Comparison of the species richness and abundance of Cerambycidae (Coleoptera) and Scolytinae (Coleoptera: Curculionidae) captured in aerial malaise traps with and without a bottom collector

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Abstract—Methods for detection and monitoring invasive insect species are continually being refined and developed. Detecting invasive pests early can improve chances of eradication or management of populations. Aerial malaise traps are successfully used in monitoring for insects such as longhorned beetles (Coleoptera: Cerambycidae) and bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae). These traps have both a top and bottom collecting cup. The bottom portion of these traps leading to the collection cup collects canopy litter at a high rate, greatly increasing time required to sort through and possibly affecting the diversity and abundance of insects captured. Traps with top and bottom collecting cups were compared with traps with only top collecting cups to determine the effect on species richness and abundance of cerambycids and scolytines. There was no significant difference in species richness and abundance of cerambycids, and abundance of scolytines, however species richness of scolytines was significantly higher in top/bottom traps. We conclude that removing the bottoms from aerial malaise traps would benefit monitoring programmes that use this type of trap in combination with funnel traps, albeit with the potential loss of information on scolytine richness.

Large scale programmes for monitoring invasive species, such as Early Detection Rapid Response (EDRR) and Cooperative Agricultural Pest Survey (CAPS), have been used effectively to detect new introductions of non-native wood inhabiting insects (Hoebeke and Rabaglia 2008; Cognato *et al*. 2011, 2013). Development and deployment of practical, effective, and standardised methods that optimise trap efficacy are important to the continued success of these programmes. Studies to compare the effects of trap type, lure placement, and habitat selection (Dodds *et al.* 2010; Dodds 2011, 2014; Graham *et al*. 2012; Miller *et al.* 2013) on diversity and abundance of wood inhabiting insects have provided some guidance on how to optimise sampling efforts. Aerial malaise traps (AMTs) were more effective at capturing cerambycid species, unique species, and rare species than funnel traps, modified funnel traps, and intercept panel traps (Dodds *et al*. 2010, 2015).

Several variations of AMTs exist and can include top and bottom collectors. Top collection cups were more effective for capturing Cerambycidae (Coleoptera) than bottom collecting cups on traps without a removable bottom, but the opposite was true for Scolytinae (Coleoptera: Curculionidae) (Dodds *et al.* 2010). Traps with the bottom collectors completely removed have not been compared with full traps to see if removal causes a reduction in efficacy. Bottom collecting cups are problematic for traps as they quickly fill with large amounts of debris and rain water, often damaging traps because of excessive weight pulling at the top. The large amounts of debris also increases processing time in the laboratory. Determining the importance of bottom collectors for surveying cerambycids and scolytines would provide guidance on whether or not this cup was necessary. To this end, we tested a variant of an AMT known as a SLAM trap (MegaView Science, Taichung City, Taiwan) with top and bottom collectors to a SLAM trap with only a top collector for their effectiveness at sampling the diversity and abundance of Cerambycidae and Scolytinae.

Received 2 June 2016. Accepted 12 October 2016. First published online 24 January 2017.

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Subject editor: Véronique Martel
doi:10.4039/tce.2016.70

Can. Entomol. **149**: 408–412 (2017)

Five replicates of the two trap types were established in a mixed red pine (*Pinus resinosa* Aiton, Pinaceae) and white pine (*Pinus strobus* Linnaeus) stand on the Massabesic Experimental Forest near Lyman, Maine, United States of America (43.56110°N, 70.63089°W). The five replicates were located throughout the stand in a randomised complete block design. Traps within each block were located ~ 20 m apart, with at least 30 m separating blocks. Traps were hung from a rope tied between two trees with at least 3 m separating the trap from each tree. The bottom collecting cup of traps with a bottom collecting cup was at least 0.5 m from the ground. Tops of all traps were hung at approximately the same height.

Each trap was baited with ultrahigh release ethanol (≈ 80 g releasing ≈ 0.4 g/day, Synergy Semiochemical, Burnaby, British Columbia, Canada), α-pinene [≈ 170 g releasing ≈ 2 g/day, enantiomeric composition 75% (–), Synergy Semiochemical], and a generic cerambycid lure (3-hydroxy-2-hexanone releasing ≈ 20 mg/day, Chemtica, Durant, Oklahoma, United States of America). Traps used wet collection cups (Morewood *et al*. 2002; Miller and Duerr 2008) filled with 3–5 cm of propylene glycol antifreeze (Prestone® RV Waterline, Lake Forest, Illinois, United States of America) as the killing and preserving agent. Collections were made approximately every two weeks from 19 July to 26 September 2013. All samples were kept frozen until processing. All scolytine and cerambycid beetles were identified to species and tallied. Voucher specimens were deposited in the Durham Field Office Forest Insect Collection (Durham, New Hampshire, United States of America).

