SYLWAN 167 (11): 695-708, November 2023
https://doi.org/10.26202/sylwan.2023066
Journal homepage: https://sylwan-journal.pl

ORIGINAL PAPER

Efficacy and costs of using breeding traps to monitor the small banded pine weevil *Pissodes castaneus* (De Geer, 1775)

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ABSTRACT

Pissodes castaneus (Coleoptera, Curculionidae) is one of the most dangerous pests to Scots pine *Pinus sylvestris* reforestations and thickets weakened by various biotic (root diseases and herbivorous mammals) and abiotic (drought, shortage, frost, hail, *etc.*) factors. In the case of a massive occurrence of *P. castaneus*, the growth of shoots can be inhibited, but the feeding of larvae is more harmful to trees as it leads to the death of trees during growing season. In the 20th century, *P. castaneus* was not the subject of much research in biology, ecology, and methods of population control which is due to the fact that this species was not an economic problem for a long time. The lack of effective and environmentally safe methods to protect young Scots pine stands from *P. castaneus* warranted conducting research to develop methods to monitor and limit its population.

The objective of the study was to evaluate the effectiveness of using the breeding trap method for monitoring the number of *P. castaneus*. The research was conducted from 2020-2022 in *P. sylvestris* reforestations aged 3-7 years and located in the Wyszków Forest District (central Poland). The traps consisted of stems of live Scots pines without branches, 5-15 cm in diameter and about 1.5 m in length, dug in May each year at a depth of about 0.5 m in rows of up to 10 pieces/ha. After 6 months, the traps were dug up and the sections in the soil were debarked to a depth of 20 cm along with the aboveground section to a height of 20 cm. The larvae and pupal chambers of *P. castaneus* were counted in the debarked sections. The obtained results were converted to 1 dm^2. In addition, the relationship between the number of *P. castaneus* and its pupal chambers was found, and the diameter of the piles was determined. In addition, the cost of the tested method was compared with the cost of the previously used method to control *P. castaneus* which consisted of uprooting and removing infested trees.

The evaluation of breeding trap colonization revealed that *P. castaneus* inhabited only the underground section of the breeding traps (from 0 to –0.2 m) as evidenced by the presence of larvae in feeding tunnels and pupal chambers as well as pupal chambers left by beetles – up to a maximum of 8 pieces/dm^2 and on average 3.8 ±1.5 pieces/dm^2. The analysis of the relationship between the number of larvae and pupal chambers and the diameter of the traps showed a higher probability of colonization by *P. castaneus* in traps with a diameter of 10-15 cm. The tested method, with the use of up to 10 traps per 1 ha, was characterized by lower implementation costs compared to the costs of *P. castaneus* controls by uprooting and removing of infested trees. The results indicate

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Received: 21 August 2023; Revised: 14 January 2024; Accepted: 15 January 2024; Available online: 10 February 2024

the usefulness of breeding traps for monitoring the occurrence of this pest in young Scots pine stands.

KEY WORDS

economic evaluation, forest protection, reforestations, Scots pine, weevils

Introduction

In Poland, the genus *Pissodes* (Coleoptera; Curculionidae, subfamily Molytinae) is represented by 7 species (Wanat and Mokrzycki, 2018). With the exception of *Pissodes validirostris* (Sahlb.), all species feed on the cambium and bast of conifers, mainly Scots pine *Pinus sylvestris* L., Norway spruce *Picea abies* (L.) H. Karst, and silver fir *Abies alba* Mill. (Långström and Day, 2004). These insects infest the trunks and branches of weakened or dying trees, often with various bark beetle species and fungal pathogens. *Pissodes castaneus* (De Geer, 1975) is a vector of root rot pathogens such as *Heterobasidion annosum* Fr. (Bref.), *Armillaria* spp., rust fungi, *e.g.*, *Cronartium pini* (Willd.) Jørst. and *Ophiostoma* Syd. & P. Syd. (Livingston and Wingfield, 1982; Kadlec *et al.*, 1992; Viiri, 2004; Jankowiak and Bilański, 2013).

Pissodes castaneus is one of the most dangerous pests of young *P. sylvestris* stands (mainly up to 10 years of age) weakened by fungal diseases of the root system and by deer as well as by abiotic factors such as drought, frost, hail, improper planting (*e.g.* curled roots) or fire (Iede *et al.*, 2010; Panzavolta and Tiberi, 2010; Santolamazza-Carbone, 2011; CABI, 2017; Skrzecz, 2017).

The dynamics of *P. castaneus* population trends over the past 20 years indicate that this species continues to be a threat to forest crops (Jabłoński, 2023). One of the most important reasons for this phenomenon are the frequent droughts and accompanying high air temperatures (≥30°C). Such weather conditions favors the weakening of reforestations, which is particularly sensitive to the negative effects of abiotic factors (Sturrock *et al.*, 2011; Skrzecz and Perlińska, 2018; Kemppinen *et al.*, 2020).

