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TECHNICAL NOTE

Elevated pan traps to monitor bees in flowering crop canopies

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Introduction

Bee behavior is strongly directed by visual cues in the visible and ultraviolet wavelength ranges, with response to color and pattern controlling location of flowers (Chittka & Menzel, 1992; Kevan et al., 1996; Gumbert, 2000). Their attraction to color can be exploited for monitoring bee populations through the use of passive colored traps filled with soap and water, which provide an inexpensive and easily replicated method to capture bees (Aizen & Feinsinger, 1994; Leong & Thorp, 1999; LeBuhn et al., 2002; Toler et al., 2005; Baum et al., 2006). The use of pan traps to monitor bee communities is a relatively recent development, but it is increasingly used as a sampling tool by researchers in urban, pastoral, and natural landscapes (Leong & Thorp, 1999; McIntyre & Hostetler, 2001; Williams et al., 2001; Russell et al., 2005; Toler et al., 2005; Brosi et al., 2007).

Pan trapping has important advantages compared to more traditional bee collection methods. It can eliminate collector bias, which is particularly important when comparing data across different studies or when using multiple collectors in the same study, and it can be easily replicated for consistent sampling intensity by collectors with minimal training at multiple sites. Specimens collected using this method can be accurately identified to species under microscope by trained personnel. As with any sampling method, there are some drawbacks. Trapped insects are removed from the population. Pan traps may be biased toward attracting some bee taxa over others (Roulston et al., 2007) and may underestimate the abundance of large bees. Unless pollen can be obtained from specimens in the trap, one cannot determine which flowers were visited. However, in combination with other methods pan trapping can be very effective for estimating bee abundance (Williams et al., 2001).

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The majority of native-bee monitoring studies that use pan traps have been conducted in habitats with little overhead plant canopy, where traps were placed directly on the ground among open, or low-growing vegetation. This deployment strategy is appropriate for many natural habitats where bees are likely to forage and so is generally recommended (e.g., LeBuhn et al., 2002). However, if this technique is to be applied successfully in agricultural habitats where there is increasing interest in bee conservation, it is important to consider that many bee-pollinated crops have dense, vertical vegetation and floral displays. The crop studied here, highbush blueberry [*Vaccinium corymbosum* L. (Ericaceae)], can reach over 2 m and the placement of traps in its canopy has been found to be important when monitoring for pest insects, including several *Rhagoletis* flies (Diptera: Tephritidae) (Drummond et al., 1984; Teixeira & Polavarapu, 2001; Pelz-Stelinski et al., 2006).

The goal of this study was to determine whether bees that forage on highbush blueberry are more likely to be captured in traps elevated within the canopy of the crop than either above or below the canopy. Specifically, we were interested in determining whether bee species foraging on *V. corymbosum* responded differently to trap placement than species not known to forage on *V. corymbosum.*

Materials and methods

Previously, a vertically adjustable pan trap platform was designed by Vega et al. (1990) for monitoring aphids and cicadellids in crops. For this study, we developed a trap mount that is less complicated, with fewer parts, and can be installed and taken down again rapidly. Yellow plastic bowls (355 ml, 'sunshine yellow'; Amscan, Elmsford, NY, USA) were used, and those that were to be elevated in the canopy were mounted onto 2.7 cm diameter polyvinyl chloride poles stabilized with rebar (Figure 1).

The study was conducted in a *V. corymbosum* planting at the Trevor Nichols Research Complex near Fennville (MI,

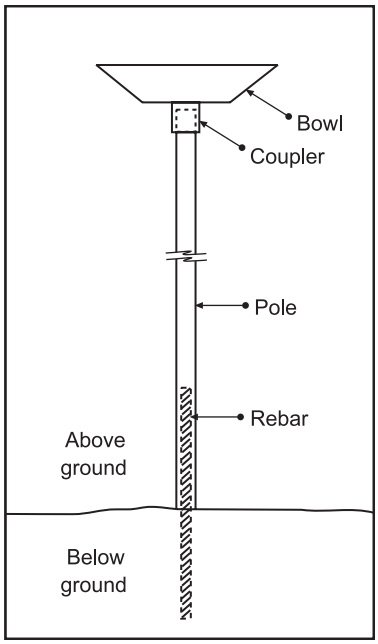

Figure 1 Diagram of an elevated pan trap. A plastic bowl is attached to the coupler with polyvinyl chloride (PVC) cement. A piece of rebar is driven into the ground with a sledge hammer, then the PVC pole is slipped over the top. Finally, the bowl/coupler combination is slipped onto the pole and the dilute soap solution dispensed into the pan trap. Varying the length of PVC pole provides traps of varying height.