Trap captures were pooled over the entire trapping period by trap type for all analyses. Trap type was compared using analysis of variance (ANOVA) with replicates as a block and trap type as the main factor (JMP 6.0; SAS, Cary, North Carolina, United States of America). We tested for differences between the top/bottom and top-only traps, as well as differences between only the top collecting cup of top/bottom traps and top-only traps. The latter test was to determine if bottom collecting cups interfered with top collecting cup effectiveness. Data were normally distributed and variances were homoscedastic.

In total, 959 cerambycid and scolytine beetles representing 27 species were captured during this study (Table 1). A total of 488 cerambycids from 18 species and 471 scolytines from nine species were captured in the two trap types. There were no differences in the mean number of total beetles ($F(1,4) = 0.578$, $P = 0.489$), cerambycids ($F(1,4) = 15.292$, $P = 0.017$), or scolytines ($F(1,4) = 2.974$, $P = 0.160$) captured in the traps (Table 2). Average number of total species ($F(1,4) = 14.155$, $P = 0.020$) and scolytines ($F(1,4) = 58.778$, $P = 0.002$) were significantly higher in the top/bottom compared with top-only traps. The number of cerambycid species captured in each trap type were not significantly different ($F(1,4) = 0.710$, $P = 0.447$).

The most abundant cerambycid species collected were *Xylotrechus sagittatus sagittatus* (Germar), *Monochamus notatus* (Drury), and *Astylopsis sexguttata* (Say) representing 42.0%, 27.3%, and 13.1% of all cerambycids captured, respectively. Trap type had no effect on abundance of these three species (Table 2). The most abundant scolytine species collected was *Ips grandicollis* (Eichhoff) representing 93.0% of all scolytines captured. Analyses showed no difference in captures of *I. grandicollis* between the two trap types ($F(1,4) = 2.236$, $P = 0.209$).

Top/bottom traps captured five unique cerambycid species and eight unique scolytines. Top-only traps captured three unique cerambycid species, while no unique scolytines were captured in these traps. Only four individuals of two cerambycid species, *X. sagittatus sagittatus* and *Stictoleptura canadensis canadensis* (Olivier), were collected in bottom cups. Of the nine scolytine species captured in top/bottom traps, only one species, *Hylastes porculus* Erichson, was captured exclusively in the top collection cup.

Our results suggest no benefit of having the bottom collector attached to traps for abundance or richness of cerambycids, and an advantage only for species richness of scolytines. Species richness is the most important variable to consider when testing effectiveness of detection traps (Dodds *et al*. 2015). Species richness and unique species captured for both families combined was greater in top/bottom than top-only traps. However, this was primarily attributed to the scolytine portion of the trapping samples where 88.9% of species (60.7% of individuals) were captured in bottom cups.

When data were analysed to compare only the top cup catch from the top/bottom traps and top-only

Table 1. Catches of cerambycid and scolytine beetles in SLAM traps with and without bottom collector.

	Number of beetles captured		
	Top/bottom	Top-only	Total
All beetles	516	443	959
Total Cerambycidae	208	280	488
Species	15	13	18
Acanthocinus obsoletus (Olivier)	6	9	15
Acanthocinus pusillus Kirby	1	0	1
Anelaphus parallelus (Newman)	1	1	2
Anelaphus villosus (Fabricius)	0	2	2
Astylopsis macula (Say)	2	0	2
Astylopsis sexguttata (Say)	28	36	64
Clytus ruricola (Olivier)	1	0	1
Eupogonius tomentosus (Haldeman)	2	2	4
Hebestola nebulosa Haldeman	0	1	1
Monochamus carolinensis (Olivier)	13	19	32
Monochamus notatus (Drury)	55	78	133
Monochamus scutellatus (Say)	1	4	5
Neoclytus mucronatus (Fabricius)	1	1	2
Stictoleptura canadensis canadensis (Olivier)	4	0	4
Tetropium schwarzianum Casey	2	0	2
Xylotrechus colonus (Fabricius)	6	5	11
Xylotrechus integer (Haldeman)	0	2	2
Xylotrechus sagittatus sagittatus (Germar)	85	120	205
Total Scolytinae	308	163	471
Species	9	1	9
Anisandrus sayi Hopkins	2	0	2
Conophthorus species	2	0	2
Dendroctonus valens LeConte	2	0	2
Dryocoetes affaber LeConte	1	0	1
Dryocoetes autographus Eichhoff	18	0	18
Gnathotrichus materiarius (Fitch)	5	0	5
Hylastes porculus Erichson	1	0	1
Ips grandicollis (Eichhoff)	275	163	438
Pityophthorus species	2	0	2

traps, there were significantly more total beetles ($F(1,4) = 15.561$, $P = 0.017$) and cerambycids ($F(1,4) = 18.424$, $P = 0.013$) in top-only traps than top cups in top/bottom traps (Table 3). There was no significance differences between total beetle species ($F(1,4) = 0.340$, $P = 0.591$), cerambycid species ($F(1,4) = 0.167$, $P = 0.704$), or number of individuals of scolytines ($F(1,4) = 1.990$, $P = 0.231$). Statistical analysis of the number of scolytine species was not practical due to the small number of species collected from the top cup in each trap type.

