JOURNAL OF FOREST SCIENCE, *61*, 2015 (8): 332–338

doi: 10.17221/45/2015-JFS

The occurrence of early-arriving saproxylic beetles on Scots pine logging residues generated by thinning

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ABSTRACT: The occurrences of early-arriving saproxylic beetles were examined on 1,200 fragments of Scots pine (*Pinus sylvestris* L.) logging residues generated by thinning in a single stand in the Drahanská Highlands in the Czech Republic. The felling was carried out on four dates in 2006 (February, May, August, November). The occurrence of early-arriving saproxylic beetles was investigated by peeling off the bark of logging residues during the first six months of the vegetative period following the felling. Beetle occurrence was significantly affected by felling date, logging residue type (trunk fragment, or branch thinner or thicker than 1 cm) and diameter. Only 16 species of early-arriving saproxylic beetles were found. The results indicate that the shaded and fairly uniform logging residues from thinning are probably of minor importance for the conservation of saproxylic beetles, but their presence might increase the risk of certain pest outbreaks (particularly, *Pityogenes chalcographus* [Linnaeus]). As an alternative to the removal of logging residues, the risk of the multiplication of this pest can be minimised if thinning is carried out in August (and probably also in September and October).

Keywords: bark- and wood-boring beetle; branch; felling date; pest; *Pinus sylvestris*; treetop

Large amounts of logging residues (LRs) are produced every year during felling in managed forests. It is generally known that these LRs can serve as a substrate for the development of many saproxylic beetles including certain forest pests, especially bark beetles (Curculionidae: Scolytinae). Thus, in certain circumstances, LRs can even facilitate pest multiplication and outbreaks (Schroeder 2008). The degree to which LRs are significant for pest multiplication as well as for saproxylic beetle conservation is dependent on many variables. However, the tree species from which LRs originate is substantial (Jonsell et al. 2007; Jonsell 2008), many other variables may also be significant. Substrate diameter and bark thickness are known to drive the occurrence of many saproxylic beetles species (Zhang et al. 1993; Schiegg 2001; Lindhe et al. 2004; Jonsell et al. 2007; Maňák 2007; Jonsell 2008; Foit 2010). Among other factors, sun exposure is a very important habitat variable that can determine the occurrence of saproxylic beetles (Jonsell et al. 2004; Lindhe, Lindelöw 2004; Lindhe et al. 2005; Jonsell 2008). The range of diameter and bark thickness as well as sun exposure of LRs are highly determined by the type of felling from which LRs originate (i.e. pre-commercial thinning, thinning and final felling). The least diverse LRs are produced during thinning, and these are composed of mostly shaded branches and tree tops of a rather small diameter (mostly < 7 cm) with thin bark. Given these facts, only a restricted number of saproxylic beetle species are likely to use LRs generated by thinning as a breeding substrate and it is questionable if there are any important pest species with the capacity to multiply significantly on these LRs. Furthermore, the date of felling (i.e. date

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Supported by the European Social Fund and the state budget of the Czech Republic, Project Indicators of Tree Vitality Reg. No. CZ.1.07/2.3.00/20.0265.

of LR origination) can strongly affect the occurrence of early-arriving saproxylic beetles (EASBs). This has been documented for several EASB species that develop in LRs of Norway spruce (*Picea abies* L. Karst.) that result from pre-commercial thinning (Kula et al. 2006, 2007), as well as in the stumps (Foit 2012a) and LRs resulting from pre-commercial thinning and final felling of Scots pine (*Pinus sylvestris* L.) (Foit 2015a, b). The effects of the felling date are likely to be driven by the breeding substrate requirements and the timing of mating and egg laying of the particular EASB species (Schwenke 1972).