USA; 42°36′N, 86°9′W) in May 2004 and 2005. Traps were placed in four positions with respect to the crop canopy, spaced 5 m apart with six replications arranged in a 4×6 Latin square design. The pan heights tested were (1) on the ground, (2) one-third of the way up in the canopy (between 0.46–0.6 m), (3) two-thirds of the way up in the canopy (between 0.9–1.2 m), and (4) just above the top of the canopy (between 1.5–1.8 m). Upon deployment, each trap was half-filled with a 2% soap solution (blue Dawn® dish soap; Procter and Gamble, Cincinnati, OH, USA). At the end of the sampling period, pan trap contents were strained; honey bees were sorted from the samples, counted, and stored in ethanol, and the remaining bees were washed, dried, and pinned for identification.

We conducted this study on 19 May 2004 in a mature stand (cv. 'Rubel') with an average height of 1.5 m. On 25 May 2005, we expanded the study to include a second mature stand of 'Rubel' and two younger stands in an adjacent plantation of cv. 'Bluecrop' that had an average height of 1 m. Traps were deployed during full bloom from 10:00–19:00 hours, when weather conditions met the criteria for bee activity described in Pywell et al. (2005).

Preliminary identifications of bees to the lowest possible taxonomic group were made using three published dichotomous keys (Mitchell, 1960, 1962; Michener et al., 1994) and the online Discover Life Apoidea Species Guides (http://www.discoverlife.org; Ascher et al., 2008). Further species identification and verification were made by JS Ascher (Division of Invertebrate Zoology, American Museum of Natural History, New York, NY, USA) by comparison with specimens held at the American Museum of Natural History. Voucher specimens are held in the Albert J. Cook Arthropod Research Collection at Michigan State University (East Lansing, MI, USA).

A mixed model analysis of variance (Proc MIXED, SAS V9.1; SAS Institute, Cary, NC, USA) was used to test whether bee abundance was significantly related to trap placement in the canopy. In 2004, trap height was the fixed effect and replicate (n = 6 traps per height) was the random effect. In 2005, bee abundance was summed across the six traps for each treatment (ground, one-third up in the canopy, two-thirds up in the canopy, and above canopy) within each of the four blocks; trap height was the fixed effect and replicate (n = 4 blocks per height) was the random effect. The resulting probabilities from the separate analyses of 2004 and 2005 were combined to obtain an overall probability estimate (Sokal & Rohlf, 1995). For both 2004 and 2005, abundance of bees in the families Andrenidae and Halictidae were examined separately and then the resulting probabilities combined using the same methods as for the complete bee fauna. Data in 2005 were $\sqrt{x}$ transformed to meet assumptions of normality (Shapiro–Wilk test) and equal variance (Levene's test) prior to analysis. The Tukey–Kramer means separation test was conducted for all analyses (Proc MIXED, SAS V9.1).

Results and discussion

Bee captures varied significantly with trap height in 2004 ($F_{3,15} = 9.17$, $P = 0.001$) (Figure 2); the number of bees recovered from traps elevated one-third of the way up in the blueberry canopy was significantly greater than traps placed at the other three levels (Tukey–Cramer: $P<0.05$). When the study was expanded in 2005 to include the adjustment of traps relative to shorter blueberry stands, the trend for traps in the canopy to collect more bees than those on the ground or above the canopy remained (Figure 2), but the number of bees captured was not significantly different among trap positions ($F_{3,9} = 3.16$, $P = 0.08$). However, the combined probability estimate for 2004 and 2005 was significant ($\chi^2 = 18.9$, d.f. = 4, $P<0.001$).

In both years, bees in the Andrenidae and Halictidae were the predominant groups collected, comprising 41 and 32% in 2004, and 28 and 66% in 2005 of the total

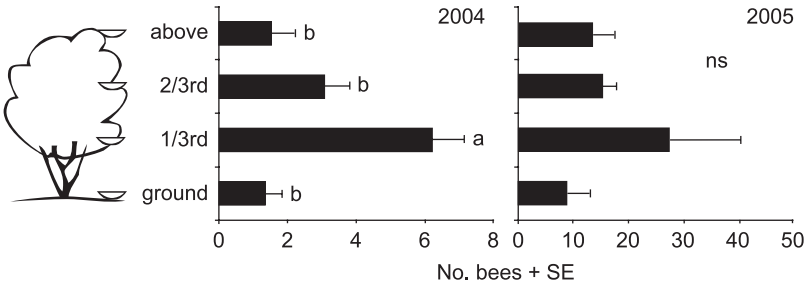

Figure 2 Average number of bees (+ SE) recovered from pan traps placed on the ground or elevated one-third (1/3rd) up into, two-thirds (2/3rd) up into, or above the canopy within highbush blueberry stands in 2004 and 2005. Bars with different letters are significantly different from one another (Tukey–Kramer means separation test: $P<0.05$).

