

Article

Effects of Forest Type and Climatic Conditions on Pheromone-Trap Catches of *Pityogenes chalcographus*

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Abstract

Pityogenes chalcographus was monitored using pheromone traps installed in different forest types across Bosnia and Herzegovina. The study was conducted within protected areas of Sarajevo Canton, including the Protected Landscapes of Bijambare and Trebević and the Skakavac Natural Monument. The investigated forest types comprised secondary fir–spruce stands and mixed beech–fir forests with spruce admixture. Data were collected between 2018 and 2021 to assess the effects of forest type and climatic factors on pheromone-trap catches of *P. chalcographus*. Mean trap catches in secondary fir–spruce forests ranged from 2317.6 to 6317.0 individuals per trap, whereas catches in mixed beech–fir forests with spruce ranged from 150.0 to 6840.0 individuals per trap. The highest mean catches were recorded in the Trebević Protected Landscape and the Skakavac Natural Monument. Overall, trap catches tended to be higher in secondary fir–spruce forests than in mixed beech–fir forests with spruce. Statistically significant differences in mean catches between forest types were detected only in 2021, while no significant differences were observed during 2018–2020. No statistically significant relationships were found between climatic variables and *P. chalcographus* trap catches during the study period.

Keywords: Curculionidae; Scolytinae; six-toothed spruce bark beetle; climatic factors; beech; fir; spruce; Bosnia and Herzegovina



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1. Introduction

During past and recent bark beetle outbreaks, controversies have arisen regarding the management of bark beetle gradations in protected areas such as nature reserves or national parks, where such areas are usually exempt from bark beetle control measures [1]. Differences in management practices, forest structure, and historical outbreak patterns may create varying conditions that influence the population dynamics of spruce bark beetles and their natural enemies [2]. Some studies have reported higher bark beetle population densities in protected areas compared with managed forests, while others have found no significant differences, and some have reported higher densities in managed forests than in nature reserves [3]. Research on spruce bark beetles in this context is rare, which is also the case in Bosnia and Herzegovina, where protected forest areas are designated as special

zones that include biological diversity, cultural heritage, and natural values, covering an area of 2082 km² or 4.06% of the country's total territory. By comparison, protected terrestrial areas worldwide cover 16.1% [4].

In Sarajevo Canton, there are five protected forest areas classified as protected landscapes and natural monuments [5], where, with respect to tree species composition, conifers dominate, particularly Norway spruce, *Picea abies* (L.) H. Karst, and silver fir, *Abies alba* Mill. Climatic conditions, particularly temperature and humidity, are especially important for the presence and spread of cambivorous and xylophagous insects [6]. The health status of forest trees depends on numerous abiotic and biotic factors, among which the impact of harmful insects is particularly significant [7].

Among the most important pests of coniferous forests are bark beetles (Coleoptera: Curculionidae: Scolytinae) [8], which are capable of killing large numbers of trees. Bark beetles are part of forest ecosystems and play an important ecological role by removing weakened trees and contributing to the initial stages of wood decomposition. However, in forest management they often present a serious problem because, under certain conditions, they may rapidly develop high population densities and cause severe damage that is difficult to control [2].

Pityogenes chalcographus L., 1761 (Coleoptera, Curculionidae, Scolytinae), is one of the most widespread bark beetles inhabiting spruce forests from Scandinavia to the Balkans [9]. This pest species attacks parts of trees and entire trees with thinner bark, for example spruce stands around 20 years of age or the upper parts of the crown [10]. According to Pfeffer [11], it measures 1.5–2.5 mm, with reddish-brown elytra and a black pronotum. Its gallery system is of a star-shaped type [12], and it mainly colonizes trees already attacked by the spruce bark beetle *Ips typographus* L., 1758 [13]. Stand conditions such as windthrow, snowbreak, or uprooting, as well as drought, contribute to the accumulation of physiologically weakened trees that are susceptible to bark beetle attack [14]. Under such conditions, population outbreaks may occur and the species may shift from being a secondary to a primary pest, causing mortality of previously un-predisposed trees [2].

