

# Effects of trap height on captures of arboreal insects in pine stands of northeastern United States of America

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**Abstract**—Knowledge of the effects of variables that can influence trapping results should help to optimise efforts in exotic species detection and other surveys. Two vertical trap placements (understorey, canopy) were tested to determine influence of these two heights on captures of Scolytinae (Coleoptera: Curculionidae), Cerambycidae (Coleoptera), and Siricidae (Hymenoptera) using semiochemical-baited multiple-funnel traps. Traps were baited with  $\alpha$ -pinene, ethanol, ipsdienol, and ipsenol. A total of 8463 insects from 65 species and one genus were captured during the study. Average species richness, species diversity, abundance, number of unique species, and expected diversity were higher in understorey compared with canopy traps. Jaccard ( $0.94 \pm 0.05$ ) and Sørensen abundance ( $0.97 \pm 0.03$ ) similarity indices suggested highly similar communities sampled at the two trap heights. *Dendroctonus valens* LeConte, *Dryocoetes autographus* Ratzeburg, *Hylastes opacus* Erichson, *Orthotomicus caelatus* (Eichhoff), *Gnathotrichus materiarius* (Fitch), *Asemum striatum* (Linnaeus), *Monochamus scutellatus scutellatus* (Say), *Rhagium inquisitor* (Linnaeus), and *Xylotrechus sagittatus sagittatus* (Germar) were more abundant in understorey traps. In contrast, *Ips pini* (Say), *Pityogenes hopkinsi* Swaine, *Monochamus carolinensis* (Olivier), *Acmaeops proteus* (Kirby), and *Astylopsis sexgutatta* (Say) were more abundant in canopy traps. The common practice of trapping in the understorey may be optimal for sampling arboreal insects as part of survey efforts. However, additional species may be found by trapping at other vertical placements.

**Résumé**—Une connaissance des effets des variables qui peuvent influencer les résultats de piégeage devrait permettre d'optimiser les efforts de détection des espèces exotiques et d'inventaires divers. Nous avons évalué l'influence de deux positions verticales (sous-bois et canopée) de pièges à entonnoirs multiples munis d'appâts sémi-chimiques sur les captures de Scolytinae (Coleoptera: Curculionidae), de Cerambycidae (Coleoptera) et de Siricidae (Hymenoptera). Les pièges ont été munis d' $\alpha$ -pinène, d'éthanol, d'ipsidiénol et d'ipsénol. En tout, 8463 insectes représentant 65 espèces et un genre ont été récoltés durant l'étude. La richesse spécifique moyenne, la diversité spécifique, l'abondance, le nombre d'espèces uniques et la diversité attendue sont plus élevés dans les pièges du sous-bois que dans ceux de la canopée. Les indices de similarité de Jaccard ( $0,94 \pm 0,05$ ) et de Sørensen ( $0,97 \pm 0,003$ ) laissent croire que des communautés très semblables ont été échantillonnées aux deux niveaux de pièges. *Dendroctonus valens* LeConte, *Dryocoetes autographus* Ratzeburg, *Hylastes opacus* Erichson, *Orthotomicus caelatus* (Eichhoff), *Gnathotrichus materiarius* (Fitch), *Asemum striatum* (Linnaeus), *Monochamus scutellatus scutellatus* (Say), *Rhagium inquisitor* (Linnaeus) et *Xylotrechus sagittatus sagittatus* (Germar) étaient plus abondants dans les pièges dans le sous-bois. En revanche, *Ips pini* (Say), *Pityogenes hopkinsi* Swaine, *Monochamus carolinensis* (Olivier), *Acmaeops proteus* (Kirby) et *Astylopsis sexgutatta* (Say) étaient plus abondants dans les pièges de la canopée. La pratique courante de placer les pièges dans le sous-bois peut être optimale pour l'échantillonnage des insectes arboricoles lors de travaux d'inventaire. Cependant, on peut obtenir des espèces additionnelles en fixant les pièges à d'autres hauteurs.

