THE SUPPRESSIVE EFFECT OF WOOD ANTS ON BARK BEETLE COLONIZATION

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ABSTRACT

Climate change supports bark beetle outbreaks in European forests, posing a significant threat to the economically important Norway spruce (*Picea abies*). While chemical control methods in pest control are increasingly restricted, biological control using natural enemies, such as wood ants (*Formica* spp.), offers a sustainable alternative. Despite their known role as generalist predators of various forest pests, the direct impact of wood ants on bark beetle colonization remains underexplored. This study investigated the suppressive effect of *Formica rufa* ants on six-toothed spruce bark beetle (*Pityogenes chalcographus*) colonization. Branch traps were installed near 34 wood ant nests across five localities in Czechia. At each nest, one trap was placed 1 meter from the nest (treatment) and another 40 meters away (control). In total, traps near ant nests showed a mean reduction of approximately 40% in beetle colonization. Results confirmed similar suppressive metrics, consistent across all study localities. Our findings demonstrate that ants significantly suppress bark beetle colonization. This confirms the crucial role of wood ants as biological control agents against bark beetle damage and supports their integration into sustainable forest management strategies.

Keywords: biological control; *Formica rufa*; forest pests; Norway spruce; non-consumptive effects; *Pityogenes chalcographus*

Introduction

Climate change is disrupting the health of economically important tree species across Europe (Jaime et al. 2019, 2024). Trees weakened by drought are particularly susceptible to pest infestations (Potterf et al. 2025; Véle and Neudertová Hellebrandová 2025). Norway spruce (*Picea abies*), a key economic tree of European forestry, is widely cultivated, often in plantations, which are ecologically less stable (Spiecker 2000). Among the most dangerous threats are bark beetles, which are responsible for large-scale diebacks of secondary spruce forests in Central Europe (Grégoire and Evans 2007; Brázdil et al. 2022). In response, there is a growing trend towards converting spruce plantations into more ecologically resilient mixed forests (Löf et al. 2023). Nevertheless, Norway spruce remains the most widely planted and economically significant tree species (MZe 2023). While chemical control methods are available for bark beetle management, their use is increasingly restricted due to negative impacts on non-target species and potential health risks (Leroy 2025).

An alternative to chemical control is the use of natural enemies, which aligns with the principles of integrated forest protection (Matyjaszczyk and Skrzecz 2020). Entomopathogenic fungi, parasitoids, and predators represent key biotic factors with strong potential for application in biological control programs (Lipták et al. 2013). Among bark beetle predators, species such as the ant beetle *Thanasimus formicarius* and woodpeckers are notable (Wegensteiner et al. 2015). In contrast, wood ants are not typically classified as significant bark beetle predators, although wood ants (*Formica* spp.) are recognized as significant natural enemies of various forest insect pests (Adlung 1966; Wegensteiner et al. 2015). Ants' advanced social structure and cooperative foraging behaviour make them highly effective generalist predators (Traniello 1989). Their pest control ability is enhanced by a positive response to volatiles emitted by infested plants (Schettino et al. 2017).

Wood ants use honeydew from aphids as their main source of food, the rest is protein food (Domisch et al. 2009). As omnivorous generalists, wood ants adapt their diet to available food resources (Richter and Economo 2023). During pest outbreaks, they may shift their foraging strategy, favouring insect predation over honeydew collection. In such instances, insects can constitute over 90% of their diet (Domisch et al. 2009). Wood ants actively prey on insects across all developmental stages: eggs, larvae, pupae, and adults. In European forests, *Formica* species prey on several defoliating pest species, which can contribute to reduced herbivore damage to trees (Adlung 1966; Skinner and Whittaker 1981; Warrington and Whittaker 1985). For example, a single *Formica rufa* colony with 500,000 workers can collect between 1,000 and 100,000 larvae of the spruce sawfly (*Pristiphora abietina*) per day (Bruns 1954). Their protective influence can extend up to tens of meters from the nest (Laine and Niemelä 1980).

