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EFFICACY OF ARTIFICIAL TRAPS TO PREVENT THE DAMAGE OF CONIFER SEEDLINGS BY LARGE PINE WEEVIL (*HYLOBIUS ABIETIS* L.) – A PRELIMINARY STUDY

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Abstract: *A field experiment was conducted within two fresh clear-cutting areas to assess the efficacy of conifer seedling protection against the pine weevil attack by insect mass-trapping, using pitfall traps baited with alpha-pinene and ethanol. The research was conducted in two areas, Valea Putnei (VP) and Şimoneac (SIM), located in the northern part of Romanian Eastern Carpathians. A block of 6x4 traps, spaced at 14 m of each other, was set up in VP, and another block of 6x5 traps, spaced at 10 m of each other, was set up in SIM. There were five control plots in each area (of 40 m^2 in VP, and 70 m^2 in SIM). Norway spruce (Picea abies (L.) H. Karst.) seedlings, 3-4 yr-old, 5000 per hectare, were planted in the experimental plots. Weevil-caused damages and mortality were assessed at the end of the growing season. The traps caught on average 215.9 ± 20.0 and 104.3 ± 10.0 weevils/traps in VP and SIM, respectively. Large mass-trapping of the large pine weevil on fresh clear-cutting areas was unable to protect the planted seedlings even using a high number of artificial traps per unit area (100 traps/ha).*

Key words: *artificial attractants, Hylobius abietis, mass-trapping, conifer seedling protection.*

1. Introduction

Hylobius abietis (Linnaeus 1758) is the main pest of conifer plantations in Europe, especially where clear-cutting is immediately followed by tree plantations [7], [2], [14]. In such areas, the presence of fresh stumps is a factor which sustains the increase and maintenance for some years of higher weevil populations.

In the past 100 years, various methods were experimented, in order to reduce weevil populations or to protect seedlings, by keeping insects away from them [7],

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[5], [14]. Mass-trapping of the large pine weevils, using materials that attract these insects (trap logs, bark pieces, fresh branches) had been extensively used in Central Europe for a long time, being mentioned early, in the first half of the 19^{th} century [30]. To reduce the workload required by the collection of weevils, those means were often used in combination with various insecticides, especially after the development of synthetic insecticides industry.

Gradually, this method was abandoned in most European countries, currently being used only in Poland and Romania [14]. The main reason why this method was dropped is that seedling protection efficiency is conditioned by the use of a large number of bark pieces - or freshly cut billets - per unit area, which need frequent replacement and, therefore, a considerable economic effort. Consequently, after [36] showed that alpha-pinene in combination with ethanol have a strong effect of attraction on the *H. abietis* beetles, it was expected that synthetic attractants in combination with effective traps could replace the traditionally used means, not only for monitoring the pest populations, but also for keeping them under control.

In general, the traps baited with synthetic attractants proved to be more effective than the natural materials in attracting and capturing the weevils [17], [34], [12], a fact which led to the wide use of this method in Poland [35], but combined with other protective measures. The presence of large areas of coniferous plantations annually susceptible to large pine weevil attack (i.e. in Romania >5000 ha) [33], requires better knowledge of the protection methods, in terms of their effectiveness.

To our best knowledge, until now, no published results have analyzed the seedling protection by diminishing the attack frequency or intensity, using only traps, without other complementary protective measures. The aim of the paper was to analyse if the mass-trapping of *H. abietis* beetles, using traps with artificial attractants, could provide any protection for spruce seedlings, when no other protective measures were applied in fresh clear-cutting areas, and also the determinant factors affecting the attack, when this method was applied.

2. Materials and Methods

2.1. Site Location

The research was conducted in two areas, Valea Putnei (VP) and Şimoneac (SIM), located in the northern part of Romanian Eastern Carpathians (Table 1), an area where spruce forests dominate, clear-cuttings are frequent and the populations of *H. abietis* are generally high.

