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ORIGINAL PAPER

Pine or spruce? Comparison of stump suitability for the large pine weevil *Hylobius abietis* (L.) development

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ABSTRACT

The Norway spruce *Picea abies* (L.) H.Karst. and Scots pine *Pinus sylvestris* L. are both species with high economic potential; as a result, they are widely cultivated on plantations. Replanted coniferous seedlings in clearings are threatened by the large pine weevil *Hylobius abietis* (L.), one of the most prevalent pests in European forests. This weevil develops in fresh conifer stumps, which can be exploited to suppress its population. This study asks whether tree species and stump diameter influence the number of hatched adults, their sex, and their body size. During the two years after the forest was logged, we captured beetles using emergence traps installed on 18 Scots pine and 18 Norway spruce stumps. Generalised linear models used for the data analysis showed that the tree species (pine or spruce) significantly affects the number of beetles and their body mass. The vast majority of beetles left the stumps in the first year after felling. Beetles hatched in spruce stumps were less abundant and had a higher mass and longer development time. The sex of the beetles did not depend on either tree species or stump diameter. These results can be explained by the greater attractiveness and higher substrate suitability of pine wood. The increased weevil larvae mortality, as well as the higher body mass and longer development of the beetles, could be attributed to the less suitable properties of spruce wood, which is of lower nutritional quality. The lower mass of beetles in pine stumps may also be ascribed to their higher abundance and greater competition for resources. The results of this study did not provide a clear view of the comparative risks of spruce and pine stumps. While more beetles hatch from pine stumps, beetles from spruce stumps are larger, contributing to their higher fitness. Moreover, larger beetles with greater food consumption will likely cause more damage.

KEY WORDS

abundance, body mass, diameter, forest protection, population, sex

Introduction

The Norway spruce *Picea abies* (L.) H.Karst. and Scots pine *Pinus sylvestris* L. are both species with high economic potential; as a result, they have been cultivated on plantations in central Europe since the early 19th century (Surmiński, 2007; Ruotsalainen and Persson, 2013). This cultivation method is prone to damage through interconnected abiotic, biotic, and anthropogenic factors, including climate change (Hlásny *et al.*, 2017; Sierota *et al.*, 2019). Over the last several years, Central Europe has been experiencing an outbreak of bark beetle pests on both these tree

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species (Kunca *et al.*, 2019; Sierota *et al.*, 2019; Liška *et al.*, 2021). As a result, the area of clearings has increased. In the Czech Republic, the area of reforested clearings increased by more than 58% between 2015 and 2020, and approximately one-half of the area has been replanted with conifer seedlings (MZe, 2021). Their survival is threatened by the harmful effects of the large pine weevil *Hylobius abietis* (L.) (Långström and Day, 2004). Pine weevils prefer conifers for feeding, mainly pine and spruce seedlings, and respond positively to warmer weather (Inward *et al.*, 2012; Wallertz *et al.*, 2014; Doležal *et al.*, 2021). For this reason, the large pine weevil is one of the most prevalent biotic pests in European forests, and its high-risk potential may increase with continuing climate change (Leather *et al.*, 1999; Thorpe and Day, 2002; Inward *et al.*, 2012; Wallertz *et al.*, 2014).

The weevil's high abundance and its consequent damage to seedlings occur under clear-cut forest management, where beetles find suitable conditions for developing a new generation and feeding adults on seedlings (Långström and Day, 2004). The weevil's heightened ability to detect monoterpenes allows it to find areas suitable for feeding and reproduction over long distances (Solbreck, 1980; Nordenhem and Eidmann, 1991; Lindelöw *et al.*, 1993; Kennedy *et al.*, 2006). After maturation feeding, females lay eggs on or near the roots of fresh stumps (Leather *et al.*, 1999). After hatching, the larvae feed and create tunnels between the cambium and the bark. Larval development takes approximately 12 weeks or longer at lower temperatures (Nordenhem, 1989; Inward *et al.*, 2012). The beetles overwinter in the roots (Nordenhem, 1989), and adults emerge in two waves. The first wave lasts from May to June and the second wave from August to September. Emergence at the turn of summer and fall is linked to a one-year generation (Švestka *et al.*, 1990; Skrzecz *et al.*, 2021).