When only comparing top collecting cups, we found no effect of the bottom collecting cup on the number of cerambycid or scolytine species collected in the top cup only, while abundance of total beetles and cerambycids were greater in the top-only trap. This suggests that having a bottom interferes in some way with top cup abundance and there was actually a benefit to having it removed. Beetles arriving at traps from below may be blocked access to the trap altogether with the bottom collector attached. It is also possible that the added weight when bottom collectors fill with debris and water may deform the trap and top collector and prevent some beetles from navigating to the cup.

It was not unexpected that the bottom collecting cup was important for capturing scolytines. Many scolytines are known to retract wings and

Table 2. Mean ± standard error of species, number of beetles for top/bottom and top-only SLAM traps with results of ANOVA.

Variable	Mean ± SE Top/bottom	Mean ± SE Top-only	*F*(1,4)	*P*
Number of species				
All beetles	14.6 ± 1.2	9.2 ± 1.0	14.155	0.020*
Cerambycidae	8.8 ± 1.1	7.4 ± 0.9	0.710	0.447
Scolytinae	5.6 ± 0.6	1.0 ± 0.0	58.778	0.002*
Number of beetles				
All beetles	103.4 ± 18.6	89.6 ± 7.9	0.578	0.489
Cerambycidae	41.6 ± 5.3	56.0 ± 3.1	15.292	0.017*
Astylopsis sexguttata (Say)	5.6 ± 0.7	7.2 ± 1.7	1.243	0.327
Monochamus notatus (Drury)	11.0 ± 2.9	15.6 ± 2.2	2.443	0.193
Xylotrechus sagittatus (Germar)	17.0 ± 2.1	24.0 ± 2.3	6.622	0.062
Scolytinae	61.6 ± 17.2	32.6 ± 6.0	2.974	0.160
Ips grandicollis (Eichhoff)	55.0 ± 15.5	32.6 ± 6.0	2.236	0.209

Note:
* Denotes significantly different means between trap types ($P < 0.05$).

Table 3. Mean ± standard error of species and number of beetles in the top cup of top/bottom and top-only SLAM traps with results of ANOVA.

Variable	Mean ± SE Top/bottom	Mean ± SE Top-only	*F*(1,4)	*P*
Number of species				
All beetles	9.8 ± 0.7	9.2 ± 1.0	0.340	0.591
Cerambycidae	8.0 ± 0.9	7.4 ± 0.9	0.167	0.704
Scolytinae[†]	1.6 ± 0.2	1.0 ± 0.0	–	–
Number of beetles				
All beetles	65.2 ± 5.9	89.6 ± 7.9	15.561	0.017*
Cerambycidae	40.8 ± 5.3	56.0 ± 3.1	18.424	0.013*
Scolytinae	24.2 ± 0.7	32.6 ± 6.0	1.990	0.231

Notes:
* Denotes significantly different means between trap types ($P < 0.05$).
[†] Not compared statistically due to low captures.

drop when striking an object in flight. Conversely, cerambycids were more diverse in top collection cups, suggesting that at least some of these species may land softer on traps than scolytines. Dodds *et al*. (2010) also found higher number of cerambycid species in top collecting cups of canopy malaise traps compared with bottom cups. Debris in the trap bottom can easily prevent a cerambycid from falling directly into the collection cup and provide a pathway out of the collection area and likely off the trap. Smaller scolytines likely fall through the debris more easily and reach the collecting cup to be captured more frequently than larger more agile cerambycids.

The results of this experiment have implications for exotic insect trapping programmes that use, or are considering using, top and bottom collecting aerial malaise traps. With the exception of total species and scolytine species captured, the addition of the bottom collecting apparatus on SLAM traps did not generally improve collections over SLAM traps with top cups only. Top cup only comparisons were not significantly different, except for total beetle and cerambycid abundance. This suggests that the bottom cup was important for improving scolytine species richness estimates only. Funnel traps or cross-vane panel traps are the standard trap used in exotic species detection efforts

(Rabaglia *et al*. 2008; United States Department of Agriculture, Animal and Plant Health Inspection Service 2011) and are effective bark-beetle traps (Lindgren 1983; Stone *et al*. 2010). Pairing a cross-vane or funnel trap with a top collecting SLAM trap should help maximise survey efforts. Funnel or panel traps would readily sample the scolytine community, while the top collecting SLAM could improve collections of cerambycids (Vance *et al*. 2003; Dodds *et al*. 2010, 2015).

Acknowledgments

We thank Jon Janelle (United States Forest Service, Northern Research Station) for help locating the study site in the Massabesic Experimental Forest. Michael Simmons (University of New Hampshire, Durham, New Hampshire) and Justin Williams (United States Forest Service, Southern Research Station) helped with trap collections.

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