Within both areas, the mature stands consisted of 100% Norway spruce [*Picea abies* (L.) H. Karst.], with younger silver fir (*Abies alba* Mill.) trees disseminated only in VP. The logging of the forest stands included in study was done during the winter of 2004-2005, while the experiment was conducted in 2005, during the first growing season after cutting.

2.2. Design of Experiment

In each area, a treated plot was installed, the treatment including the presence of the traps. The treated plots included 24 squares (4 x 6, 14 m side) in VP and 30 squares in SIM (5 x 6, 10 m side) (Figures 1-2).

In the middle of each square, a trap was installed, based on an assumption that each trap will independently work within its related area, because the active attraction radius of the trap does not exceed 2.5 m [31]. The size of treated plots was 4704 m^2 (VP) and 3000 m^2 (SIM).

Main characteristics of the experimental areas Table 1

Site	Geographical coordinates	Area [ha]	Altitude [m]	Aspect	Slope [g]	Habitat type[1]	Soil type[2]
VP	47°25’39’’N 25°25’19’’E	5.2	1135-1175	South West	20	R4205	Dystric cambisol
SIM	47°41’34’’N 25°07’16’’E	9.5	1200-1300	South East	25	R4205	Entic podzol

Note. [1]Habitat typeR4205: South-east Carpathian spruce forests (*Picea abies*) with *Oxalis acetosella* [3].
[2]Soil type according to [11].

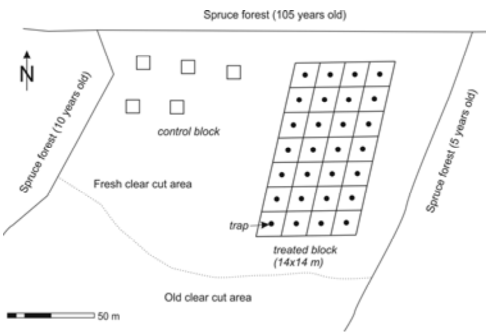

Fig. 1. *Placement outline of traps block and control plots in Valea Putnei*

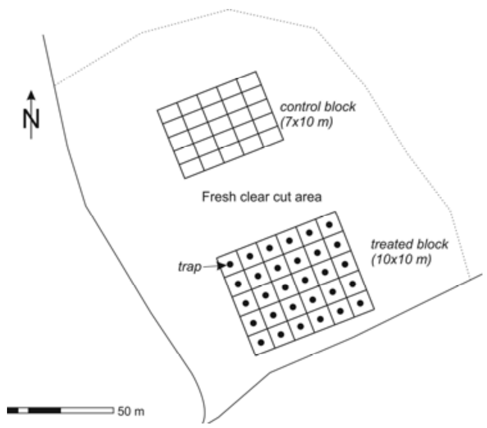

Fig. 2. *Placement outline of traps block and control plots in Simoneac*

The control (not containing traps) consisted of five smaller plots, in both cases. In VP the control squares were about 40 m^2 each and were spread among the piles of slash at 30-50 m from the traps block. In SIM the control plots were randomly selected rectangles (7 m x 10 m) within a continuous strip of land (35 m x 50 m), being located at about 50 m from the traps block.

The design differences within and between experimental areas were related to the constraints imposed by fieldwork conditions (small area of clear-cuttings, presence of high quantities of slash or the natural regeneration in some areas).

2.3. Traps and Dispensers

The traps were built from a galvanized funnel with a diameter of 25 cm, with a plastic bottle of 2-dm^3 capacity attached at the bottom (Figure 3). The funnel lid had 52 holes, with a diameter of 10 mm, quite uniformly arranged concentrically.

