds to 50% survival rate).

The non-parametric test (K-W test: H(17, N = 2430) = 888.08, p = 0.000) evaluating the efficiency of insecticides with a week interval confirmed its decrease in time from the application. In the Dinastia insecticide, the efficiency was declining continually up to Week 4 (Dinastia 0 to 4) while it did not change in the following four weeks (Dinastia 5 to 8). In the Forester insecticide, the efficiency was declining up to Week 3 (Forester 0 to 3) and after a significant decrease recorded between Week 4 and Week 5 was not changing (Forester 5 to 8). With an average number of surviving imagoes > 6 (i.e. > 50%), the efficiency is already classified as low (Fig. 5). This detailed record in the changing efficiency of both insecticides in the course of 8 weeks from application explains the partial difference in the summary assessment (Fig. 4). Both previews are consistent.

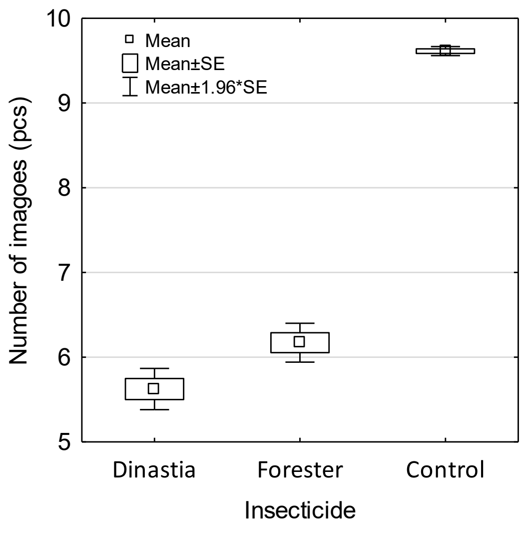

Fig. 4. Mean number of live *Ips typographus* (L.) imagoes after the application of Dinastia and Forester insecticides and control (laboratory conditions; pooled for all weeks; 18 July–11 September, 2023).

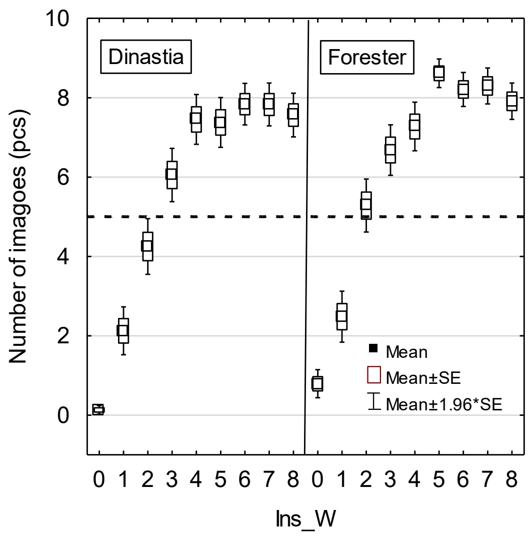

Fig. 5. Mean number of live *Ips typographus* (L.) imagoes after the application of Dinastia and Forester insecticides in the respective weeks after application (Ins_W) (laboratory conditions).

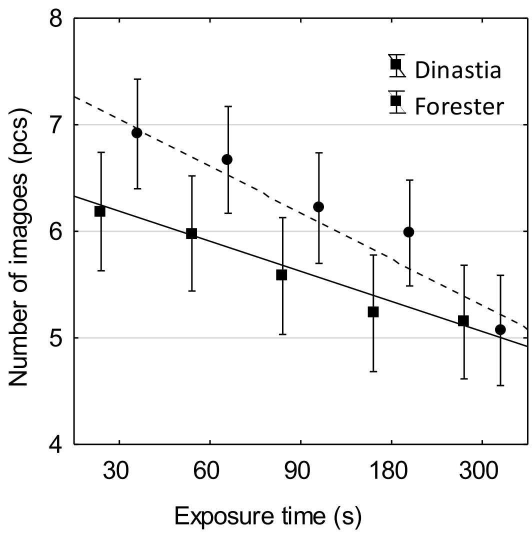

Fig. 6. Mean number of live *Ips typographus* (L.) imagoes after the application of Dinastia and Forester insecticides for individual exposure times (laboratory conditions; pooled for all weeks).

