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SPATIAL COMPETITION BETWEEN *IPS ACUMINATUS* AND OTHER MAIN PINE TREE COLONIZING PESTS

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Abstract
The sharp-toothed bark beetle (*Ips acuminatus* (Gyllenhal, 1827)) is one of the major pests of Scots pine (*Pinus sylvestris* L.). In addition to *I. acuminatus*, several other pests attack healthy or weakened pine trees, including pine shoot beetles (*Tomicus* spp.), the six-toothed bark beetle (*Ips sexdentatus*), pine bark beetles (*Pityogenes* spp.) and pine weevils (*Pissodes* spp.). The results of two separate studies are presented in this paper. (1) We analysed how *I. acuminatus* breeding success is influenced by other major stem-colonizing pests in a pine stand affected by forest fire. The spatial distribution of the four most found insect pest species - *I. acuminatus*, *Tomicus piniperda*, *T. minor*, and *Pissodes* spp. - within the tree trunk was mapped. It was determined that the length of the stem section colonized by *I. acuminatus* is significantly affected by the presence of *Pissodes* weevils but not by *Tomicus minor* or *T. piniperda*. Although *Tomicus minor* typically colonizes the same part of the pine trunk as *I. acuminatus*, they were rarely found on the same tree. If *I. acuminatus* colonizes a pine tree first, *Tomicus minor* tends to avoid it. The length of the section colonized by *I. acuminatus* increases with tree height, with taller trees supporting longer infestations. (2) Additionally, data on *I. acuminatus* reproduction rates in pine waste after thinning activities was collected. On average, 2.19 ± 0.65 mother galleries per 1 m² of bark were found on the remaining treetops and branches, indicating that forest management practices contribute to the availability of suitable breeding material for this species.
Keywords: *Ips acuminatus*, forest fire, insect pests, stem colonisation, *Pinus sylvestris*.

Introduction

In recent years, bark beetle populations have been rising across Europe, causing widespread damage to forests and posing significant challenges to forest management and conservation efforts. Scots pine (*Pinus sylvestris* L.) is primarily attacked by bark beetle species from the *Ips* and *Tomicus* genera. However, other pests, such as *Pissodes* spp. weevils and *Phaenops* spp. jewel beetles, can also cause significant damage (Ozols, 1985; Vega and Hofstetter, 2015). All these insects are considered secondary pests, as they primarily attack hosts with impaired defences. Climate variability and weather extremes, such as floods, droughts and fires, accelerate pest outbreaks, by weakening trees natural defences (Hlávková & Doležal, 2022). In response to these stressors, trees accumulate and produce volatiles that might attract insect species and further weaken host trees. The sharp-toothed bark beetle (*Ips acuminatus* Gyllenhaal) has experienced a notable surge in population growth and the damage it causes within pine ecosystems (Grégoire & Evans, 2004; Papek et al., 2024). *I. acuminatus* predominantly targets mid- to mature-aged, weakened Scots pine stands, particularly the upper part and branches of the tree with thin phloem.

One key factor contributing to pest multiplication is the presence of logging residues, and their timely removal can help prevent outbreaks. *I. acuminatus* can successfully breed in pine logging residues left after final felling (Foit, 2015). Understanding *I. acuminatus* presence in logging residues and its interactions with other stem-colonizing insects in pine stands is crucial for assessing its impact on forest health.

This research consisted of two separate studies: (1) analysing the occurrence of *I. acuminatus* in logging waste after clearcuts, and (2) examining *I. acuminatus* interactions with other major stem-colonizing pests in fire-affected pine stands, while also mapping the spatial distribution of the four most commonly found insect pest species - *I. acuminatus*, the common pine shoot beetle *Tomicus piniperda* L., the lesser pine shoot beetle *T. minor* Hart., and *Pissodes* spp. weevils - within the tree trunk.

Materials and Methods

The occurrence of *I. acuminatus* and other stem-colonizing insects in fresh wood waste was evaluated in 11 pine stand clearcuts during the summer of 2003 and 2004. Samples of branches and treetops were collected from logging residues piled in stacks as well as from those placed on skidding trails. Each sample consisted of a 30 cm long section, which was fully debarked, and insect galleries were counted.

The densities of insect colonies (larval galleries and pupal chambers) were calculated per 1 m^2 of bark surface based on sample diameter. In total, 114 samples were taken from stacks and 68 from skidding trails. Sample diameters ranged from 2.1 cm to 37.2 cm, with an average of 7.5±0.4 cm.