Three major spruce bark beetle severe outbreaks were recorded in Bosnia and Herzegovina during the periods 1928–1934, 1945–1950, and 1998 [15]. The damage was attributed to the spruce bark beetle and *P. chalcographus*, with losses estimated at around 8 million m³ of timber.

Increased harmful effects of *P. chalcographus* have been recorded throughout the Eurasian region [16]. According to Seidl et al. [17], bark beetle damage to Norway spruce and pine in Europe has increased by approximately 700% over the past four decades.

The increase in catastrophic climatic events and errors occurring in forest management practices contribute to increased bark beetle damage [18]. A sufficient quantity of physiologically weakened trees, together with the state of bark beetle populations and favorable climatic conditions, enables population outbreaks. As bark beetle population density increases, so does the risk of tree mortality [19].

Since effective forest management requires reliable assessments of insect population status, such assessments are ensured through high-quality monitoring. For these purposes, pheromone traps are most commonly used; these consist of a pheromone attractant and a trap housing in which the captured individuals are collected. Pheromone traps are mainly used for monitoring, although there have been attempts to use them for control and population reduction [20]. In forestry, for the protection of forests against spruce bark beetles, black flight-barrier pheromone traps of the Theysohn® type (Theysohn Kunststoff GmbH, Salzgitter, Germany) are most commonly used. For attracting individuals of *P. chalcographus*, the pheromone preparation Chalcoprax® (BASF, Ludwigshafen, Germany) is most frequently applied.

The density of spruce bark beetles and their natural enemies was compared in northern Europe across different forest management regimes: managed forests and two protected areas [3]. This research highlights the importance of local forest characteristics in managing bark beetle outbreaks, suggesting that risk assessments should focus on these variables rather than forest protection status, although potential variations at larger spatial scales were not included in the study.

The objective of this research is to determine whether there is a relationship between forest type and significant climatic factors in a protected area and the population of *P. chalcographus*, through analysis of the number of individuals captured in pheromone traps. The null hypothesis was that protected area had no effect on the mean catches of *P. chalcographus* during the 2018–2021 study period ($p < 0.05$).

2. Materials and Methods

The catch of *P. chalcographus* was investigated using pheromone traps installed in three protected areas (PAs) of Sarajevo Canton, Bosnia and Herzegovina: the Bijambare Protected Landscape, the Trebević Protected Landscape, and the Skakavac Natural Monument (Figure 1). Within these protected areas, traps were established in two forest types: (i) secondary fir–spruce forests and (ii) mixed beech–fir forests with spruce. Both forest types were represented within each protected area.

Secondary fir–spruce forests developed as a consequence of historical beech exploitation and are characterized by structurally degraded stands with a high proportion of small-diameter trees. In contrast, mixed beech–fir forests with spruce represent productive, high-quality forest ecosystems in which the three dominant tree species attain large dimensions in both height and diameter, with many trees reaching advanced age.

The catch of *P. chalcographus* was monitored over a four-year period (2018–2021) using 54 permanent Theysohn[®] pheromone traps baited with Chalcoprax[®] pheromone lures (BASF Agro B.V., Wädenswil, Switzerland). The traps were distributed among the three protected areas (Figure 1). The same pheromone attractant has been widely used in previous studies investigating *P. chalcographus* populations [21].

The traps were installed during the last week of March and remained in the field until the first week of October each year. Traps were positioned at least 20 ± 2 m from the nearest living coniferous tree, and the geographic coordinates of each trap were recorded using a Global Positioning System (GPS) receiver. Pheromone lures were replaced twice during each growing season according to the manufacturer's recommendations.

Trap inspections and beetle collection were performed every 10–15 days throughout the monitoring period. Dry pheromone traps were used; therefore, no killing agent was placed inside the traps. Captured beetles remained mechanically retained within the collecting container until trap inspection. After collection, trap contents were transferred into PVC bags containing cotton wool soaked with alcohol for preservation during transport to the laboratory of the University of Sarajevo—Faculty of Forestry. In the laboratory, captured specimens were identified to species level using the morphological identification keys of Pfeffer [11]. Subsequently, *P. chalcographus* individuals were separated from other captured insects and counted.