The complete removal or disintegration of LRs (e.g. hauling, burning, and chipping) is the simplest way to prevent pest multiplication (DeGomez et al. 2008). However, the extensive removal of LRs that account for a substantial portion of dead wood in managed forests can lead to the extinction of rare saproxylic species and a loss of overall diversity (Siitonen 2001; Jonsell et al. 2007; Maňák 2007; Jonsell 2008; Victorsson et al. 2013). A better understanding of the actual significance of various LRs for the multiplication of forest pests is necessary to make the right decisions on the following: (*i*) which LRs should be removed and which can be left in the forest to support biodiversity, (*ii*) when to carry out fellings to reduce the risk of EASB pest multiplication on the LRs.

The aims of this study are to investigate which EASB species multiplies on Scots pine LRs that are generated by thinning and to assess the effects of habitat variables, including the diameter of the LR fragments and the felling date, on the occurrence of the recorded species.

MATERIAL AND METHODS

Study site. The research was conducted in a single stand in the southern Drahanská Highland in the Czech Republic. The climate is characterised by a mean annual temperature of 8.4–8.5°C and an average annual rainfall of approximately 580–590 mm. The 1.6 ha study stand (49°15'38''N and 16°36'52''E) was between 350 and 380 m in elevation and was located on a southwest-facing slope with a gradient of approximately 5–10%. The even-aged stand was 61 years old in 2006, when the thinning was conducted. The main canopy was mainly composed of Scots pine (60%) and European larch (35%, *Larix decidua* Miller). Sessile oak (*Quercus petraea* [Mattuschka] Liebl) and Norway spruce were also present. The forests in the study area were traditionally managed using a clear-cutting system and the prevailing artificial regeneration.

Sampling. The study stand was divided into four sections of equal area, and the thinning was conducted on a different date in each stand section. The felling dates were February 10, May 11, August 14 and November 10, 2006. With each felling, LRs were produced from 40 (or slightly more) pine trees. Only Scots pine trees were felled and most of the trees were removed from the main canopy. Thinning decreased the number of pine trees from 450 to 350 trees per ha.

Sampling began 14 days after felling and was repeated every 14 days within the vegetative period (23rd April through 10th October) until 12 repetitions were performed in each of the four sections. During sampling, ten branches (2–5 cm in diameter) and five trunk fragments from tree tops (1 m in length and 5–18 cm in diameter) were sampled in each of the four plots. Consequently, 720 LR fragments (i.e. 360 branches and 180 trunk fragments in each of the 4 stand sections) were sampled. Only branches that were at least 1 m in length and 2 cm in diameter at the base were sampled. The parts of the sampled branches that were less than 1 cm were sampled separately; a total of 1,200 samples were collected. The branch or trunk length and diameter were recorded for each sampled LR fragment. Each sample was entirely debarked, and the EASB (phloeo-, xylo- and xylomycetophagous) species present were identified based on the characteristics of the galleries or on the morphological traits of adults or larvae (Švácha et al. 1986, 1987, 1988; Bílý 1989; Bense 1995; Pfeffer 1995). Furthermore, the occurrence of each species was evaluated on a semiquantitative, six-degree scale based on a visual estimation of the percentage of the area exploited by the species within the sample mantle (< 1, 1–5, 6–25, 26–50, 51–75 and > 75%, see Braun-Blanquet 1964).

Statistical analyses. The frequency of occurrence of each species was expressed as the proportion of samples in which the species was present. For a further statistical analysis, the six-point scale of gallery coverage was represented by the following middle values of the percentage intervals: 0.5, 3, 15.5, 38, 63 and 88%. Because it was not possible to correct the non-normal distributions of the data regarding the gallery coverage of particular species (as tested using Shapiro-Wilk tests) by data transformation, such statistic methods were used that do not assume that the data distribution is normal. Canonical correspondence analysis (CCA) was used to assess the effects of the habitat variables on the species composition of the beetle assemblages. The CCA does not require normally distributed data, is not affected by the correlation of habitat factors, and assumes unimodal models for the relationships between the responses of each species and the habitat variables. This approach is appropriate for the data because a preliminary detrended correspondence analysis showed long gradient lengths (> 3 SD) (ter Braak 1986, 1987). In the CCA, a Monte Carlo permutation test (Manly 2001) with 999 permutations was used to compute the significance of the relationships between the species responses and the habitat factors. All recorded species were included in the analyses; however, to avoid an undesirably high influence of low-frequency species, rare species were downweighted as a separate step in the analyses. To illustrate the associations between the occurrence of the most frequent species and the diameter of LR fragments, Poisson generalised linear models (GLM) with a quadratic function using LR diameter as a predictor were fitted. GLM does not assume normal data distribution (Dobson et al. 2008). All these analyses were performed using CANOCO for Windows (ter Braak 1987).