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## Introduction

Large-scale efforts to detect invasive wood-inhabiting insects occur in North America and elsewhere (Brockerhoff *et al.* 2006; Rabaglia *et al.* 2008). Scolytinae (Coleoptera: Curculionidae), Cerambycidae (Coleoptera), and Siricidae (Hymenoptera) are common targets of these surveys as several have successfully invaded new environments causing considerable economic and ecological impacts (Ciesla 2003; Mayfield 2007; Haack *et al.* 2010). These survey efforts generally involve deploying semiochemical-baited traps with the hopes of detecting invasive insects early in the establishment phase of invasion where eradication efforts have the best chance of success. Maximising the chances of traps intercepting invading insects relies on selecting high-risk sites for survey and various other factors that influence traps. Trapping factors, such as semiochemical blends, trap placement in an environment, and selection of trapping habitats all can influence trapping success (Miller and Rabaglia 2009; Dodds 2011; Graham *et al.* 2012).

For most surveys, traps are deployed in the understorey with the base of traps ~0.5–1.0 m off the ground. Little empirical data exist to support trapping only in the understorey, but lower trap heights are logistically easier to set and maintain. Many wood-inhabiting species preferentially colonise different portions of trees but dispersal behaviour for most common species is unknown. It is possible that insects colonising upper portions of trees may not disperse below their habitat height and may be missed in sampling efforts concentrated in the understorey. Several studies have demonstrated the importance of sampling at various heights (Su and Woods 2001; Vance *et al.* 2003; Ulyshen and Hanula 2007; Wermelinger *et al.* 2007; Bouget *et al.* 2008), but it is unknown what influence trap height has when used in conjunction with common detection lures such as  $\alpha$ -pinene, ethanol, ipsdienol, and ipsenol. The objective of this study was to determine the influence traps placed at two heights had on a subset of arboreal (scolytine, cerambycid, and siricid) insects in northeastern pine forests.

## Materials and methods

### Site

Traps were deployed in two pine stands on the Massebesic Experimental Forest near Alfred, Maine, United States of America. These stands were ~0.5 km from one another and separated by an unthinned mature eastern white pine, *Pinus strobus* Linnaeus (Pinaceae) stand. Sample stands were similar in structure and both had undergone thinning treatments during the fall/winter 2008. One stand was entirely *P. strobus*, while the second stand contained a mix of *P. strobus* and red pine, *Pinus resinosa* Aiton. Average tree diameter was 32 cm and basal area ranged from 11 to 18 m<sup>2</sup>/ha in the stands. The thinning treatments resulted in open stand conditions with a noncontiguous canopy throughout the majority of the area.

### Experimental design

Two treatments (understorey, canopy level) were selected to test the effect of trap height on arboreal insect catches. Canopy-level traps (hereafter referred to as canopy traps) were hung between two codominant trees separated by at least 15 m. Height of traps ranged from 10 to 12 m, which generally corresponded to the height of the lower third of the live crown. A Big Shot<sup>®</sup> (SherrillTree, Greensboro, North Carolina, United States of America) was used to shoot a 283.5 g (10 ounce) weighted bag with a throwline attached through the lower canopy of one tree. This throwline was then used to feed a stronger nylon rope through the lower portion of the live-crown branches. This procedure was repeated for the second tree and each end of the nylon rope was fastened to a 5 cm diameter metal ring. A smaller nylon rope was fed through the metal ring with one end tied to the multiple-funnel trap. Both ends of the horizontal line were then raised and positioned so that the metal ring guiding the vertical line was in the middle of the two trees. The opposite ends of the horizontal nylon line were then fastened to eyehooks in adjacent cut stumps. The vertical line fed through the metal ring was used to raise and lower canopy traps for insect collection. Understorey traps were hung from metal conduit poles placed in between the two co-dominant pine trees that were used to rig the canopy trap.

These traps were hung so that the collection cup was  $\sim 0.5$  m from the ground. Ten replicates (five in each stand) of the two treatments were set 2 May 2011 and collections were made biweekly until 4 November 2011.