Indirect evidence of wood ants' influence on bark beetle populations was provided by Trigos-Peral et al. (2021), who observed a lower incidence of bark beetle-infested trees around ant nests. However, this descriptive study did not clarify whether the observed differences could

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be attributed to other factors, such as variations in soil quality near the nests leading to increased tree vitality (White 1985). Furthermore, it is known that bark beetle outbreaks can occur even in the vicinity of ant nests (Véle and Frouz 2023). Driven by the need for empirical evidence, we designed and executed an experimental study to further elucidate the role of wood ants in mitigating bark beetle attacks on trees. Specifically, we examined whether there is a difference in the number of galleries and maternal holes on branch traps placed within the territory of ant nests compared to those on control sites.

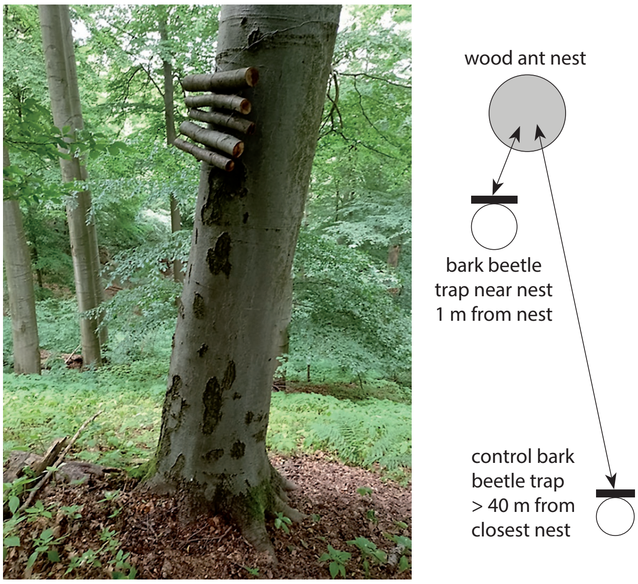

Fig. 1 Picture of bark beetle trap on the tree and schematic of the location of bark beetle traps in relation to wood ant nest.

Methods

This study was conducted across five localities in the Czech Republic near Březí nad Oslavou (49.5058447N, 15.9550525E), Račín (49.6344272N, 15.8346483E), Horní Řasnice (50.9808175N, 15.1750342E), Chuchelna (50.6165419N, 15.2904494E), and Bítouchov (50.6222733N, 15.3334508E). The five localities were selected to represent a gradient of bark beetle outbreak intensity, from severely affected (Březí nad Oslavou, Račín) to moderately affected (Horní Řasnice) and minimally affected areas (Chuchelna, Bítouchov), as documented by Lubojacký et al. (2023, 2024). All localities were situated in pure even-aged managed Norway spruce stands at least 50 years of age, at elevations ranging from 450 to 610 m a. s. l. (Březí nad Oslavou: 550 m, Račín: 610 m, Horní Řasnice: 450 m, Chuchelna: 450 m, Bítouchov: 470 m).

For our investigation, we selected isolated nests of *Formica rufa*, which were sparse and widely spaced across the study areas. The nest mounds were of medium size, characterized by a mean diameter of 147 ± 31 cm and a height of 64 ± 15 cm. At each nest, we installed two branch traps. One trap was placed 1 meter from the nest, within the ant's territory, and the second was positioned 40 meters away, outside the territorial range. The traps were constructed from bark beetle-uninfested trees that were felled approximately 14 days before installation. Each trap consisted of two branches, each 7 cm in diameter and 1.1 meters in length. Traps were placed on tree trunks at a height of approximately 4 meters (Fig. 1) and oriented toward the south to increase the probability of bark beetle colonization (Wermelinger 2004). Traps were not, however, exposed to intense direct sunlight due to canopy shading. A total of 68 traps were installed in the second half of March 2024, before the start of bark beetle swarming, which typically occurs at the turn of April and May. The traps were collected in early June, after the first swarming period (Holuša and Fiala 2024). Following collection, the bark was removed from the traps, and the numbers of galleries and maternal holes were counted. A *Pityogenes chalcographus* male first creates a short nuptial chamber and then attracts the female. Each female then makes her own maternal chamber (Holuša and Fiala 2024). Thus, one counted gallery indicates the presence of one male, while the number of maternal holes corresponds to the number of females.