For solitary larval galleries (e.g. *Monochamus* spp.), the number of galleries were recorded. For insect colonies (e.g. *I. acuminatus*), nuptial chambers were counted, while for *Pissodes* weevils pupal chambers were counted.

To assess the tree mortality and breeding success of pine pests, 9 permanent circular study sites, each covering 500 m², were established. The study area is in the northwestern part of Latvia, where an extensive forest fire occurred in Stikli Bog in July of 2018, affecting large areas of peatland and forest ecosystems. Study sites were all Scots pine dominated on dry and wet organic soils (*Myrtillosa* and *Caricoso-phragmitosa*).

At each study site, all standing trees, both dead and alive, with a diameter exceeding 12 cm at a height of 1.3 m were marked. For living trees (trees with a green crown), crown defoliation was assessed in 5% increments, interpreting defoliation intensity, (Table 1), and needle discoloration (yes/no). For both living and recently dead trees, the presence of beetle exit holes on the visible part of the trunk bark was evaluated. Evaluation was done four times (2019 July and September 2020 January and August).

Table 1
Pine crown defoliation percentage and descriptive level

Needle loss percentage	*Defoliation level*
0–10 %	No defoliation
11–25 %	Mild defoliation
26–60 %	Moderate defoliation
61–99 %	Severe defoliation
100 %	Dead tree

In the area, data on species presence were obtained by felling pine trees with visible fresh crown discoloration: 22 trees in 2019, 25 in 2020, and 15 in 2022. Up to three pine trees were felled at each study site. Tree lengths were measured, and the bark was removed to assess the presence of bark beetles and weevils. Species or genus identification was based on their characteristic gallery systems.

For the *Tomicus piniperda*, *T. minor*, *I. acuminatus*, and *Pissodes* spp., the shortest distance from the felling point where the species was detected, and the trunk diameter at that location were recorded for each tree. Additionally, the farthest distance from the felling point and the trunk diameter at the last recorded location of the species were also measured. For the *Pissodes* weevils, no separation based only on pupal chambers was possible; therefore, all individuals were recorded as *Pissodes* spp.

To analyse the factors influencing *I. acuminatus* tree colonization success and potential competition from other major pine wood-boring pest species, a Linear Mixed-Effects Model was used (*lmer* procedure in R). The following model was applied:

model = lmer (Ia ~ L + Tm + Tp + P + (1 | Year)), family = gaussian,

where:

Ia – proportion of the pine stem colonized by *I. acuminatus* (% of total tree length),

L – pine tree length (m),

Tm – proportion of the pine stem colonized by *Tomicus minor*,

Tp – proportion of the pine stem colonized by *Tomicus piniperda*,

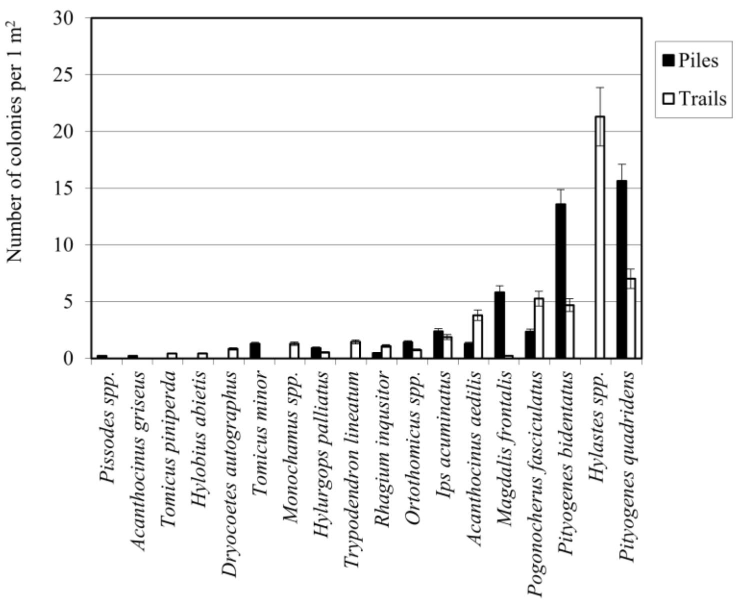
P – proportion of the pine stem colonized by *Pissodes* spp.,

Year – year in which trees were sampled (random effect).

Results and Discussion

The analysis of dendrophagous insect colonization in fresh logging residues revealed significant differences in species abundance between residues stored in stacks (piles) and those placed on skidding trails (trails). Overall, most species exhibited higher colonization rates in piles compared to trails, indicating a preference for stacked wood as a breeding habitat 'Figure 1'.