Twelve-unit multiple-funnel traps (Lindgren 1983) with wet collection cups were used along with semiochemical baits to collect insects. Propylene glycol was used as the collection and preservation liquid. Traps were baited with  $\alpha$ -pinene (releasing  $\sim 2$  g/day), ethanol (releasing  $\sim 0.4$  g/day), racemic ipsdienol, and racemic ipsenol lures. Ipsdienol and ipsenol were released from plastic bubblecap lures at rates of 0.2 and 0.4 mg/day, respectively. All release rates were provided by the manufacturer (Synergy Semiochemicals, Burnaby, British Columbia, Canada). The  $\alpha$ -pinene and ethanol lures were changed every four weeks, whereas ipsdienol and ipsenol were changed every six weeks. Insects were collected every two weeks by straining the propylene glycol and captured insects through a paper/nylon paint filter and placing this filter in a labelled plastic sample bag. The rigging of one canopy trap was problematic throughout the latter portion of sampling and compromised sample collection on several occasions. In these instances, the understorey trap collections from the same replicate were not used in the analyses. Samples were later processed in the laboratory where scolytines, cerambycids, and siricids were separated from debris and bycatch and identified to species. No attempt was made to identify individual *Pityophthorus* Eichhoff (Coleoptera: Curculionidae) species because of the taxonomical challenges this genus presents. Voucher specimens were deposited in the United States Forest Service, Durham Field Office, Forest Insect Collection (Durham, New Hampshire, United States of America).

### Statistical analyses

Trap catches were pooled over the entirety of the trapping period for all analyses except average species richness estimates. Only species that accounted for more than 1% of total trap catches of a family were analysed separately. The number of species each trap accumulated over the trapping period were summed and used for comparisons of average species richness.

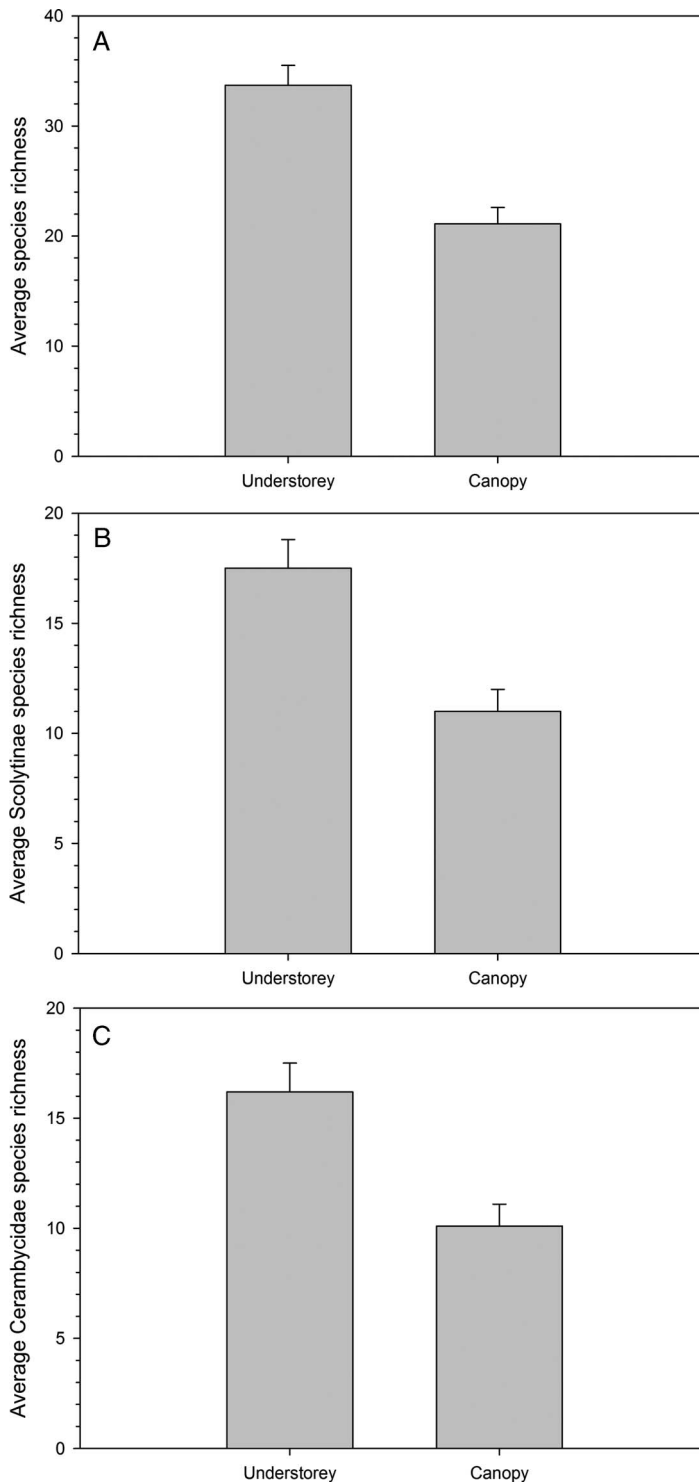
Trap catches were analysed using a generalised linear mixed model (Proc GLIMMIX) via maximum likelihood estimation with replicates as blocks. Replicates were considered a random factor and trap height was a fixed factor in the model. Data were modelled with the negative binomial function with log link (SAS version 9.3, SAS Institute, Cary, North Carolina, United States of America). Collections of *Dryocoetes autographus* Ratzeburg were not modelled because this species was not captured in canopy traps compared with 900 captured in understorey traps.