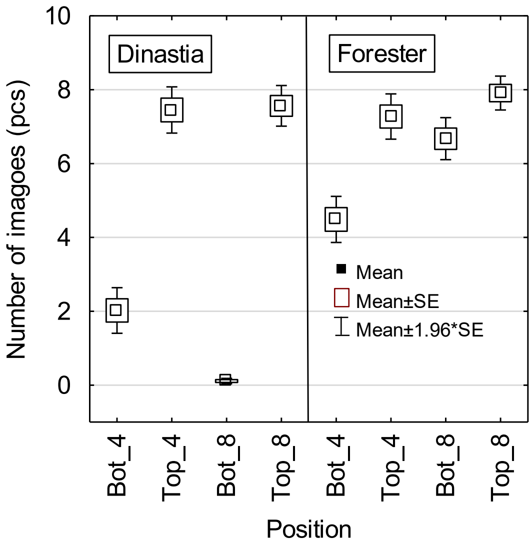

Fig. 7. Mean number of live *Ips typographus* (L.) imagoes on the upper and lower side of the treated section, Week 4 and Week 8 after insecticide application (Top – Top side, Bot – Bottom side).

An important factor affecting the efficiency of insecticide and survival of imagoes is exposure time (ET) on the treated surface. With the increasing ET, the mortality of imagoes was gradually increasing (K-W test: Dinastia H(4 N = 1215) = 18.20; p = 0.001; Forester H(4 N = 1215) = 38.40; p = 0.000). The trend of the dependence of the mean number of surviving imagoes on ET (pooled for all weeks) is shown in Fig. 6. The efficiency of the Forester insecticide is mildly lower. The values are cumulative and corresponding to the given ET for all monitored weeks.

The analysis of insecticide efficiency on the upper (Top) and lower (Bottom) side of treated logs (Fig. 1A) was used to monitor the influence of direct weather (climatic) conditions. The non–parametric test (K-W test: H(7, N = 1080) = 441.98; p = 0.000) demonstrated that such an influence exists. In the Dinastia insecticide, the mortality of imagoes after the contact the protected bottom of the log was high in both weeks of monitoring (presumably for the whole time), in contrast to the unprotected part where it was low. In the Forester insecticide, the efficiency between the positions was different; however, in the protected part of the log it was medium in Week 4, otherwise it was low with no regard of the position (Fig. 7).

The current costs of preparing a solution for the treatment of 1 m^3 of poisoned traps are almost the same for the recommended insecticides Forester (price 1,327 CZK per litre, 1% concentration, consumption 5 l m^{-3}) and Dinastia (price 2,000 CZK per litre, concentration 0.5%, consumption 5–8 l m^{-3}). Due to the proven longer effectiveness of the 0.5% Dinastia insecticide by 2–3 weeks compared to the 1% Forester insecticide, the economic efficiency lies in the interval of recommended repeat spraying (Forester every four weeks, Dinastia every six weeks). When applying 0.75% Dinastia insecticide, costs increase.

4. Discussion

Insecticides against bark beetles with alpha–cypermethrin that were used in forestry under various commercial names for about half a century (Vaztac, Fastac 100 EC) (Švestka et al. 1996; Novotný & Zúbrik 2000; Skrzecz et al. 2015) were replaced by insecticides – Dinastia and Forester containing different active substances (deltamethrin, cypermethrin). Therefore, both the survival rate of *I. typographus* (L.) imagoes was evaluated since the application, and also the significance of exposure time/contact with the treated trap tree surface.

