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Optimizing trap placement for monitoring *Monochamus galloprovincialis* and minimizing bycatch of beneficial insects

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ABSTRACT

The pine sawyer beetle *Monochamus galloprovincialis* is the only known vector of the pine wood nematode (PWN) in Europe. Pheromone traps are one of the tools used for monitoring *M. galloprovincialis* and PWN. Numerous studies have been conducted to improve trapping efficiency, but the effects of habitat type and trap exposure in relation to forest have received the least attention. Bycatch of non-target species has also been rarely considered. The aim of this study was to evaluate the effects of (1) site type such as forest interior, forest edge, and open field adjacent to forest, (2) open field type (clear-cut or plantation), (3) trap location (west or east) relative to the forest on catches of *M. galloprovincialis* and selected non-target insect species. The study plots were established in 86-91 years old Scots pine stands and adjacent open fields. White, PTFE-covered, cross-vane traps baited with Galloprotect Pack lure were used for insect capturing. Site type had a significant effect on catches of *M. galloprovincialis* and 14 non-target species. *M. galloprovincialis*, *Hylurgus ligniperda*, *Spondylis buprestoides*, and *Prionychus ater* were most abundant at the forest edge. Catches of three longhorn beetles (*Acanthocinus aedilis*, *A. griseus*, and *Arhopalus rusticus*) and three predatory species (*Thanasimus formicarius*, *T. femoralis*, and *Corticeus pini*) had a decreasing trend from the forest interior towards the open field. The opposite was observed for *Chalcophora mariana*, *Phaenops cyanea*, *Magdalis violacea*, *Cardiophorus ruficollis*, and *Pseudocistela ceramboides*. The west side of the forests was significantly preferred by *M. galloprovincialis* (females) and *Ph. cyanea*, while it was avoided by *S. buprestoides*, both *Thanasimus* species, and *C. ruficollis*. The type of open field had a significant effect on catches of seven non-target species but not on *M. galloprovincialis* catches. Possible causes of the observed patterns in insect catches are discussed. In summary, for efficient monitoring of *M. galloprovincialis* with reduced bycatch of beneficial insects traps should be deployed at the westerly exposed forest edge. This trap location can also be recommended for catching higher numbers of forest pests such as *Ph. cyanea* and *H. ligniperda* and minimizing bycatch of predatory beetles. Furthermore, trap placement a few meters from the tree line should reduce the probability of bark damage for oviposition and eventual PWN transmission to healthy trees by *M. galloprovincialis* females attracted to the traps.

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Introduction

The pine wood nematode *Bursaphelenchus xylophilus* (Steiner et Buhrer) Nickle (hereafter PWN) is an invasive parasitic organism responsible for lethal pine wilt disease (Mamiya, 1985; Futai, 2021) and is thus considered one of the major pests of coniferous forests worldwide (Mota and Vieira, 2008; Futai, 2021). Infestation of new areas occurs when the PWN larvae are transmitted to healthy trees by insect vectors, mainly longhorn beetles of the genus *Monochamus* Dej. (Coleoptera, Cerambycidae) (Linit *et al*., 1983; Akbulut and Stamps, 2012). In Europe, the only known vector of PWN is the pine sawyer beetle *Monochamus galloprovincialis* (Oliv.) (Sousa *et al*., 2001). In many regions of Europe the preferred host tree of *M. galloprovincialis* is Scots pine, *Pinus sylvestris* L., which is of great economic and ecological importance and is also one of the tree species most susceptible to PWN infestation (Evans *et al*., 1996; Menéndez-Gutiérrez *et al*., 2018). Therefore, mandatory surveillance aimed at early detection of PWN in samples of imported wood, in symptomatic trees, and in the bodies of vector insects captured with semiochemical-baited intercept traps has been introduced in EU countries (Commission, 2017; EPPO, 2018). The latter method has gained importance as it allows detection of PWN in the early stages of introduction into natural environments, thus allowing rapid implementation of phytosanitary measures (Berkvens *et al*., 2017; EPPO, 2018).

The priority for the successful use of traps is their high efficiency. Numerous studies have shown that trap design (Álvarez *et al*., 2015; Allison and Redak, 2017), size (Morewood *et al*., 2002; De Groot and Nott, 2003), colour (Sukovata *et al*., 2022 and literature cited therein), lubricant treatment (Graham and Poland, 2012; Jaworski *et al*., 2022), attractant composition (Álvarez *et al*., 2016), and lure placement on the trap (Dodds *et al*., 2010) have significant effects on *Monochamus* catches. However, other factors may also be important. For example, recent studies have shown that trap placement along the horizontal gradient of an open space, forest edge and forest interior significantly influenced *Monochamus* catches in North America (Allison *et al*., 2019) and northern Europe (Schroeder, 2019). Interestingly, contrasting effects of trap location have been observed in co-occurring *Monochamus* species. Therefore, further studies focusing on specific *Monochamus* taxa and considering country-specific forest management practices as well as environmental conditions are needed.

When developing an optimal monitoring procedure, possible negative aspects of trap use should also be taken into account. One of them is that a portion of the *M. galloprovincialis* beetles attracted by traps suspended between trees are not captured by the traps, but land on the trunks of neighboring trees where they can make scars such as slits and/or pits (personal observations) increasing the risk of PWN transmission to healthy trees. Another major obstacle to the use of semiochemical-baited traps for capturing *Monochamus* beetles is the bycatch of non-target insects. For example, traps attract large numbers of *Spondylis buprestoides* (L.) (Jurc *et al*., 2012, 2016; Rassati *et al*., 2012) that often destroy captured *M. galloprovincialis* specimens and other insects in dry traps (Jaworski *et al*., 2022) which could impede their counting, especially if camera-integrated traps are used (Rassati *et al*., 2016). Furthermore, traps often capture beneficial insects including natural enemies of bark beetles (Pajares *et al*., 2004; Jurc *et al*., 2012; Sukovata *et al*., 2022). Traps may also catch other non-target insects that play important ecological roles in forests, *e.g.*, species involved in the decomposition of dead wood (Morewood *et al*., 2002; Francardi *et al*., 2009; Jurc *et al*., 2016) or in pollination (Cavaletto *et al*., 2021). Although solutions to mitigate these negative impacts have been proposed with respect to trap design (Bonifácio *et al*., 2021) and lure composition (Pajares *et al*., 2004; Álvarez *et al*., 2016; Sukovata *et al*., 2022), studies to minimize the capture of non-target insects by optimizing trap placement are sparse.

The aim of this study was to assess the effects of (1) site type such as forest interior, forest edge, and open field (clear-cut or plantation) adjacent to the forest, (2) the type of open field mentioned above, and (3) trap location (west or east) relative to the forest on catches of *M. galloprovincialis* and selected non-target beetle species. For the purpose of this study, a clear-cut included a current clear-cut and plantation of up to two years old, because young and small pine saplings were assumed to have no substantial impact on the microclimate of a clear-cut. A four-year-old pine plantation in which saplings form a denser ground cover than in younger plantations was considered to be a plantation. It is worth noting that in both types of open fields, the area was cleared of most woody debris (tree tops, branches, and twigs; excluding stumps) after the stands were harvested. Woody debris was either collected by companies and/or individuals as fuel or chopped into small pieces and scattered over the cleared area. In Poland, the longer side of clear-cuts is usually oriented north-south (also northwest-southeast and northeast-southwest) as the wind blows predominantly from the west/northwest (Bartoszek, 2017). Therefore, we hypothesized that the trap location (west or east of forests) at forest edges or in open fields could have a significant effect on catches of *M. galloprovincialis* and other insect species. We expected that traps located west of forests should primarily attract insects from forests, whereas traps located east of forests should primarily attract insects from areas adjacent to forests, *i.e.*, clear-cuts or plantations.