For all species richness and diversity measures, trap collections were pooled by treatment for the entire sampling period. Simpson's index (1-D) was calculated using the software PAST (Hammer *et al.* 2001). Adjusted Jaccard and Sørensen abundance estimates of community similarity (Chao *et al.* 2006) were calculated between the trap treatments using SPADE (Chao and Shen 2010). SPADE was also used to determine Chao1 estimates of species richness for each trap position. Individual-based rarefaction curves were calculated for understorey and canopy traps by pooling all catches by each treatment in PAST.

## Results

A total of 8463 scolytine, cerambycid, and siricid specimens from 65 species were captured in understorey and canopy traps. Scolytines represented 73.9% of trap catches with specimens from 28 species and one genus (*i.e.*, *Pityophthorus*), while cerambycids accounted for 25.8% of trap catches from 33 species. *Hylastes opacus* Erichson and *Xyleborinus alni* (Niisima) were the only exotic scolytines captured. No exotic cerambycids were captured. Siricids only represented 0.3% of the catch and included specimens from four native species. Significantly more total cerambycids, scolytines, and siricids were captured in understorey ( $567.7 \pm 36.0$ ) compared with canopy ( $231.3 \pm 15.1$ ) traps ( $F_{1,9} = 97.2$ ,  $P < 0.0001$ ). Higher average species richness was captured in understorey ( $33.7 \pm 1.8$ ) compared with canopy ( $21.1 \pm 1.5$ ) traps ( $F_{1,9} = 28.5$ ,  $P = 0.0005$ ; Fig. 1A). Understorey traps captured higher proportions of total species captured for both scolytines and cerambycids (Fig. 2). Forty-two percent of

**Fig. 1.** Average total (A), Scolytinae (B), and Cerambycidae (C) species richness captured in understory and canopy traps baited with  $\alpha$ -pinene, ethanol, ipsdienol, and ipsenol in southern Maine, United States of America.



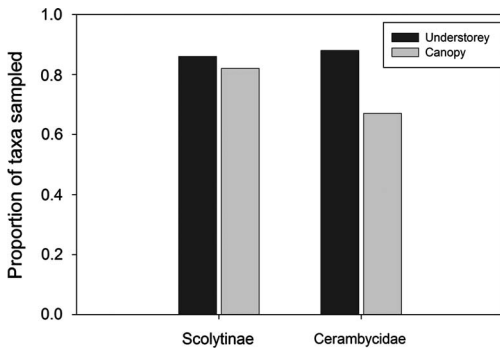
species were captured five or fewer times, and 24% of the species were captured only once (*i.e.*, singlets).

**Scolytinae**

*Dendroctonus valens* LeConte and *Ips grandicollis* (Eichhoff) were the most abundant

scolytines, representing 24% and 21% of total scolytine captures, respectively. Other abundant species included *D. autographus* (14%), *Orthotomicus caelatus* (Eichhoff) (13%), *Ips pini* (Say) (8%), and *Pityogenes hopkinsi* Swaine (7%). Singlets accounted for 18% of the scolytine species captured. *Pityophthorus* was treated as a genus, but at least four morphospecies were present in the collections.

**Fig. 2.** Proportion of total Scolytinae and Cerambycidae taxa sampled with understorey and canopy traps in southern Maine, United States of America.