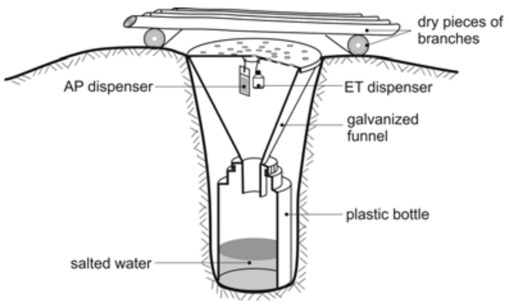

Fig. 3. *The design of the traps used in the experiment*

The traps were buried in the soil with the cover at ground level. The surface area of the ground was prepared on site, so that insects might reach without difficulty to the holes in the lid. Each trap contained salted water (of about 2 cm depth). In order to avoid the destruction of the traps and to prevent the accumulation of a large quantity of rain water, they were covered with dry pieces of branches, arranged so as not to hinder the movement of the beetles to the holes in the cover.

The traps were baited with individual lures of (-)-alpha-pinene (AP) and ethanol (ET), which were attached to wires at 2-3 cm below the trap lid.

An AP lure consisted of an envelope of low density polyethylene foil with a thickness of 100 μm (60 mm x 75 mm) and a cellulosic absorbent material (45 mm x 65 mm x 3 mm) impregnated with about 8 ml AP. The envelope was closed by thermal welding, the releasing of terpene to occur only through the pores of the polythene film. The AP volatilization rate under laboratory conditions (15° C, 85% RH) was 680.8 ± 21.2 mg/day. The AP baits were made by "Raluca Râpan" Institute of Chemistry (Cluj-Napoca, Romania).

ET was released from a polypropylene bottle with a capacity of 25 ml and a circular aperture of 9 mm diameter, containing 15 ml of 96% alcohol. ET volatilization was carried out directly through the bottle opening, with a rate (determined under laboratory conditions) of 510.2 ± 9.1 mg/day. The continuous operation of the lures throughout the experiment period was provided by re-freshening them every two weeks.

The traps were operated from 9th of May to 14th of September at VP, and from 20th of May to 12th of September at SIM. They were set up in the field at the same time with the reforestation of the two experimental areas. The traps were checked and the captures were collected every two weeks, the collected insects being further sorted in the laboratory. The individuals of *H. abietis* were separated by sex, based on the depression in last sternite in males, and the convex abdomen in females [5].

2.4. Seedlings Damage Assessment

Bare root spruce seedlings, untreated with insecticide before planting, were planted in both experimental areas. The plantations were made with a density of 5000 seedlings/ha, and – due to the expected losses – they were extended only in the area occupied by the experiment. Each seedling was planted in the centre of an area of about 60 cm x 60 cm, with tillage ground, without vegetation. In VP, the used seedlings were three years old, but in SIM four-yr-old seedlings were planted.

The extent of injuries was checked between 22nd of September and 4th of October at VP, and between 5th and 12th of October at SIM, when it was expected that the feeding of the beetles should stop.

In VP, the number of seedlings corresponding to each trap, was not the same. Theoretically, it should have been 98, but it varied between 51 and 112 (79.6 individuals ± 21.6 S.D.), because the debris occupied a large part of the ground. Overall, 1912 seedlings were checked in the traps block, and 114 seedlings in the control plots. For each seedling, the size of deep and shallow wounds was recorded separately; in the case of dead seedlings, the presumed cause of death was also noted.

In SIM traps block, the seedling density (based on 30 squares of 100 m^2) ranged between 29 and 62 (46.8 ± 9.3 S.D). Due to unfavourable weather conditions, in the autumn, during the assessment of the weevil attack, all the saplings were carefully inspected in only 6 randomly chosen squares, and the same parameters as in VP were assessed. In the other squares, all the seedlings were inspected just for establishing the presence/absence of wounds and the possible causes of seedling mortality. In the control plots of SIM, there were 152 seedlings on which the frequency of attack and seedling mortality, as well as the debarked area were assessed.