Materials and methods

STUDY SITES AND EXPERIMENTAL DESIGN. The study was conducted in 2021 in the Międzychód Forest District (N 52.6921, E 15.8282). The study plots had to meet the following requirements: Scots pine stands with similar species composition and age, growing under similar habitat conditions, and adjacent to a clear-cut or plantation east or west of the stand. A visual analysis of the characteristics and spatial distribution of Scots pine stands, clear-cuts, and plantations in the forest district using data available in the Forest Data Bank (BDL, 2021) allowed selection of a set of suitable plots. After selection, all of the plots were visited and further plot selection was based on the presence of tree tops on the ground after thinning in the previous year (*i.e.*, April-June 2020) with signs of *M. galloprovincialis* infestation (visible sawdust on forest litter beneath tree tops and the presence of larval galleries under the bark). Finally, the study plots were established in 11 pure pine stands aged 86-91 years growing in a fresh coniferous forest site with mossy vegetation cover and in 12 adjacent open fields of two types: clear-cut or plantation (six of each type). The species composition of the plantations was dominated by Scots pine with up to 20% *Betula pendula* Roth. The complete randomized block design was used for setting the experiments with a total of 20 blocks (1-3 blocks per stand and adjacent open area) (Table 1). Each block consisted of one trap per site type. In open fields and at edges, traps were located either west or east of the forest.

Table 1.
Experimental design of the study

Site type sets	Trap location at the forest edge and in open fields	Number of blocks
forest – edge – clear-cut	west	5
	east	5
forest – edge – plantation	west	5
	east	5

Data on wind directions for the study period (see below) were taken from the forest meteorological station in Sowia Góra (N 52.7007, E 15.8457) located east of the study plots (about 10 km from the furthermost plot).

TRAPS. The beetles were captured using the white, unpainted cross-vane IBL-5 traps (Chemipan R&D Laboratories, Poland) baited with Galloprotect Pack (SEDQ, Spain). This trap type was selected based on the studies by Sukovata *et al.* (2022). The traps consisted of a lid and two crossed coroplast vanes (50×20 cm) inserted into a 17-cm diameter funnel. The traps were equipped with insect collectors each containing approximately 300 ml of propylene glycol with a small amount of an odorless detergent to reduce the surface tension of the liquid. To increase the effectiveness of the traps, they were coated with a 60% water solution of polytetrafluoroethylene (PTFE) (Chemours, USA) (Graham and Poland, 2012; Jaworski *et al.*, 2022). In the forest interior, the traps were suspended from a string stretched between trees at a height of about 1.5 m. At the other site types (forest edge, clear-cut, and plantation) traps were suspended at a height of about 1 m above the ground from wooden posts fixed at an angle in the ground. The lure consisted of three dispensers that were attached to the traps according to the producer's guidelines. The dispensers, which had to be hung on the side of the traps, were attached to the northeast side of the traps to minimize exposure to sun radiation.

A total of 60 traps were used with 2 sets of 3 site types × 2 trap locations × 5 blocks. Traps in the forest interior and open fields were placed approximately 100 m and 20-30 m from the forest edge, respectively. The distance of 100 m inside the forest allowed the avoidance of influence of the forest edge on insect catches in the traps as much as possible, while the distance from the forest edge in an open field was limited by the width of the clear-cuts (traps could not be deployed further than half the width of the open fields). At the forest edge the traps were placed 3-5 m from the tree line towards an open field to avoid the attracted beetles landing on the trees. Based on the studies by Torres-Vila *et al.* (2015) and Jactel *et al.* (2019), blocks were spaced usually over 120 m apart except two cases. The distance between the nearest blocks in the same stand or open field ranged from 71 to 383 m with a mean distance of 186.8 m.

The traps were set in the study plots between 16-18 June, and the experiment lasted until 20 July. Insects captured were identified, counted, and sexed (*M. galloprovincialis* only) in the laboratory and divided into target species (*M. galloprovincialis*) and non-target species (other taxa).

STATISTICAL ANALYSIS. For the separate analyses insect species with at least six specimens per trap captured in at least three traps were selected. This criteria was sufficient to ensure (for each set of site types and trap locations) that at least one specimen was captured in at least three of five traps (blocks) and at least at two site types (see experimental design in Table 1). Due to differences in trap exposure duration (32-34 days), insect catches were standardized to the number of beetles captured per 33 days.

The effect of site type on catches of target and non-target insects was estimated separately for two combinations of the following site types: forest – edge – clear-cut and forest – edge – plantation. As this experiment had a randomized complete block design, a generalized linear mixed model (GLMM) was used with a Poisson, a Conway-Maxwell Poisson or a negative binomial distribution of the dependent variable. Blocks were included in the models as a random variable. The effect of site type (the fixed variable) was tested using a Wald χ^2 test (Bolker *et al.*, 2009). This was followed by a *post-hoc* χ^2 test with a Holm correction for multiple mean comparisons.

When an excess of zero values was observed in insect catches, a zero-inflated GLMM was used. However, when this failed, a nonparametric Friedman test was used because it handled data without variation better than the GLMM. Pairwise comparisons were made using a Wilcoxon test with a Bonferroni correction.

The effect of trap location, when deployed at the forest edge and in open fields of two types, on the total number of *M. galloprovincialis* (males, females, and both sexes) and selected non-target species captured was estimated using a generalized linear model with a Poisson (P-GLM) or negative binomial distribution (NB-GLM) of the dependent variable. The significance of the fixed variable was tested with a likelihood-ratio test (LR). The same approach was used to test the effect of open field type (clear-cut and plantation) on insect catches.

The model's goodness of fit was estimated by checking for overdispersion using a χ^2 test (Zuur *et al.*, 2009; Mangiafico, 2016).

All analyses were undertaken using R environment, version 4.0.3, (R Core Team, 2020) with RStudio, version 1.1.463, (R Studio Team, 2016). The following R packages were used: rcompanion (Mangiafico, 2021) for P-GLM, MASS (Venables and Ripley, 2002) for NB-GLM, lmtest (Zeileis and Hothorn, 2002) for the LR test, glmmTMB (Brooks *et al.*, 2017) for GLMM, car (Fox and Weisberg, 2019) for the Wald χ^2 test, emmeans (Lenth, 2020) for multiple comparisons of means, and stats (a part of R) for the Friedman test and the Wilcoxon test. The significance level was set at $\alpha=0.05$ for all analyses.

Results

DIVERSITY AND NUMBERS OF BEETLES. In the period between mid-June and mid-July (32-34 days), 32,172 beetles of 88 species were captured in 60 traps. *M. galloprovincialis* was most abundant (32.1% of all beetles), followed by *S. buprestoides* (22.9%) and *Thanasimus femoralis* (Zett.) (16.1%). The complete list of insect species and their numbers at each site type (10 traps/site) as well as total numbers are provided in Appendix. Single individuals were captured for the 24 beetle species. Statistical analysis was performed for 15 species including *M. galloprovincialis* as the target species and 14 non-target species from six families: Buprestidae [*Chalcophora mariana* (L.) and *Phaenops cyanea* (F.)], Cerambycidae [*Acanthocinus aedilis* (L.), *A. griseus* (F.), *Arhopalus rusticus* (L.), and *S. buprestoides*], Cleridae [*Thanasimus formicarius* (L.) and *T. femoralis*], Curculionidae [*Hylurgus ligniperda* (F.) and *Magdalis violacea* (L.)], Elateridae [*Cardiophorus ruficollis* (L.)] and Tenebrionidae [*Corticeus pini* (Panz.), *Prionychus ater* (F.), and *Pseudocistela ceramboides* (L.)].

Total insect catches were highest at the forest edge (6,051 and 7,114 beetles in the site sets with plantation and clear-cut, respectively) followed by the forest interior (4,849 and 5,852 beetles, respectively) and open fields (3,849 beetles in plantations and 4,457 beetles in clear-cuts). The numbers of species were slightly lower in the forest interior than at the edge or at the plantations (43, 51 and 54 species, respectively), while they were comparable in the site set: forest – edge – clear-cut set (50, 52 and 51 species, respectively) (Appendix).