Nonparametric Kruskal-Wallis tests that do not require normally distributed data (Hollander et al. 1999) were used to evaluate the statistical significance of differences in the gallery coverage of the most frequent species found on LRs that originated from different felling dates. If significant differences were found, then the Mann-Whitney *U* tests with critical *p*-values that were decreased by Bonferroni adjustment (i.e. in this case critical $P = 0.008$) were used to identify the pairs of datasets with significant differences. These calculations were performed in Statistica 10.0 (StatSoft 2013).

RESULTS

Of the 16 species of EASB found in LRs (Fig. 1), the family Curculionidae (12 species) was the most abundant. The majority of the curculionids (10 species) were bark beetles (Scolytinae), and *Pityogenes chalcographus* (Linnaeus) was the species that was encountered most frequently (Fig. 1).

All of the studied habitat variables significantly affected the species composition of the EASB assemblages and, combined, the habitat variables explained 23.3% of the observed variance in the gallery coverage of species (Table 1). The felling date was the most significant variable affecting the species composition of the EASB assemblages. The type of LR (trunk fragment, or branch thinner or thicker than 1 cm) and LR diameter also had strong effects.

The three tested species that were found at least on 50 LR fragments exhibited significant differ-

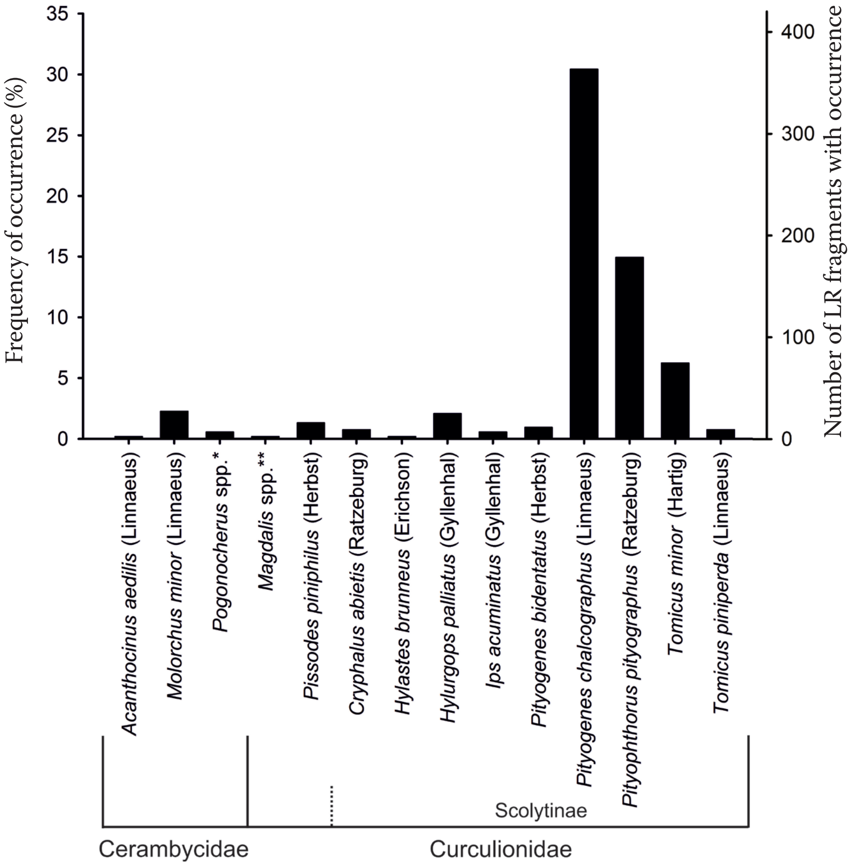

Fig. 1. Frequencies of taxa occurrence

*includes two species: *Pogonocherus fasciculatus* (De Geer) and *Pogonocherus decoratus* Fairmaire, **includes two species: *Magdalis frontalis* (Gyllenhal) and *Magdalis rufa* Germar

Table 1. Results of canonical correspondence analysis including Monte Carlo permutation tests for significance of the habitat factors for the species composition of early-arriving saproxylic beetle assemblages

Factor	*F*	*P*	Explained variance (%)	Covariables
Felling date	10.5 (11.3)	0.001 (0.001)	11.0 (10.3)	LR type, diameter, sample date
LR type (trunk fragment, or branch thinner or thicker than 1 cm)	13.8 (14.5)	0.001 (0.001)	9.7 (9.1)	felling date, sample date