The influence of climatic conditions on *P. chalcographus* populations was evaluated using bioclimatic variables derived from monthly values of minimum, maximum, and mean air temperature, precipitation, solar radiation, wind speed, and air pressure. Bioclimatic variables were obtained from the WorldClim version 2 database by overlaying raster layers of climatic variables with the exact geographic coordinates of the pheromone traps.

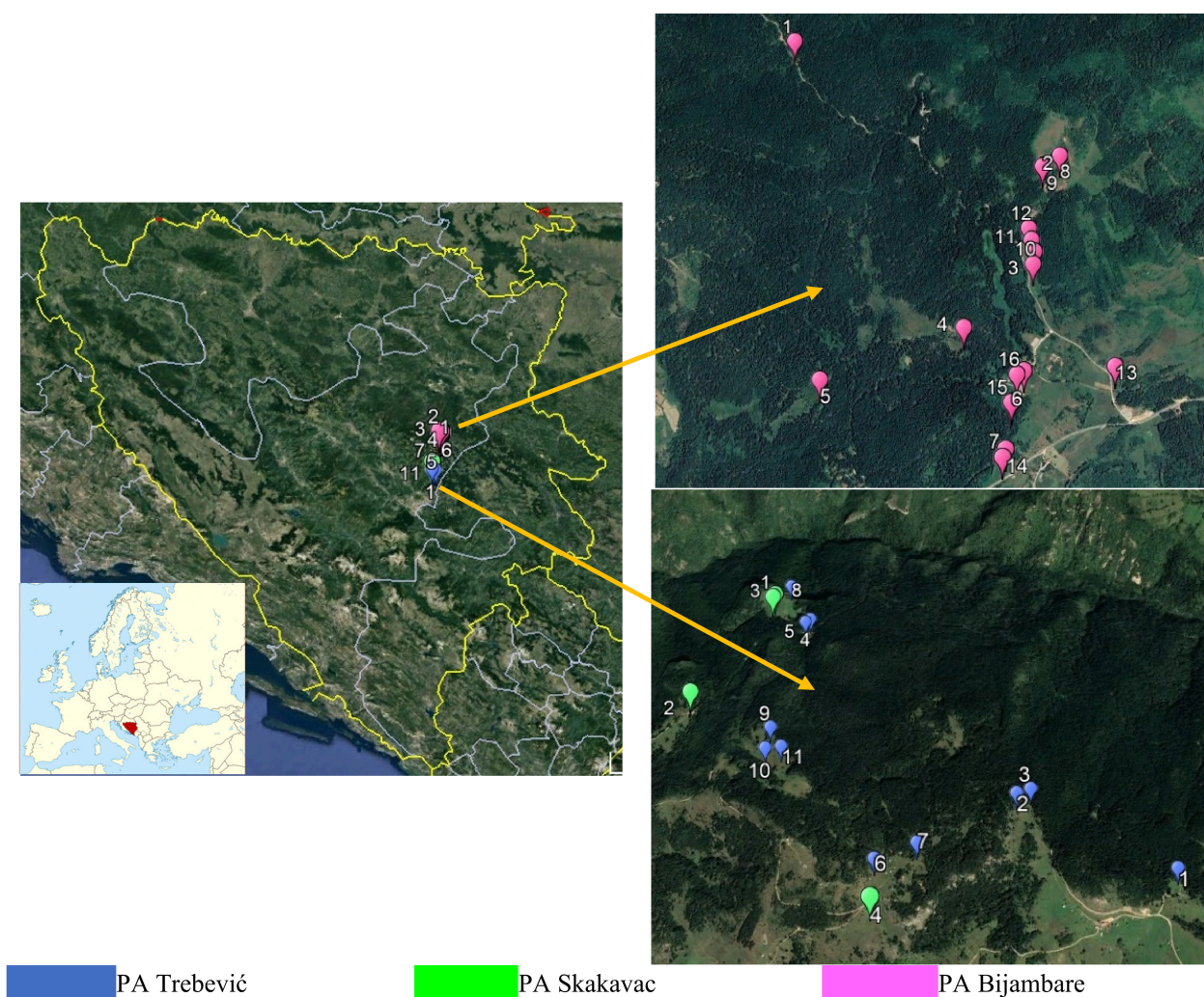


Figure 1. Position of pheromone traps in Bosnia and Herzegovina, PA Trebević, PA Skakavac and PA Bijambare (Google Earth Pro).

In order to analyze the effect of forest type on the number of captured *P. chalcographus* individuals, statistical significance testing of differences between means was carried out using one-way analysis of variance (Table 1).

Table 1. Number of pheromone traps used in different localities.

Protected Area	Mixed Forests	Secondary Coniferous Forest	Total
Skakavac	3	16	19
Bijambare	6	16	22
Trebević	1	16	17
Total	10	48	58

Differences in the mean catches of *P. chalcographus* among protected areas and forest types, as well as the relationships between bioclimatic variables and trap catches, were evaluated using the statistical procedures described below. Statistical analyses were performed using IBM SPSS Statistics version 20. In addition to descriptive statistics, one-way analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) post hoc test were used to evaluate differences in trap catches among protected areas and forest types and to assess the influence of climatic variables on trap catches.

3. Results

During the research, a total of 1,038,600 individuals were captured in the Bijambare Protected Landscape, 3,105,240 individuals in the Trebević Protected Area, and 1,372,480 individuals of *P. chalcographus* in the Skakavac Natural Monument, with variation in catches between 2018 and 2022 (Figure 2).