The following management measures can be used to reduce weevil damage: insecticides, physical protection of seedlings, trapping-out, population suppression, and silvicultural countermeasures, including reforestation methods, fallow periods, soil scarification, shelter trees, alternative food and seedling properties (Långström and Day, 2004; Lalík *et al.*, 2020, 2021). Following integrated pest management guidelines, the primary method should be the prevention of population growth (Švestka *et al.*, 1990; Flint, 2012). For this reason, it is beneficial to determine which stumps are more suitable for beetle development.

This study compared the suitability of spruce and pine stumps for weevil development. Specifically, we examined whether tree species and stump diameter influence the number of hatched adults, their sex, and their body mass. These population characteristics influence beetle fitness and population dynamics (Neal, 2018). Body mass determines the potential fecundity of females, larvae survival rates, reproductive maturity, and mating competition (Honěk, 1993; Wainhouse *et al.*, 2001; Thorpe and Day, 2008; Neal, 2018). Furthermore, the sex ratio affects mating opportunities and, subsequently, the dispersal probability (Lawrence, 1986).

Some traditional protection methods, such as mechanical protection of seedlings or pitfall trapping, are often time-consuming or expensive (Långström and Day, 2004; Lalík *et al.*, 2019). The European Commission Directive on the Sustainable Use of Pesticides (European Commission, 2019) and the FSC Forest Management certifications (FSC, 2019) restrict chemical protection. Moreover, alternative insecticides are largely ineffective (Willoughby *et al.*, 2020). For this reason, sustainable approaches to protection against weevils are still in demand (Tudoran *et al.*, 2021). Finally, this study focused on beetle rearing from stumps in their natural habitat, which means that it has a higher predictive value and, therefore, is better suited for forest management use (Brakefield and Mazzotta, 2002; Flint, 2012).

Material and methods

The study examined a clear-cut in the vicinity of Nová Pec (Šumava foothils, Czech Republic, 48.7861944 N, 13.9104656 E). This location is characterised by a moderately cold climate with an average temperature of 6.2°C and annual precipitation of 797 mm (CHMI, 2021). The clear-cutting took place in the summer of 2019, coinciding with the weevil's reproductive period (Örlander *et al.*, 1997; Skrzecz *et al.*, 2021). The clear-cut area was ca 1 ha, the maximum legally allowed clearing size in the Czech Republic. There was almost no undergrowth vegetation present in the clear-cut. We randomly selected 18 pine and 18 spruce stumps. All stumps were created by harvesting an 87-year-old mixed pine-spruce stand. The stumps of both tree species were mixed in the plot. None of the studied stumps was located at the clearing edge. The stumps in the study were separated by a minimum distance of 7 m, and at least one stump between the traps remained unused. The diameter of the pine stumps was 38.4 ±1.6 cm, and the diameter of the spruce stumps was 41.9 ±2.3 cm.

A modified emergence trap designed by Dillon *et al.* (2006) was set up on each stump. The basic shape of the trap was a square with an area of 2.25 m^2. A transparent trapping bottle was attached to the side of the pyramid. The bottles were filled with a mixture of ethylene glycol, water, and a small amount of wetting agent, which guaranteed high capture efficiency and attribute preservation with only a slight change in dead beetle mass over time (Schmidt *et al.*, 2006; Braun *et al.*, 2009). The traps remained installed from early March until the end of October in the two years following the tree logging (2020 and 2021). The weevils were regularly collected from the bottles at the end of each month. The beetle's sex was determined according to the last abdominal sternite (Öhrn *et al.*, 2008). Generalised linear models were used to evaluate the impact of the predictors (stump diameter, tree species) on the number, mass, and sex of the beetles. Spearman's rank coefficient was used to determine the correlation between the capture date and body mass. All tests were performed in the IBM SPSS Statistics software (Denis, 2019).

Results

A total of 65 individuals (3.6 ±3.16 per stump) weighing 61.2 ±25.6 mg emerged from spruce stumps, and 164 individuals (9 ±11.44) weighing 52.6 ±27.8 mg emerged from pine stumps. Only four stumps (three spruce and one pine) yielded no hatched beetles. The generalised linear models showed that only tree species significantly affected beetles' number and body mass. The sex of the beetles did not depend on either tree species or stump diameter (Table 1).The proportion of heavier individuals increased slightly with longer development times ($r=0.22$, $p\leq0.05$). The first beetles were caught in May 2020, the year following the forest logging. Most individuals (83%) were detected in late summer and early autumn. The sex ratios during this period were similar. A small number of beetles were captured between May and July 2021. In the second year after the logging, weevils were collected only from spruce stumps (Figs. 1, 2).