Due to their diameter, the traps were primarily designed to capture *P. chalcographus*. This is a smaller species (1.6–2.9 mm) that often accompanies the larger spruce bark beetle (*Ips typographus*, 4.2–5.5 mm) on older trees. Both species have similar bionomics and often occur together on the same tree (Pfeffer 1955), leading us to hypothesize that the impact of ants on both species would be similar.

To evaluate the effect of ant nest proximity on bark beetle colonization, we performed a two-way Analysis of Variance (ANOVA). The independent variables were "locality" (representing the different study sites) and "ant nest" (a binary factor representing traps placed 1 meter from the nest vs. 40 meters from the nest). The dependent variables were the number of males, females, and the total count of beetles. A post hoc LSD test was used to identify statistically homogeneous groups and to determine significant differences between the nest and control traps. All statistical analyses were performed in Statistica 10.0.

Results

Our results demonstrated that the presence of *Formica rufa* nests significantly suppressed colonization by *P. chalcographus* on experimental traps. The mean number of galleries as well as maternal holes was significantly lower on traps placed 1 meter from an ant nest compared to control traps placed outside nest territory (Fig. 2). Specifically, traps located near nests recorded an average of 10.03 ± 11.77 males and 40.10 ± 57.16 females, while

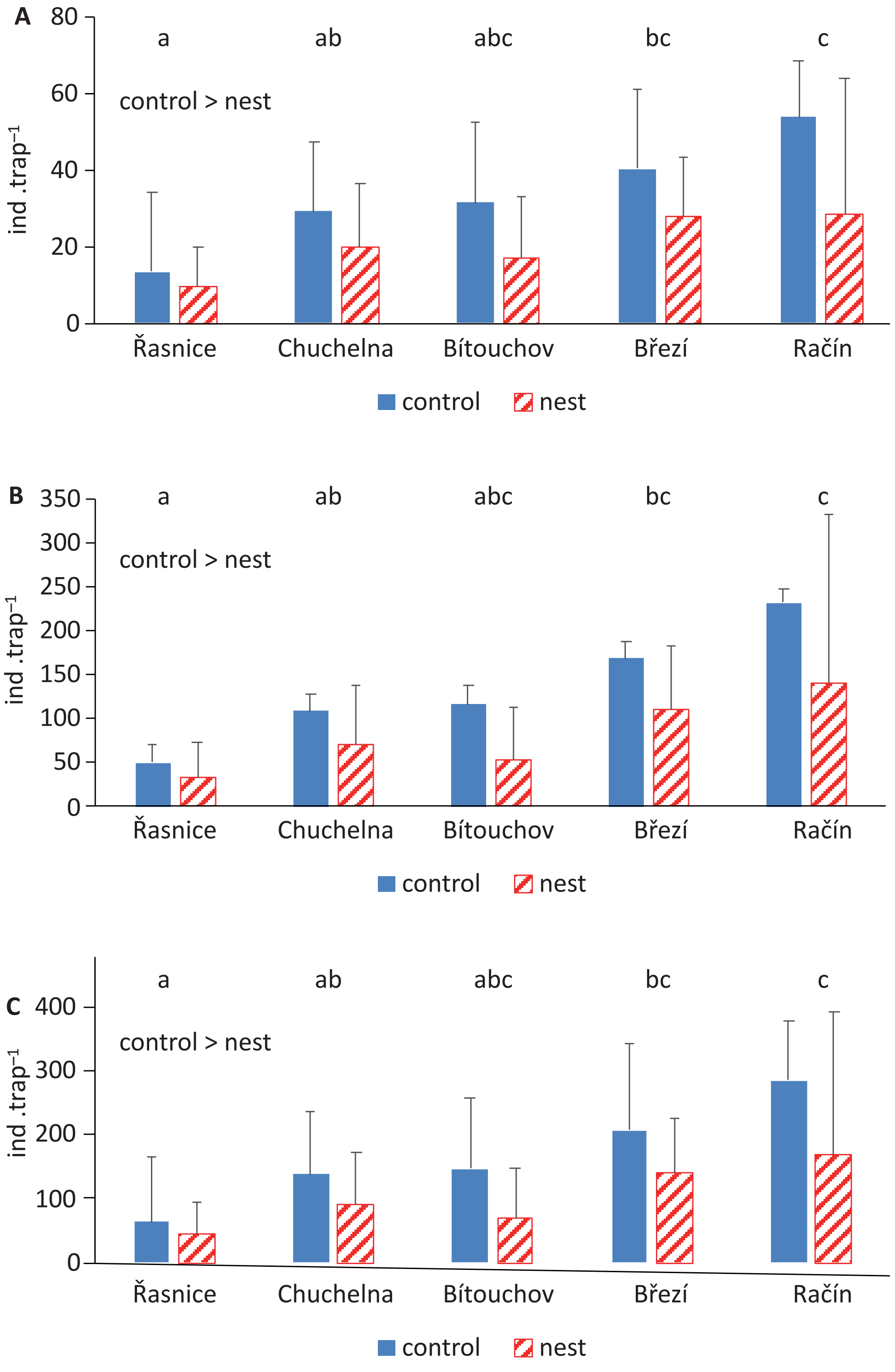

Fig. 2 Number of bark beetle individuals trapped in traps located wood ant nests and in control nests away from the nest, shown for males (A), females (B) and total (C). Means and SD are shown, statistically homogeneous groups are labelled by the same letters (LSD post hoc test p<0.05), significant differences between nest and control traps are indicated, for p values of two-way ANOVA see Table 1.