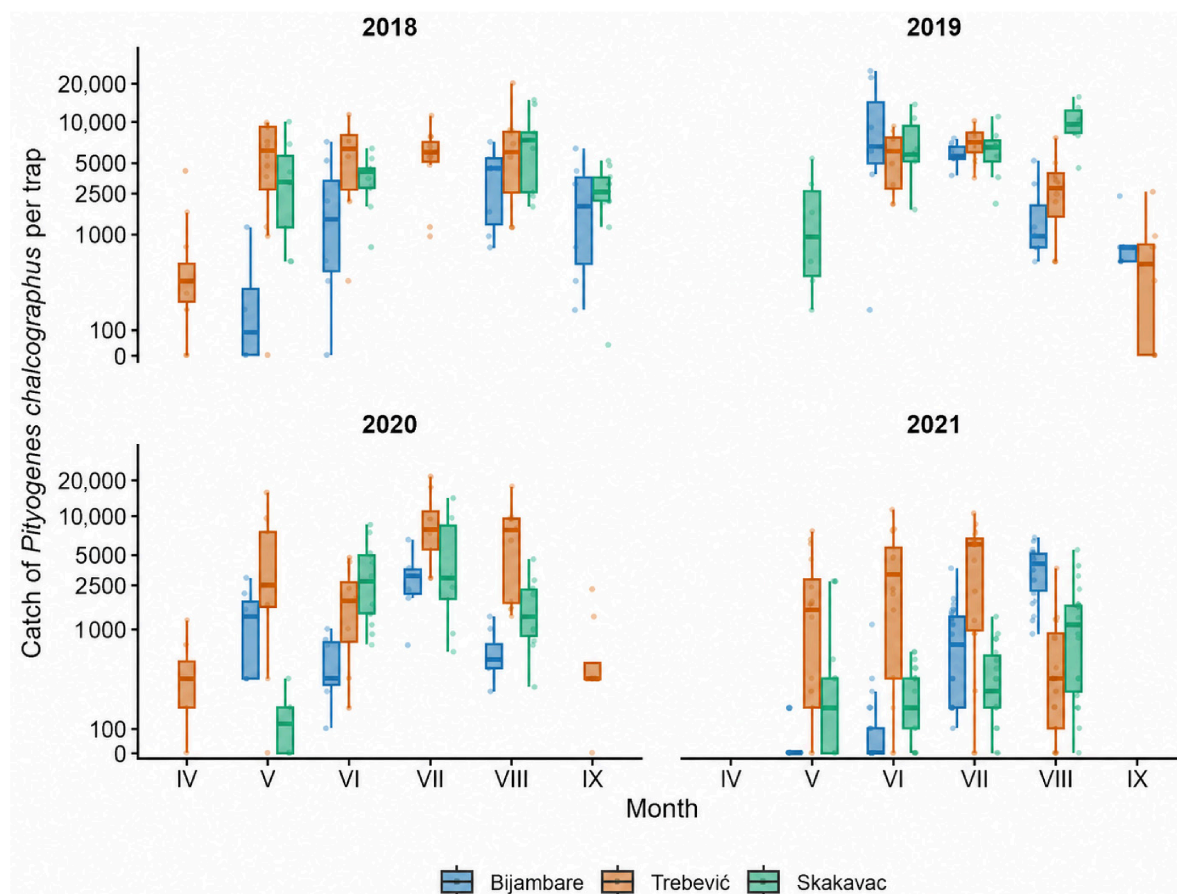


Figure 2. Seasonal variation in catches of *Pityogenes chalcographus* across the Bijambare, Trebević, and Skakavac protected areas from 2018 to 2021. The y-axis is displayed on a pseudo-logarithmic scale.

The statistical analysis showed that there are statistically significant differences in the mean catches of *P. chalcographus* for 2018, 2020, and 2021 depending on the protected area, at a probability level of $p < 0.05$ (Tables 2 and S1).

Table 2. Multiple tests of average differences in catch of bark beetles *Pityogenes chalcographus* for 2018, 2019, 2020 and 2021 depending on protected area (Tukey HSD).

Dependent Variable	Protected Area (A)	Protected Area (B)	Mean Difference (A – B)	Std. Error	Sig.
2018	Protected area Bijambare	Protected area Trebević	−2535.551	936.203	0.020 *
		Protected area Skakavac	−1851.122	1049.524	0.185
	Protected area Trebević	Protected area Bijambare	2535.551	936.203	0.020 *
		Protected area Skakavac	684.429	780.669	0.656
	Protected area Skakavac	Protected area Bijambare	1851.122	1049.524	0.185
		Protected area Trebević	−684.429	780.669	0.656

Table 2. Cont.

Dependent Variable	Protected Area (A)	Protected Area (B)	Mean Difference (A – B)	Std. Error	Sig.