2.5. Characteristics of Stumps and Slashes

All debris (except the stumps) were collected and burned at SIM, while most of them were gathered into piles at VP, partly remaining spread on the ground. We expected the beetle response to the traps and the damage of seedlings to be influenced by the presence of fresh stumps and debris, because these ones release monoterpenes and ethanol [9], [37]. Consequently, the basic characteristics of each stump (tree species, age, diameter and the distance to the centre of the closest trap) were assessed. For each pile, we recorded its height, the two basal diameters and the distance to the closest trap. The volume of the pile was calculated considering each pile as a hemispherical cap. In calculations, only the fresh spruce stumps and the debris from VP were considered; the stumps of silver fir were avoided, as *Hylobius abietis* do not colonize this tree species [24].

In the two areas, there were many natural sources of volatile substances that emitted terpenes and alcohols simultaneously with the dispensers from the traps. Thus, in the trap blocks, after the cutting of mature trees at VP and SIM, a total of 196 and 713 fresh spruce stumps per hectare remained, with a mean diameter of 49.4 cm and 27.7 cm, summing up a cut area of 39.0 m^2/ha and 57.2 m^2/ha, respectively (Table 2).

At VP, there were also 55 fresh stumps of silver fir per hectare, with an average diameter of 25.1 cm, and 16 piles of debris, with a mean stack volume of 3.3 m^3 each, as well as a big pile located in the middle of the traps block, with a stacked volume of 16.3 m^3.

Compared to SIM, the stump density in VP was 3.4 times lower, and the trap density was about two times lower. Consequently, the average distance between traps and stumps was 5.13 m in V.P. and 3.79 m at SIM respectively. The average distance between the centre of debris piles and traps was 5.83 m in VP. In the control plots, at VP and SIM, there were 531 and 750 stumps per hectare, with a cut area of 128.2 m^2/ha and 60.2 m^2/ha, respectively.

2.6. Data Analysis

The experiment does not have true replications, because the treated squares were not interspersed with control plots. Consequently, when comparing the proportions of wounded or dead seedlings, as well as the mean debarked area of wounded plants in treated and control plots respectively, no inferential statistics were computed, as suggested by [10] for such circumstances.

Abundance and distribution of stumps and debris Table 2

Site	Plots	Area [m^2]	Fresh spruce stumps			
			No. / ha	Mean diameter [cm]	Mean distance to traps [m]	Mean cumulated cut area [m^2/ha]
VP	traps	4.704	196	49.4 ± 5.2	5.13 ± 0.20	39.0
	control	245	531	52.7 ± 4.9	-	128.2
SIM	traps	3000	713	27.7 ± 1.1	3.77 ± 0.1	57.2
	control	1400	750	26.2 ± 1.5	-	60.2

Note. The values following "±" represents the standard error of mean.

Because the spatial autocorrelation (SA) among field experiments replications, especially the short range, can impede the basic hypothesis of independence between samples [15], we tested the data with Moran's *I* index [16]. Prior to the testing, we constructed and then derived spatial weights for the queen neighbours lists, based on the polygons of treated replications. The VP results indicated no SA in the number of captures (I = 0.0951, p = 0.6794), proportion of wounded seedlings (I = -0.0342, p = 0.4666), size of debarked area (I = 0.1147, p = 0.0723) and only slight SA was found in *Hylobius*-caused seedling mortality (I = 0.1529, p = 0.0382). Nor was SA found in the number of captures at SIM (I = 0.8175, p = 0.2068).

The relationship between the different summaries of damages (proportion of wounded seedlings, size of debarked area, *Hylobius*-caused seedling mortality) and the potential factors of influence (wood residues), were analysed by ordinary regression models (OLS). The selection of the best fit model was conducted with a forward stepwise selection based on Akaike Information Criterion (AIC), for each final model being assessed the multicolianearity of independent variables and their relative contribution. If Moran's I indicated the presence of spatial dependence, we tested alternative models, namely spatial autoregressive models (SAR). To identify the right source of SA, we used Lagrange Multiplier test statistics for spatial error models (SA in residuals) or spatial lag models (additional lagged dependent variable as predictor), choosing the right model as the most significant [1]. The analysis was conducted in *R* [28]; the package *relaimpo* [8] was used in the relative contribution of covariates, while *spdep* in spatial tests [27].