Average species richness of scolytines was higher in understorey compared with canopy traps ( $F_{1,9} = 14.6, P = 0.004$ ; Fig. 1B). More total scolytines were also captured in understorey than canopy traps ( $F_{1,9} = 80.9, P < 0.0001$ ; Table 1). *Dendroctonus valens* ( $F_{1,9} = 200.2, P < 0.0001$ ), *D. autographus*, *H. opacus* ( $F_{1,9} = 76.6, P < 0.0001$ ), *O. caelatus* ( $F_{1,9} = 182.6, P < 0.0001$ ), and *Gnathotrichus materiarius* (Fitch) ( $F_{1,9} = 49.4, P < 0.0001$ ) were all more abundant in understorey compared with canopy traps. Only *I. pini* ( $F_{1,9} = 8.6, P = 0.02$ ) and *P. hopkinsi* ( $F_{1,9} = 10.3, P = 0.01$ ) were more abundant in canopy traps. Species that were captured in similar numbers at the two

**Table 1.** Mean  $\pm$  SE of scolytines and cerambycids captured in understorey and canopy traps baited with  $\alpha$ -pinene, ethanol, ipsdienol, and ipsenol in southern Maine, United States of America.

Variable	Understorey	Canopy
Total Scolytinae	437.7 $\pm$ 36.0*	151.1 $\pm$ 12.8
<i>Dendroctonus valens</i>	129.5 $\pm$ 21.8*	1.6 $\pm$ 0.5
<i>Dryocoetes autographus</i>	84.6 $\pm$ 8.1	0 $\pm$ 0
<i>Gnathotrichus materiarius</i>	11.4 $\pm$ 1.3*	0.6 $\pm$ 0.2
<i>Hylastes opacus</i>	21.4 $\pm$ 2.8*	2.4 $\pm$ 0.6
<i>Ips grandicollis</i>	51.2 $\pm$ 8.5	73.6 $\pm$ 12.1
<i>Ips pini</i>	15.7 $\pm$ 3.0	29.4 $\pm$ 5.3*
<i>Orthotomicus caelatus</i>	71.1 $\pm$ 8.1*	3.2 $\pm$ 0.7
<i>Pityogenes hopkinsi</i>	15.6 $\pm$ 2.9	24.8 $\pm$ 4.5*
<i>Pityokteines sparsus</i>	3.2 $\pm$ 1.0	2.8 $\pm$ 0.9
<i>Pityophthorus</i> species	3.1 $\pm$ 0.6	3.9 $\pm$ 0.6
Total Cerambycidae	124.5 $\pm$ 14.0*	75.6 $\pm$ 8.7
<i>Acanthocinus obsoletus</i>	6.7 $\pm$ 1.5	4.2 $\pm$ 1.0
<i>Acmaeops proteus</i>	1.5 $\pm$ 0.4	3.6 $\pm$ 0.7*
<i>Aseum striatum</i>	30.8 $\pm$ 4.7*	0.1 $\pm$ 0.1
<i>Astylopsis sexguttata</i>	3.2 $\pm$ 0.7	12.9 $\pm$ 2.0*
<i>Monochamus carolinensis</i>	4.1 $\pm$ 1.2	28.5 $\pm$ 7.6*
<i>Monochamus notatus</i>	6.8 $\pm$ 1.3	7.6 $\pm$ 1.4
<i>Monochamus scutellatus scutellatus</i>	19.9 $\pm$ 2.8*	6.6 $\pm$ 1.1
<i>Rhagium inquisitor</i>	30.6 $\pm$ 3.8*	2.0 $\pm$ 0.5
<i>Xylotrechus sagittatus sagittatus</i>	10.4 $\pm$ 1.9*	4.1 $\pm$ 0.9

\* $P < 0.05$ .

trap heights included *I. grandicollis* ( $F_{1,9} = 2.4$ ,  $P = 0.2$ ), *Pityokteines sparsus* (LeConte) ( $F_{1,9} = 0.09$ ,  $P = 0.8$ ), and *Pityophthorus* Eichhoff species ( $F_{1,9} = 0.9$ ,  $P = 0.4$ ).