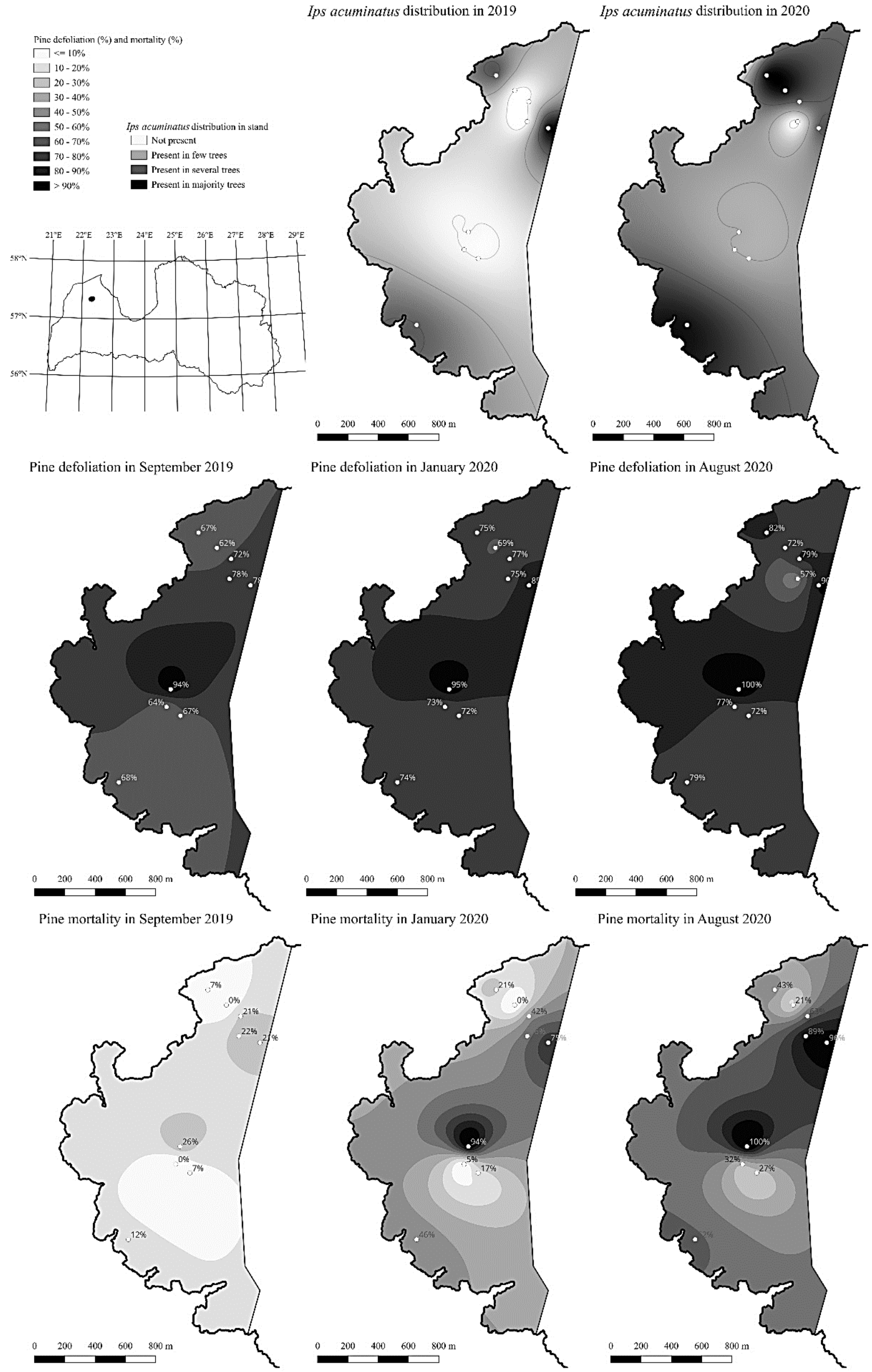
Figure 1
The occurrence of Ips acuminatus and other dendrophagous insects in fresh logging residues piled in stacks (piles) and placed on skidding trails (trails)



I. acuminatus were found in both wood waste storage conditions, with a slightly higher density in piles. On average, 2.19 ± 0.65 colonies (nuptial chambers and associated mother and larval galleries) per 1 m² of bark were found on the remaining treetops and branches, indicating that forest management practices contribute to the availability of suitable breeding material for this species.