In Poland, until the end of the 20th century no intensive research was carried out on the biology, ecology and control methods of *P. castaneus* because for many years this species did not represent an economic problem. There is a limited amount of information in the available literature on the prevention of damage and protection of young *P. sylvestris* stands against *P. castaneus* (Långström and Day, 2004; Panzavolta and Tiberi, 2010). The only method of limiting the population of this species used currently in practice is to remove and destroy the trees infested by *P. castaneus* (Grégoire and Evans, 2004; IOL, 2012). In the 1950s, Górnaś (1957) investigated the usefulness of fragments of fresh, non-debarked pine stems dug into the soil to limit the population of *P. castaneus*. After two years of research, he concluded that this type of breeding trap (Górnaś used the term ‘standing trap’) attracts the pest and can, therefore, be used to reduce its numbers. In Poland, digging the stem fragments without branches (hereafter referred to as ‘breeding traps’) obtained from living, several years old *P. sylvestris* trees is the recommended method for monitoring and reducing pest infestations in threatened stands (IOL, 2012). As the results of this method are ambiguous, it is controversial among foresters who use it. As stated above, only Górnaś (1957) dealt with this issue, but there is no current data in the literature to evaluate the effectiveness and usefulness of this method based on empirical data in the conditions of long-term drought and high air temperatures systematically occurring during the growing season, especially over the last 20 years. The lack of effective, and at the same time environmentally safe methods, was the reason for conducting research to verify the method of planting pine poles to monitor and reduce the number of *P. castaneus* in Scots pine stands in the conditions of a warming climate. Evaluation of the effectiveness of this method for monitoring and reducing the number of *P. castaneus* adults using natural traps from live *P. sylvestris* pines was conducted based on the comparing:

– the intensity of breeding trap colonization by *P. castaneus*,
– comparing the potential cost of using the method tested in this research with the cost of currently used protection methods.

Material and methods

FIELD EXPERIMENTS. The study was conducted from 2020-2022 in a total of five *P. sylvestris* reforestation stands aged 3-7 years located in Wyszków Forest District (central Poland, coordinates: 52.63704, 21.45341) (Table 1). Pine traps consisting of fragments of fresh pine stems with bark with a diameter of 5-15 cm and a length of 1.5-1.8 m were used for the study. The traps prepared in this way were dug into the soil in the reforestations in the first half of May at a depth of about 0.5 m and in rows of containing 5 or 10 breeding traps along the transects from the edge to the center of the crop (Fig. 1). A total of 75 traps were set of which there were 25 in 2020, 20 in 2021, and 30 in 2022 (Table 1). The distance between the traps was about 10 m. After digging, the diameter of the traps was measured just above the ground surface.

Assessment of breeding trap colonization by the pest occurred each year in October which was approximately 6 months after the traps were placed in the ground. After digging up the breeding traps, they were debarked. Due to the consistent lack of pests in the above-ground section, detailed measurements were taken in the soil to a depth of about –0.2 m, and the aboveground fragments were debarked from the soil to a height of 0.2 m. *P. castaneus* larvae were counted in the feeding tunnels and pupal chambers. Since the traps were characterized by different diameters,

Table 1.
Characteristics of the experimental plots and breeding traps in the Wyszków Forest District

Year	Experimental plots*			Traps		
	Forest subcompartment	area [ha]	age [year]	number [pcs.]	diameter [cm]	height [m]
2020	74 m	1.8	3	25	7.8 ±1.4	1.5
2021	68 a	3.9	7	10	11.1 ±1.9	1.8
	75 j	3.4	6	10		
2022	67 b	4.0	3	15	10.6 ±2.7	1.6
	75 k	3.3	3	15		

* all experimental plots on the site of fresh mixed coniferous forest

Fig. 1.
Breeding traps in the reforestations threatened by *P. castaneus*

the number of larvae and pupal chambers per 1 dm^2 of debarked area was calculated. In addition, the relationship between the number of larvae and pupal chambers of *P. castaneus* and the diameter of the traps was determined. This relationship was expressed by Pearson's correlation coefficient r. The calculations were performed using the Statistica 13.3 (TIBCO, 2017) software.

Cost comparison. To compare the cost of the breeding trap method (*i.e.*, the method tested) with the cost of the mechanical method currently in practice, which consists of uprooting and removing the trees inhabited by *P. castaneus* from the forest (*i.e.*, the reference method), analyzes were conducted to determine the following:

1) the potential cost of using the method tested with breeding traps,
2) the actual cost of controlling *P. castaneus* in pine stands using the mechanical method (*i.e.*, the reference method),
3) comparison of the cost between the tested method and the reference method.