Diameter	18.2 (20.8)	0.001 (0.001)	6.6 (6.6)	felling date, sample date
Sample date	2.6	0.045	1.0	–
Factors combined (except sample date)	12.8 (13.0)	0.001 (0.001)	23.3 (23.0)	sample date

percentage of the variance in the gallery coverage of species explained by the factors is included for particular cases; values in parentheses show the results without the effects of specific variables considered to be covariables (listed in the last column)

Table 2. Statistical significance of the associations between the gallery coverage of particular species and logging residues with different characteristics

Species	Felling date Kruskal-Wallis tests		Diameter generalised linear models		
	KW-H (3, 1200)	*P*	*F*	*P*	*AIC*
Pityogenes chalcographus	200.5	< 0.001	29.8	< 0.001	7,177
Pityophthorus pityographus	17.2	0.007	35.4	< 0.001	1,820
Tomicus minor	12.9	0.005	35.4	< 0.001	2,523

differences in the gallery coverage for particular species on logging residues generated on different dates (i.e. different felling dates) were tested using the Kruskal-Wallis tests; generalised linear models were used to examine the associations between the gallery coverage of a particular species and the diameter of logging residues; only species recorded at least on 50 logging residue fragments were tested

ences in the gallery coverage on the LRs that were produced on the different dates (Table 2), and particular species had characteristic patterns (Fig. 2) of occurrence. *P. chalcographus* was found most frequently on LRs from February and May; in contrast, it was very seldom found on LRs from August. *Pityophthorus pityographus* (Ratzeburg) and *Tomicus minor* (Hartig) were most often found on LRs that were produced in November. The above-

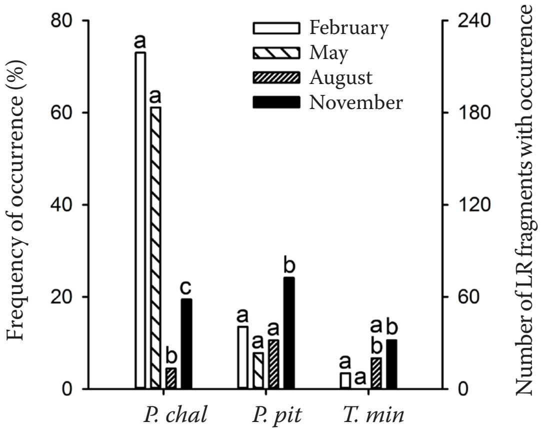

Fig. 2. Frequencies of species occurrence according to felling date

P. chal – Pityogenes chalcographus, P. pit – Pityophthorus pityographus, T. min – Tomicus minor; significant differences in gallery coverage were found for all species shown (Table 2); to determine which pairs of datasets were significantly different, columns representing datasets that did not differ significantly are labelled with the same letter; only species recorded at least on 50 LR fragments are shown