Discussion

Beetles hatched from most pine and spruce stumps, confirming that spruce and pine are the most suitable tree species for weevil development, which is in keeping with other studies (*e.g.*, Nordlander, 1991; Nicolai and Valentina, 2007; Dillon *et al.*, 2008). Weevil numbers observed in this study correspond to the findings of other studies, which have recorded several individuals to dozens of beetles per stump (Moore *et al.*, 2004; Dillon *et al.*, 2006, 2007; Skrzecz *et al.*, 2019). The prevailing one-year development and balanced sex ratio are also consistent with other studies

Table 1.

Dependence of the number of hatched beetles, their sex, and body mass on tree species and stump diameter. Significant dependencies are marked in bold.

Predictor	Response	χ^2	p-value
Tree species	No. of beetles	5.706	**0.017**
	Mass	4.24	**0.039**
	Sex	0.164	0.685
Diameter	No. of beetles	0.007	0.935
	Mass	0.025	0.875
	Sex	0.086	0.769

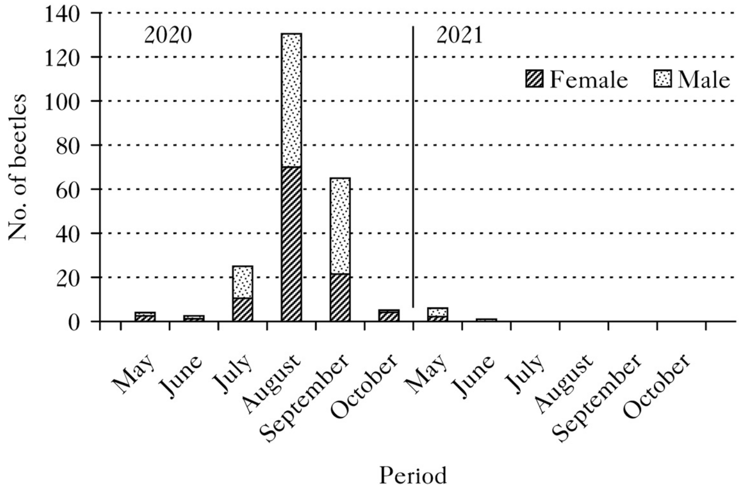

Fig. 1.

Number of females and males in each capture period (March and April are not shown, as no individuals were captured)

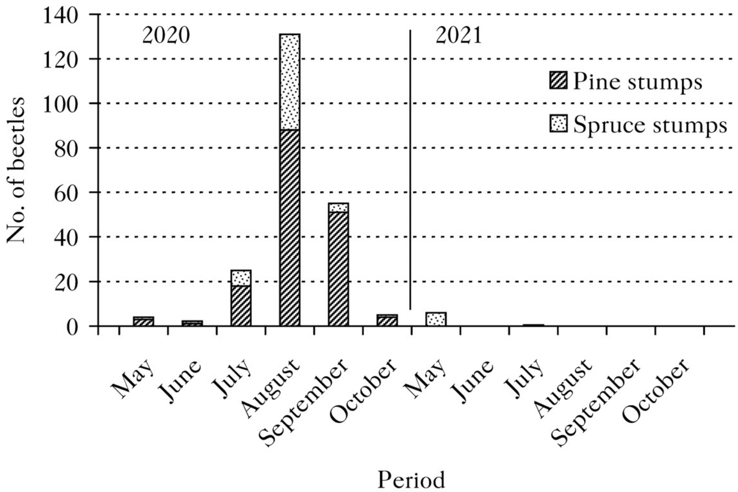

Fig. 2.

Number of beetles hatched from pine stumps and spruce stumps in each capture period (March and April are not shown, as no individuals were captured)

(Lalík *et al.*, 2020, 2021). Lalík *et al.* (2020) explained that the current dominance of the one-year generation in central Europe is due to the warmer weather.

More beetles originated from pine stumps. These results can be explained by the pine wood's greater attractiveness and higher substrate suitability (Sydow and Birgersson, 1997). While spruce stumps decompose more slowly, pine stumps emit more terpenes, such as a-pinene, and have a higher ethanol content, which the beetles respond to positively (Nordlander *et al.*, 1986; Tilles *et al.*, 1986; Englund and Nussbaum, 2000; Shorohova *et al.*, 2012; Czajka *et al.*, 2020). After felling, spruce stumps have a higher residual resistance and a greater propensity for fungal infestation, resulting in the increased mortality and limited development of weevils (Sydow, 1993; Wainhouse *et al.*, 2001).