Note 1) The actual cost of mechanical control of *P. castaneus* in pine stands was determined based on State Forests financial data collected from the State Forest Information System (SILP) database. They included the cost of Scots pine stand protection activities carried out from 2017-2021 in the areas of the 16 forest districts characterized by the largest *P. castaneus* control area in Poland (Fig. 2).

Note 2) The potential cost of monitoring and controlling *P. castaneus* using the method tested was determined based on the methodology used in the studies presented as follows:
- material: fresh, unbarked breeding traps from healthy pines (diameter 5-15 cm, length 1.5-1.6 m), 5-10 pieces per 1 ha of reforested area;
- labour-intensive: production of breeding traps, their transport to the forest and planting in the soil, monitoring of traps at least 3 times per growing season.

Based on the methodology assumptions, the potential costs of monitoring or controlling *P. castaneus* with breeding traps (K_{BT}) was calculated as follows:

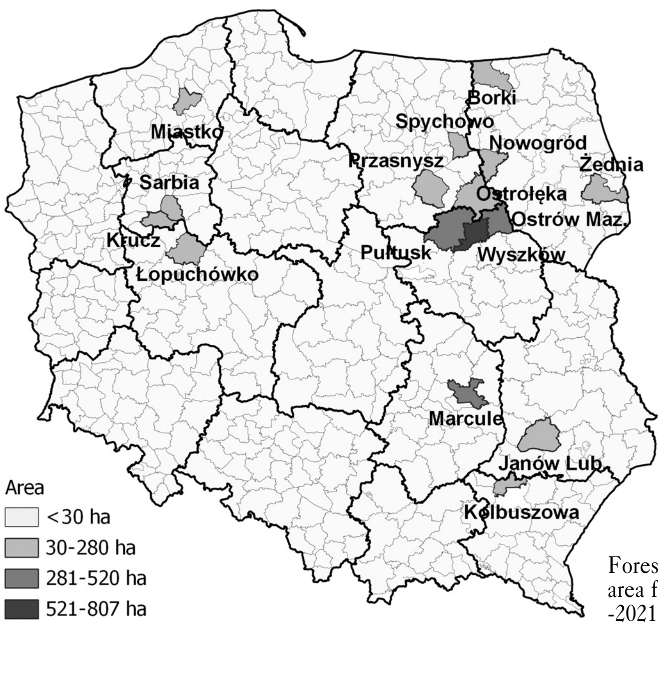

Fig. 2.
Forest districts with the largest total area for *P. castaneus* control from 2017--2021

$$K_{BT} = k_{bt} + k_w + k_d + k_u + k_k \quad (1)$$

k_{ps} – cost of the wood used to make the traps [PLN (EUR)/ha],
k_w – cost of making traps [PLN (EUR)/ha],
k_d – cost of delivering traps [PLN (EUR)/ha],
k_u – cost of digging traps [PLN (EUR)/ha],
k_k – cost of controlling the colonization of traps by *P. castaneus* [PLN (EUR)/ha].

The analysis assumed the costs applicable in Poland in November of 2022 and the EUR exchange rate according to the National Bank of Poland (Table B of November 9, 2022). The cost of the wood used for the production of breeding traps was determined based on the average price of 1 m^3 of Scots pine wood from the portal e-drewno (September 2022) which was PLN 385 (EUR 85). The cost of making the breeding traps was calculated on the basis of the time standard for forestry work in timber harvesting (total timber production without debarking with the help of a saw using medium-sized stacked timber with a length of more than 1.5 m equating to a labour time of 1.4 hours/m^3) (Lasy Państwowe, 2022). The cost of transporting the traps was calculated on the basis of the working time standard for the timber chassis by mechanical means (use of a chassis for large-sized and medium-sized stacked timber with a length of more than 1.5 m, delivery to a maximum of 5 km distance equating to 0.2 hours/m^3) (Lasy Państwowe, 2022). The cost of setting breeding traps and their monitoring (at least three times per growing season) was calculated on the basis of the time standard for silvicultural activities of forest management (setting weevil traps equating to 0.1 hour/trap) (Lasy Państwowe, 2022). The minimum hourly rate was assumed to be PLN 20/hour (EUR 4.4/hour).

Note 3) The comparison of the cost between the tested method and the reference method concerned the cost dimension resulting from the labor and material consumption required to perform a given protection method.

Results

Efficiency assessment. During the three-year study, *P. castaneus* was found to inhabit only the underground fragments of breeding traps (from 0 to –0.2 m) as evidenced by the presence of larvae in feeding tunnels and pupal chambers as well as abandoned pupal chambers.