### Cerambycidae

*Monochamus carolinensis* (Olivier) and *Rhagium inquisitor* (Linnaeus) were the most abundant cerambycids, representing 18% and 17% of total cerambycid captures, respectively. Other abundant species included *Asemum striatum* (Linnaeus) (15%), *Monochamus scutellatus* (Say) (14%), *Astylopsis sexguttata* (Say), *Monochamus notatus* (Drury) (8%), and *Xylotrechus sagittatus sagittatus* (Germar) (7%). Singlets accounted for 27% of the cerambycid species captured.

Average species richness of cerambycids was higher in understorey compared with canopy traps ( $F_{1,9} = 13.9$ ,  $P = 0.005$ ; Fig. 1C). More total cerambycids were also captured in understorey ( $124.5 \pm 14.0$ ) than canopy ( $75.6 \pm 8.7$ ) traps ( $F_{1,9} = 21.8$ ,  $P = 0.001$ ; Table 1). Of the cerambycids statistically tested, *M. scutellatus* ( $F_{1,9} = 34.9$ ,  $P = 0.0002$ ), *R. inquisitor* ( $F_{1,9} = 116.3$ ,  $P < 0.0001$ ), *A. striatum* ( $F_{1,9} = 31.5$ ,  $P = 0.0003$ ), and *X. sagittatus* ( $F_{1,9} = 12.44$ ,  $P = 0.007$ ) were found more often in understorey traps. Cerambycids caught at significantly higher numbers in canopy traps included *M. carolinensis* ( $F_{1,9} = 49.2$ ,  $P < 0.0001$ ), *Acmaeops proteus* (Kirby) ( $F_{1,9} = 7.1$ ,  $P = 0.03$ ), and *A. sexguttata* (Say) ( $F_{1,9} = 52.3$ ,  $P < 0.0001$ ). Trap catches of *M. notatus* ( $F_{1,9} = 0.52$ ,  $P = 0.5$ ) and *Acanthocinus obsoletus* (Olivier) ( $F_{1,9} = 4.7$ ,  $P = 0.06$ ) did not significantly differ between understorey and canopy traps.

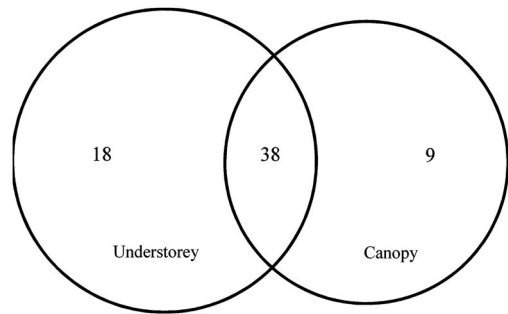
### Siricidae

The most abundant siricid captured was *Sirex nigricornis* Fabricius (83%), followed by *Tremex columba* (Linnaeus) (10%). *Urocerus albicornis* (Fabricius) and *Urocerus cressoni* Norton were only captured one time each. Too few siricids were captured to statistically analyse. Of the 29 specimens collected, the majority were captured in the understorey (76%) compared with canopy (24%) traps. The three specimens of *T. columba* were captured exclusively in canopy traps. Only female siricids were captured.

**Table 2.** Species richness, abundance, and diversity estimates in understorey and canopy traps baited with  $\alpha$ -pinene, ethanol, ipsdienol, and ipsenol in southern Maine, United States of America.

Variable	Understorey	Canopy	P-value
Richness	56	47	0.5
Abundance	6129	2334	0
Simpson Index	0.88	0.84	0.001
Chao1	$75.5 \pm 14.8$	$71.0 \pm 16.4$	

**Fig. 3.** Venn diagram depicting the number of species captured in understorey and canopy traps, similarity among trap catches, and unique species captured at each height in southern Maine, United States of America.