2019	Protected area Bijambare	Protected area Trebević	−1449.559	1429.964	0.569
		Protected area Skakavac	−2085.714	1641.081	0.414
	Protected area Trebević	Protected area Bijambare	1449.559	1429.964	0.569
		Protected area Skakavac	−636.155	1429.964	0.897
	Protected area Skakavac	Protected area Bijambare	2085.714	1641.081	0.414
		Protected area Trebević	636.155	1429.964	0.897
2020	Protected area Bijambare	Protected area Trebević	−3939.286	927.497	0.000 *
		Protected area Skakavac	−1041.349	986.516	0.543
	Protected area Trebević	Protected area Bijambare	3939.286	927.497	0.000 *
		Protected area Skakavac	2897.937	859.418	0.003 *
	Protected area Skakavac	Protected area Bijambare	1041.349	986.516	0.543
		Protected area Trebević	−2897.937	859.418	0.003 *
2021	Protected area Bijambare	Protected area Trebević	−1201.641	268.260	0.000 *
		Protected area Skakavac	565.228	250.308	0.063
	Protected area Trebević	Protected area Bijambare	1201.641	268.260	0.000 *
		Protected area Skakavac	1766.869	267.486	0.000 *
	Protected area Skakavac	Protected area Bijambare	−565.228	250.308	0.063
		Protected area Trebević	−1766.869	267.486	0.000 *

(*) The differences in *P. chalcographus* catches in relation to the protected area are highly statistically significant at the 0.05 probability level.