EFFECT OF SITE TYPE
M. galloprovincialis. The site type had a significant effect on the catches of males, females, and beetles of both sexes of *M. galloprovincialis* in both the following site sets: forest – edge – plantation (males – $\chi^2=16.8$, df=2, P=0.0002; females – $\chi^2=35.7$, df=2, P<0.0001; both sexes – $\chi^2=33.4$, df=2, P<0.0001) and forest – edge – clear-cut (males – $\chi^2=16.6$, df=2, P=0.0002; females – $\chi^2=17.9$, df=2, P=0.0001; both sexes – $\chi^2=19.2$, df=2, P<0.0001). However, trends in catches from the forest interior towards the open field differed between the sets.

In the forest – edge – plantation set, differences in the numbers of females and both sexes were significant between each pair of site types with the highest catches at the edge (116.1 ±8.65 beetles/trap and 177.0 ±11.88 beetles/trap, respectively) and the lowest catches in the forest interior (70.2 ±5.49 beetles/trap and 111.0 ±7.68 beetles/trap, respectively) (Fig. 1). The numbers of males in the traps at the edge and in the plantation were comparable (60.6 ±4.69 beetles/trap and 55.6 ±4.39 beetles/trap, respectively) but significantly higher than in the forest interior (40.1 ±3.32 beetles/trap).

In the forest – edge – clear-cut set, catches of males, females, and both sexes in the forest interior and in the clear-cut were comparable and significantly lower than at the edge (Fig. 1) where the beetle catches reached 102.5 ±13.50 males/trap, 153.2 ±16.30 females/trap and 257.0 ±28.00 beetles of both sexes/trap.

Non-target species. The effect of site type on catches of non-target species was significant for 13 of 14 species analyzed (except *C. pini*) in the forest – edge – plantation set and for 11 species (except *M. violacea*, *P. ater*, and *P. ceramboides*) in the forest – edge – clear-cut set (Table 2).

The forest interior, regardless of site set, was preferred by three species of longhorn beetles (*A. aedilis*, *A. griseus*, and *A. rusticus*) and the two species of checkered beetles (*T. femoralis* and *T. formicarius*). Their catches in the forest were significantly higher than at the edge (except for *A. aedilis* in the plantation site set and *A. rusticus* in the clear-cut set where catches were comparable) and in the open field regardless of its type (Table 3). The number of *C. pini* (Tenebrionidae) was also highest in the forest interior and significantly different from the catches in the other two site types but only in the clear-cut site set (Table 3). In the plantation set, the numbers of *C. pini* captured in different site types were comparable.

A clear preference for the forest edge (with a decreasing trend in catches through the open field to the forest interior) was observed for *S. buprestoides* in both site sets and for *H. ligniperda* in the forest – edge – plantation set with significant differences among all site types (Table 3). In the forest – edge – clear-cut set, *H. ligniperda* also avoided the forest interior but catches at the edge and in the clear-cut were similar.

The open field was preferred significantly more by *Ch. mariana* (in both site sets) and by *Ph. cyanea*, *M. violacea*, and *C. ruficollis* (in the set with plantation) than the two other site types (Table 3). Catches of these species were lowest in the forest interior and were significantly dif-
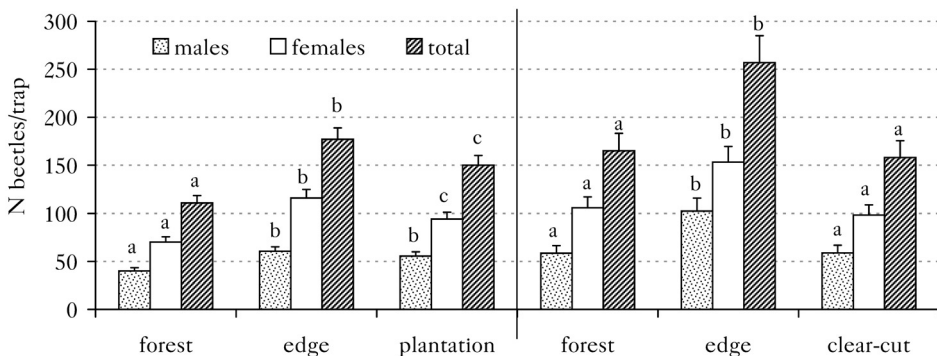

Fig. 1.

The number (means and SEs) of *M. galloprovincialis* beetles (males, females, and both sexes) captured in 33 days (from 16 June-20 July 2021) in traps deployed at different site types (in sets with the plantation or the clear-cut). Different letters indicate significant differences among site types within each site set for each insect sex and total catches separately, χ^2 test with a Holm correction at $\alpha=0.05$

Table 2.

The results of testing the effect of site type on catches of non-target species in two sets of site types (df=2 in all cases)

Insect family	Insect species	Tests for the site type combinations			
		forest – edge – plantation		forest – edge – clear-cut	
		Wald or Friedman*χ^2	P	Wald χ^2	P
Buprestidae	*Chalcophora mariana*	17.0*	0.0002	58.6	<0.0001
	Phaenops cyanea	29.7	<0.0001	17.4	0.0002
Cerambycidae	*Acanthocinus aedilis*	18.5	0.0001	38.6	<0.0001
	Acanthocinus griseus	76.8	<0.0001	92.6	<0.0001
	Arhopalus rusticus	34.7	<0.0001	10.7	0.0047
	Spondylis buprestoides	60.0	<0.0001	36.3	<0.0001
Cleridae	*Thanasimus femoralis*	116.0	<0.0001	91.0	<0.0001
	Thanasimus formicarius	132.4	<0.0001	93.4	<0.0001
Curculionidae	*Hylurgus ligniperda*	35.1	<0.0001	115.0	<0.0001
	Magdalis violacea	90.0	<0.0001	5.8	n.s.
Elateridae	*Cardiophorus ruficollis*	19.5	0.0001	14.4	0.0008
Tenebrionidae	*Corticeus pini*	3.6*	n.s.	13.5	0.0012
	Prionychus ater	23.2	<0.0001	5.4	n.s.
	Pseudocistela ceramboides	12.3	0.0021	5.8	n.s.

ferent from the catches in the open field and at the forest edge (except *Ch. mariana*). Similarly, high numbers of beetles in traps in the open field and at the forest edge, both significantly higher than in the forest interior, were found for two darkling beetles (*P. ater* and *P. ceramboides*) in the plantation site set as well as for *H. ligniperda*, *Ph. cyanea*, and *C. ruficollis* in the clear-cut set (Table 3).

EFFECT OF THE OPEN FIELD TYPE
M. galloprovincialis. The catches of *M. galloprovincialis* in the plantation and clear-cut did not differ significantly for males (56.1 ±7.82 beetles/trap and 62.1 ±8.62 beetles/trap, respectively), females (95.6 ±9.32 beetles/trap and 100.5 ±9.77 beetles/trap, respectively), and both sexes (152 ±16.3 beetles/trap and 163.1 ±17.4 beetles/trap, respectively).

Non-target species. The effect of open field type on the number of beetles captured was significant for seven non-target species (Table 4). Three species, *i.e.*, *Ch. mariana*, *A. griseus*, and *H. ligniperda*, were significantly more abundant in the clear-cut than in the plantation, while an inverse relationship was observed for *Ph. cyanea*, *M. violacea*, *C. ruficollis*, and *P. ater*.

EFFECT OF TRAP LOCATION IN RELATION TO FOREST
Actual wind direction. In the period from 16 June-20 July 2021, the wind blew mainly from southerly directions (SSE, SE, and SSW) (Fig. 2). Its speed was low and in the range of 0.4-1.4 m/s on all days except one.

M. galloprovincialis. Trap location had a significant effect only on catches of *M. galloprovincialis* females (LR χ^2=7.4, df=1, P=0.0065) and only for traps placed at the forest edge. Beetles were much more abundant on the west side of the forest than on the east side (163.0 ±13.95 females/trap and 113.0 ±9.84 females/trap, respectively) (Fig. 3). The numbers of males in the traps at different locations (west and east) in relation to the forest were similar (83.7 ±9.45

Table 3.