control traps showed 16.44 ± 12.95 and 66.13 ± 59.5 individuals, representing a 39% and 39.4% reduction, respectively.

A two-way ANOVA confirmed that the distance from the ant nest had a statistically significant effect on total colonization, as well as on male and female counts individually. The effect of locality was also significant, reflecting differences in beetle abundance across study locations. However, no significant interaction was found between locality and nest distance, indicating that the suppressive effect of ants was consistent across all areas, regardless of local beetle population density (Table 1).

Table 1 The effect of locality and distance from wood ant nest on bark beetle infestation, p-values of two-way ANOVA are given.

Effect of	Males	Females	Total
Locality	0.0071	0.0051	0.0053
Ant nest	0.0157	0.0388	0.0328
Interactions	ns	ns	ns

Discussion

Our study demonstrates a clear suppressive effect of red wood ant (*Formica rufa*) presence on bark beetle *P. chalcographus* colonization. We found that trees located near ant nests experienced approximately 40% fewer beetle infestations compared to control trees in areas without ants. This suppressive effect remained consistent across all study localities, regardless of the overall intensity of bark beetle infestation in the region.

These findings align with previous research of Trigos-Peral et al. (2021), who described a significant correlation between an increasing number of *Formica polyctena* nests and a reduction in the number of bark beetle-infested trees. Similarly, other studies have reported comparable levels of pest abundance reduction. Total sawfly *Pristiphora abietina* larvae populations were reduced by more than 50% within 29 meters from wood ant nests (Wellenstein 1957). Lower pest abundances near wood ant nest have been recorded in many species, for example: *Diprion pini*, *Neodiprion sertifer*, *Coleophora laricella*, *Tortrix viridana*, *Operophtera brumata*, *Panolis flammea*, *Lymantria monacha* (Adlung 1966).