3. Results

3.1. Size, Variability and Dynamics of Weevil Catches

During field operation (128 days at VP and 116 days at SIM, respectively), the traps captured 5182 pine weevils at V.P. and 3128 pine weevils at SIM, yielding an average of 215.9 (±98.2 S.D.) beetles/trap at VP and 104.3 (±54.5 S.D.) beetles/trap at SIM.

The dynamics of the capture from the trap installation until mid-September (Figure 4) shows that the fresh cutting areas were invaded by a large number of pine weevils during the first two weeks after planting, the populations remaining very high until mid-August, although gradually some of the insects were captured. During the first two weeks, the populations were mainly constituted of males.

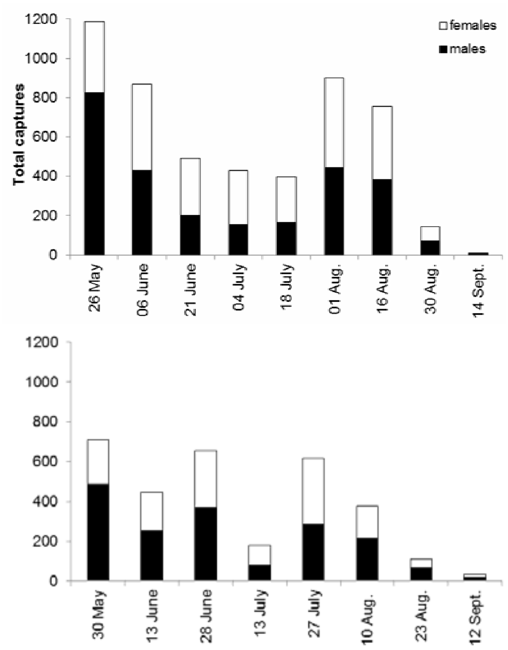

Fig. 4. *Dynamics of pine weevil captures (left - VP, right - SIM)*

When reporting the number of captured weevils by all traps to the surface of traps block, 1.10 weevils/m^2 at VP and 1.04 weevils/m^2 at SIM were captured. The catch variability in the two experimental blocks was relatively low (45.5% and 52.3% at VP and SIM, respectively), indicating a relatively uniform distribution of pine weevils in the field. OLS models showed that no factors influenced the number of captures in VP, nor in SIM.

3.2. Proportion of Wounded Seedlings, the Wound Size and the Weevil-Caused Seedling Mortality

The results concerning the proportion of wounded seedlings and the size of debarked area were different in the two experimental areas. In VP, the damaged seedling proportion and the seedling mortality caused by the pine weevil in the traps block were different from the control plots (Table 3). Similarly, the average size of the debarked area was reduced for the seedlings within the traps block, as against the control plots (Table 3), regardless if it was only by deep biting (55.7% reduction), or by deep and superficial biting together (53.1% reduction). Instead, at SIM, the presence of traps did not affect the proportion of damaged seedlings and the intensity of the attack.

As regards the proportion of wounded seedlings, the only significant covariates influencing the variability were the trap-stumps distance (positively) and the number of captures (negatively), with an almost double contribution of the former to the model, which explained about 36% of variance (Table 4). The same factors (but with a non-significant contribution to the number of captures) and with comparable weights, determined the size of the debarked area, suggesting that these two measures refer in fact to the same process. From our measured determinants, *Hylobius*-caused seedling mortality was equally influenced by the stumps cut area and their number, respectively. The Global Moran's I for regression residuals was significant ($I = 1.6865$, $p = 0.04585$), thus we further applied the SAR model as the above OLS. The best but not significant model resulted from the Lagrange multiplier test, was the spatial lag model (LMlag = 1.6756, $df = 1$, p-value = 0.1955), indicating that SA could be ignored.