In the Dinastia insecticide, the share of live imagoes was increasing from Week 3 to Week 8 from the application in the exposure times 12/24 h more gradually: 2/0% (Week 3), 15/3% (4), 13/6% (5), 43/12% (6), 37/12% (7), 32/11% (Week 8) than in the Forester insecticide 10/0% (Week 3), 21/8% (4), 67/42% (5), 62/34% (6), 56/31% (7), 55/43% (Week 8). The efficiency of Forester was decreasing with the increasing time from the application, and after 24 hours, the share of live imagoes was 3–4 times higher than in Dinastia. The higher efficiency of Dinastia insecticide corresponds with the greater toxicity of deltamethrin (Zheng et al. 2011; Zhu et al. 2020).

Rain precipitations (154 mm) might have contributed to the statistically significant difference in the efficiency of the insecticides, namely of the Forester insecticide as increased humidity reduces the time of cypermethrin efficiency (Class 1992). At the same time, the statistically significant difference in the efficiency between the upper (Top) unprotected side and the lower (Bottom) side of treated logs was confirmed in both insecticides.

The hypothesis about mortality of *I. typographus* (L.) imagoes decreasing in dependence on time elapsed from the insecticide application was confirmed but also a partial difference between the tested insecticides. The Forester insecticide exhibited more rapidly decreasing efficiency in spite of the fact that Class (1992) detected cypermethrin in the spruce bark several months since the application.

The length of the contact of imagoes with the treated surface was established within a range from tens of seconds to several minutes. This is why the laboratory analyses to determine probability of the death of contaminated individuals were based on five different exposure times (30–300 s).

In the Forester insecticide, the efficiency decline differentiated from Week 4 in dependence on the exposure time while no essential differences were recorded in the Dinastia insecticide.

Although some repellent effect of pyrethroids are stated (Kohnle et al. 1992; Peña et al. 1998), no attempt to fly away was recorded in the laboratory during the contact of imagoes with the treated surface. The repellent effect is mentioned in deltamethrin (Rodríguez et al. 2003; Ruano et al. 2009), while it is not mentioned in cypermethrin (Hansen et al. 2019).

The behaviour of imagoes, the length of their stay, repeated arrival and departure from the surface of the poisoned trap tree can be influenced by increased pheromone concentration, which may even eliminate the repellent effect of pyrethroid. Our observations indicate that it can disrupt stimulus for the creation of entrance hole as well as the search for individuals of the opposite sex.

The effect of the length of movement of imagoes on the surface of poisoned trap tree was significant only with the decreasing efficiency (Forester).

If Raty et al. (1995) assumed that contaminated beetles can die outside the poisoned trap tree surface, then efficiency is affected by the length of time for which the imagoes move on the contaminated surface and which may not be sufficient. Dead individuals caught on frass sheets represent only a part of imagoes observed on the trap tree surface because some *I. typographus* (L.) imagoes fly away from the poisoned trap tree (Ruano et al. 2009; Zhu et al. 2020; Kula et al. 2023). Skrzecz et al. (2015) admit that the mortality of imagoes determined on Storanet nets is underestimated as some imagoes died after flying away from the insecticidal net. Similarly, Ruano et al. (2009) maintain that a cause to the reduced occurrence of dead bark beetle imagoes on the control frass sheets is their flying away from the logs treated with deltamethrin. Conditions under which the imagoes fly away or what is the share of individuals that die after flying away are not mentioned.

Therefore, if we want to reach death of imagoes flying away from the poisoned trap tree, namely at the time of swarming culmination, it is necessary to spray with the Forester in an interval not longer than one month and Dinastia insecticides every six weeks.

Based on our research results, both insecticides can be recommended for the treatment of poisoned trap trees in the outbreaks of bark beetles and whole–area danger to forest stands when protection is focused on the elimination of *I. typographus* (L.) imagoes lured by pheromones to lying poisoned trap trees (Drumont et al. 1992; Grodzki & Skrzecz 2017; Kula et al. 2022). When the imagoes move on the surface contaminated with insecticide, their nervous system is disturbed and they die (Garbaliński 1995). The rate of their death depends on the type of insecticide, its concentration and dose, time and quality of application, climatic conditions after application (rain, sunshine, temperature) as well as on the weight of insects.