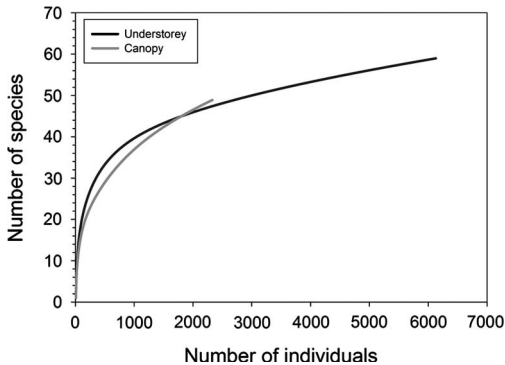


### Species richness and diversity

Species richness of understorey (56) and canopy traps (47) were not significantly different (Table 2). There were 38 shared species between understorey and canopy traps with more unique species found in understorey traps (Fig. 3). Simpson's Index (1-D) estimates were statistically higher for understorey compared with canopy traps (Table 2). Adjusted Jaccard abundance ( $0.94 \pm 0.05$ ) and Sørensen abundance ( $0.97 \pm 0.03$ ) similarity indices suggested traps sampled similar communities.

Individual-based rarefaction curves for understorey and canopy traps followed similar patterns with neither reaching an asymptote (Fig. 4). While understorey traps captured more individuals, rarefaction curves suggest canopy traps have the potential to capture higher species richness. Chao1 estimated species richness was slightly higher in understorey traps compared with canopy traps (Table 2).

**Fig. 4.** Individual-based rarefaction curves for understorey and canopy traps baited with  $\alpha$ -pinene, ethanol, ipsdienol, and ipsenol in southern Maine, United States of America.



## Discussion

Resources to conduct exotic species surveys are often limited. Placing traps to optimise trap catches (*i.e.*, increase species richness) and sample surrounding communities as completely as possible is critical to success of these surveys. Insights gained by trapping indigenous species provide guidance for exotic species surveys as well as efforts to sample native communities. Trap type (Flechtmann *et al.* 2000; de Groot and Nott 2001; Dodds *et al.* 2010), surface treatments (Graham *et al.* 2010; Allison *et al.* 2011), collection method (Morewood *et al.* 2002; Miller and Duerr 2008), colour (Strom and Goyer 2001), and semiochemical blends (Miller and Rabaglia 2009) all can influence trap captures. Placement variables, such as habitat selection, location of traps within or near habitat patches, and height can also influence trap catches and the portion of a community sampled (Vance *et al.* 2003; Ulyshen and Hanula 2007; Wermelinger *et al.* 2007; Dodds *et al.* 2010; Dodds 2011; Graham *et al.* 2012). In the current study, traps placed in the understorey and canopy captured many of the same species, but differences in effectiveness between the treatments existed.

Species richness and abundance were higher in understorey traps compared with canopy traps for total abundance of arboreal species counted, and for scolytines and cerambycids separately. Understorey traps captured 86% of total species sampled at both heights, while canopy traps

captured 72%. Proportions of scolytines and cerambycids captured were also higher in understorey than canopy traps. While both heights sampled the majority of species captured, understorey traps caught a larger proportion of the community. Average species richness and number of species were higher in understorey traps. Understorey traps also captured more unique species than canopy traps. Higher abundance of arboreal insects were also captured in understorey traps, with over 2.5 times as many insects trapped at this height compared with canopy traps. While abundance estimates are not relevant to exotic species surveys, they may be important if population monitoring is the goal of trapping efforts. Results support placement of traps in the understorey for both increasing species richness and catching larger numbers of insects.

There was variation in response of individual scolytines to the two trapping heights. *Dendroctonus valens*, *H. opacus*, *O. caelatus*, and *D. autographus* inhabit lower portions of tree boles and roots (Wood 1982; Hoebeke 1994; Owen *et al.* 2010) and were more abundant in understorey traps. Very low numbers of each, with the exception of *D. autographus*, were captured in canopy traps as well, indicating that flight level or trap height does not necessarily indicate habitat preference. The ambrosia beetle *G. materiarius* was also more abundant in understorey traps. This species has been previously associated with lower sections of dead pine trees (Ryan *et al.* 2011). *Pityogenes hopkinsi* was more abundant in canopy traps, which may relate to its habit of colonising smooth bark sections of tree boles and broken limbs and branches (Baker 1972; Wood 1982). Abundance of *P. sparsus* and *Pityophthorus* species was not different between the two trap heights. Because of the difficulty separating species of *Pityophthorus*, we did not attempt to differentiate individual species and treated the group at the genera level. Consequently, any behavioural differences of individual species may have been lost.