4. Discussion

4.1. Size, Variability and Dynamics of Weevil Catches

Pine weevil catches in the two experimental areas throughout the growing season are comparable with those from other experiments in fresh spruce felling areas, using similar [22] or different traps [43], [44], [26], [38]. The variability in catches in the two blocks of traps was similar to the results of [34], but much lower than found by [26]. Our results can be attributed to the homogeneity of site conditions and to a relatively uniform distribution of stumps, as pine weevil adults gather around the fresh stumps [7], [29], [32].

Although the logging debris was not removed from the trap block at VP, the catch variability was not greater than in SIM, maybe because - being collected in the piles – it did not affect the weevil possibilities to move, as possible if the debris were scattered on the ground [26].

Table 3

Between sites and plots comparison of the pine weevil attack and weevil-caused seedling mortality

Site	Plot	Number inspected seedlings	% seedlings		Mean size of debarked areas[1] [mm^2]	
			damaged	dead	Deep wounds	Deep + shallow wounds
VP	With traps	1912	60.6	5.9	106.2 ± 3.7	149.4 ± 4.7
	Control	114	85.1	37.7	239.9 ± 24.9	318.4 ± 32.0
SIM	With traps	1349	83.0	26.1	305.0 ± 15.8	477.3 ± 27.4
	Control	152	81.6	32.9	273.9 ± 20.4	397.2 ± 27.8

Note. [1] There were taken into account only the damaged seedlings, even though some were only superficially wounded.

Results of the Hylobius damages OLS models Table 4

Covariables/dependent variables	Dependent variable		
	Damaged seedlings [%]	Debarked area [mm^2]	Weevil-caused mortality [%]
Distance between traps and stumps (m)	6.801^{***} (2.198) 0.697	18.367^{**} (7.841) 0.753	
Number of captures	-0.061^{**} (0.028) 0.303	-0.147 (0.099) 0.247	
Stumps cut area [m^2]	-	-	11.985^{**} (5.597) 0.532
Number of stumps	-	-	-2.040^{*} (0.986) 0.467
Constant	36.910^{***} (12.173)	24.575 (43.420)	4.416^{**} (1.889)
Observations	24	24	24
R^2	0.365	0.237	0.181
Adjusted R^2	0.305	0.164	0.103
Residual Std. Error (df = 21)	12.789	45.618	4.255
F Statistic (df = 2; 21)	6.041^{***}	3.257^{*}	2.322
VIF	1.5753	1.3102	1.2217

Note. In independent variables, the values in parenthesis are the standard errors, while the third represents the relative contribution to the model.
Significance abbreviations: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

According to the average number of captures/trap, one might infer that the population of pine weevil at VP was two times higher than the one at SIM; but, when reported relatively to the surface on which the traps were installed, the catches in the two experimental blocks were similar, i.e. 1.1 and 1.04 weevils/m^2, respectively. These values show a density of *Hylobius abietis* over 10,000 beetles per hectare in both experimental areas, which cannot be considered too high [5], and comparable to other results (about 14,000 beetles/ha, according to [20]).

The attractiveness of traps placed within the fresh clear cutting areas is affected by the abundance of natural volatile substances released from the stumps and debris [21], [4]. This could explain the greater efficiency of traps in VP, where the attraction exerted on beetles by the stumps was lesser than in SIM, since the stump aggregated area was 1.47 times smaller, and the average distance to traps 1.36 times greater than in SIM.

However, our analyses did not reveal any connection between the fresh stumps size and abundance, and the weevil catches, in either VP or SIM, a fact which could be due precisely to the high concentration of natural volatiles which overwhelmed the volatiles released from the traps within both experimental areas.

The dynamics of the catches was similar to the other fresh clear cuttings [42], [26], [22], [23], which shows that large populations of beetles were present immediately after the installing of plantations until the mid-August, when the post-reproductive weevils began to withdraw into the hibernation places [26].