In 2020, *P. castaneus* development was noted on 23 out of 25 breeding traps. Their colonization was the lowest within the time span of the study period, *i.e.*, up to 4 pieces/dm^2, averaging 1.2 ±1.0 pieces/dm^2 (Fig. 3). No live or dead *P. castaneus* were found in 2021 with only the remaining pupal chambers on 18 of the 20 pine traps. Numerous pupal chambers of *P. castaneus* were found on the debarked fragments of the traps (up to 8 pieces/dm^2) with an average of 3.8 ±1.5 pieces/dm^2. At the same time, this was the highest colonization level of breeding traps in the whole 3-year study period. In 2022, 27 of 30 breeding traps were colonized by *P. castaneus* with up to 6 individuals/dm^2 and an average of 2.6 ±2 individuals/dm^2. The most important developmental stage of *P. castaneus* (based on which the degree of trap colonization was determined) was larvae in the feeders and pupal cradles. In addition, several dozen larvae of *Rhagium* spp. and a single larva of the pine weevil *Hylobius abietis* L. were found on the debarked fragments of the traps. In 2020 and in 2021, two traps were not colonized by *P. castaneus* and three traps in 2023 were not colonized, all of which were most likely colonized by saprotrophic fungi.

Analysis of the relationship between the number of *P. castaneus* larvae and pupal chambers found and the diameter of the traps showed a statistically significant correlation (p<0.001) (Fig. 4).

The relationship was positive meaning that an increase in the value of one variable directly affected the increase in the other variable. The value of the correlation coefficient (r) at the level of 0.903 indicates a very strong relationship, while the value of the coefficient of determination (r^2) indicates that 81% of the observations of the variable abundance of *P. castaneus* can be explained by the variable trap thickness (Table 1). This means that *P. castaneus* is more likely to colonize the underground sections of traps (–0.2-0 m) with a larger diameter, *i.e.* 10-15 cm (Fig. 4).

COST COMPARISON. Any method introduced into forestry practice should not only be effective, but also have an acceptable cost for its application based on the expected labor costs as well as

Fig. 3.
Debarked fragment of the breeding trap with visible pupal chambers of *P. castaneus*

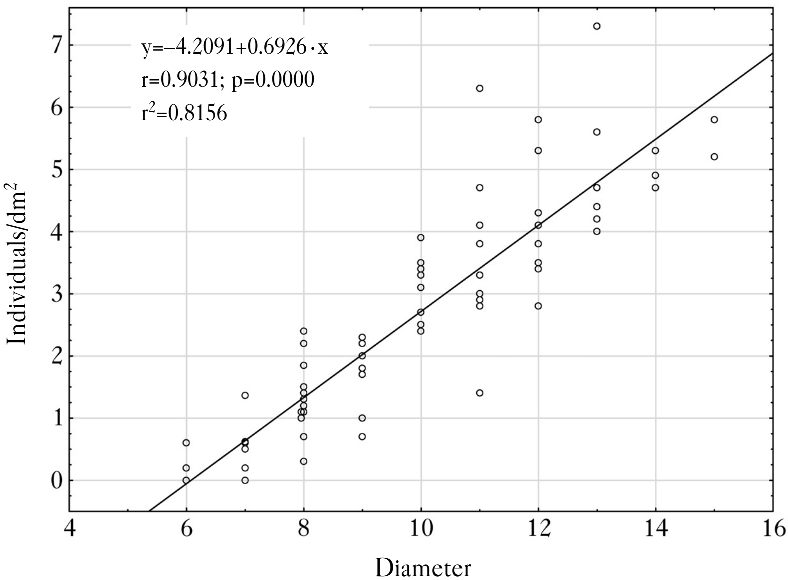

Fig. 4.
Relationship between the diameter of a breeding trap and the abundance of *P. castaneus* on the underground sections of breeding traps (–0.2-0 m)

demand for materials and services. Therefore, the potential cost of the tested method was compared with the actual cost of the currently used mechanical protection method (reference method including the uprooting and removal of infested trees).

Actual costs of protective treatments from 2017-2021. The primary method of controlling *P. castaneus* from 2017-2021 was to search for and uproot infested trees and then remove them by digging or burning. The average costs of controlling *P. castaneus* using this method in forest districts during the 2017-2021 period are shown in Table 2. Significant variability is shown both depending on the forest district (from 26 to 1986 PLN/ha, see Table 2) and in individual years (from 299 to 760 PLN/ha, see Fig. 5). The different colonization intensities of individual reforestation stands by *P. castaneus* and the related differences in the labor intensity of protective measures consisted of identification and uprooting of infested trees.

The average cost of controlling *P. castaneus* in pine stands, based on the collected data, was PLN 445/ha (99 EUR/ha) (Fig. 5). During the further course of the study, this value was used as a reference for the calculated costs of the tested method.

Potential costs of using breeding traps. Cost of the tested method (for 10 traps per ha) was PLN 208 (EUR 46.2) including the following values:

- the value of the wood used – 115.5 PLN (25.7 EUR),
- production of traps – 8.4 PLN (1.9 EUR),
- delivery of the traps (optional costs, not incurred if the traps are made on site) – 4 PLN (0.9 EUR),
- trap digging – 20 PLN [4.4 EUR],
- monitoring of the traps – 60 PLN (13.3 EUR).