Pairwise comparisons of catches [mean ±SE or median (min–max)*] of non-target species in two sets of site types (bold, standard and italic numbers indicate the highest, intermediate and the lowest values, respectively, in each set of sites; different letters indicate significant differences between site types within each set, χ^2 test with a Holm correction or the Wilcoxon test with a Bonferroni correction* at α=0.05)

Insect family	Insect species	Site type sets									
		forest	–	edge	–	plantation	forest	–	edge	–	clear-cut
Buprestidae	*Chalcophora mariana*	*0 (0–0)*a*		*0 (0–2)*a*		**3 (0–4)*b**	*0.1 ±0.10a*		0.9 ±0.32b		**8.1 ±1.24c**
	Phaenops cyanea	*0.6 ±0.35a*		8.7 ±2.30b		**12.2 ±3.13c**	*1.2 ±0.46a*		**7.4 ±2.01b**		6.7 ±1.84b
Cerambycidae	*Acanthocinus aedilis*	**3.9 ±0.95a**		3.0 ±0.78a		*0.9 ±0.32b*	**5.4 ±1.22a**		2.2 ±0.59b		*0.6 ±0.26c*
	Acanthocinus griseus	**21.2 ±5.97a**		9.6 ±2.84b		*4.4 ±1.45c*	**45.2 ±9.94a**		21.8 ±5.07b		*12.9 ±3.17c*
	Arhopalus rusticus	**11.1 ±2.01a**		3.7 ±0.84b		*1.7 ±0.49c*	**1.8 ±1.07a**		1.6 ±0.91a		*0.7 ±0.42b*
	Spondylis buprestoides	*57.4 ±8.59a*		**169.5 ±18.52b**		102.3 ±12.78c	*65.9 ±11.70a*		**185.3 ±25.50b**		129.4 ±19.30c
Cleridae	*Thanasimus femoralis*	**162.9 ±14.51a**		80.6 ±9.24b		*12.9 ±3.23c*	**159.3 ±18.26a**		81.6 ±11.36b		*9.7 ±3.06c*
	Thanasimus formicarius	**75.7 ±10.91a**		36.2 ±5.76b		*11.8 ±2.45c*	**84.7 ±15.34a**		32.7 ±6.15b		*7.7 ±1.63c*
Curculionidae	*Hylurgus ligniperda*	*3.6 ±1.26a*		**45.9 ±16.09b**		18.4 ±5.80c	*3.4 ±0.88a*		65.8 ±13.19b		**66.2 ±13.67b**
	Magdalis violacea	*0.5 ±0.24a*		3.3 ±1.01b		**13.0 ±3.33c**			n.s.		
Elateridae	*Gardiophorus ruficollis*	*0 (0–0)*a*		3.0 (0–7)*b		**8.5 (1–24)*c**	*0.5 ±0.27a*		**3.8 ±0.73b**		2.5 ±0.60b
	Corticeus pini			n.s.			**4.9 ±1.14a**		*1.3 ±0.43b*		1.2 ±0.67b
Tenebrionidae	*Priortychus ater*	*3.3 ±0.94a*		**15.1 ±2.14b**		10.6 ±1.78b			n.s.		
	Pseudocistela ceramboides	*0.7 ±0.34a*		3.0 ±0.74b		**4.2 ±1.12b**			n.s.		

males/trap and 81.0 ±9.16 males/trap, respectively). The difference in total catches was also not significant.

NON-TARGET SPECIES. Similar to *M. galloprovincialis* females, the numbers of the jewel beetle *Ph. cyanea* was significantly higher in traps located west of the forest than on the east side, and this difference was observed at the forest edge and in the plantation (Table 5) but not in the clear-cut.

Table 4.

The effect of the open field type on catches (mean ±SE) of non-target species (only significant differences are presented; bold numbers indicate higher values; df=1 in all cases)

| Insect family	Insect species	Type of open field		LR χ^2	P
		plantation	clear-cut		
Buprestidae	*Chalcophora mariana*	2.8 ±0.59	**8.5 ±1.22**	14.1	0.0002
	Phaenops cyanea	**14.7 ±3.25**	6.7 ±1.60	5.0	0.0251
Cerambycidae	*Acanthocinus griseus*	6.6 ±1.29	**16.0 ±2.75**	9.2	0.0024
Curculionidae	*Hylurgus ligniperda*	18.5 ±4.45	**71.0 ±16.48**	11.4	0.0007
	Magdalis violacea	**14.7 ±4.42**	0.8 ±0.37	17.0	<0.0001
Elateridae	*Cardiophorus ruficollis*	**10.0 ±2.34**	2.6 ±0.75	9.9	0.0016
Tenebrionidae	*Prionychus ater*	**10.0 ±1.73**	4.7 ±0.96	6.5	0.0109
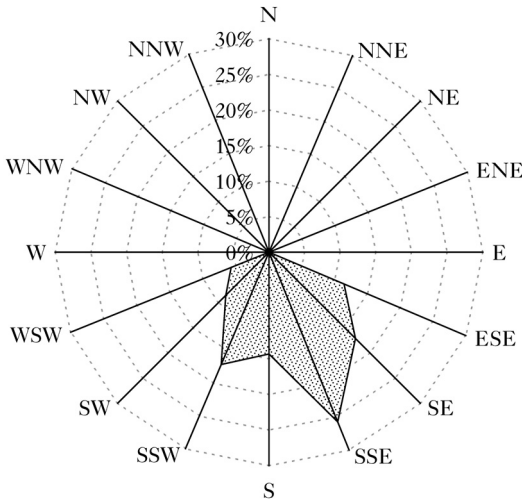
Fig. 2.

Average daily wind direction (% of all days) in the period from 16 June-20 July 2021 (data from the forest meteorological station in Sowia Góra, Poland)
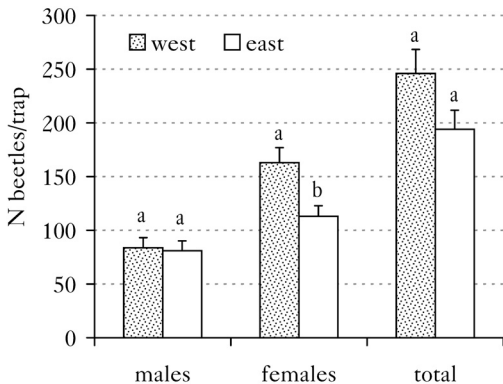

Fig. 3.

The number (means and SEs) of *M. galloprovincialis* beetles (males, females, and both sexes) captured in 33 days (from 16 June-20 July 2021) in traps deployed at the forest edge west or east of the forest. Different letters indicate significant differences between trap locations for each insect sex separately and for total catches, χ^2 test with a Holm correction at α=0.05

Table 5.

The effect of trap location relative to the forest on catches (mean ±SE) of non-target species in different site types: forest edge, plantation, and clear-cut adjacent to the forest (only significant differences are presented; bold numbers indicate higher values; df=1 in all cases)

Insect family	Insect species	Site type	Trap location		LR χ^2	P
			west	east		
Buprestidae	*Phaenops cyanea*	edge	**15.6 ±2.04**	2.6 ±0.58	27.1	<0.0001
		plantation	**20.2 ±4.61**	9.2 ±2.32	4.2	0.0393
Cerambycidae	*Spondylis buprestoides*	plantation	78.0 ±8.90	**132.0 ±14.50**	7.6	0.0059
Cleridae	*Thanasimus femoralis*	clear-cut	3.8 ±1.11	**15.0 ±3.22**	9.5	0.0021
	Thanasimus formicarius	plantation	7.6 ±1.81	**18.2 ±3.71**	5.9	0.0149
Elateridae	*Cardiophorus ruficollis*	clear-cut	1.2 ±0.49	**4.0 ±0.89**	7.9	0.0048

In contrast, significantly more *S. buprestoides*, *T. formicarius*, *T. femoralis*, and *C. ruficollis* were captured in traps east of the forest than in the traps on the west side (Table 5). For the former two species, the effect of trap location was significant only in the plantation, while for the latter two species it was significant only in the clear-cut.