According to the Tukey HSD test, a difference in the mean catches of *P. chalcographus* was determined in 2018 between the Bijambare Protected Area and the Trebević Protected Area. In 2020, a difference in the mean catches of *P. chalcographus* was determined between the Bijambare Protected Area and the Trebević Protected Area, as well as between the Trebević Protected Area and the Natural Monument. In 2021, a difference in the mean catches of *P. chalcographus* was determined between the Bijambare Protected Area and the Trebević Protected Area, and between the Trebević Protected Area and the Skakavac Natural Monument.

The results of the analysis of statistical significance of differences in bark beetle catches for the period 2018–2021 depending on forest type are presented in Table S2; one-way analysis of variance was applied.

The null hypothesis stated that there are statistically significant differences between the mean catches of *P. chalcographus* for the period 2018–2021 depending on climatological factors at a probability level of $p < 0.05$ (Tables S3–S6).

The statistical analysis showed that there were effects, but no statistically significant differences in the mean catches of *P. chalcographus* for the specified period.

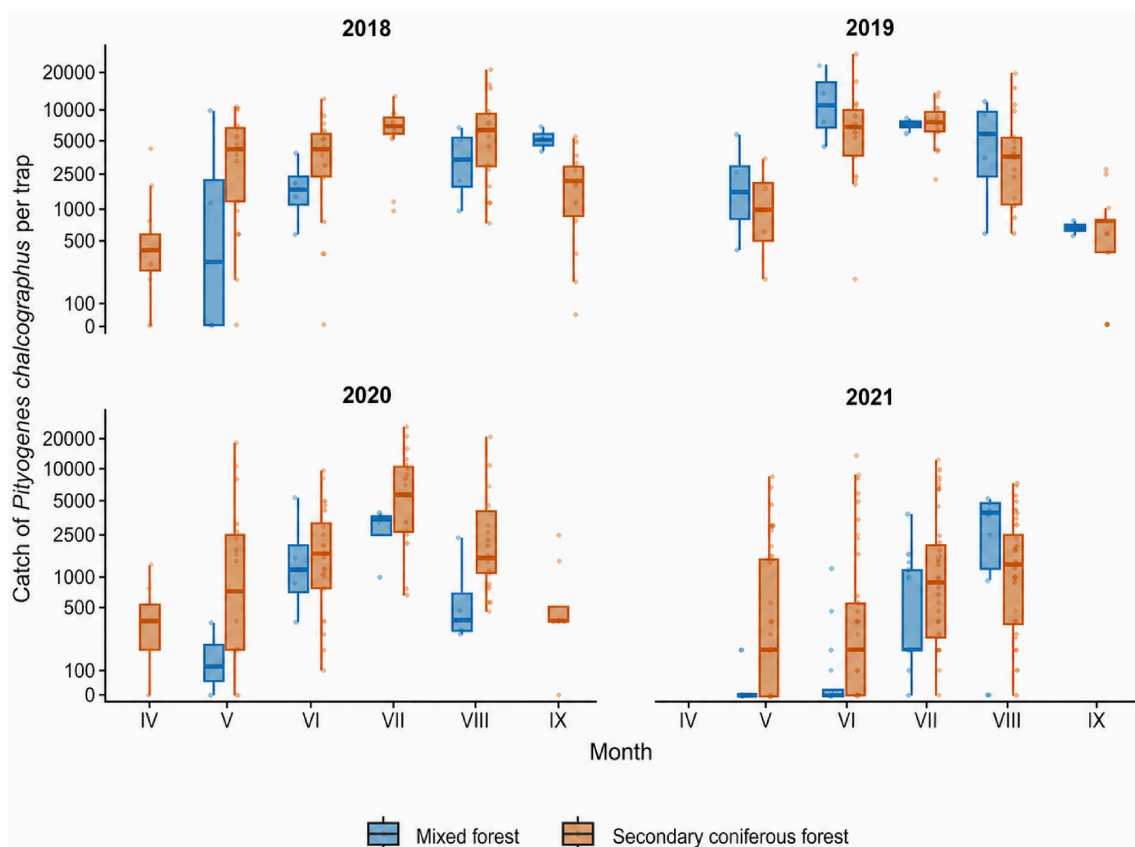


Figure 3. Seasonal variation in catches of *Pityogenes chalcographus* in mixed forests and secondary coniferous forests from 2018 to 2021. The y-axis is displayed on a pseudo-logarithmic scale.

4. Discussion

Bark beetles are the most significant biotic disturbance agent in Europe, having damaged a total of 870 million m³ of timber between 2000 and 2022 [22]. Of this volume, 92% relates to spruce, with a worrying negative trend from 2015 to the present [22]. The main cause of damage is *I. typographus* (84%), which is mostly accompanied by *P. chalcographus*. There is a significant temporal correlation among spruce bark beetle populations at the European level, and the data from this study fit that pattern. Monitoring populations of spruce bark beetles is part of an integrated forest protection system aimed at mitigating the harmful impacts of these insect species. The use of pheromone traps for monitoring spruce bark beetles enables assessment of insect population status in a manner that is environmentally and human-health friendly compared with historical use of insecticides [21].

This study includes an analysis of the abundance of *P. chalcographus* individuals captured in pheromone traps, indicating the level of attack in different protected areas of Sarajevo Canton and in different forest types.

The research was conducted during the period 2018–2021 in three protected areas (the Bijambare Protected Area, the Trebević Protected Area, and the Skakavac Natural Monument) (Figure 1). The highest number of traps was used in 2021, namely 54, while in the previous years the number was significantly lower: 22 traps in both 2018 and 2019, and 27 traps in 2020.