Table 2.

Average cost of eradicating *P. castaneus* using the mechanical reference method in selected forest districts during the 2017-2021 period

Forest District	Average cost						
	2017 [PLN]	2018 [PLN]	2019 [PLN]	2020 [PLN]	2021 [PLN]	Average 2017-2021 [PLN]	Average 2017-2021 [EUR]
Borki		340				340.18	75.60
Janów Lubelski	201	259	308		1986	688.64	153.03
Kolbuszowa	413	366	330		271	344.87	76.64
Krucz		824				824.39	183.20
Łopuchówko		368	951			659.64	146.59
Marcule	106	93	142	161	157	132.08	29.35
Miastko		546	362			453.98	100.88
Nowogród		851	491			671.09	149.13
Ostrołęka	388	565	436	486	560	486.96	108.21
Ostrów Mazowiecka		26	57			41.41	9.20
Przasnysz		691	200			445.53	99.01
Pułtusk		693	292	718		567.69	126.15
Sarbia		800				800.00	177.78
Spychowo		419	79		827	441.98	98.22
Wyszków	388	595	366	75		356.09	79.13
Żednia		346	112			229.33	50.96

The main component affecting the price of tested method was the value of the wood used for the traps (55% of the total cost in Fig. 6).

Comparison of pine trap using costs with reference costs of *P. castaneus* controls from 2017-2021. The tested method is characterized by lower average costs compared to the average costs of controlling *P. castaneus* with the mechanical reference method from 2017-2021 (Fig. 7). The main reason for this is the significantly lower labor cost of the tested method (breeding traps) compared to the method in which the entire stand is inspected and the infested trees are removed.

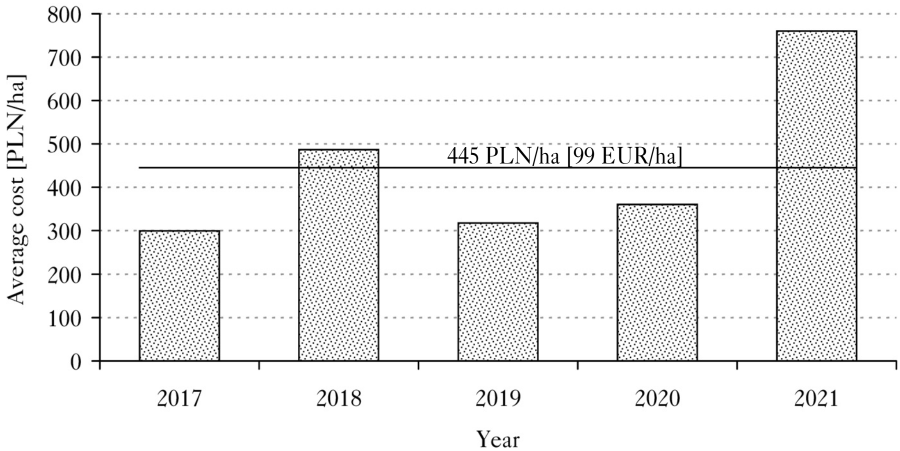

Fig. 5.
Average cost of controlling *P. castaneus* with the mechanical reference method in the period 2017-2021; the graph shows the cost in individual years and the average cost for the entire study period [PLN/ha]

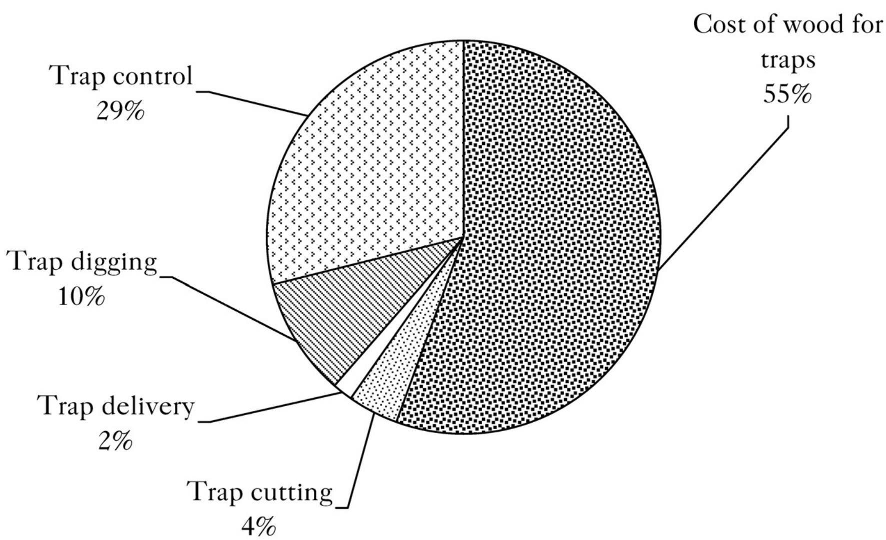

Fig. 6.
Contribution [%] of the main cost categories of *P. castaneus* control using the test method (breeding traps)