Due to the negative influence on natural enemies, the treatment should be carried out only when the economic threshold of harmfulness is exceeded and the forest stability is put into threat (Skrzecz et al. 2015).

5. Conclusions

Efficiency of insecticides Forester (active substance cypermethrin) and Dinastia (active substance deltamethrin) was assessed that were used to prepare baited poisoned trap trees intended for the elimination of *Ips typographus* (L.).

For three weeks from the application of insecticides Forester and Dinastia, the time of imagoes staying (Exposure time 30–300 s) on the treated surface of trap trees did not essentially affect the difference in their mortality. From Week 4 from the treatment, the efficiency of the Forester insecticide was influenced by the exposure time (ET).

Three weeks from the treatment, a decreased effect of both insecticides was demonstrated on the decline of individuals in ET collected from the contaminated tree trap surface (simulated disruption of contact by their departure). In the Forester insecticide, the efficiency was decreasing more rapidly than in the Dinastia insecticide.

The assumption that flying individuals die after contact with the treated surface of the trap was confirmed. It was demonstrated that the spraying with both insecticides used to defend forest stands against the infestation by *Ips typographus* (L.) during its gradation has to be repeated in an interval not longer than one month (Forester) and every six weeks (Dinastia).

Although the efficiency tests were carried out in laboratory conditions, the full effectiveness of the poisoned traps can be expected, since the surface of the treated sections was exposed to normal climatic conditions throughout the experiment.

Acknowledgements

The authors would like to thank the Forests of the Czech Republic, state enterprise, for their cooperation during the fieldwork. The publication is based on the results of the project "Optimization of the poisoned trap for maximum capture of the spruce bark beetle (Ips typographus (L.))" financed by the Grant Agency of the Forests of the Czech Republic. Forests of the Czech Republic are the largest owner of the forest and, through their own Grant Agency, announce important topics applicable in forestry practice.

References

Adlung, K. G., Schicke, P., O'Sváth, J., 1986b: Analysis of an investigation to control the spruce bark beetle (*lps typographus* L.) by means of pheromones. I. Planning and evaluation of the individual trial. Journal of Plant Diseases and Protection, 93:462–478.

Adlung, K. G., Schicke, P., O'Sváth, J., 1986a: Analysis of an investigation to control the spruce bark beetle (*Ips typographus* L.) by means of pheromones II. Summary and comparison of two locations. Journal of Plant Diseases and Protection, 96:574–584.

Aznar-Alemany, Ò., Eljarrat, E., 2020: Introduction to Pyrethroid Insecticides: Chemical Structures, Properties, Mode of Action and Use. In: Eljarrat Ethel (ed.): Pyrethroid Insecticides. The Handbook of Environmental Chemistry, vol 92. Cham, Springer, pp. 1–16.

Bakke, A., 1989: The recent *Ips typographus* outhreak in Norway – experiences from a control program. Holartic Ecology/Ecography, 12:515–519.

Blaženec, M., Majdák, A., Jakuš, R., 2021: Improvement of *Ips typographus* catches in pheromone trap barriers by altering of sex assigned pheromone blends. Folia Oecologica, 48:25–34.

Burr, S. A., 2014a: Cypermethrin. In: Richardson, R. J. (ed.): Encyclopedia of toxicology (3rd ed.) Amsterdam, The Netherlands, Elsevier, pp. 1120–1121.

Burr, S. A., 2014b: Deltamethrin. In: Richardson, R. J. (ed.): Encyclopedia of toxicology (3rd ed.) Amsterdam, The Netherlands, Elsevier, pp. 1158–1159.