number of bees collected, respectively. Andrenid bees were more often recovered from mid-canopy traps than ground-level or above-canopy traps (2004: $F_{3,15} = 7.49$, $P = 0.002$; 2005: $F_{3,9} = 6.93$, $P = 0.01$; combined: $\chi^2 = 20.83$, d.f. = 4, $P<0.005$) (Figure 3), including *Andrena carolina* Viereck (cited as *A. longifacies* in LaBerge, 1980) (Table 1), which is a specialist on *Vaccinium* species. In contrast, variation in halictid bees, which tend to be polylectic (Michener, 2000), was only marginally significant in response to trap placement with respect to the blueberry canopy (2004: $F_{3,15} = 3.54$, $P = 0.04$; 2005: $F_{3,9} = 2.36$, $P = 0.14$; combined: $\chi^2 = 10.37$, d.f. = 4, $P<0.05$) (Figure 3), although *Lasioglossum (Dialictus)* spp. were more often collected in elevated traps regardless of height (Table 1).

Apis mellifera L. (honey bees) are rarely caught in studies that use pan traps, so it has been generally assumed that pan traps are not a good method for monitoring honey bees (Cane et al., 2001). For example in southern Costa Rica, honey bees were rarely caught in pan traps, whereas they were collected in great abundance in netting samples (Brosi et al., 2007). Likewise in northern Virginia (USA), only a single honey bee was captured in pan traps compared with 204 honey bees netted or observed foraging in the same area (Roulston et al., 2007). Both of these studies placed pans directly on the ground. In this study, honey bees were also not captured in traps placed on the ground; however, they were captured in canopy level traps (Table 1).

These results emphasize the need to place pan traps in the zone of the plant canopy where bees are actively foraging when deploying this method for monitoring pollinators and is in close agreement with many studies examining the distribution of flying insects in plant canopies. Traps are most likely to catch insects where they are predicted to be most active. For instance, insects that oviposit in soil are

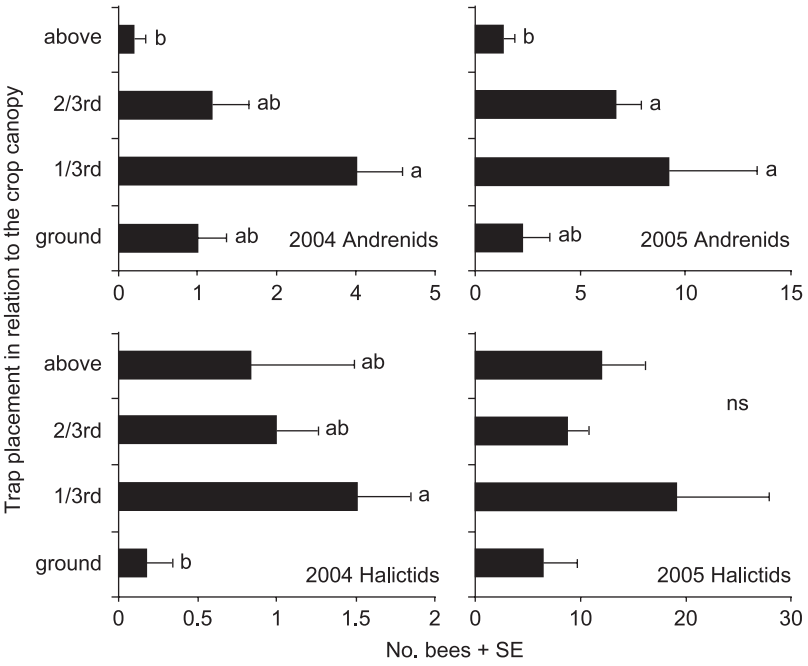

Figure 3 Average number of andrenid and halictid bees (+ SE) recovered from pan traps placed on the ground or elevated one-third (1/3rd) up into, two-thirds (2/3rd) up into, or above the canopy within highbush blueberry stands in 2004 and 2005. Data were transformed to meet assumptions of normality and equal variance; untransformed data are depicted in graphs. Means with different letters are significantly different from one another (Tukey–Kramer means separation test: $P<0.05$).

