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Felled trap trees as the traditional method for bark beetle control: Can the trapping performance be increased?

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ABSTRACT

Felled trap trees have been traditionally used to control bark beetles in central Europe. There is, however, little research on the method and on factors affecting trap tree performance. We therefore evaluated the effect of felling date, tree diameter, site shading, and weather conditions on the pattern of trap tree infestation by bark beetles. An experiment was conducted at two localities with contrasting forest damage rates and bark beetle outbreak phases in the Czech Republic during three periods: December to April of 2004–2005, 2005–2006, and 2006–2007. For each of the three periods, eight dates of trap tree felling were equally spaced. On each date and at each locality, 5–7 trees located at the open forest edge were felled (295 trap trees in total). The number of *Ips typographus* (Linnaeus, 1758) entry holes dm^{-2} counted in May each year was used as the response variable. Neural network-based regression models were used to identify the variables that most affected trapping performance.

The performance of the regression models in terms of Pearson's correlation between observed and predicted entry hole densities ranged from 0.15 to 0.93. The effect of predictor variables on the recorded entry hole density was much lower in the forest with a culminating bark beetle outbreak than in the forest with outbreak in retrogradation phase. For trap trees felled before winter, trapping performance was positively associated with the length of the period that the trap trees were covered by snow. The trap trees exposed to higher heat sums tended to show lower entry hole density than trap trees exposed to lower heat sums.

The results indicate that, in forests with high beetle densities, there are few options for increasing trap tree performance based on selection of specific sites, tree characteristics, or felling dates. The identified sensitivity of trap trees to weather indicates that trees should be felled just before beetles emerge if conditions have been relatively warm and snowless but can be felled far in advance under cooler conditions with regular snow. Finally, the results indicate that foresters should continue to use large-diameter trees located on non-shaded sites as felled trap trees.

1. Introduction

Bark beetles are the most important insect pests in Europe, where bark beetle damage to forests has been steadily increasing in recent decades (Schelhaas et al., 2003; Seidl et al., 2014). Projections indicate that this damage is likely to continue to increase (Jönsson et al., 2007; Seidl et al., 2014), which underscores the importance of novel or optimized methods for forest protection.

Although a variety of methods can be used to combat bark beetles, surprisingly little is known about the efficacy of these measures in different environments and with different population densities of bark beetles. In managed spruce forests, an intensive removal of infested trees, i.e., sanitary felling, is considered to be the most effective way to reduce bark beetle densities and to prevent or reduce outbreaks (e.g., Stadelmann et al., 2013); the method, however, is controversial, for example, for impacts on biodiversity (e.g., Thorn et al., 2017). To further reduce bark beetle densities, foresters often combine sanitary felling with trapping by trap trees, log traps, or pheromone traps (Wichmann and Ravn, 2001; Jakuš and Blaženec, 2002; Grégoire and Evans, 2004). Trap trees in particular are frequently used (Martinek, 1953; Pfister, 1999; Grégoire and Evans, 2004), even though the method requires substantial labour and time (Bakke, 1989; Pfister, 1999). The trap trees are either left standing or are felled. Felled trap trees, which are the focus of the current study, have been used for almost 200 years (Pfeil, 1827). A felled trap tree is typically a main-storey tree; the branches are removed and are used to cover the trunk to slow

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tree drying and to therefore extend its trapping ability (Pfeffer, 1952; Kula and Šotola, 2017). Trap trees can be made more attractive by addition of a pheromone lures, which can increase trapping performance, especially in forests where stressed trees, which attract beetles, are abundant. In some countries, standing trap trees with an added pheromone lures are also used (Fettig and Hilszczański, 2015). Trap trees can be sprayed with insecticide (Raty et al., 1995) or removed from the forest and processed before the beetles that penetrated have had time to re-emerge (Zumr, 1985). Recently, pyramid-like constructions made of three or four pheromone-baited and poisoned stems have became increasingly used (Lubojacký and Holuša, 2011; Hurling and Stetter, 2012; Koleva et al., 2012). One disadvantage of felled trap trees is that, under favourable conditions for the beetles and in the absence of insecticide application, the beetles that penetrate can reproduce and leave the trap tree before the trap tree is transported to a saw mill. Moreover, trap trees can capture only a limited number of beetles and require regular attention (Abgrall and Schvester, 1987).

The performance of felled trap trees is thought to be related to tree dimension, trapping-site irradiation, tree baiting, or felling date (Martinek, 1953; Zumr, 1985; Schmidt-Vogt, 1989). The effect of date of felling and of climate in the period from tree felling to tree removal are rather unexplored (see, e.g., Nagel et al., 1957; Kohnle, 1984; Johann, 1986). These factors, however, can be expected to affect trapping if one considers that the trees can be felled over a substantial time period before the beetles start to fly and can be trapped. Jahn (1982), for example, found that infestation rates were especially high for trees felled during a full moon; the findings, however, seem controversial for methodological reasons. Other studies have recommended the optimal dates for trap tree felling but without empirical justification. For example, Slander (1948) suggested that trees should be felled 2–3 weeks before bark beetles swarm, and Martinek (1953) and Schmidt-Vogt (1989) suggested that trees be felled 4 weeks before beetles swarm. The recommendation for Czech foresters (Zumr, 1985) is that trap trees should be felled in mid-February and March at medium elevations and in April at high elevations. For practical reasons, Zumr recommended preparing the trap trees at the beginning of winter in regions where snow cover is likely because the snow would help keep the trees fresh until the beetles begin to fly and because it can be difficult to prepare such trap trees when snow is on the ground or when snow is melting.