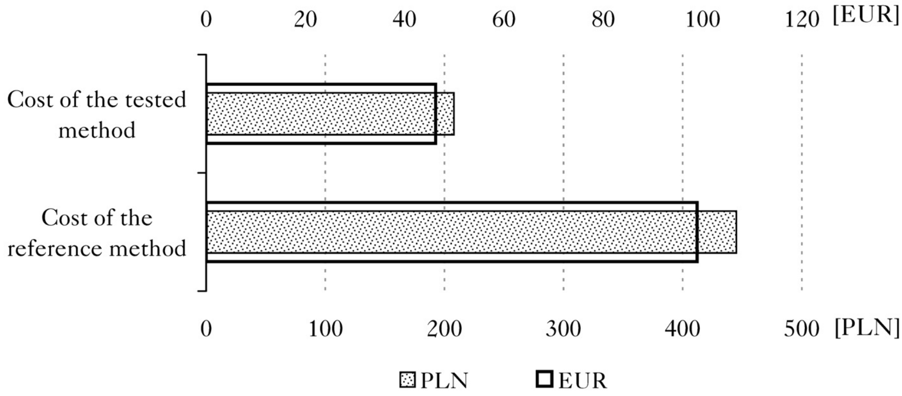

Fig. 7.

Comparison of the average cost [PLN (EUR)/ha] of the tested method with the average cost of eradication of *P. castaneus* using the reference method from 2017-2021

Discussion

There is some information in the literature on methods to predict and control *P. castaneus*. It comes mainly from South America and Europe (Grégoire and Evans, 2004; Iede *et al*., 2007; Prokocka *et al*., 2016; Skrzecz *et al*., 2016, 2019). Iede *et al*. (2007) pointed out the possibility of using parasitoids from the Chalcididae, Ichneumonidae, and Braconidae families and confirmed that in Brazil some pest treatments using fenitrothion (the active ingredient of organophosphate insecticides) were carried out. A series of studies was conducted in Poland to develop protection methods against the pine weevil in 2-5 year old Scots pine stands using biological and chemical methods. The work included spraying trees with the fungus *Beauveria bassiana* (Bals.) Vuill. and pyrethroids alpha-cypermethrin and cypermethrin (Prokocka *et al*., 2016; Skrzecz *et al*., 2016, 2019; Skrzecz, unpublished data). Field spraying with *B. bassiana* did not result in a reduction of pine damage caused by *P. castaneus*. In contrast, the use of pyrethroids resulted in the significant reduction of damage caused by the small banded pine weevil to young Scots pine trees. Despite the high efficacy, it seems that the use of chemical protection methods on young stands have no future because of the need to protect the environment as well as the health of animals and people. To meet these priorities, the use of insecticides has been systematically reduced in European Union countries. This applies in particular to polytoxic pyrethroids whose use has negative effects on non-target insects (Matyjaszczyk *et al*., 2019). Therefore, alternative methods need to be developed including pest monitoring in threatened reforestation areas.

In the 1980s, compositions of aggregation pheromones of *Pissodes strobi* (Peck), *P. nemorensis* (Germar) and *P. approximatus* (Hopkins) were detected and identified in the USA consisting of grandisol and grandisal in different proportions for each species. In addition, strong synergy between the aggregation pheromones and the primary attractants (compounds secreted by the branches of a tree inhabited by *P. castaneus*) was detected (Booth *et al*., 1983). Marques *et al*. (2011) showed that the same compounds are also pheromones that attract *P. castaneus* beetles. These results inspired research to be conducted in Poland to develop a pheromone dispenser containing compounds secreted by pine (*e.g.*, α-pinene and ethanol) and the aggregation pheromones of *P. castaneus*, namely grandisol and grandisal. The results obtained indicated the possibility of developing a pheromone that could be used in conjunction with the Unitrap trap (trap with green bucket) to monitor the number of pests (Skrzecz *et al*., 2019). These studies are currently still continuing and aim to develop the final form of the pheromone dispenser (Skrzecz, unpublished data).