Figure 2

Ips acuminatus distribution, pine defoliation and mortality over studied period in Stikli bog



A much higher occurrence of *I. acuminatus* in logging residues was reported in a study from the Czech Republic, where the sharp-toothed bark beetle was one of the most abundant species, surpassed only by *Pityogenes calcographus* (Foit, 2015). This difference may be partly explained by the fact that our data were collected in 2004. Since then, *I. acuminatus* populations have increased across Europe (Papek et al., 2024).

The most abundant species in the study were *Hylastes* spp., *Pityogenes bidentatus*, and *P. quadridens*, with densities reaching approximately 20 - 25 colonies per m² in piles. These species also showed considerable presence in trails, though at slightly lower densities. The significant presence of *Pityogenes* genus aligns with their known preference for fresh coniferous logging residues, emphasizing the role of storage conditions in influencing pest outbreaks. Conversely, species such as *Pissodes* spp., *Acanthocinus griseus* and *Tomicus* spp. who are less dependent on wood storage conditions exhibited relatively low overall densities

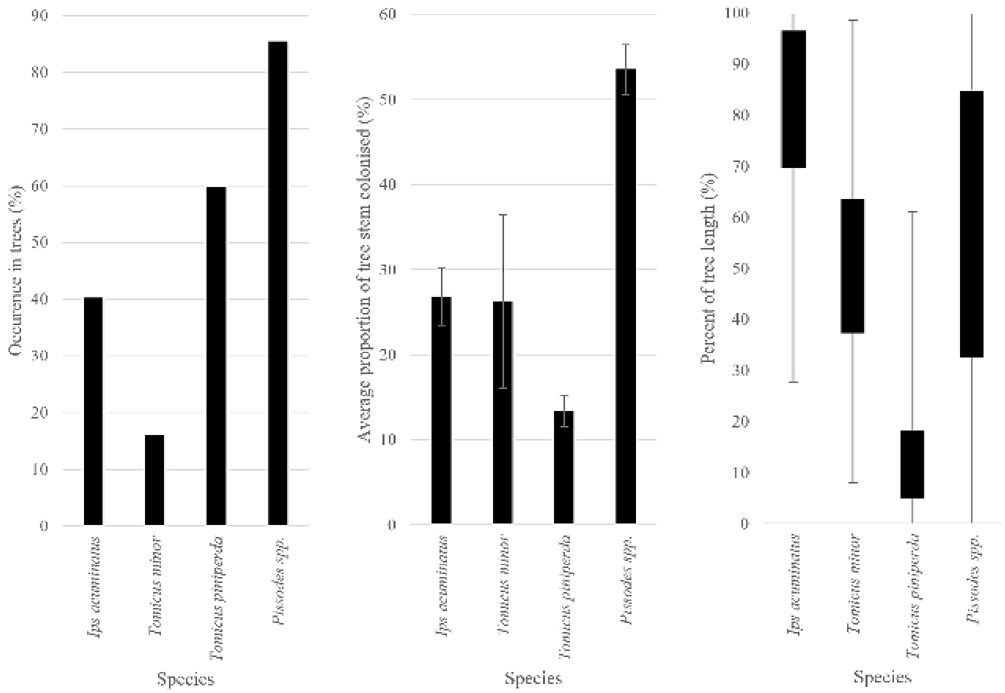
The observed variation in insect colonization highlights the importance of forest residue management in pest control. The higher densities of bark beetles and weevils in piles indicate that stacking fresh wood residues may unintentionally promote pest population growth.

The study in Stikli bog revealed a slightly different tendency in *Ips acuminatus* distribution in the area.

The average tree defoliation in the sample plots at their establishment in the summer of 2019 in Stikli bog was 71.4%, with 8.4% of the assessed pine trees already dead. In September 2019, the average tree defoliation in the sample plots was 66.5%. By January 2020, it had increased to 72.9%, and by August 2020, it reached 75.6% 'Figure 2'. Tree crown defoliation worsened significantly over a year and a half. The decline in tree crown condition is likely even greater than estimated, as several trees with severe defoliation had already died by the 2020 surveys and were therefore not included in the defoliation assessment. By January 2020, the proportion of dead trees in the sample plots had increased to 29% of all trees surveyed, and by August 2020, 59% of the trees had died 'Figure 2'. At one sample plot the defoliation by January had reached 90% and all trees were dead by August, indicating more severe fire intensity at this location.

The most common pest species found in weakened pine trees were *Pissodes* weevils, occurring in 53 out of 62 sampled trees (85.5%) 'Figure 3A'. However, it should be noted that *Pissodes* spp. were much less common in logging residues 'Figure 1', with pupal chambers found in only one out of 182 samples.