Class, T. J., 1992: Environmental Analysis of Cypermethrin and its Degradation Products After Forestry Applications. International Journal of Environmental Analytical Chemistry, 49:189–205.

Drumont, A., Gonzales, R., Windt, N., Grégoire, J.–C., Proft, M. D., Seutin, E., 1992: Semiochemicals and the integrated management of *Ips typographus* (L.) (Col., Scolytidae) in Belgium. Journal of Applied Entomology, 114:333–337.

Fettig, C. J., Hilszczański, J., 2015: Chapter 14 – Management Strategies for Bark Beetles in Conifer Forests. In: Vega, F. E., Hofstetter, R. W. (eds.): Bark Beetles. San Diego, CA, USA Academic Press, pp. 555–584.

Fettig, C. J., Lowrey, L. L., Blackford, D. C., McMillin, J. D., Munson, A. S., Mortenson, L. A., 2018: Efficacy of Spring and Fall Treatments of Carbaryl for Protecting Ponderosa Pine From Mortality Attributed to Mountain Pine Beetle (Coleoptera: Curculionidae). Journal of Economic Entomology, 111:2979–2982.

Fettig, C. J., Asaro, C., Nowak, J. T., Dodds, K. J, Gandhi, K. J. K., Moan, J. E., et al., 2022: Trends in Bark Beetle Impacts in North America During a Period (2000–2020) of Rapid Environmental Change. Journal of Forestry, 120:693–713.

Garbaliński, P., 1995: Aktywność biologiczna zetacypermetryny – nowej substancji owadobójczej z grupy pyretroidów. Sylwan, 9:29–36. (In Polish)

Grégoire, J. C., Evans, H. F., 2004: Damage and Control of BAWBILT Organisms an Overview. In: Lieutier, F., Day, K. R., Battisti, A., Gregoire, J.-C., Evans, H. F. (eds.): Bark and wood boring insects in living trees in Europe: a synthesis. Bark and Wood Boring Insects in Living Trees in Europe, a Synthesis. Dordrecht, Boston & London, Kluwer Academic Publishers, pp. 19–37.

Grodzki, W., Skrzecz, I., 2017: Trinet P as an innovative method in the protection of Norway spruce stands against *Ips typographus* (L.). Sylwan, 161:34–39.

Hall, R. W., Shea, P. J., Haverty, M., 1982: Effectiveness of Carbaryl and Chlorpyriphos for Protecting Ponderosa Pine Trees from Attack by the Western Pine Beetle (Coleoptera: Scolytidae). Journal of Economic Entomology, 75:504–508.

Hansen, E. M., Munson, A. S., Wakarchuk, D., Blackford, D. C., Graves, A. D., Stephens, S. S., et al., 2019: Advances in Semiochemical Repellents to Mitigate Host Mortality From the Spruce Beetle (Coleoptera: Curculionidae). Journal of Economic Entomology, 112:2253–2261.

Hastings, F. L., Holsten, E. H., Shea, P. J., Werner, R. A., 2001: Carbaryl: A Review of Its Use Against Bark Beetles in Coniferous Forests of North America. Environmental Entomology 30:803–810.

Hnatek, J., Stejskal, V., Vendl, T., Aulicky, R., Malkova, J., Zouhar, M., 2021: Fumigation of Insect-Infested Wooden Logs by EDN Using Two Scenarios of Plastic Tent-Tarpaulin Sealing: Wooden Logs Stacks Placed on Bottom Plastic Sheets or Directly on Underlying Soil. Sustainability, 13:13377.

Holuša, J., Resnerová, K., Berčák, R., Koreň, M., Kula, E., 2021: Optimalizace používání stromových lapáků proti lýkožroutům na smrku. Lesnický průvodce, 12:1–42. (In Czech).

Hurling, R., Stetter, J., 2012: Untersuchungen zur Fangleistung von Schlitzfallen und Fangholzhaufen bei der lokalen Dichteabsenkung von Buchdrucker (*Ips typographus*) – Populationen. Gesunde Pflanzen, 64:89–99. (In German).