Discussion

EFFECT OF TRAP PLACEMENT ON CATCHES OF *M. GALLOPROVINCIALIS*. Environmental factors play an important role in the insect life both directly by affecting their development, flight, feeding activity, *etc.*, and indirectly through availability and suitability of breeding material and food resources (Peltonen *et al.*, 1997; Jokimäki *et al.*, 1998). The amount and quality of breeding material depends also on forest management. In general, species richness and abundance of wood-associated beetles have been shown to increase when woody debris is left in open areas adjacent to forests after logging (Jonsell *et al.*, 2007; Zumr *et al.*, 2021). Among *Monochamus* species such a pattern was observed in *M. sutor* (L.) in Sweden which was more abundant in clear-cuts with woody debris than in adjacent Scots pine stands (Schroeder, 2019) and in *M. mutator* LeConte and *M. scutellatus* (Say) in North America (Allison *et al.*, 2019). When suitable breeding material was not available in open fields, catches of *M. alternatus* (Hope) decreased exponentially with increasing distance from the forest edge to the open field (rice plantations) (Ma *et al.*, 2018). Furthermore, catches of *M. carolinensis* (Oliv.) and *M. titillator* (F.) were higher at the forest edge and in the forest interior than in open fields with a gas pipeline, railroad line or highway (Allison *et al.*, 2019). In contrast to *M. sutor*, *M. mutator*, and *M. scutellatus*, the presence of woody debris (on clear-cuts or hail-damaged areas) did not affect trap catches of *M. galloprovincialis* (Rassati *et al.*, 2012; Schroeder, 2019). Differences in distribution among *Monochamus* species are most likely related to the availability of food for maturation feeding and material for oviposition. Each species has its preferred host tree species under different climatic and site conditions and is adapted to feed on specific plant parts (needles, bark on shoots, twigs, branches and/or trunks of healthy or freshly felled trees) and use breeding sites depending on bark characteristics and sun exposure (Trägårdh, 1929; Nakamura *et al.*, 1995; Peddle, 2000; Aguayo Fuentealba, 2007; Koutroumpa *et al.*, 2009; Fan, 2014; Schenk *et al.*, 2020; Nan *et al.*, 2023).

In Poland, *M. galloprovincialis* is most abundant in Scots pine monocultures growing on poor sandy soils, usually with mosses in the vegetation cover. For maturation, adults feed on the bark of shoots and twigs and possibly on needles as suggested by the laboratory studies (Koutroumpa *et al.*, 2009; personal observations). Shoots of young, *e.g.*, 7-year-old, and old trees can serve equally as a food source (own observations during laboratory rearing). For oviposition, females select tree

parts with a diameter of more than 2 cm and thin bark on weakened or dying trees and also dying large branches in crowns of healthy trees. They are usually already colonized by bark beetles, whose pheromones are used by *M. galloprovincialis* as a cue for finding a suitable host tree (*e.g.*, Pajares *et al*., 2004). Fresh (up to one month old) woody material left on the ground after stand thinning and broken branches are also readily infested (Tomminen, 1993; Brin *et al*., 2010; personal observations). *M. galloprovincialis* seems to avoid the upper, sun-exposed parts of lying woody material for oviposition, because of its faster desiccation (personal observations).

In this study, catches of *M. galloprovincialis* were higher in the plantation than in the forest interior, while no difference was found between the clear-cut and forest interior. As mentioned earlier, immature beetles can use plant parts from both young and old trees as food, thus one could expect no difference in catches of beetles after maturation feeding between the forest interior and the plantation. However, traps deployed about 1.5 m above the ground were at a close distance to the feeding sites (tree crowns) in the young plantation, and thus were able to attract more mature beetles than in the interior of old stands where crowns were more than 15 m above the ground. This reasoning may be supported by the significantly higher catches of some *Monochamus* species in the crowns than at breast height mainly in the first half of flight season, *i.e.*, when beetles undergo maturation feeding (Bodart, 2017). The lack of difference in catches of *M. galloprovincialis* between the clear-cut and the forest interior was likely due to the limited, if any, amount of fresh woody material suitable for oviposition as no additional thinning was done in the study stands and most woody debris was removed or chipped in the open fields prior to the experiment.

Interestingly, catches of *M. galloprovincialis* were highest at the forest edge, and females preferred the west-facing side. While planning the experiment, it was hypothesized that traps deployed west of the forest (either at the edge or in the open field) would catch more *M. galloprovincialis* because the prevailing wind was expected to blow from the west (Bartoszek, 2017) and to attract insects from the downwind forest. Indeed, traps located at the edge west of the forest captured more beetles than traps deployed to the east. However, the mechanism behind this must be different because the analysis of wind direction records revealed that the wind blew mainly from southerly directions (SE, SSE, and SSW). Catches at the edge could be higher than in the open field because the traps were closer to the beetles' emergence site, *i.e.*, the forest interior with wood infested by beetles in the previous year. Although this should result in the highest catches in traps in the forest interior, they were actually as low as in the clear-cut and significantly lower than in the plantation. It can be assumed that the observed pattern resulted from the indirect effect of the interaction of high solar radiation, particularly at the west-facing sunlit forest edges, and prevailing wind. High solar radiation creates specific microclimatic conditions such as higher air and soil temperature as well as lower soil moisture and air humidity (Chen *et al*., 1993; Murcia, 1995). These abiotic effects, even more severe at the most sun-exposed forest edges, could be detrimental to tree health, particularly when the forest edges are created by a sudden opening after clear-cutting (Chen *et al*., 1993, Kautz *et al*., 2013, Buras *et al*., 2018). As a result of tree weakening and increased temperatures, the emission of highly volatile monoterpenes from sun-exposed trees increases (Janson, 1993; Tarvainen *et al*., 2005; Vanhatalo *et al*., 2020). A high concentration of monoterpenes serves as a sign of suitable breeding material availability and attracts various bark- and wood-boring insects (Allison *et al*., 2004; Schütz *et al*., 2004; Wermelinger *et al*., 2007; Kautz *et al*., 2013), including *Monochamus* species (Allison *et al*., 2004; Fan *et al*., 2007; Bonifácio *et al*., 2012; Álvarez *et al*., 2016). The behavior of these volatiles in the environment, *i.e.*, the direction and speed of dispersion, is determined by numerous factors but

primarily wind and air turbulence (Murlis *et al*., 1992; Thistle *et al*., 2004; Riffell *et al*., 2008). Higher wind velocity in an open environment (under the conditions of a stable atmosphere, *i.e*., without strong wind and turbulences), wind channeling by tree free areas (*e.g*., forest roads) as well as higher numbers of odor sources and/or the size of patches (numerous trees, roots, *etc*. along the forest edge) that emit attractive odor are among the factors that increase the distance of odor dispersal and thus the potential range of beetle attraction to suitable material (Brady *et al*., 1995; Lin *et al*., 2006; Riffell *et al*., 2008; Andersson *et al*., 2013; Yeo *et al*., 2020; Nunes *et al*., 2021; Han *et al*., 2023). Therefore, traps at the forest edge could have attracted mature beetles from the adjacent young plantation and canopies of older trees, but also beetles recruited from further away by monoterpene-concentrated odor dispersed by the prevailing wind blowing along the forest edge from southerly directions.

Although the effects of distance of the traps from the nearest trees at the forest edge on landing frequency and attempted oviposition of *M. galloprovincialis* was not directly estimated, it can be assumed that placing the traps 3-5 meters from the tree line towards an open field will reduce the probability of attack by this insect and PWN transmission to healthy trees during oviposition. This assumption is based on previous observations that a portion of beetles attracted to traps deployed in the forest interior landed on trees closest to the traps (1-2 m from the trap) and made scars on the bark.