While no differences existed between the catches of *I. grandicollis* at the two heights, *I. pini* was twice as abundant in canopy compared with understorey traps. These results differ from previous work that documented more abundant *I. pini* catches in traps at 2 m compared with 9 m (Raffa 1991). *Ips pini* has been reported

to colonise mid-bole of trees (Ayres *et al.* 2001) but trapping height may not relate to bole-colonisation patterns. *Ips grandicollis* colonised basal portions of trees (Ayres *et al.* 2001), but was captured in equal numbers at the two trapping heights used in this study.

More total cerambycids were captured in understorey compared with canopy traps, however, there was variation in response to trap height by individual species. *Asemum striatum*, a lower bole specialist (Baker 1972), was captured almost exclusively in understorey traps. *Rhagium inquisitor*, a species reported to colonise dead and dying tree boles (Baker 1972) was also more abundant in understorey traps. Two cerambycid species, *A. sexguttata* and *A. proteus* were trapped more frequently in canopy traps. Little is known about their colonisation behaviour on host trees, but a larger percentage of *A. sexguttata* emerged from branch sections compared with large bolts (Reagel *et al.* 2012). No information could be found on *A. proteus* colonisation behaviour.

*Monochamus* Dejean species abundance varied in response to trap height. The three *Monochamus* species captured all share a common resource (*i.e.*, stressed and dying pines) but little is known about specific colonisation patterns. Resource partitioning of host trees is common in wood-inhabiting beetles that temporally and spatially co-occur (Nord and Knight 1972; Paine *et al.* 1981; Ayres *et al.* 2001), but caution must be taken in drawing conclusions from trapping studies on this behaviour. While *M. notatus* was captured in equal numbers at the two heights, both *M. carolinensis* and *M. scutellatus* showed strong responses to different trap heights. Over six times the number of *M. carolinensis* were captured in canopy compared with understorey traps. The opposite was found for *M. scutellatus* where three times as many were found in understorey compared with canopy traps. It is unknown if this flight pattern will relate directly to colonisation behaviour on pine trees. However, in a study of *Sirex noctilio* (Fabricius) distribution along the length of tree boles, Ryan *et al.* (2011) found *M. carolinensis* throughout the entire tree bole with a slight increase in the upper portions. In a separate study, *M. scutellatus* preferred larger diameter sections of felled *P. strobus* in West

Virginia, United States of America for oviposition (Hughes and Hughes 1982). It is possible that *Monochamus* species are partitioning tree boles in a similar way seen in scolytines.

As in many surveys implementing semi-chemical lures, low numbers of siricids were captured during the approximately six months of sampling. The majority of siricids were captured in understorey traps. However, the very low number of *T. columba* captured were exclusively found in canopy traps. Dodds *et al.* (2012) reported relatively large numbers of *T. columba* in multiple-funnel traps hung at 6 m on artificially stressed pine trees.

The key component to successful surveys is maximising species richness to define a community present at a trapping site. Understorey traps captured the highest observed species richness and unique species of the two trap placements. Individual-based rarefaction curves and Chao1 estimates suggested there were species present at both heights that were not sampled during the survey. Neither rarefaction curve plateaued, but it appears that canopy traps may be capable of sampling more species over time. Chao1 species richness estimates were similar for each trap placement, with species richness higher than what was observed during the trapping period. The addition of different trap types to surveys may increase species richness by capturing insects not sampled with multiple-funnel traps (Dodds *et al.* 2010). Diversity estimates were significantly higher in understorey traps, but whether or not this was biologically meaningful is debatable. Interestingly, both Jaccard and Sorensen abundance-based similarity indices suggested very similar communities were trapped at each height.

## Conclusions

Understorey traps captured more species than canopy traps and the portion of the community sampled from each height were very similar. Common practice in exotic species and other survey types is to place traps in the understorey hanging between two trees, from conduit, or on a low tree branch. Results from this study suggest traps in the understorey sample larger portions of the community present than canopy traps. However, much overlap in trap captures at



understorey and canopy heights suggested there is leeway in vertical trap placement. Because unique species were captured at each height, multiple trapping heights may be beneficial in survey of high-risk forests to ensure the largest portion of the arboreal insect community present on a site is sampled.

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