There are very little data in the available literature on the possibility of using traps made from stem fragments of young pines for monitoring and controlling *P. castaneus*; therefore, comparison of the obtained results is extremely difficult. Górnaś (1957) demonstrated extremely high colonization rates of 1.5 m long and 5-12 cm thick stem fragments of young pines. This possibility is pointed out by Grégoire and Evans (2004), who, in an informational summary on the European species of *Pissodes*, mention Poland and Hungary as countries where this method is used without giving further details. More specific information was provided by Iede *et al.* (2007), who noted that this method is used in Brazil, where it is recommended that several 2 m long and 6-10 cm thick stem fragments of young pines be laid out in the form of a pile that provides protection against drying of the individual fragments (Iede *et al*., 2007). Our research has demonstrated the usefulness of traps made of healthy pines dug into the ground for monitoring the occurrence of the pest in 2-5 year old forest stands. We demonstrated that the degree of colonization of traps depends on their diameter. Traps with a diameter of 10-15 cm and a total height of about 1.5 m had the highest level of colonization. Pine traps with such parameters did not dry out during the growing season and were, therefore, attractive breeding material for the pest in reforestation stands. It should be emphasized that the youngest stands were intensively exposed to the extremely high air temperatures (above 30°C) that prevailed in Poland during most of the summer in recent years, especially since 2015 (Boczoń, 2019; Jabłoński, 2019; Szmidla, 2023). Therefore, the trap diameter we recommend is larger than that recommended by IOL (2012), *i.e.*, 6-10 cm and Górnaś (1957), *i.e.* 5-12 cm. The faster drying of the above-ground section due to high air temperatures was most likely the reason why *P. castaneus* inhabited only the belowground section of the traps, where the soil provides more favorable conditions for its development due to higher humidity and lower temperature. Thus, the relationship found by Górnaś (1957) was not confirmed, because in his studies only the aboveground section of the traps with thick bark was inhabited by *P. castaneus*.

In addition, care should be taken not to make traps from fungus-infected trees, since saprotrophic or pathogenic fungal material is not colonized by *P. castaneus*. Similar relationships were shown by Skrzecz (2001), who demonstrated that the pine weevil *H. abietis*, also an economically important pest in *P. sylvestris* crops, does not develop in roots infected with a saprotrophic fungus *Phlebiopsis gigantea* (Fr.) Jülich. For monitoring the pest, the placement of 5-10 breeding traps per hectare is recommended, preferably along the transect from the edge to the center of the reforestation, to assess the presence of the pest in locations with different levels of sunlight. However, in order to control the pest, increasing the number of traps to 10-20 per 1 ha, as advised in IOL (2012), is recommended.

Many authors point out the important role of weevils (Curculionidae) in the decline of tree crops. This problem is particularly important in pine crops (Lieutier *et al*., 2004). The growing role of *P. castaneus* is causing large economic losses (economic damage) as highlighted by Iede *et al*. (2007) and Ukan *et al*. (2013).

Unfortunately, the cost of protecting pine stands against weevils has not been adequately considered and is even ignored in Poland. Andrzejczyk (1980) included the cost of forest protection along with the cost of fire protection when calculating the cost of timber production. Arbatowski *et al*. (1989) suggested calculating the efficiency index for the poorest forest areas based on, for example, costs of establishing reforestation stands and other costs connected with maintaining the reforestation areas. It is reasonable to assume that the costs of reforestation protection may fall into the latter category. Długosiewicz *et al*. (2019) pointed out the significant proportion of costs associated with corrections to reforestations. However, they did not consider the costs associated with their protection.

In view of the increasing threat of *P. castaneus*, an extremely important aspect of the protection methods used in practice is based on their economic costs. The method used so far to protect pine stands against *P. castaneus* (uprooting of infested trees) is highly dependent on the number of pests. Therefore, the cost of protecting pine stands against this pest is highly variable and unpredictable. In extreme cases, they can exceed the costs spent on planting. In addition to the direct costs of protective treatments, which are labor-intensive, the successive removal of trees from cultivation can lead to their self-destruction and to additional costs for the renewal of gaps or of entire stands.

The tested method (breeding traps) is characterized by much higher stability and cost predictability which is essential for planning the costs of monitoring and protecting pine stands against *P. castaneus* in forest districts. It is also significant that the breeding trap method requires less labour compared to the protection method which involves uprooting and removing infested trees. This also applies to the monitoring of *P. castaneus* which requires 2-3 checks of *P. castaneus* infestation to be carried out in the season with 10 pine traps (per ha) instead of examining the entire stand.

This is reflected in the results obtained in this research. The potential cost of monitoring *P. castaneus* using breeding traps was twice that of the reference method. If pine traps are used to control the pest, their number should be increased to at least several dozen/ha. In this case, the cost of this method increases to 2-3 times higher than that of the calculated cost of the reference method. It should also be emphasized that the costs of using pine traps determined by this research may be subject to changes due to external economic forestry conditions, *e.g.* an increase in the minimum wage, changes in timber prices as well as services and labor intensity standards in forestry (Kocel, 2004; Kwiecień and Kocel, 2006).

Conclusions

The hypothesis on the usefulness of pine traps for monitoring and/or controlling the occurrence of *P. castaneus* in 3-7-year-old pine stands was confirmed.

Only the underground section of the traps (from 0 to –0.2 m) was colonized. The degree of colonization depended essentially on the diameter of the traps. Traps with a diameter of 10-15 cm were the most colonized. Traps with these parameters did not dry out during the growing season and were attractive breeding material for the pest. Traps colonized by fungus were not colonized by *P. castaneus*.