Several mechanisms likely contribute to the observed reduction in beetle colonization near ant nests. The primary mechanism is that, just like bark beetles, ants move along trees to find most of their food, which they acquire through hunting and collecting honeydew (Sudd and Lodhi 1981; Lenoir 2003; Domisch et al. 2009). The most well-known mechanism is predation. Wood ants prey on many insect species, but they are generally considered primarily predators of herbivorous insect larvae, which are often found in places accessible to worker ants (Adlung 1966). However, hunting the developmental stages of bark beetles is impossible, as the entry holes of small beetles like *P. chalcographus* are too narrow for wood ants to pass through. Therefore, only adult beetles can be preyed upon. This aligns with observations that beetles constitute over 10% of the wood ants' diet, with adult *Curculionidae* (weevils) being numerically well-represented, while the presence of their larvae in the food spectrum is low (Domisch et al. 2009).

Beyond direct predation, non-consumptive effects (NCEs) are another crucial way ants might regulate bark beetle populations. NCEs play a significant role in predator-herbivore interactions by modifying prey and predator behaviour. These modifications can include altered foraging strategies, changes in habitat selection, shifts in life history traits, and heightened anti-predator responses. Such effects are well-documented across many animal species, including ants (Wills and Landis 2018; Batabyal 2023).

A typical example of these interactions, which often occur indirectly, is the relationship between ants and aphids on plants, because honeydew is a predominant part of the ants' diet (Rico-Gray and Oliveira 2007; Domisch et al. 2009). Ants also use aphids as a supplementary food source to alleviate the effects of acute fungal infections (Rissanen et al. 2023). For this reason, ants tend to protect aphids from their natural enemies (Novgorodova and Gavrilyuk 2012). For instance, when *Formica rufa* ants encountered adult ladybugs *Hippodamia variegata* (which is a predator of aphids) near aphid colonies, they frequently exhibited aggressive behaviour, leading to a significant reduction in beetle egg-laying (Mir et al. 2024). Ants may behave similarly towards other animals they encounter on trees. Animals may also be deterred by volatile compounds produced by ants, as demonstrated with spiders and ticks (Mestre et al. 2014; Gooding et al. 2024). Even large beetles, like carabids, actively try to avoid individual contact with moving ants (Dorosheva and Reznikova 2006). Seedlings of conifer species artificially made attractive to ants suffered less feeding damage by the large pine weevil *Hylobius abietis*, suggesting that ant presence deters this pest, likely through tactile cues but possibly also via volatile chemicals and visual signals (Maňák et al. 2013, 2016). Furthermore, the influence of ant-bird competition has been observed. Birds visited trees without ants more frequently and foraged there for longer periods than trees with ant activity (Haemig 1994). This suggests that ants can indirectly affect other organisms by altering their foraging behaviour.

There is a complex balance between the bark beetle infestation density required to successfully overcome a tree's defences, which depends on tree vitality (Mulock and Christiansen 1986; Schroeder and Lindelöw 2002). Because of this, we cannot definitively say whether the observed reduction in the number of infesting beetles guarantees a tree's survival. However, it's well-known that a "mass attack" is necessary to overcome a healthy tree's defences (Lehmanski et al. 2023). In such cases, we can expect that healthy trees will be protected by ants. This could explain observations of bark beetle-infested trees near ant nests (Véle and Frouz 2023), as that study was conducted after a period when trees were weakened by severe drought (Brázdil et al. 2022). Despite their proven suppressive effect, the use of wood ants as a biological control agent has significant limitations. Their protective effect is inherently local, extending only tens of meters from the nest (Adlung 1966; Laine and Niemelä 1980), and cannot be scaled up to the landscape level without a sustained density of nests throughout the managed area. Their presence also has a negative impact on beneficial insect populations (Véle and Dobrosavljević 2021). Furthermore, the mutualism between wood ants and aphids represents a trade-off, as ant colonies actively protect aphid populations, which can themselves negatively affect tree vitality (Kilpeläinen et al. 2009). These limitations should be taken into account when integrating wood ants into forest conservation strategies. Nevertheless, wood ants should be considered an integral part of pest management strategies, as their presence supports the protection of valuable trees and the prevention of bark beetle infestations.

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