EFFECT OF TRAP PLACEMENT ON CATCHES OF NON-TARGET BEETLES. Longhorn beetles and jewel beetles have often been found in open fields because many of them are thermophilic species or feed on flowers (Wermelinger *et al*., 2007; Haack, 2017; Monné *et al*., 2017). However, their occurrence at different sites depends on their biology. Of the four most abundant longhorn beetles captured in our study plots, *S. buprestoides* was the only species whose trap catches at different site types showed a relatively similar trend to that of *M. galloprovincialis*. The highest numbers of beetles were observed in traps at the forest edge, and the lowest numbers were in traps in the forest interior. However, due to the differences in biology, the explanatory factors are also different. *S. buprestoides* seems to not require any feeding for maturation (Haack, 2017). Eggs are usually laid on roots and in bark crevices of stumps or dead and weakened trees (Dominik, 1954; Kolk *et al*., 1996; Monné *et al*., 2017). Tree stumps in open fields (after clear-cutting) and in the forest interior (after thinning), their roots, and the roots of weakened trees serve as breeding sites for this insect. However, their amount was much higher in open fields and at the forest edge than in the forest interior. A high emission of α-pinene and ethanol from these woody materials is likely used by *S. buprestoides* as a chemical cue as evidenced by significantly higher catches of this insect in traps baited with lures containing α-pinene with or without ethanol (Jurc *et al*., 2012, 2016; Hoch *et al*., 2020; Jaworski *et al*., 2022).

In contrast to *S. buprestoides*, three other longhorn beetles (*A. aedilis*, *A. griseus*, and *A. rusticus*) were most abundant in the forest interior and least abundant in the open field, regardless of their type. Interestingly, the biology of the last species is more similar to that of *S. buprestoides* than to the *Acanthocinus* species. Both *A. rusticus* and *S. buprestoides* respond to α-pinene and ethanol (Jurc *et al*., 2012; Fan *et al*., 2019), but *A. rusticus* does not infest roots deep in the soil, and its main breeding material includes relatively fresh stumps available after thinning, large standing dead or severely weakened old trees, and fresh wind-felled, broken or cut-and-left trees (Dominik, 1954). This explains the highest catches of *A. rusticus* in the forest interior followed by the forest edge, although the overall abundance of this species was low probably due to the limited amount of suitable breeding material. On the other hand, beetles of the *Acanthocinus* species prefer trees

already infested by bark beetles because they use their entrance and ventilation holes for egg-laying (Schroeder, 1997; Dodds *et al.*, 2002). This results in the much stronger attraction of *A. aedilis* and *A. griseus* to bark beetle associated kairomones than to host tree volatile compounds such as α-pinene and ethanol (Jurc *et al.*, 2012; Cocoş *et al.*, 2017; Fan *et al.*, 2019). Although these two insect species share the same host tree in pine stands, they develop in different ecological niches. *A. aedilis* usually infests the lower part of tree trunks (Dominik *et al.*, 1998) with thick bark inhabited by related bark beetles such as *Tomicus piniperda* (L.), while *A. griseus* seems to prefer the upper part of trees (Martikainen, 2002; personal observations of saproxylic beetles emerging from pine tops without branches in rearing cages) with the related assemblage of bark beetles. The close relationship of these longhorn beetles with bark beetles, which in pine stands are generally more abundant in the forest interior and at the forest edge than in open fields (Dodds *et al.*, 2002; Wermelinger *et al.*, 2007; Dodds, 2011), particularly without woody debris, explains the highest catches of both *Acanthocinus* species in the forest interior followed by catches at the edge.

Similar arguments can explain the highest numbers of the predatory beetles (*T. formicarius*, *T. femoralis*, and *C. pini*) in the forest interior with a clear decreasing trend towards the open fields. These predatory species feed mainly on adult bark beetles during infestations and at the later stages of their development (larvae and young beetles) in host trees (Warzée and Grégoire, 2003; Thomaes *et al.*, 2017) and are considered beneficial insects due to their high effectiveness in reducing bark beetle populations (Hagen *et al.*, 1999; Schroeder, 1999). It is known that the density of *Thanasimus* species depends on the abundance of their prey and is also positively correlated with the number of their prey host trees in an area (Warzée *et al.*, 2006). It is worth noting that both *T. femoralis* and *A. griseus*, associated rather with the upper part of pines (Thomaes *et al.*, 2017) and smaller bark beetles (*e.g.*, *Pityogenes* spp., *Pityophthorus* spp.), were generally more abundant in the study plots than *T. formicarius* and *A. aedilis* which are associated with the lower parts of trees and larger bark beetles (*e.g.*, *T. piniperda*) (Schroeder and Weslien, 1994; Schroeder, 1999). This is likely due to the overall good health conditions of the Scots pine stands in the study area. The small number of weakened standing trees limits the breeding material for *T. piniperda*, *Ips sexdentatus* (Börner) and other species that prefer a thick bark niche, while large branches either on standing trees or on the ground (particularly those remaining after thinning) provide favorable conditions for the development of small bark beetles and associated insects. This could also explain the significantly lower catches of *A. griseus* in traps set in the plantation than in the clear-cut where relatively large pieces of branches could still be present, although not abundant.

As noted above, most jewel beetles prefer warm habitats and are generally associated with open sites like forest edges, gaps, and clear-cuts (Evans *et al.*, 2004; Wermelinger *et al.*, 2007; Francese *et al.*, 2008; Imrei *et al.*, 2020). Catches of *Ch. mariana* and *Ph. cyanea* in our studies followed this pattern. In managed forests, *Ch. mariana* larvae usually develop in tree stumps in clear-cuts (Dominik *et al.*, 1998; Filipiak *et al.*, 2016). This insect was significantly more abundant in traps installed in the clear-cuts than in the plantations, because the stumps in the plantation were in a later stage of decomposition and thus either had been colonized by *Ch. mariana* earlier (before our experiments) or were already unsuitable for infestation. The second jewel beetle, *Ph. cyanea*, colonizes mainly weakened and recently dead pines, but it can also attack relatively healthy trees and is therefore considered a pest in managed forests (Wermelinger *et al.*, 2007). The preference for sun-exposed trees (Sowińska *et al.*, 2000; Evans *et al.*, 2004) explains the highest catches of *Ph. cyanea* at the west-exposed forest edges which typically experience more intense sunlight and higher temperatures (Hofmeister *et al.*, 2019). The significantly higher

abundance of *Ph. cyanea* in the plantation compared to the clear-cuts could be due to the possible migration of adults to pine saplings for supplementary feeding on needles (Sowińska *et al*., 2000).

Likewise the jewel beetles, all other insect species that were abundantly captured in our study (*H. ligniperda*, *M. violacea*, *C. ruficollis*, *P. ater,* and *P. ceramboides*) avoided the forest interior but the reasons were different. *H. ligniperda* usually attacks large roots and fresh conifer stumps in clear-cuts as well as freshly felled logs and stored timber (see Lin *et al*., 2021 and literature cited therein). Therefore, similarly to *S. buprestoides* and *A. rusticus*, this species is attracted to α-pinene and ethanol (Reay and Walsh, 2002). The preference for relatively fresh stumps was confirmed in our studies by the significantly higher catches of *H. ligniperda* in clear-cuts than in the plantation. In contrast, *M. violacea* was significantly more abundant in the plantation as it develops in the shoots of young conifers (Hůrka, 2005). *C. ruficollis* was also most abundant in the plantation, but unlike *M. violacea*, it develops in highly decomposed dead wood of conifers or in soil humus (Hůrka, 2005). The highest catches of *P. ater* and *P. ceramboides* at the forest edge and in the plantation can be explained by their development in already decayed wood of trunk cavities and at the base of trees/stumps of deciduous trees as well as conifers (Burakowski *et al*., 1983, 1987; Hůrka, 2005; Milberg *et al*., 2016). Fresh stumps in clear-cuts or in the forest interior (after thinning) are rather unsuitable for these species.

The effect of trap location relative to the forest on beetle catches was significant for five species. *Ph. cyanea* was the only species more numerous in the sun-exposed, western location, which was consistent with its ecological preferences. All the other four species, *S. buprestoides*, *C. ruficollis*, *T. femoralis*, and *T. formicarius*, were significantly more abundant east of the forest. The former two species appear to be more sensitive to the condition of their breeding material than the other species studied. A shorter period of exposure to solar radiation and consequently lower temperatures would have less of an adverse effect on the quality and duration of breeding site suitability. Predatory *Thanasimus* species either avoid sunlit sites or find prey in greater numbers/diversity and/or for longer periods in shadier habitats (Warzée, 2005; Johansson *et al*., 2007; Akkuzu *et al*., 2009).