Hübertz, H., Larsen, J. R., Bejer, B., 1991: Monitoring spruce bark beetle (*Ips typographus* (L.)) populations

under non-epidemic conditions. Scandinavian Journal of Forest Research, 6:217–226.
Jakuš, R., 1998: A method for the protection of spruce stands against *Ips typographus* by the use of barriers of pheromone traps in north–eastern Slovakia. Anzeiger für Schädlingskunde, Pflanzen– und Umweltschutz/ Journal of Pest Science 71:152–158.
Jakuš, R., Blaženec, M., 2002: Influence of proportion of (4S)-cis-verbenol in pheromone bait on *Ips typographus* (Col., Scolytidae) catch in pheromone trap barrier and in single traps. Journal of Applied Entomology, 126:306–311.
Jakuš, R., Schlyter, F., Zhang, Q.–H., Blaženec, M., Vaverčák, R., Grodzki, W., et al., 2003: Overview of development of an anti-attractant based technology for spruce protection against *Ips typographus*: From past failures to future success. Anzeiger für Schädlingskunde/Journal of Pest Science, 76:89–99.
Jeger, M., Bragard, C., Caffier, D., Candresse, T., Chatzivassiliou, E., Dehnen-Schmutz, K., et al., 2017: Pest categorisation of *Ips typographus*. EFSA Journal, 15:4881.
Jirošová, A., Kalinová, B., Modlinger, R., Jakus, R., Unelius, C. R., Blaženec, M., et al., 2022: Anti-attractant activity of (+)-trans-4-thujanol for Eurasian spruce bark beetle *Ips typographus*: Novel potency for females. Pest Management Science, 78:1992–1999.
Juha, M., Turčány, M., 2008: Netradiční způsoby boje s lýkožroutem smrkovým – *Ips typographus* L. (Coleoptera: Scolytidae). Zprávy lesnického výzkumu, 53:1–5. (In Czech).
Knížek, M., Liška, J., 2023: Výskyt lesních škodlivých činitelů v roce 2022 a jejich očekávaný stav v roce 2023. Strnady, Výzkumný ústav lesního hospodářství a myslivosti, v. v. i., 86 p. (In Czech).
Kohnle U., Densborn S., Duhme D., Vité J. P., 1992: Bark beetle attack on host logs reduced by spraying with repellents. Journal of Applied Entomology, 114:83–90.
Kula, E., Šotola, V., Špoula, J., Wasserbauer, J., 2022: Otrávené lapáky versus trojnožky se sítí Storanet, *Ips typographus* (L.) a necíloví bezobratlí. Zprávy lesnického výzkumu, 67:246–258. (In Czech).
Kula, E., Holuša, J., Hrdlička, P., Resnerová, K., Koreň, M., Špoula, J., et al., 2023. Optimalizace otráveného lapáku pro maximální odchyt lýkožrouta smrkového (*Ips typographus* L.). Brno, Czech Republic, Mendel University in Brno, pp. 76. (In Czech).
Laskowski, D. A., 2002: Physical and Chemical Properties of Pyrethroids. Reviews of Environmental Contamination and Toxicology, 174:49–170.
Lubojacký, L., Holuša, J., 2011: Comparison of spruce bark beetle (*Ips typographus*) catches between treated trap logs and pheromone traps. Šumarski List, CXXXV:233–242.