4.2. Proportion of Wounded Seedlings, the Wound Size and the Weevil-caused Seedling Mortality

Although we did not monitor the evolution of the attack within the trap blocks, it was observed in the control plots at VP (unpublished data), and most damage occurred by the end of June, similar to those observed by [13] and [23] in fresh clear cutting areas (during the first growing season after felling).

The proportions of seedlings damaged by pine weevil in the control plots at VP and SIM were very close, presumably another indication that the level of the two weevil populations was similar. However, the intensity of the attack was somewhat higher in SIM than in VP, which is most likely due to the presence of the logging debris in VP, an alternative source of food for weevils, at least at the beginning of the growing season, when the attack on seedlings was most intense. [26] consider that debris has no particular food value for weevils, as it dries relatively quickly, but in VP it was gathered in piles, which could slow down the debris drying, especially during a rainy growing season as in 2005.

Within the traps block of VP - where the average catch was twice higher than in SIM - both the proportion of damaged seedlings and the seedlings mortality caused by the pine weevil decreased from 85.1% to 60.6% and from 37.7% to 5.9%, respectively, while the size of debarked area, by over 50%. Both the proportion of the damaged seedlings and the wound size were negatively related to the weevil captures, which suggests that catching a greater number of weevils resulted in stronger decrease in population density and, implicitly, in a reduction of the attack. However, the correlation was statistically significant only for the proportion of damaged seedlings, and a stronger impact on the attack characteristics was attributed to the distance between stumps and traps.

As the distance from traps to stumps was higher, the percentage of injuries and biting intensity was higher. This leads to two complementary explanations: i) beyond a certain threshold-distance (2-2.5 m) the stumps and the traps do not interact in attracting the weevils, as the active attraction radius of the trap does not exceed 2.5 m [31]; or (ii) increasing distance between traps and stumps means fewer stumps to the unit area and - most likely - fewer alternative food sources for beetles [39], a situation which forced the weevils to feed on seedlings. Similar results were obtained by [29] when studying the correlation between the distance from the stump pile and the seedling damage.

The weevil-caused mortality positively correlates with the fresh stumps area, but negatively with their number, albeit these factors account for only little variability in weevil-caused mortality. It was assumed that a larger cut area of stumps released a larger amount of volatile and thus led to a higher concentration of beetles in their vicinity, as also noted by [29]. More stumps per unit area could be a more abundant and potentially more affordable food source (smaller stumps, thinner roots and closer to the topsoil).

Considering the lesser influence of the number of captures on the seedling mortality (evidenced by OLS models), compared to the influence of aggregated cut area of the stumps, it is likely that the observed differences between traps block and control in VP are mainly a result of the stumps abundance in the control areas (cut area: 39 m^2/ha vs. 128.2 m^2/ha) and are not due to the protective effect of the traps.

At SIM, the traps did not contribute to reducing the proportion and intensity of the attack, although their density was twice higher compared with VP, i.e. 100 pieces/ha. Here, the synthetic attractants released from the traps could not compete with the natural volatiles released from stumps and thus the reduction of weevil population was minor. Therefore, trapping had almost no effect on the attack characteristics, as [32] suggested.

On one-year-old clear cutting areas, under the same conditions, i.e. where the beetle population is substantially lower than on fresh cutting areas [40], [6], where the young beetles have not yet started to emerge from the stumps, and the stumps do not compete the traps in attracting the weevils [4], it is likely that the efficiency of seedling protection with traps baited with synthetic attractants may be greater. However, after the appearance of young beetles - from July to August-September [17], [25] - the positive results may be compromised through the maturation feeding of the young beetles, which are less attracted to AP and ET [19], [18], and are mainly looking for food sources and very intensely feed on seedlings [23].

5. Conclusions

The results of the experiment suggest that, when used alone, mass-trapping of the large pine weevil on fresh clear-cutting areas cannot protect the planted seedlings, even if a large number of artificial traps per unit area (100 traps/ha) is employed. However, a more extensive study, with true replications, needs to be conducted in order to confirm or to disprove these results.

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