Conclusions

The results of our studies suggest that for efficient use of traps for monitoring *M. galloprovincialis* in stands dominated by Scots pine traps should be deployed at the edge between forest and open field (clear-cut or plantation), preferably on the western, sun-exposed side of the forest.

Other positive outcomes of trap placement at the forest edge, preferably at the western exposure, compared to the forest interior are the following: 1) a significant reduction in the bycatch of beneficial insects, particularly predatory beetles of the genus *Thanasimus* and *C. pini*, and many other non-target species with the exception of *S. buprestoides*, 2) a significant increase in catches of forest pests/potential pests, *e.g.*, *Ph. cyanea*, *H. ligniperda*, and *M. violacea*. In addition, placement of traps 3-5 meters from the tree line towards an open field will most likely reduce the probability of bark damage for oviposition and eventual PWN transmission to healthy trees by attracted *M. galloprovincialis* females if they were carrying nematodes.

Authors' contributions

L.S. – conceptualization, methodology, investigation, formal analysis, writing-original draft, writing-review and editing, visualization, project administration, supervision; T.J. – investigation, writing-original draft, writing-review and editing; A.D. – investigation; A.R. – investigation; R.P. – investigation, writing-review and editing.

Conflicts of interest

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Appendix

A list and total numbers of insect species captured in the traps deployed at different site types in two site combinations (N traps/site = 10)

Family	Species	Site type combination incl. plantation			Site type combination incl. clear-cut			Total
		forest	edge	4-year-old plantation	forest	edge	fresh or replanted (up to 2-year-old) clear-cut	
	Abundance	4849	6051	3849	5852	7114	4457	32172
	No. species	43	51	54	50	52	51	88
Anthicidae	*Notoxus monoceros* (Linnaeus, 1760)			1		1	3	5
Buprestidae	*Agrilus angustulus* (Illiger, 1803)		14	1	1		6	22
	Agrilus betuleti (Ratzeburg, 1837)		1					1
	Agrilus laticornis (Illiger, 1803)		1	2	3	4		10
	Agrilus olivicolor Kiesenwetter, 1857					1		1
	Agrilus sulcicollis Lacordaire, 1835					1		1
	Agrilus viridis (Linnaeus, 1758)			5			4	9
	Anthaxia quadripunctata (Linnaeus, 1758)		2	12		2	5	21
	Buprestis novemmaculata Linnaeus, 1767		10	14		4	34	62
	Buprestis octoguttata Linnaeus, 1767			4				4
	Chalcophora mariana (Linnaeus, 1758)*		3	28	1	10	85	127
	Chrysobothris igniventris (Reitter, 1895)	1	14	4	5	14	14	52
	Phaenops cyanea (Fabricius, 1775)*	4	110	149	12	74	67	416
	Phaenops formaneki Jacobson, 1913		1	11		4	4	20
Cerambycidae	*Acanthocinus aedilis* (Linnaeus, 1758)*	45	35	10	62	25	7	184
	Acanthocinus griseus (Fabricius, 1793)*	323	148	66	573	273	160	1543
	Acmaeops marginatus (Fabricius, 1781)	1						1

Appendix continued (1)

A list and total numbers of insect species captured in the traps deployed at different site types in two site combinations (N traps/site = 10)

Family	Species	Site type combination incl. plantation			Site type combination incl. clear-cut			Total
		forest	edge	4-year-old plantation	forest	edge	fresh or replanted (up to 2-year-old) clear-cut	
Cerambycidae	*Arhopalus rusticus* (Linnaeus, 1758)*	110	37	17	40	34	15	253
	Leptura quadrifasciata Linnaeus, 1758	1	10	4	1	5	1	22
	Monochamus galloprovincialis (Olivier, 1800)*	**1105**	**1787**	**1514**	**1679**	**2613**	**1626**	**10324**
	Monochamus saltuarius (Gebler, 1830)	2	1	2		4		9
	Monochamus sutor (Linnaeus, 1758)				1	1	1	3
	Phymatodes testaceus (Linnaeus, 1758)	1						1
	Pogonocherus fasciculatus (DeGeer, 1775)						1	1
	Prionus coriarius (Linnaeus, 1758)			6		4	1	11
	Rhagium inquisitor (Linnaeus, 1758)	13	4	3	16	9		45
	Saperda scalaris (Linnaeus, 1758)		1					1
	Spondylis buprestoides (Linnaeus, 1758)*	587	1740	1043	688	1945	1353	7356
	Stenurella melanura (Linnaeus, 1758)	2	20	7	3	5	1	38
	Stictoleptura maculicornis (De Geer, 1775)	1	18	8	5	11	12	55
	Stictoleptura rubra (Linnaeus, 1758)	2	7	10	3	12	11	45
	Strangalia attenuata (Linnaeus, 1758)			1				1
Cerylonidae	*Cerylon ferrugineum* Stephens, 1830				5			5
	Cerylon histeroides (Fabricius, 1793)	1		2			1	4
Cleridae	*Thanasimus femoralis* (Zetterstedt, 1828)*	1657	815	120	1674	831	94	5191
	Thanasimus formicarius (Linnaeus, 1758)*	814	384	127	873	344	80	2622
Curculionidae	*Brachyderes incanus* (Linnaeus, 1758)	5	4	12	2	8	9	40
	Hylastes ater (Paykull, 1800)	1						1
	Hylastes cunicularius Erichson, 1836	2	1		1	2		6
	Hylastes opacus Erichson, 1836		12	4	3	7	2	28
	Hylobius abietis (Linnaeus, 1758)				1	1	3	5
	Hylurgus ligniperda (Fabricius, 1787)*	38	546	185	35	670	710	2184
	Ips acuminatus (Gyllenhal, 1827)			1				1
Curculionidae	*Ips sexdentatus* (Börner, 1766)	2		1	2		2	7
	Magdalis violacea (Linnaeus, 1758)*	6	35	149	23	14	8	235
	Orthotomicus suturalis (Gyllenhal, 1827)	2	1		1	1		5
	Pissodes piniphilus (Herbst, 1797)			2			1	3
	Pityogenes bidentatus (Herbst, 1784)			1				1
	Pityogenes quadridens (Hartig, 1834)						1	1
	Scolytus intricatus (Ratzeburg, 1837)	1						1
	Tomicus piniperda (Linnaeus, 1758)	3			2	2	2	9
Elateridae	*Ampedus balteatus* (Linnaeus, 1758)	15	7	13	10	18	5	68
	Ampedus pomorum (Herbst, 1784)		1	1		1		3
	Ampedus sanguineus (Linnaeus, 1758)	2	6			6	2	16
	Athous subfuscus (Müller, 1764)		1					1
	Cardiophorus ruficollis (Linnaeus, 1758)*		30	100	5	38	26	199
	Dalopius marginatus (Linnaeus, 1758)		1		3	1		5

Appendix continued (2)