The average cost of controlling *P. castaneus* in Scots pine stands, which consisted of removing infested trees, was PLN 445/ha. This cost showed significant variations both based on forest district (from 41 PLN/ha to 824 PLN/ha) and individual years (from 299 PLN/ha to 760 PLN/ha).

The cost of monitoring *P. castaneus* with breeding traps was 208 PLN/ha (using 10 traps/ha). If this method is used to control *P. castaneus*, the estimated cost increases to 400-600 PLN/ha (using 20-30 traps/ha).

Authors' contributions

T.J. and I.S. – data analysis, writing manuscript, A.R. and R.W. – field trials and data collection, M.T. – statistical analysis. All authors improved the manuscript.

Acknowledgments

This work was supported by General Directorate of State Forests in Warsaw, project No. 500 460.

Conflict of Interest Statement

The authors declare no conflict of interest.

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STRESZCZENIE

Przydatność i koszty zastosowania pułapek lęgowych do monitoringu smolika znaczonego *Pissodes castaneus* (De Geer, 1775)

Smolik znaczony *Pissodes castaneus* (De Geer) (Coleoptera, Curculionidae) jest jednym z najgroźniejszych szkodników, najczęściej występującym w uprawach i młodnikach sosnowych *Pinus sylvestris* L. osłabionych działaniem różnych czynników biotycznych (choroby korzeni, uszkodzenia

powodowane przez roślinożerne ssaki) i abiotycznych (susza, niedobory, przymrozki i mrozy, grad itp.). Przy masowym występowaniu chrząszczy smolika znaczonego może dojść do zahamowania przyrostu pędów, jednak bardziej szkodliwy dla drzewek jest żer larw, które w krótkim czasie powodują zamieranie drzewek.

W XX w. smolik znaczony nie był przedmiotem wielu badań dotyczących biologii, ekologii oraz metod ograniczania jego liczebności, ze względu na to, że przez szereg lat gatunek ten nie stanowił problemu gospodarczego. Brak skutecznych i jednocześnie bezpiecznych dla środowiska metod ochrony młodych drzewostanów przed *P. castaneus* uzasadnił podjęcie badań mających na celu opracowanie nowych sposobów monitoringu i ograniczania liczebności. W niniejszej pracy podjęto próbę weryfikacji hipotezy o przydatności stosowania pułapek lęgowych do monitoringu i zwalczania *P. castaneus* w uprawach sosnowych.

Badania prowadzono w latach 2020-2022 w 5 uprawach *P. sylvestris* w wieku 3-7 lat zlokalizowanych na terenie Nadleśnictwa Wyszków (centralna Polska – tab. 1). Pułapki lęgowe wykonywano z pozbawionych gałęzi pni żywych sosen o średnicy 5-15 cm i długości około 1,5 m, które w maju każdego roku wkopywano na głębokość około 0,5 m, w rzędach do 10 szt./ha (ryc. 1). Następnie po 6 miesiącach pułapki wykopano i okorowywano ich części znajdujące się w glebie do głębokości 20 cm oraz część nadziemną do wysokości 20 cm. Na okorowanych częściach policzono larwy i kolebki poczwarkowe smolika znaczonego. Uzyskane wyniki przeliczano na 1 dm^2. Ponadto określono zależność między liczbami znalezionych larw i kolebek poczwarkowych smolika znaczonego a średnicą pułapki. Dodatkowo porównano koszty testowanej metody z kosztami dotychczas stosowanej metody zwalczania smolika polegającej na wyrywaniu i usuwaniu zasiedlonych drzewek (ryc. 2 i 5; tab. 2).

Ocena zasiedlenia pułapek lęgowych wykazała, że smolik znaczony zasiedlał wyłącznie podziemne części pułapek sosnowych (od 0 do –0,2 m), o czym świadczyła obecność larw w żerowiskach i w kolebkach poczwarkowych oraz opuszczone przez chrząszcze kolebki poczwarkowe: maksymalnie do 8 szt./dm^2, średnio 3,8 ±1,5 szt./dm^2 (ryc. 3). Analiza zależności między liczbami znalezionych larw oraz kolebek poczwarkowych a średnicą pułapek wykazała większe prawdopodobieństwo zasiedlenia przez smolika pułapek o średnicy 10-15 cm (ryc. 4). Testowana metoda z użyciem do 10 pułapek na 1 ha charakteryzowała się niższymi kosztami wykonania w porównaniu do kosztów zwalczania smolika poprzez wyrywanie i usuwanie zasiedlonych drzewek (ryc. 6 i 7). Uzyskane wyniki wskazują na przydatność pułapek sosnowych wykonanych ze strzałek kilkuletnich sosen do monitoringu występowania szkodnika w uprawach leśnych.