Do visual cues associated with larger diameter trees influence host selection by *Tetropium fuscum* (Coleoptera: Cerambycidae)?

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Abstract—*Tetropium fuscum* (Fabricius) (Coleoptera: Cerambycidae) is an invasive phloeophagous beetle established in Atlantic Canada that infests stressed and moribund *Picea* Dietrich (Pinaceae) species. Successfully colonised trees tend to be large in diameter (> 10 cm diameter at breast height), but whether diameter influences host selection, larval performance, or both, is unknown. We tested the hypothesis that *T. fuscum* host selection is influenced by visual cues associated with tree diameter by counting the number of adults landing on 29 *Picea rubens* Sargent ranging in diameter at breast height from 12.2 to 37.5 cm. All trees were wrapped with sticky bands and baited with aggregation pheromone and host volatiles to make them equally attractive with regard to olfactory cues. We found significant positive relationships between the mean number of *T. fuscum* per sticky band and tree diameter, and also between phloem thickness and tree diameter. We conclude that the positive association between host diameter and *T. fuscum* infestation is at least partially due to the positive influence of diameter on landing rate, and that this may benefit the beetle because larger diameter trees have more food for developing larvae. However, there was no effect of tree diameter on the mean number of adults per m^2 of sticky band and thus no evidence that *T. fuscum* actively selects larger diameter hosts based on visual cues. The positive relationship between landing rate and host diameter may simply be due to greater chances of airborne beetles being passively intercepted on larger versus smaller trees.

The brown spruce longhorn beetle, *Tetropium fuscum* (Fabricius) (Coleoptera: Cerambycidae), is an invasive insect native to Europe that has been established in Nova Scotia, Canada since at least 1990 (Smith and Hurley 2000). In both Europe and Nova Scotia, it primarily infests spruce, *Picea* Dietrich (Pinaceae) species, that are stressed, weakened, or of low vigour (Juutinen 1955; Flaherty *et al*. 2013a). Flaherty *et al*. (2013b) showed that adult *T. fuscum* preferred to land on and lay more eggs on red spruce trees (*Picea rubens* Sargent) that had been moisture stressed by girdling compared with unmanipulated trees, and further showed that the beetles were more discriminating before they landed on the host than afterward. As larval development rate and survival of *T. fuscum* were also greater in girdled trees than in healthy trees (Flaherty *et al*. 2011, 2013a) the preference for girdled trees supported the preference–performance hypothesis (Jaenike 1978; Flaherty *et al*. 2013b).

Tetropium fuscum also tends to colonise mature trees of large diameter. In Europe, *T. fuscum* infestation has not been observed in trees smaller than 9 cm in diameter at breast height (Juutinen 1955) and in Nova Scotia, the mean diameter at breast height of red spruce is significantly larger in trees infested with *T. fuscum* than in uninfested trees growing on the same site (J.D.S., unpublished data). The positive association observed between host diameter and *T. fuscum* infestation could result from a preference of foraging females

Received 23 January 2017. Accepted 26 April 2017. First published online 21 June 2017.

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Subject editor: Kevin Floate
doi:10.4039/tce.2017.22

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to land on and/or subsequently lay eggs on larger versus smaller diameter trees. Ito (1999) observed greater numbers of adult *Semanotus japonica* Larcordaire (Coleoptera: Cerambycidae) on larger diameter Japanese cedars, *Cryptomeria japonica* (Thunberg ex Linnaeus) Don (Cupressaceae), than on smaller ones, and positive correlations between host diameter and oviposition have been recorded for both *S. japonica* (Shibata *et al*. 1994) and another cerambycid, *Aerenea quadriplagiata* Boheman (Riquelme *et al*. 2013). Alternatively, it may be that *T. fuscum* landing rate and oviposition are random with regard to host diameter, but that larval survival and colonisation success tend to be higher on larger diameter trees because they have more food and space for developing larvae, or that *T. fuscum* both prefers and performs better on larger diameter hosts. Attack density of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae), increases with host tree diameter (Safranyik and Carroll 2006) and larger diameter trees tend to have thicker phloem that is positively associated with brood survival (Amman 1972).

In the current study, we tested the hypothesis that *T. fuscum* host selection is influenced by host tree diameter by measuring adult landing rate on red spruce trees of varied diameters. We assumed that landing rate on sticky bands indicated pre-alighting host selection for oviposition (Flaherty *et al*. 2013b). If the positive association between *T. fuscum* infestation and host diameter is due to greater attack rate on larger diameter hosts, we predicted a positive relationship between the number of *T. fuscum* adults landing per sticky band and diameter at breast height. If *T. fuscum* preferentially and actively selects larger diameter hosts based on visual cues, then we predicted a positive relationship between the number of adults per m^2 of sticky band and diameter at breast height.