Based on the conducted research, the average number of *P. chalcographus* individuals captured per trap amounted to 7753.75 individuals. Similar results for Bosnia and Herzegovina have been reported by other authors [15]. Other studies, however, report different catch values for this species [23–25]. Economic damage threshold for *P. chalcographus* in a study was defined as 20,000–60,000 individuals captured per trap annually [26].

Considering the diverse catch values reported by numerous authors [24,27–29], it is important to emphasize that these values are meaningful only when expressed as a result of certain site or climatological influences. Accordingly, this paper examined the influence of locality as a set of micro-site conditions, stand conditions represented through two forest types (beech–fir–spruce forests and secondary fir–spruce forests), and micro-climatic factors on the number of captured *P. chalcographus*.

One-way analysis of variance was used to test the differences between mean *P. chalcographus* catches depending on protected area, and it was determined that differences existed in the years 2018, 2020, and 2021 (Table S1). In 2018, a difference in catches was determined between the Bijambare Protected Area and the Trebević Protected Area. In 2020 and 2021, differences in catches were determined between the Bijambare Protected Area and the Trebević Protected Area, as well as between the Trebević Protected Area and the Skakavac Natural Monument (Table 2). The existence of significant differences in the number of captured individuals among the research localities may be associated with the development of local population size, which has also been reported by other authors [20].

According to the results of the research for the period 2018–2021, differences in bark beetle catches were determined depending on forest type (Figures 2 and 3), as well as statistically significant differences in the mean catches of *P. chalcographus* for 2021, whereas no such differences were found for 2018, 2019, and 2020 depending on forest type (Table S2). The research established that the catch of this species was 1.43 times higher in secondary fir and spruce forests compared with beech and fir forests (with spruce). From a silvicultural-structural perspective, secondary fir and spruce forests are characterized by a higher share of thin trees or generally trees with poorly differentiated diameters. This forest type is also typically associated with a lower canopy closure, which results in stronger exposure to solar radiation and other factors that influence tree development, reduce vitality, and affect diameter and height structure. These stand parameters of secondary fir and spruce forests, compared with beech–fir–spruce forests, may favor the development of *P. chalcographus* populations. The explanation of these significant differences through spruce stand structure in two different stand types is also reported by other authors. According to Bertheau [30], no significant influence was found between spruce stands dominated by larger-diameter trees (DBH > 60 cm) and the abundance of *P. chalcographus* populations.