The adults that hatched from spruce stumps were significantly heavier than those from pine stumps and were also detected in the second year after felling. This finding corresponds with Inward *et al.* (2012), who showed that the rate of weevil development is slower on spruces than pines, although they studied different representatives of these two genera. The difference in mass may also be explained by the poor nutritional quality of the spruce wood, which is linked with slower development and larger adult size (Torres-Vila *et al.*, 2018). The bark of spruce roots contains lignified stack-cell masses that can physically obstruct larvae feeding, which is why larger larvae are better equipped to initiate feeding and develop into adults (Wainhouse *et al.*, 2001). For pine weevils, the general rule applies that higher temperatures increase the larval development rate, often at the cost of decreasing the final adult size (see Irwin *et al.*, 2014). Spruce stumps are associated with higher wood moisture, (Sydow, 1993; Meyer and Brischke, 2015) leading to heat loss (MacLean, 1941). Thus, weevils develop more slowly due to the lower temperature (Inward *et al.*, 2012). The lower mass of beetles in pine stumps may also be ascribed to their higher abundance and subsequent greater resource competition (Eidmann, 1977). The body mass of the larvae is often reduced in dense populations, which is known, for example, from bark beetles (Safranyik and Linton, 1985). In conclusion, lower temperature in conjunction with lower wood quality and competition may have resulted in fewer but larger individuals emerging from spruce stumps in this study.

While a larger stump may offer more resources and could be expected to host more individuals, this assumption could not be confirmed by this study. Similarly, Tarasova and Sukhovol'skii (1986) found that stump diameter did not impact the number of beetles. An explanation may lie in the small differences between stump diameters (Moore *et al.*, 2004). Spruces have a slightly larger diameter than pines, but the difference of a few centimetres likely has no effect.

The differences in adult mass and abundance can be helpful when considering management tactics since the choice of an adequate protection method should correspond to the potential damage (Leather *et al.*, 1999; Långström and Day, 2004; Flint, 2012; Torres-Vila *et al.*, 2018). The results of this study did not provide a clear view of the comparative risks of spruce and pine stumps. While more beetles hatch from pine stumps, beetles from spruce stumps are larger, contributing to their higher fitness (Beukeboom, 2018; Neal, 2018). Moreover, larger beetles with greater food consumption will likely cause more damage (Irwin *et al.*, 2014). Rather than focusing on stumps, foresters may find it more useful to concentrate on the seedlings' species composition, which strongly influences population dynamics (Wainhouse *et al.*, 2001; Awmack and Leather, 2002; Doležal *et al.*, 2021).

Conflict of interest

The authors have declared that no competing interests exist.

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STRESZCZENIE

Sosna czy świerk? Porównanie przydatności pniaków w rozwoju szeliniaka sosnowca *Hylobius abietis* (L.)

Sadzonki sosnowe wysadzane na zrębach są zagrożone przez szeliniaka sosnowca *Hylobius abietis* (L.), jednego z najbardziej rozpowszechnionych biotycznych szkodników w lasach europejskich (Långström i Day, 2004). W badaniach porównano przydatność pniaków świerkowych i sosnowych w rozwoju szeliniaka. W szczególności zbadano, czy gatunki drzew i średnica pniaków wpływają na liczbę wylęgłych osobników dorosłych, ich płeć i rozmiar ciała. Uogólnione modele liniowe potwierdziły, że tylko gatunki drzew znacząco wpłynęły na liczbę i masę ciała chrząszczy (tab. 1). W badaniu zarejestrowano 65 osobników, które wyszły z pniaków świerka i 164, które pochodziły z pniaków sosny (ryc. 1-2). Większość osobników wykryto pod koniec lata i na początku jesieni w roku następującym po pozyskaniu drewna. Dorosłe osobniki, które wyszły z pniaków świerkowych, były znacznie cięższe i wykryto je również w drugim roku po ścince.

Wyniki badań nie pozwalają na dokonanie jednoznacznego porównania zagrożenia w odniesieniu do pniaków świerka i sosny. Z pniaków sosnowych wylęgło się więcej osobników, natomiast chrząszcze z pniaków świerkowych były większe, co decyduje o ich większej przydatności (Beukeboom, 2018; Neal, 2018). Ponadto większe chrząszcze przy większym spożyciu pokarmu prawdopodobnie spowodują większe szkody (Irwin i in., 2014).