Our study site was a mature forest dominated by red spruce, balsam fir (*Abies balsamea* (Linnaeus) Miller (Pinaceae)), and red maple (*Acer rubrum* Linnaeus (Sapindaceae)), located near Sandy Lake in Bedford, Nova Scotia (44°44'13.74"N, 63°41'30.60"W). On 21 May 2015, near the beginning of the flight period of the beetle, we selected 29 red spruce trees with diameter at breast height ranging from 12.2–37.5 cm, and wrapped a 15.2-cm-wide sticky band (Alpha Scents, Portland, Oregon, United States of America) around the bole of each tree at breast height (1.3 m above the ground). Host diameter near the basal 1–2 m of the stem is particularly relevant to *T. fuscum* as this is the area of the tree that is most often colonised by the beetle (Juutinen 1955). All trees had full green crowns and no sign of infestation by *T. fuscum* (*e.g.*, unexplained resinosis, exit holes on the main stem) and were within a total area of ~ 1.5 ha. On each tree, we pruned three to five branches from the basal 1.3 m to allow easier attachment of the sticky band. We also baited each tree with the same three lures used to bait traps for *T. fuscum* surveys: (1) a rubber septum emitting racemic fuscumol at ~ 1 mg/day (Sylvar Technologies, Fredericton, New Brunswick, Canada); (2) a brown spruce longhorn beetle kairomone lure emitting a blend of five spruce monoterpenes (Sweeney *et al*. 2006) at ~ 2000 mg/day (Scotts Canada; Delta, British Columbia, Canada); and an ethanol lure with a release rate of ~ 275 mg/day (Scotts Canada). (*S*)-fuscumol (2S,5E)-6, 10-dimethyl-5,9-undecadien-2-ol, or "fuscumol", is the aggregation pheromone emitted by male *T. fuscum* that attracts both sexes when combined with the volatiles emitted by stressed host trees (spruce monoterpenes and ethanol) (Silk *et al*. 2007; Sweeney *et al*. 2010). We baited the trees to increase overall landing rates and to try to make them equally attractive to *T. fuscum* in terms of olfactory cues, thereby increasing the probability that any discrimination among trees would be based on visual stimuli such as tree diameter.

Sticky bands were checked every two weeks between 21 May and 26 August 2015. On each check, all *Tetropium* adults were counted and removed from sticky bands using forceps and transported in centrifuge tubes to the Atlantic Forestry Centre in Fredericton, New Brunswick, Canada for identification to species and sex. On 18 September 2015, a 0.52-cm-diameter core sample was taken from the north and south side of each tree with an increment borer. Mean phloem thickness between cores was measured on site with a digital vernier caliper.

Simple linear regressions were used to evaluate the relationship between diameter at breast height and (1) phloem thickness, (2) total number of *T. fuscum* adults per sticky band, and (3) total number of *T. fuscum* adults per m^2 of sticky band.

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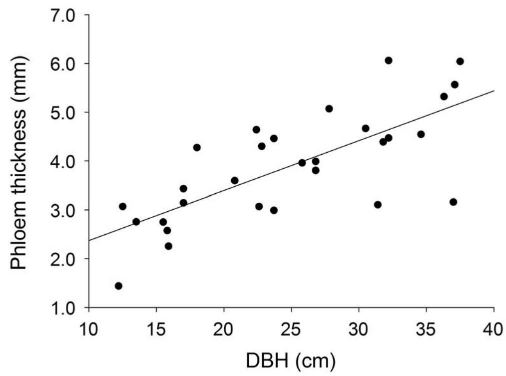
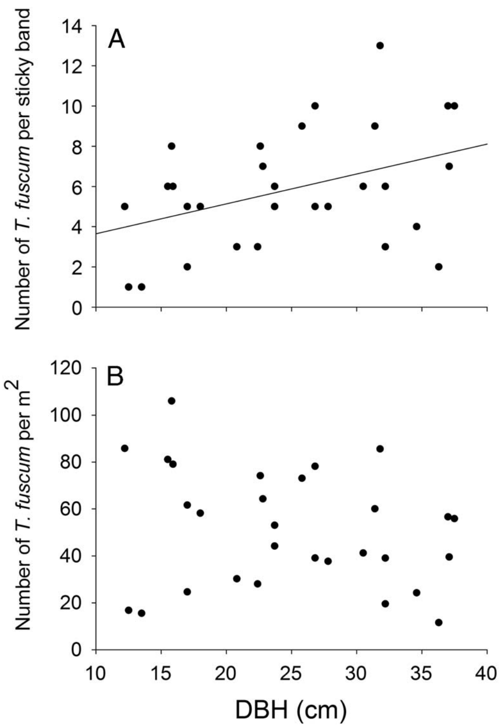
Fig. 1. Phloem thickness versus diameter at breast height (DBH) of red spruce near Sandy Lake, Nova Scotia in 2016 ($F(1,27) = 31.3$; df = 1, 27; $P < 0.0001$, $r^2 = 0.54$).