Figure 3
The occurrence (A), average proportion of tree trunk colonized (B), and location of colonized section (C – average top, maximum top, average bottom and maximum bottom) of major wood boring pest on pine tree trunks



I. acuminatus was recorded in 25 sampled trees, *Tomicus piniperda* in 37, and *Tomicus minor* in only 10 trees. No *Ips sexdentatus* galleries were found in the sampled trees. Contrary to our findings, *I. sexdentatus* was the most abundant pest species in pine stands two years after a forest fire in Ukraine (Andreieva et al., 2018).

Pissodes weevils were usually found on large sections of the tree trunk, sometimes colonizing the entire tree length ʻFigure 3B'. *I. acuminatus* typically colonized approximately one-quarter of the pine tree, primarily in the upper part of the trunk ʻFigures 3B', C'. *Tomicus minor* occupied the section below *I. acuminatus* ʻFigure 3C', with some overlap between their colonized areas. However, this conclusion is based on only two observed cases where both species were present in the same tree. *Tomicus piniperda* was typically found in the lower section of the trunk, where the bark is thicker, making direct competition with *I. acuminatus* unlikely ʻFigure 3C'.

The colonization success of *I. acuminatus* was found to be negatively affected by the presence of *Pissodes* weevils (Table 2). When *Pissodes* weevils colonized a larger proportion of the trunk, *I. acuminatus* occupied a shorter section ʻFigure 4'. In contrast, *Tomicus* species had no negative effect on *I. acuminatus*. It is possible that *Tomicus minor* avoids trees already colonized by *I. acuminatus* and vice versa. *T. minor* is considered relatively less aggressive than *I. acuminatus* (Wermelinger et al., 2008).

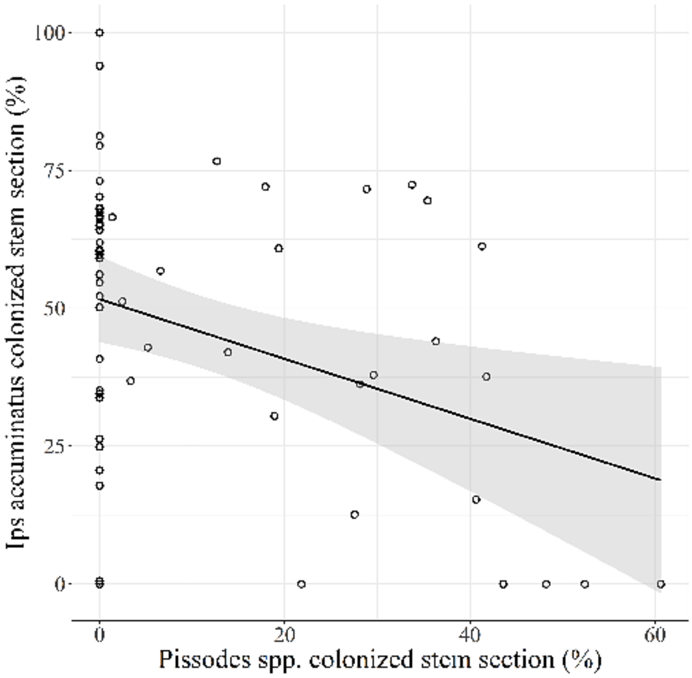
Table 2

*Analysis of Deviance Table (Type II Wald chi-square tests) of the model for factors influencing I. acuminatus tree colonizing success. Significant codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Response: Ia				
	Chisq	Df	Pr(>Chisq)	
Tree length	1.5679	1	0.211	
Tomicus minor	3.1071	1	0.078	
Tomicus piniperda	3.1794	1	0.075	
Pissodes spp.	8.7079	1	0.003	**

Figure 4

Effect of Pissodes spp. presence on Ips acuminatus tree colonization success



Forest fire at the study site occurred on July 17. *I. acuminatus* second-generation beetles had opportunity to attack fire-weakened trees in the same year when forest fire occurred. *Tomicus* has only one generation per year (Vega & Hofstetter, 2015). Therefore, *Tomicus* beetles could colonize weakened pine trees only next spring. This may explain higher occurrence of *I. acuminatus* beetles in sampled trees.

Tree length had no effect on the section length that was colonized by sharp-toothed bark beetle.

Conclusions

1. *Ips acuminatus* can reproduce in pine logging waste after final felling; however, its occurrence in wood residues in Latvia is low.
2. The *Ips acuminatus* population and its damage to pine stands increase rapidly within 1 - 3 years after a forest fire.
3. *Ips acuminatus* competes with *Pissodes* weevils for breeding space when colonizing fire-weakened pine trees.

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