Although trap trees are extensively used for bark beetle control, empirical research on trap tree performance is lacking, and thus the use of trap trees may not be optimal. We therefore conducted a 3-year study to identify factors that affect trap tree performance. The study included almost 300 trap trees located in two forests with contrasting damage rates and bark beetle outbreak phase. We focused on the effect of date of felling and the effect of selected tree (with respect to stem diameter), site, and weather variables on the number of beetles trapped. Another objective was to identify the species of bark beetles in the felled trees and determined whether the pattern of stem colonization by bark beetles is similar in felled trees and standing trees; this information would indicate to forest managers which parts of the stem should be inspected for determining whether the stems have been colonized and when they should be removed.

In support to these objectives, we tested the following hypotheses: (i) the effects of variables such as trap tree diameter, site irradiation, or weather are stronger in forests with a low rather than a high abundance of stressed trees and are reduced in forests where bark beetle outbreaks are peaking; (ii) trap tree performance can be influenced by weather, particularly by the temperature and snow regime during the period from trap tree felling to trap tree removal; and (iii) although middle sections of tree stems are preferentially colonized by beetles in standing trees, the colonization pattern might differ for felled trap trees that are lying on the ground and are covered with branches.

Table 1
Description of the two investigated localities.

Variable/locality	Petrvald	Psare
Forest characteristic	Norway spruce > 60%, ca. 100 years old	Norway spruce > 90%, ca. 100 years old
Position	49.8177289N, 18.4150581E	49.7516667N, 14.9383333E
Elevation (m a.s.l.)	285–295	390–410
Climate	T[a] 9 °C, P[b] 700 mm	T[a] 8 °C, P[b] 650 mm
Forest conditions	Forest suffering from drought, honey fungus, and long-term bark beetle outbreaks	Healthy stands experiencing bark beetle outbreak triggered by the 2003 drought
Nearest meteorological station	Slezská Ostrava; 269 m a.s.l.; 7.4 km[c]	Vlašim; 415 m a.s.l.; 6.7 km[c]

[a] Mean annual air temperature for the period 1961–1990.
[b] Mean annual precipitation totals for the period 1961–1990.
[c] Distance from the locality to the station.

2. Materials and methods

2.1. Study localities

The research was conducted at two localities in the Czech Republic; one locality was near the town of Petrvald, and the second was near the village of Psare (Table 1). The localities were ca. 250 km apart. The study was conducted in the three winter to spring periods (December to May) in years 2004–2005, 2005–2006, and 2006–2007.

The population density of bark beetles and the outbreak phase were estimated based on the salvaged volume of spruce timber ($m^3\ ha^{-1}$) relative to the total area of spruce forest within the administrative district where the experimental sites occur (Forest Protection Service of the Czech Republic) and based on the mean number of beetles caught in five pheromone traps (Theysohn type) installed near each experimental site (Fig. 1). The pheromone traps were installed during the period from the mid-April to the late June each year to assess the abundance of swarming parental beetles of *I. typographus*.

The two investigated localities are in forests with contrasting health conditions, damage rate, and bark beetle outbreak phase. Petrvald is located in a region where forests have been suffering from drought and bark beetle outbreaks for the last 15 years (Holuša and Liška, 2002; Grodzki, 2007; Lubojacký and Holuša, 2014). At the time of the study, Psare was experiencing the end of a bark beetle outbreak (i.e., outbreak retrogradation); this outbreak had been triggered by drought in 2003 (Fig. 1). In the period 2006–2007 of the current study, the salvaged volume due to bark beetle infestation was less than half at Psare than at Petrvald (4.1 vs. 9.7 $m^3\ ha^{-1}$). At the same time, the number of beetles caught in the pheromone traps had the same trend like volumes of wood infested by bark beetles; it was decreasing at Psare while the number of beetles was constant at Petrvald. As indicated by the presence of mycelial fans under the bark and of rot in the lower stem core, more than 90% of the trap trees felled in the current study were infected by the honey fungus (*Armillaria* sp.) at Petrvald but infection was scarce at Psare.

The three study periods differed in weather conditions and in snow conditions in particular (Appendix A). Snow cover was almost absent in the period 2006–2007, which was the warmest of the three investigated periods (the mean air temperature from December to March was 3.2 °C). In contrast, the period 2005–2006 had the longest snow cover (from December 16 to March 27) and the lowest mean air temperature, which was −2.7 °C. The period 2004–2005 had intermediate conditions, with snow persisting from January 24 to March 17 and with a mean air temperature of −1.1 °C. The daily air temperature data from several surrounding stations were recalculated according to the position of the experimental localities based on distance-weighted interpolation