Table 1 Bee species recovered from pan traps placed either on the ground, in mid-canopy (0.46–1.2 m), or above the canopy (1.5–1.8 m) in a highbush blueberry field during bloom near Fennville (MI, USA) in 2004–2005

Species	Ground level	Mid-canopy	Above canopy	Floral records[1]
Andrenidae				
Andrena algida Smith		♀		
A. arabis Robertson		♀		
A. carlini Cockerell	♀	♀	♀	1, 2
A. carolina Viereck		♀		1, 2
A. commoda Smith		♀		
A. cressonii Robertson	♀	♀		
A. forbesii Robertson		♀		1
A. hippotes Robertson		♀		1
A. imitatrix Cresson or *A. morrisonella* Say[2]		♀	♀	1[3]
A. miserabilis Cresson	♀	♀	♀	
A. nasonii Robertson	♀	♀		
A. perplexa Smith		♀		
A. vicina Smith		♀	♀	1, 2
Apidae				
Apis mellifera L.		♀	♀	1
Bombus impatiens Cresson			♀	1
Ceratina calcarata Robertson	♂	♂		
C. calcarata or *C. dupla* Say[4]	♀	♀	♀	1
C. dupla	♂			1
C. strenua Smith	♀	♀		1
Eucera hamata (Bradley)				
Colletidae				
Hylaeus affinis (Smith)	♂	♀♂		
Halictidae				
Agapostemon virescens (Fabricius)	♀	♀	♀	
Augochlorella aurata (Smith)	♀	♀	♀	1
Halictus confusus Smith	♀	♀		2
H. ligatus Say		♀	♀	
H. rubicundus (Christ)		♀		2
Lasioglossum (*Dialictus*) *admirandum* (Sandhouse)	♀	♀	♀	
L. (*D.*) *anomalum* (Robertson)			♀	
L. (D.) cressonii (Robertson)		♀	♀	
L. (D.) imitatum (Smith)	♀	♀	♀	2
L. (*D.*) *nymphaearum* (Robertson)		♀		
L. (*D.*) *pectorale* (Smith)		♀		
L. (*D.*) *pilosum* (Smith)	♀	♀	♀	
L. (D.) quebecense (Crawford)		♀		2
L. (*D.*) *rohweri* (Ellis)		♀	♀	
L. (*D.*) *tegulare* (Robertson)		♀	♀	
L. (*Hemihalictus*) *lustrans* (Cockerell)	♀			
L. (Lasioglossum) coriaceum (Smith)		♀	♀	2
L. (*L.*) *leucozonium* (Schrank)		♀	♀	
Sphecodes spp.		♀	♀	
No. of ♀ (♂) bees:	43 (4)	226 (12)	63 (0)	
No. of species:	15	34	20	

♀ and ♂ indicate the presence of females or males, respectively.

[1]*Vaccinium* floral records listed by (1) Hurd (1979) and (2) MacKenzie & Eickwort (1996).

[2]These species are difficult to distinguish after specimens have been wet.

[3]Record for *A. imitatrix* only.

[4]Females of these species are morphologically indistinct.

more likely to be captured in traps close to the ground than in traps above ground. This was found for two beetle species, the Japanese beetle (*Popillia japonica* Newman) (Ladd & Klein, 1982) and the garden chafer (*Phyllopertha horticola* L.) (Ruther, 2004). Male Japanese beetles were more likely to be captured in traps slightly elevated off the ground where they were in line with mate-cruising altitude (Alm et al., 1996). For insects that oviposit on fruit in tree and shrub canopies, such as fruit fly species in the genus *Rhagoletis*, traps placed level with the canopy, where most oviposition activity occurs, captured the greatest number of females (for apple, see Drummond et al., 1984; for blueberry, see Teixeira & Polavarapu, 2001; for cherry, see Pelz-Stelinski et al., 2006). Similarly, parasitic Hymenoptera responded to trap height based on the typical location of their hosts (Weseloh, 1986). Likewise in this study, bees visiting flowers in the highbush blueberry canopy were more likely to be captured in traps elevated at the level of the majority of highbush blueberry flowers than in traps on the ground or above the canopy.

Future studies that use pan traps to monitor bee communities associated with flowering trees and shrubs, in which other sampling methods may be difficult (e.g., net sampling in tall trees) or time consuming (e.g., observations across multiple sites), should consider elevating pan traps in the canopy. The optimum height to obtain samples with the highest bee abundance and diversity should be determined for crops of different heights, but this may be more or less important depending on the bee groups of interest. The use of pan traps has some important advantages compared to more traditional bee collection methods. Pan traps eliminate collector bias, are relatively inexpensive, are easily replicated, and can be used over a longer period of time at multiple sites simultaneously. From the results presented here, we suggest that attention should be given to vertical plant structure during bee faunal studies, and that elevated pan traps placed in flowering canopies may ensure the greatest sensitivity in studies that require quantification of bee abundance and diversity in crop fields.

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