Family	Species	Site type combination incl. plantation			Site type combination incl. clear-cut			Total
		forest	edge	4-year-old plantation	forest	edge	fresh or replanted (up to 2-year-old) clear-cut	
	Drapetes mordelloides (Host, 1789)			1			1	2
	Melanotus villosus (Geoffroy, 1785)	6	2	2	2	4	3	19
Elateridae	*Prosternon tessellatum* (Linnaeus, 1758)	2	8	8	3	1	5	27
	Sericus brunneus (Linnaeus, 1758)			1				1
	Stenagostus rufus (De Geer, 1774)	13	4	2	3	5	4	31
Erotylidae	*Dacne bipustulata* (Thunberg, 1781)				1			1
	Triplax russica (Linnaeus, 1758)	1			11	1		13
Eucnemidae	*Hylis foveicollis* (Thomson, 1874)	2	1	1	1		6	11
Histeridae	*Platysoma angustatum* (Hoffmann, 1803)		1		1			2
	Corticaria rubripes Mannerheim, 1844					1		1
Latridiidae	*Enicmus rugosu*s (Herbst, 1793)				1			1
	Melanophthalma maura Motschulsky, 1866		1	2			1	4
Lycidae	*Lygistopterus sanguineus* (Linnaeus, 1758)	1			3			4
Melandryidae	*Serropalpus barbatus* (Schaller, 1783)				1			1
Monotomidae	*Rhizophagus dispar* (Paykull, 1800)	7	7		17	4		35
	Rhizophagus fenestralis (Linnaeus, 1758)				1			1
Salpingidae	*Salpingus ruficollis* (Linnaeus, 1761)	1						1
	Cetonia aurata (Linnaeus, 1758)		1	1			3	5
	Gnorimus variabilis (Linnaeus, 1758)			4		1		5
Scarabaeidae	*Phyllopertha horticola* (Linnaeus, 1758)		1					1
	Protaetia metallica (Herbst, 1782)	2	15	38		2	1	58
	Serica brunnea (Linnaeus, 1758)	2	3	1	2	3	1	12
	Tropinota hirta (Poda, 1761)			2			2	4
Sphindidae	*Sphindus dubius* (Gyllenhal, 1808)		1					1
	Corticeus linearis (Fabricius, 1790)					2		2
Tenebrionidae	*Corticeus pini* (Panzer, 1799)*	18	6	9	20	10	6	69
	Prionychus ater (Fabricius, 1775)*	32	157	100	38	61	47	435
	Pseudocistela ceramboides (Linnaeus, 1758)*	6	26	27	3	7	13	82
	Uloma culinaris (Linnaeus, 1758)				1		1	2
Throscidae	*Trixagus dermestoides* (Linnaeus, 1767)	9	9	10	9	12	6	55
Trogossitidae	*Nemozoma elongatum* (Linnaeus, 1761)				1			1

* species subjected to statistical analyses

STRESZCZENIE

Optymalizacja lokalizacji pułapek do monitoringu *Monochamus galloprovincialis* i ograniczenia odłowów owadów pożytecznych

Żerdzianka sosnówka *Monochamus galloprovincialis* (Oliv.) jest gatunkiem kambio- i ksylofagicznym zasiedlającym silnie osłabione, zamierające oraz świeżo zamarłe drzewa, w Polsce głównie sosnę zwyczajną. Znaczenie tego gatunku wzrosło po stwierdzeniu w Portugalii przenoszenia przez chrząszcze węgorka sosnowca *Bursaphelenchus xylophilus* (Steiner et Buhrer) Nickle, inwazyjnego gatunku nicienia powodującego (w sprzyjających warunkach) gwałtowne zamieranie sosny, tzw. chorobę więdnięcia sosen. Do monitoringu występowania węgorka zaleca się m.in. odłowy i analizę jego wektorów. Dotychczas przeprowadzono liczne badania na temat możliwości zwiększenia efektywności pułapek do odłowu żerdzianek, ale wpływowi lokalizacji pułapek na skuteczność odławiania tych chrząszczy poświęcono niewiele uwagi. Rzadko również podejmowano prace mające na celu ograniczenie odłowów innych, niecelowych gatunków owadów, szczególnie pożytecznych. Celem niniejszej pracy było określenie wpływu: (1) typu powierzchni (wnętrze drzewostanu, brzeg drzewostanu lub sąsiadująca powierzchnia otwarta), (2) typu powierzchni otwartej (zrąb lub uprawa), (3) ekspozycji pułapki (zachodnia lub wschodnia) względem drzewostanu na odłowy *M. galloprovincialis* i innych gatunków chrząszczy. Planując doświadczenie (3), przyjęto założenie, że dominujący w Polsce kierunek wiatru (zachodni) może sprzyjać zwiększeniu odłowów żerdzianek do pułapek umieszczonych po zachodniej stronie drzewostanu.

Badania przeprowadzono w 86-91-letnich drzewostanach sosnowych oraz w sąsiadujących powierzchniach otwartych 2 typów: zręby zupełne (włączając 2-letnie uprawy) oraz 4-letnie uprawy. Do odłowu owadów zastosowano białe krzyżowe pułapki IBL-5 (ZD Chemipan, Polska) pokryte suchym teflonem w sprayu z atraktantem Galloprotect Pack (SEDQ, Hiszpania). Doświadczenie zaplanowano w układzie losowanych bloków (tab. 1), po jednej pułapce na różnych typach powierzchni/ekspozycji w ramach jednego bloku.

Od połowy czerwca do połowy lipca 2021 r. do pułapek odłowiono 88 gatunków chrząszczy. Najliczniejszymi gatunkami były *M. galloprovincialis* (32,1%), *Spondylis buprestoides* (22,9%) i *Thanasimus femoralis* (16,1%).

Typ powierzchni miał istotny wpływ na odłowy obu płci *M. galloprovincialis* (ryc. 1), a także 14 innych gatunków chrząszczy (tab. 2). *M. galloprovincialis*, *Hylurgus ligniperda*, *S. buprestoides* i *Prionychus ater* były najliczniejsze na obrzeżu drzewostanu, choć w niektórych przypadkach nie stwierdzono różnic w ich liczebności między obrzeżem a sąsiadującą powierzchnią otwartą (tab. 3). Odłowy *M. galloprovincialis* w uprawie były istotnie większe niż w drzewostanie, podczas gdy różnice między zrębem a drzewostanem były nieistotne (ryc. 1). Liczebność 3 gatunków kózek (*Acanthocinus aedilis*, *A. griseus* i *Arhopalus rusticus*) oraz 3 gatunków owadów drapieżnych (*T. formicarius*, *T. femoralis* i *Corticeus pini*) malała w kierunku od wnętrza drzewostanu do powierzchni otwartej. Odwrotny trend stwierdzono w przypadku *Chalcophora mariana*, *Phaenops cyanea*, *Magdalis violacea*, *Cardiophorus ruficollis* i *Pseudocistela ceramboides*.

Typ powierzchni otwartej miał istotny wpływ na odłowy 7 gatunków chrząszczy (tab. 4), ale nie *M. galloprovincialis*. Od ekspozycji pułapki względem drzewostanu istotnie zależała liczebność samic *M. galloprovincialis* (ryc. 3) oraz chrząszczy *Ph. cyanea*, *S. buprestoides*, *T. formicarius*, *T. femoralis* i *C. ruficollis* (tab. 5). Pierwsze 2 gatunki były liczniejsze na stronie zachodniej względem drzewostanu, a pozostałe – na stronie wschodniej.

Przeciwnie do założeń, w okresie badań dominowały wiatry z kierunków południowych (ryc. 2). Wydaje się zatem, że na odłowy *M. galloprovincialis* największy wpływ ma nasłonecznie-nie, czynniki decydujące o rozprzestrzenianiu się związków zapachowych ze środowiska natural-nego i pułapek, a także obecność i stan bazy pokarmowej oraz lęgowej. Artykuł zawiera obszerną dyskusję na temat potencjalnego wpływu poszczególnych czynników na liczebność zarówno *M. galloprovincialis*, jak i innych najliczniej odławianych gatunków chrząszczy.

Uzyskane wyniki sugerują, że w celu zwiększenia efektywności pułapek do monitoringu *M. galloprovincialis* należy je wywieszać na obrzeżu drzewostanu, 3-5 m od ściany lasu, szczegól-nie na jego zachodniej, bardziej nasłonecznionej stronie. Pozytywnymi elementami takiej loka-lizacji pułapek jest też: 1) znaczna redukcja odłowów owadów pożytecznych, zwłaszcza drapież-nych chrząszczy z rodzaju *Thanasimus* i *C. pini*, a także innych gatunków owadów (z wyjątkiem *S. buprestoides*), 2) znaczne zwiększenie odłowów szkodliwych owadów leśnych i potencjalnych szkodników, np. *Ph. cyanea*, *H. ligniperda* i *M. violacea*. Wywieszanie pułapek w pewnej odległości od ściany lasu w kierunku powierzchni otwartej (np. na drewnianych palikach) może również ograniczyć uszkadzanie kory celem składania jaj na sąsiadujących żywych drzewach przez zwabione do pułapek chrząszcze *M. galloprovincialis*, a tym samym ich ewentualną infekcję węgorkiem sosnowcem.