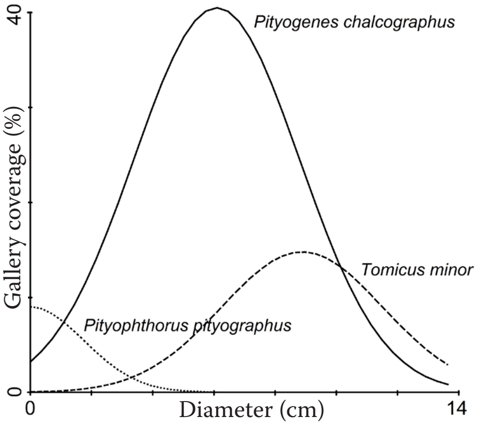

Fig. 3. Generalised linear models fitting associations between gallery coverage of particular species and diameter of LR fragments

all the shown models are statistically significant (Table 2); only species recorded at least on 50 LR fragments were included in the analysis mentioned three species were also significantly associated with LR diameter (Table 2, Fig. 3). Gallery coverage of *P. pityographus* decreased with LR diameter, reaching its highest values on the thinnest branches. The remaining species exhibited a unimodal pattern of gallery coverage with obvious optimum values (*P. chalcographus* – app. 6 cm and *T. minor* – app. 9 cm).

DISCUSSION

Only 16 species of EASBs were found to develop in LRs generated by thinning that consisted of branches and thin-barked top parts of trunks and that were also situated in the shade of the remaining stand (Fig. 1). The number of species found was considerably lower than the number of species found in similar studies conducted in the Czech Republic on LRs resulting from pre-commercial thinning (28 species – Foit 2015b) and on LRs from final felling (25 species – Foit 2015a); however, more samples of LRs were examined in these studies. The higher number of species found on the LRs resulting from pre-commercial thinning was probably caused by the more diverse LRs that were also composed of the thick-barked parts of trunks. In the case of LRs from final felling, species richness was likely to be increased as a result of the much greater sun exposure of the resulting LRs (Bouget et al. 2004; Lindhe, Lindelöw 2004; Lindhe et al. 2005; Fossestøl et al. 2009). The relatively low number of EASB species found in the present study on LRs generated by thinning suggests that these LRs are, in general, of minor importance for the diversity of saproxylic beetles. In contrast, LRs generated by thinning were documented to support the substantial multiplication of *P. chalcographus* in the present study. However, the main host tree of this important forest pest is Norway spruce (Pfeffer 1955; Schwenke 1972; Gregoire et al. 2004; Bertheau et al. 2009), its common development on Scots pine LRs was previously documented at several localities in the Czech Republic (Foit 2012b).

All of the habitat factors that were studied (felling date, LR type and LR diameter) significantly affected the composition of the EASB assemblages and were able to explain a large portion (23.3%) of the variance in the gallery coverage of species (Table 1). Unsurprisingly, the felling date (i.e. date of LR generation) had the highest explanatory power, and all of the species that occurred at least on 50 LR fragments exhibited significant differences in gallery coverage depending on the LR generation date (Table 2, Fig. 2). Felling date was previously documented as an important factor in studies dealing with various types of Norway spruce and Scots pine LRs (Kula et al. 2006, 2007; Foit 2012a, b, 2015a, b) and its effects are most likely associated with the timing of the species mating and egg laying and with the requirements of particular species regarding the stage of the substrate dieback or decay. Thus, *P. chalcographus*, a very early-arriving species (Schwenke 1972; Gregoire et al. 2004; Foit 2014) that exhibits spring and early summer mating and egg laying, colonised fresh LRs immediately after felling. The overwintering generation primarily colonised LRs from February, and the next generation colonised LRs from May. In contrast, the LRs produced in August and November were not colonised during the year of felling, and the LRs were too wilted to attract *P. chalcographus* during its subsequent mating and egg-laying period (the LRs from August were particularly unattractive). Similarly, like in other studies conducted in the Czech Republic on various Scots pine LRs (Foit 2012b, 2015a, b), *P. chalcographus* obviously avoided Scots pine LRs produced during late summer and early autumn (August, September and October). In contrast, *P. pityographus* and *T. minor* seemed to prefer LRs generated during November in the present study. In early spring, when *T. minor* has its mating and egg-laying period (earlier than the other studied species) (Schwenke 1972), LRs from November remained fresh enough, and *P. pityographus* with a mating and egg-laying period starting in May (Schwenke 1972) is probably more of a secondary species with a higher tolerance to more degraded substrates (Foit 2014).