Lubojacký, J., Holuša, J., 2013: Comparison of lure–baited insecticide–treated tripod trap logs and lure–baited traps for control of *Ips duplicatus* (Coleoptera: Curculionidae). Journal of Pest Science, 86:483–489.
Lubojacký, J., Holuša, J., 2014: Attraction of *Ips typographus* (Coleoptera: Curculionidae) beetles by lure–baited insecticide–treated tripod trap logs and trap trees. International Journal of Pest Management, 60:153–159.
Novotný, J., Zúbrik, M., 2000: Biotic pests of Slovak forests. Bratislava, Slovak Republic, Ministry of Agriculture of the SR, 206 p. (In Slovak).
Økland, B., Nikolov, Ch., Krokene, P., Vakula, J., 2016: Transition from windfall- to patch-driven outbreak dynamics of the spruce bark beetle *Ips typographus*. Forest Ecology and Management, 363:63–73.
Peña, A., Lozano, C., Sánchez–Raya, A. J., Campos, M., 1998: Ethylene Release under Field Conditions for the Management of the Olive Bark Beetle, Phloeotribus scarabaeoides. Journal of Agricultural Entomology, 15:23–32.
Raty, L., Drumont, A., De Windt, N., Grégoire J.-C., 1995: Mass trapping of the spruce bark beetle *Ips typographus* L.: traps or trap trees? Forest Ecology and Management, 78:191–205.
Ray, D. E., Burr, S. A., 2014: Pyrethrins/Pyrethroids. In: Richardson, R. J. (ed.): Encyclopedia of toxicology (3rd ed.) Amsterdam, The Netherlands, Elsevier, pp. 1152–1158.
Rivera-Dávila, O. L., Sánchez-Martínez G., Rico-Martínez, R., 2022: Toxicity tests, bioaccumulation and residuality of pyrethroid insecticides commonly used to control conifer bark beetles in Mexico. Ecotoxicology, 31:782–796.
Rodríguez, E., Peña, A., Sánchez Raya, A. J., Campos, M., 2003: Evaluation of the effect on arthropod populations by using deltamethrin to control *Phloeotribus scarabaeoides* Bern. (Coleoptera: Scolytidae) in olive orchards. Chemosphere, 52:127–134.
Ruano, F., Campos, M., Sánchez-Raya, A. J., Peña, A., 2009: Evaluation of decreasing deltamethrin concentration in the treatment of olive logs: effects on the olive bark beetle and its associated parasitoids. International Journal of Pest Management, 55:175–179.
Seidl, R., Schelhaas, M.-J., Rammer, W., Verkerk, P. J., 2014: Increasing forest disturbances in Europe and their impact on carbon storage. Nature Climate Change, 4:806–810.
Senf, C., Pflugmacher, D., Zhiqiang, Y., Sebald, J., Knorn, J., Neumann, M., et al., 2018: Canopy mortality has doubled in Europe's temperate forests over the last three decades. Nature Communications, 9:4978.
Schiebe, C., Blaženec, M., Jakuš, R., Unelius, C. R., Schlyter, F., 2011: Semiochemical diversity diverts bark beetle attacks from Norway spruce edges. Journal of Applied Entomology, 135:726–737.
Schlyter, F., Zhang, Q.-H., Liu, G.-T., Ji, L. Z., 2001: A successful case of pheromone mass trapping of the bark beetle *Ips duplicatus* in a forest island, analysed