For all study years (2018–2021), although a trend exists, no influence of climatological factors on the mean catch of *P. chalcographus* was determined (Tables S3–S6). However, according to Mujezinović et al. [5], climatological factors did influence the mean catch of *I. typographus* at the same research sites. This may be explained by the broader ecological tolerance of *P. chalcographus*. Other authors have also reported no significant relationship between extreme weather conditions and *P. chalcographus* populations [31]. Given these results regarding the influence of climatological factors on the population of this bark beetle species, further research over a wider area of Bosnia and Herzegovina is warranted.

One limitation of this study is that the field data were collected during the 2018–2021 period, whereas environmental conditions, particularly climate, have continued to change in recent years. Consequently, current population levels and seasonal dynamics of *P. chalcographus* may differ from those observed during the study period. Despite this limitation, the present dataset provides a robust four-year baseline for understanding the relationships between forest type, climatic conditions, and pheromone-trap catches, and it may serve as a valuable reference for future long-term monitoring studies.

The synchronized damage caused by spruce bark beetles in Europe demonstrates the importance of researching bark beetle fluctuations across all forest types and highlights the urgency of strengthening socio-ecological resilience as a key strategy for ecosystem management under increasingly unstable and unpredictable conditions [32,33]. During

a four-year study in Northern Europe, bark samples were analyzed to assess bark beetle colonization density, production, reproductive success, predator abundance, and forest characteristics. The results showed that variations in density were more pronounced during different outbreak phases and under different forest conditions [3]. Complex interactions between forest conditions, outbreak phase, and the presence of certain predators play a more decisive role in bark beetle dynamics than whether the forest is a protected area or not [3]. Natural enemies, particularly predators, can be monitored using pheromone traps [29], which should represent the next step in our research.

5. Conclusions

The four-year monitoring of *Pityogenes chalcographus* in protected forest areas of Sarajevo Canton revealed substantial spatial and temporal variation in pheromone-trap catches. Population levels differed significantly among protected areas in 2018, 2020, and 2021, indicating that local site and stand conditions may play an important role in determining the abundance of this species.

Trap catches tended to be higher in secondary fir–spruce forests than in mixed beech–fir forests with spruce, with an overall 1.43-fold higher catch in secondary forests. However, statistically significant differences between forest types were detected only in 2021, suggesting that forest type alone does not consistently explain annual variation in *P. chalcographus* populations. No statistically significant relationships were found between the analyzed climatic variables and pheromone-trap catches during the 2018–2021 study period.

These findings emphasize the importance of long-term, site-specific monitoring of *P. chalcographus* populations in protected forest ecosystems. Particular attention should be given to stand structure and local conditions rather than relying solely on broad climatic variables when assessing population dynamics and potential outbreak risk. Continued monitoring over a wider geographical area and a longer time period, combined with assessments of stand characteristics and natural enemies, would provide a more comprehensive understanding of the factors regulating *P. chalcographus* populations in Bosnia and Herzegovina.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/f17080979/s1>. Table S1: Analysis of variance of statistically significant differences in *Pityogenes chalcographus* catches depending on protected area; Table S2: Analysis of variance of statistically significant differences in *Pityogenes chalcographus* catches depending on forest type; Table S3: Analysis of variance of statistically significant differences in *Pityogenes chalcographus* catches depending on climatological factors in 2018; Table S4: Analysis of variance of statistically significant differences in *Pityogenes chalcographus* catches depending on climatological factors in 2019; Table S5: Analysis of variance of statistically significant differences in *Pityogenes chalcographus* catches depending on climatological factors in 2020; Table S6: Analysis of variance of statistically significant differences in *Pityogenes chalcographus* catches depending on climatological factors in 2021.

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remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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