Full factorial analyses of covariance (SAS: PROC GLM) (SAS Institute 2008) were used to test whether the slopes of the regressions between landing rate (per sticky band and per m^2 sticky band) and diameter at breast height differed between males and females. The residuals of each regression were checked for normality by examining scatterplots and histograms and by the Shapiro–Wilk test (SAS: PROC Univariate); residuals did not depart significantly from normality for any regression ($P = 0.25$–0.97). A χ^2 test with Yates' correction for continuity was used to test whether the sex ratio departed significantly from a 1:1 ratio (Zar 1999).

In total, 170 *T. fuscum* were captured; 92 were female, 66 were male, and the sex of 12 could not be identified due to missing or damaged genitalia, likely caused by predation. The sex ratio was significantly female biased ($\chi^2 = 3.96$, $P < 0.05$), as previously observed in traps baited with the same lures, *i.e.*, fuscumol, spruce monoterpenes and ethanol (Sweeney *et al.* 2010). Phloem thickness increased significantly with tree diameter at breast height ($F(1,27) = 31.3$, $P < 0.0001$, $r^2 = 0.54$) (Fig. 1). There was also a positive linear relationship between the total number of *T. fuscum* adults per sticky band and tree diameter at breast height ($F(1,27) = 5.4$, $P < 0.05$, $r^2 = 0.16$) (Fig. 2A), and the slopes of the regression did not differ significantly between sexes ($F(1,27) = 0.07$, $P = 0.80$). However, the regression between the number of *T. fuscum* per m^2 of sticky band and diameter at breast height was not significant for either sex ($F(1,27) = 0.67$–0.81, $P > 0.38$) or when sexes were pooled ($F(1,27) = 1.49$, $P = 0.23$, $r^2 = 0.05$) (Fig. 2B).

Fig. 2. The number of *Tetropium fuscum* adults collected on sticky bands versus diameter at breast height (DBH) of red spruce trees baited with fuscumol and host kairomones, near Sandy Lake, Nova Scotia from May to August 2016. (A) Number per sticky band ($F(1,27) = 5.4$; df = 1, 27; $P = 0.028$; $r^2 = 0.17$). (B) Number per m^2 surface area of sticky band ($F(1,27) = 1.49$; df = 1, 27; $P = 0.23$; $r^2 = 0.05$).



The positive relationship between the number of *T. fuscum* landing per sticky band and host diameter at breast height is consistent with our hypothesis that host diameter positively influences the number of *T. fuscum* landing per tree and may partially explain the positive association between infestation and host tree diameter. Furthermore, the significant positive linear relationship between phloem thickness and tree diameter at breast height indicates that, all other things being equal, larger diameter red spruce

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should contain more food as well as more space for developing *T. fuscum* larvae, and that preference for larger diameter hosts may be adaptive. However, we found no evidence for diameter-based host selection by *T. fuscum*. The regression between number of *T. fuscum* landing per m^2 and diameter at breast height was not significant, suggesting the positive relationship between landing rate and host diameter was not due to any active preference or selection of larger diameter trees by the beetles. Our results suggest instead that larger diameter trees are more likely to intercept airborne beetles than are smaller diameter trees, simply due to their greater surface area. Other host factors, such as tree condition and associated pre-alighting olfactory cues, which may be correlated with tree diameter, likely have a much greater effect on *T. fuscum* host selection than visual cues associated with tree diameter (Flaherty *et al*. 2013b).

Acknowledgements

The authors thank Halifax Regional Municipality and John Simmons for granting them permission to work in the Sandy Lake forest in Bedford, Nova Scotia; Kate Van Rooyen, Cory Hughes, and Mary Luco for technical assistance; Leah Flaherty, Rob Johns, and two anonymous reviewers for helpful comments on earlier versions of the manuscript; and the Forest Invasives Alien Species Project of Natural Resources Canada and the Canadian Forest Service for funding.

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