LR type (trunk fragment, or branch thinner or thicker than 1 cm) and diameter were also important factors determining the composition of EASB assemblages (Table 1). Naturally, these factors were strongly associated. However, the type of LR had a considerably greater explanatory power than the LR diameter, possibly because the LR type was more strongly correlated with unstudied variables, such as the presence or absence of needles on particular LR fragments. The significance of the LR diameter was expected, because the diameter of the breeding substrate is well known to affect saproxylic beetle occurrence (Schiegg 2001; Lindhe, Lindelöw 2004; Lindhe et al. 2005; Jonsell et al. 2007; Maňák 2007; Jonsell 2008; Foit 2010; Brin et al. 2011). All three of the tested species were significantly associated with LR diameter in the present study (Table 2). *P. pityographus* preferred the thinnest fragments of LR and mostly developed in branches thinner than 2 cm (Fig. 3), which corresponds to its association with thin branches that has been documented in some other studies (Foit 2010, 2015a, b). *P. chalcographus* and *T. minor* exhibited preference to LR fragments of larger diameters with the optimal sizes being approximately 6 and 9 cm, respectively (Fig. 3). In the case of *P. chalcographus*, similar diameters (6–7 cm) represented the mean value of the substrate diameter within the distribution of its occurrence on standing Scots pines (Foit 2010), so branches and tree tops of about 6 cm in diameter might represent the optimum size for this species developing on Scots pine, or at least the optimum of the realised niche under local conditions. However, in the present study, *T. minor* had the highest amount of gallery coverage on LR of around 9 cm in diameter. This value probably does not represent the real optimum for this species, since only 20 LR samples were thicker than 9 cm and this species is known to develop frequently in much thicker substrates, such as the whole thin-barked part of the trunks of grown Scots pines (Schwenke 1972; Foit 2010), which may reach 20 cm in diameter or even more.

LRs generated by thinning are a part of the deadwood habitats in the managed forests of central Europe. These mostly shaded and not very diverse LRs (composed of only thin-barked branches and tree tops of restricted diameter) provided a substrate for the development of a restricted number of EASB species in the present study and are probably of minor importance for saproxylic beetle diversity. Results of the present study bring evidence that the felling date, LR type (trunk fragment, or branch thinner or thicker than 1 cm) and diameter are important variables in determining the occurrence of particular EASB species and thus the overall composition of assemblages.

Additionally, in the present study the LRs resulting from thinning enabled certain pest species to multiply, most importantly *P. chalcographus* (less significantly *P. pityographus* and *T. minor*). The occurrence of all of these species was significantly affected by felling date. Based on these results and others (Foit 2012b, 2015a, b), we suggest that the risk of multiplication of *P. chalcographus* would be minimised if fellings were conducted in August (and probably also in September or October). Regarding nature conservation, this treatment represents a much better solution than the removal of LRs. However, the removal of LRs generated by thinnings might be less detrimental than the removal of LRs resulting from final fellings or pre-commercial thinnings that likely have a greater value for the conservation of saproxylic beetles (Jonsell 2008; Fossestøl et al. 2009; Foit 2015a, b; Jonsell et al. 2015).

Acknowledgements

I appreciate the assistance of I. Březina with the experimental fellings.

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Received for publication May 11, 2015
Accepted after corrections June 22, 2015

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