by 20-year time-series data. Integrated Pest Management Reviews, 6:185–196.

Skrzecz, I., Grodzki, W., Kosibowicz, M., Tumialis, D., 2015: The alpha-cypermethrin coated net for protecting Norway spruce wood against bark beetles (Curculionidae, Scolytinae). Journal of Plant Protection Research, 55:156–161.

Skuhravý, V., 2002: Lýkožrout smrkový *Ips typographus* (L.) a jeho kalamity. Praha, Agrospoj, 196 p. (In Czech).

Stadelmann, G., Bugmann, H., Meier, F., Wermelinger, B., Bigler, C., 2013: Effects of salvage logging and sanitation felling on bark beetle (*Ips typographus* L.) infestations. Forest Ecology and Management, 305:273–281.

Špoula, J., Kula, E., 2023: Evaluating the effectiveness of installations for monitoring and control of *Ips cembrae* (Heer). Sylwan, 167:233–244.

Švestka, M., Hochmut, R., Jančařík, V., 1996: Praktické metody v ochraně lesa. Praha, Silva Regina, 309 p. (In Czech).

Víctor, J., Zúñiga, G., 2016: Phylogeny of *Dendroctonus* bark beetles (Coleoptera: Curculionidae: Scolytinae) inferred from morphological and molecular data. Systematic Entomology, 41:162–177.

Weslien, J., 1992: Monitoring *Ips typographus* (L.) populations and forecasting damage. Journal of Applied Entomology, 114:338–340.

Wichmann, L., Ravn, H. P., 2001: The spread of *Ips typographus* (L.) (Coleoptera, Scolytidae) attacks following heavy windthrow in Denmark, analysed using GIS. Forest Ecology and Management, 148:31–39.

Wood, L. D., 1982: The Role of Pheromones, Kairomones, and Allomones in the Host Selection and Colonization Behavior of Bark Beetles. Annual Review of Entomology, 27:411–446.

Zahradník, P., Kapitola, P., 1993: Zhodnocení účinku preventivního ošetření dříví na lýkožrouta smrkového (*Ips typographus* L.) na ostatní entomofaunu. Zprávy lesnického výzkumu, 38:9–17. (In Czech).

Zahradník, P., Knížek, M., Kapitola, P., 1993: Zpětné odchyty značených lýkožroutů smrkových (*Ips typographus* L.) do feromonových lapačů v podmínkách smrkového a dubového porostu. Zprávy lesnického výzkumu, 38:28–34. (In Czech).

Zahradník, P., Zahradníková, M., Mikulčíková, P. 2023. Integrovaná ochrana rostlin – lesní porosty. Příloha 1 Seznam povolených přípravků a dalších prostředků na ochranu lesa. Metodická příručka. Kostelec nad Černými lesy, Lesnická práce, s. r. o., 92 p. (In Czech).

Zahradníková, M., Zahradník, P., 2015: Ochrana skládek dřeva před napadením lýkožroutem smrkovým – *Ips typographus* (L.) (Coleoptera: Curculionidae: Scolytinae). Lesnický průvodce 7/2015. Strnady, Výzkumný ústav lesního hospodářství a myslivosti, v. v. i., 21 p. (In Czech).

Zheng, Z., Wang, J., Zhang, D., Guan, X., Gao, S., Chen, Z., et al., 2011: Design, synthesis, and insecticidal activities of novel monohalovinylated pyrethroids. Journal of Agricultural and Food Chemistry, 59:1171–1177.

Zhu, Q., Yang, Y., Zhong, Y., Lao, Z., O'Neill, P., Hong, D., et al., 2020: Synthesis, insecticidal activity, resistance, photodegradation and toxicity of pyrethroids (A review). Chemosphere, 254:126779.

Other sources

Agriphar, S. A., 2009: Forester. Rule Number: CA 701731. Safety Data Sheet, pp. 17 (In Czech).

Data Logger HOBO MX 1101 Temp. Available at https://www.scaledinstruments.com/shop/onset/data-logger/onset-mx1101-hobo-temperature-relative-humidity-data-logger/?gad_source=1&gclid=EAIaIQobChMIw_nIs8qTgwMVJ5eDBx0Uvg4lEAAYAyAAEgL5RfD_BwE. (accessed 15 January 2024).

eAGRI, 2022: Forester (4744-0) Register of plant protection products. Available at https://eagri.cz/public/app/eagriapp/POR/Detail.aspx?id=37756&stamp=638377241838766481 (accessed 09 December 2023) (In Czech).

eAGRI, 2023: Dinastia (4244-16) Register of plant protection products. Available at https://eagri.cz/public/app/eagriapp/POR/Detail.aspx?id=37766&stamp=638377262301136216 (accessed 09 December 2023) (In Czech).

European Comission, 2023: EU Pesticides Database. Available at https://food.ec.europa.eu/plants/pesticides/eu-pesticides-database_en (accessed 05 December 2023).

TIBCO Software Inc. 2018. STATISTICA (data analysis software system), version 13.